Doctoral Dissertation

Executive Control Enhancement and Cognitive Training

(Mejora del Control Ejecutivo y Entrenamiento Cognitivo)

International PhD Candidate
María Jesús Maraver Romero

Advisors
Mª Teresa Bajo Molina
Carlos J. Gómez-Ariza

PhD in Psychology
Department of Experimental Psychology

University of Granada
November, 2017

Editor: Universidad de Granada. Tesis Doctorales
Autora: María Jesús Maraver Romero
ISBN: 978-84-9163-731-8
URI: http://hdl.handle.net/10481/48948

Front and back cover design by Pablo Carpio Maraver, 2017.

El doctorando / *The doctoral candidate* **María Jesús Maraver Romero** y los directores de la tesis / *and the thesis supervisor/s*: **María Teresa Bajo Molina** y **Carlos J. Gómez Ariza**

Garantizamos, al firmar esta tesis doctoral, que el trabajo ha sido realizado por el doctorando bajo la dirección de los directores de la tesis y hasta donde nuestro conocimiento alcanza, en la realización del trabajo, se han respetado los derechos de otros autores a ser citados, cuando se han utilizado sus resultados o publicaciones.

/

Guarantee, by signing this doctoral thesis, that the work has been done by the doctoral candidate under the direction of the thesis supervisor/s and, as far as our knowledges reaches, in the performance of the work, the rights of other authors to be cited (when they results and publications have been used) have been respected.

Lugar y fecha / *Place and date:*

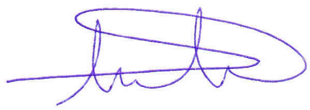
Granada, 02 de noviembre de 2017

Director/es de la Tesis / *Thesis supervisor/s:*

Fdo./*Signed*: **María Teresa Bajo Molina**

Fdo./*Signed*: **Carlos J. Gómez Ariza**

Doctorando / *Doctoral candidate:*



Fdo./*Signed*: **María Jesús Maraver Romero**

A todos los que me enseñaron que en la vida no hay problemas,
sino soluciones esperando ser encontradas.

Agradecimientos

No estaría escribiendo estas líneas si Teresa no hubiese confiado en mí, aún sin apenas conocerme. Gracias Tere por abrirme las puertas a Granada, y por hacerla mi casa, gracias por tu fuerza, tu ilusión y por darme tantas oportunidades de crecer. Gracias Carlos por la armonía. Por inspirar seguridad y por despertar inquietudes, gracias por esa conexión y por tus infalibles recargas de pilas. Gracias jefes por hacer tan buen equipo, por ser exigentes, por vuestras ideas, por vuestra complicidad y profesionalidad, por vuestro cariño, y por las muchas más razones que me hacen sentir afortunada de trabajar con vosotros. De todo corazón, gracias por vuestro *endless support*.

Gracias a todos y cada uno de los miembros de mi grupo de investigación. Al apoyo y la experiencia de los veteranos y a Jose, que nunca falla. A los consejos de Luis, Julia y Laura. A las discusiones con Ana. A la alegría de Almu. A la complicidad con Manolo, y con Gemma. A la generosidad de Tania. A la energía de Ana. A la espontaneidad de Antonio y Alba. A las ideas abstractas, y concretas, de Borja. A la ilusión y confianza infinita de Marta y Laura, gracias por enseñarme a enseñar. A los que no pongo el nombre pero pusieron su grano de arena en esta tesis. Al paralelismo con Javi. A las postales, los cafés *all over the world*, la paciencia y a la comprensión sin fin de Carmen. Pero sobre todo en los últimos meses, gracias a la sonrisa y a la paz de Nuria. A todos, gracias por compartir conmigo este viaje de cuatro años.

My warmest thanks to Susanne Jaeggi and to all the Working Memory and Plasticity Lab in the University of California-Irvine. Thanks for making me feel at home even at the West Coast. Grazie a Claudia, Eugenio e Erika Borella per aver creato un gruppo di lavoro in cui è stato davvero molto piavecole lavorare.

A todos los participantes, niños, jóvenes y mayores, por su tiempo, por su interés en la investigación y hacer posible este trabajo. En especial, gracias a Gabriel por su dulce apoyo.

A mis amigos, por darme aliento siempre. Javi, Jesús, Marian y, en especial, Julia, gracias por seguir siendo mis compañeros más allá de Madrid. Laurita, gracias por tu cariño y tu empatía a través de los charcos. Beatriz, Alicia, Cristina, Natalia, Helen, Marta, Anaís, Jose, Carlos, Nacho y todos los demás, gracias por vuestra fuerza y por entenderme. Merci María, por tener siempre las palabras exactas. Maribel, gracias a la vida por nuestros caminos paralelos y a ti por hacer que viajemos en tándem. Vero, gracias a Granada por darnos tanto que compartir y a ti por hacerme la vida fácil.

A mi familia, por entender mis ausencias. A Maribel y Guillermo, por su interés y su apoyo incondicional. A Pablo, por la guinda artística y por su paciencia. A Marisa, por animarme siempre. A Clemencia, por ser ejemplo de mujer fuerte. Y a Felipe, por enseñarme a no olvidarme de reír.

A los que me ayudaron a empezar esta carrera de fondo y se quedaron en el camino. A los que aparecieron en la recta final, creyeron en mí, y me acompañaron al otro lado del puente.

A mis padres, por ser mi ejemplo de superación, por hacerme ser quien soy, y por sostenerme. Y a Rocío, gracias por confiar en mí más que yo misma.

Introductory note

This work has been developed thanks to the doctoral research grant BES-2013-066842 to the author between 2014 and 2017, and by grants from the Spanish Ministerio de Economía y Competitividad to Mª Teresa Bajo (PSI2012–33625 and PCIN-2015-132), and Carlos J. Gómez-Ariza (PSI2011-25797 and PSI2015-65502-C2-2-P).

The content of this doctoral dissertation has been drawn up according to the regulations of the University of Granada to obtain the International Doctorate Mention in the Psychology Doctoral Program. According to this, the majority of the thesis has been written in English. Specifically, in Chapters I to III a theoretical introduction to the subject of the investigation is presented in English. Next, the empirical chapters (from IV to VII) also proceeds in English. Finally, the general discussion and concluding remarks are written both in English (Chapter VIII) and in Spanish (Chapter IX).

List of Contents

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

AC: Active Control

ACC: Anterior Cingulate Cortex

ADHD: Attention Deficit Hyperactivity Disorder

ANOVA: Analysis of Variance

ANCOVA: Analysis of Covariance

AX-CPT: AX version of the Continuous Performance Task

BSI: Behavioral Shift Index

CT: Control Training

DMC: Dual Mechanisms of Control

EC: Executive Control

ECT: Executive Control Training

EFs Executive Functions

EEG: Electroencephalography

ERPs: Event-related potentials

fMRI: Functional Magnetic Resonance Imaging

Gf: Fluid Intelligence

IC: Inhibitory Control

ICT: Inhibitory Control Training

IDT: Inhibitory Deficit Theory

IMI: Intrinsic Motivation Inventory

MMSE: Mini-Mental Scale Examination

PC: Passive Control

PFC: Prefrontal Cortex

RAPM: Raven's Advanced Progressive Matrices

SSRT: Stop-Signal Reaction Time

WM: Working Memory

WMC: Working Memory Capacity

WMT: Working Memory Training

Prefacio

"Todo hombre puede ser, si se lo propone, escultor de su propio cerebro."

Santiago Ramón y Cajal.
Reglas y consejos sobre investigación científica (1897).

Querido lector, intenta pensar en un día cualquiera de tu vida. Durante la jornada, probablemente te plantees la lista de cosas que necesitas hacer (ir a trabajar, una reunión a las tres, terminar de escribir un artículo, ir al gimnasio, y comprar fruta). Seguramente vayas controlando el paso de tiempo e intentarás terminar el trabajo a su hora, mientras vas haciendo más de una cosa a la vez. Recordarás eventos pasados, y mantendrás en tu memoria las conversaciones mientras hablas con tus amigos y compañeros. Harás un gran esfuerzo para evitar distracciones e intentarás no equivocarte mientras lees, escribes y piensas. En ese día en concreto, y en todos los días de tu vida, sacarás el máximo provecho de una propiedad fundamental de los seres humanos: la flexibilidad cognitiva. A lo largo de nuestra vida, aprendemos una cantidad inmensa de habilidades y conocimientos, y tanto nuestro cerebro como nuestro comportamiento se enfrentan constantemente a distintos cambios en el ambiente que hacen que debamos adaptarnos a ellos en consecuencia. Los seres humanos somos muy flexibles en cuanto a cómo reaccionamos ante distintas situaciones, lo que hace imprescindibles los procesos de control ejecutivo. Para los humanos, ser cognitivamente flexible no es una opción – es algo esencial.

Los procesos de control ejecutivo se refieren un conjunto de mecanismos cognitivos que se encargan de planificar y regular nuestros pensamientos y nuestras acciones. Este trabajo pretende responder a la pregunta de si estos procesos de control ejecutivo son plásticos y si sería posible modificarlos, y en particular mejorarlos, en distintos grupos de edad. El término plasticidad se utiliza para describir la propiedad que nuestro cerebro tiene para cambiar. Se refiere tanto a cambios en el comportamiento como también en la estructura y función cerebral. La plasticidad tiene como resultado aprendizajes nuevos o habilidades cognitivas mejoradas, como podría ser la adquisición de una nueva lengua o una mejor habilidad para recordar eventos pasados. La plasticidad es más evidente durante la niñez y adolescencia, como se puede ver, por ejemplo, en la mayor habilidad de los niños para aprender un nuevo idioma en comparación a la de los adultos. Sin embargo, los adultos y mayores también mantienen su capacidad de aprender. Los planteamientos tradicionales que consideraban el envejecimiento como un periodo de rigidez cognitiva, en términos de dificultad para establecer nuevos aprendizajes y mejorar habilidades, están cambiando. Numerosos resultados de investigación demuestran que la plasticidad es posible en las distintas etapas de la vida.

El término en inglés "*cognitive enhancement*" se refiere al resultado de utilizar diferentes medios (p.e., entrenamiento cognitivo, estimulación cerebral, meditación, ejercicio físico, estilo de vida o suplementos alimentarios) para mejorar el funcionamiento cognitivo. Este enfoque pretende entender y explicar cómo y por qué determinadas intervenciones pueden mejorar una función cognitiva concreta. En las últimas décadas, ha crecido considerablemente el interés por investigar la plasticidad cerebral y mejorar las funciones cognitivas mediante el entrenamiento cognitivo. Éste se refiere a aquellas intervenciones que implican la práctica sistemática con actividades demandantes para nuestras funciones cognitivas y que pretenden conseguir cambios y mejorar así funciones y procesos cognitivas específicos. Debido al papel tan importante que los procesos de control ejecutivo tienen en la cognición, en la literatura, y en el presente trabajo, encontramos intentos de fortalecerlos mediante el entrenamiento cognitivo.

En los tres primeros capítulos de este trabajo resumimos los modelos teóricos de funcionamiento ejecutivo más recientes, junto con sus bases neurales y las diferencias que existen entre individuos. También revisamos la literatura actual sobre entrenamiento cognitivo, que constituye un tema de investigación bastante controvertido actualmente con resultados a favor y en contra. Dentro de la sección experimental, describimos distintos estudios de entrenamiento cognitivo en los que evaluamos a participantes antes y después de las intervenciones para estudiar si funciones cognitivas tales como la memoria de trabajo, la inhibición, el modo de control cognitivo, la memoria episódica y la comprensión lectora, podrían mejorarse. Ya que no todas las personas se benefician igual de las intervenciones de entrenamiento, consideramos distintas variables que podrían modular los efectos del entrenamiento, tales como el nivel de rendimiento cognitivo con que los participantes comienzan o su motivación. Nuestros experimentos incluyen poblaciones de adultos jóvenes, mayores y niños con distintas habilidades de lectura. Por último, resumimos las principales contribuciones de nuestro trabajo, y discutimos su relevancia e implicaciones dentro de los modelos teóricos más recientes de *cognitive enhancement*.

Preface

"Any man could, if he were so inclined, be the sculptor of his own brain."

Santiago Ramón y Cajal.
Advice for a young investigator (1897).

Dear reader, try to think of your life on a regular day. During the journey, you might probably put together the list of tasks that you need to fulfill (go to work, meeting at three, finish writing a paper, go to the gym, and buy some fruit). You might keep track of time and, hopefully, finish work on time, while also keeping track of more than one thing at once. You will remember things that you have done previously and events that you have lived, and you might keep in mind a conversation while talking to others. You might put considerable effort in avoiding distractions and try not to make errors while reading, writing, and thinking. During that particular journey, and very single day of your life, you might take advantage of an essential hallmark of human beings: cognitive flexibility. We are dependent on learning great amounts of knowledge and skills; our brain and behavior constantly face new environmental demands and need to adapt accordingly. Humans are highly flexible in terms of how to react to given situations, which makes executive control processes necessary. For humans, being cognitively flexible is not a choice – it is paramount.

In executive control processes, we understand a range of cognitive mechanisms that are in charge of planning and regulating all our thoughts and actions. This work attempts to answer the questions of whether these executive control processes are plastic and whether it would be possible to modify them in different age groups. Plasticity is used to describe the property of our brain to change. It refers to changes in behavior and brain functions that result in new knowledge or enhanced skills, such as the acquisition of a new language or a greater ability to recall past events. It should be noted that the brain and one's behavior change continuously; however, plasticity implies some degree of stability amid that change. In comparison with cognitive flexibility, whereas the latter describes a current change in performance, plasticity means extending brain limits. Plasticity is more prominent during childhood, which can be exemplified in children's superior ability to learn a new language or their motor skills compared to those of adults. However, older adults do retain the ability to learn. The earlier view that old age was considered a period of rigidity in terms of learning and plasticity has changed, as research widely supports that plasticity shapes the human brain throughout life.

Cognitive enhancement is the use of any means (i.e., cognitive training, brain stimulation, meditation, physical exercise, life style, or food supplements) aimed at enhancing performance. It is an approach that seeks to understand and explain how and why an intervention can enhance a targeted cognitive function. In recent decades, there has been a steady interest in research on brain plasticity and in enhancing cognitive functioning by means of cognitive training. Cognitive training refers to interventions involving the systematic practice with cognitively demanding tasks, aimed at enhancing specific cognitive processes or knowledge structures, with the goal of plastic changes. Because of the essential role that executive control processes play in cognition, there have been attempts at strengthening them through cognitive training.

In the three first chapters of this work, we summarize the most recent models of executive functioning, their neural substrates, and the differences that exist across individuals. We also review the current literature on cognitive training, which is a highly controversial area of research nowadays, with findings both in favor and against. In the experimental section, we describe different studies of cognitive training, wherein we assessed participants before and after the intervention in order to explore whether cognitive functions, such as working memory, inhibition, cognitive control, episodic memory, and reading comprehension, could be improved. As no two people benefit from a training intervention in exactly the same way, we considered different variables that could modulate the effects of training, such as the cognitive level from which the participants started or even their motivation. Our experiments include populations of young healthy adults, as well as older adults and children with different reading abilities, and considered cognitive training as a means to counteract the negative effects of cognition. Finally, we summarize the main contributions of our work, discussing its relevance within the recent theoretical framework of cognitive enhancement.

PART I

INTRODUCTION

"It is imperfection - not perfection - that is the end result of the program written into that formidably complex engine that is the human brain, and of the influences exerted upon us by the environment and whoever takes care of us during the long years of our physical, psychological and intellectual development."

Rita Levi-Montalcini.
In praise of imperfection (1988)

CHAPTER I
Executive Control

Theoretical Models of Executive Control

A weighty property of the human brain – critical to adaptive behavior – are its flexibility and plasticity. Every situation we experience is essentially unique, and we need to be able to act appropriately in different contexts. This flexibility requires us to integrate current environmental contingencies with our internal goals and the goals around us (Stokes, Buschman, & Miller, 2017). In particular, the ability to maintain and flexibly regulate thought and action according to our internally represented behavioral goals is central to the psychological construct of *executive control* (Chiew & Braver, 2017).

A hallmark of human cognition is its flexibility, a property that is strongly related to executive control mechanisms (Chiew & Braver, 2017). Rather than merely acting from internal and external impulses, executive control includes all those mechanisms that are in charge of flexibly regulating, adjusting, and coordinating thoughts and actions in a goal-driven manner. Importantly, this ability demands a complex balance between maintaining current goal representations against distracting information, while also flexibly updating these representations as goals and environmental factors change (Chiew & Braver, 2017). The terms "cognitive control" and "executive control" are often considered similar, and even though they are not completely synonymous, they are highly similar regarding their operationalization. Thus, they will hereafter be used interchangeably to refer to the same concept.

There is a relative consensus in the literature regarding what kinds of tasks and situations require executive control, such as multi-tasking contexts, task switching, or tasks that require maintaining and updating relevant information while overriding irrelevant and interference stimuli.

In spite of this general agreement, we can find different theoretical models in the cognitive psychology literature on the structure of executive functions and, in particular, on whether they can be better described as a general unitary construct or as a composition of specific and distinct cognitive functions.

In an influential empirical work, Miyake and collaborators (2000; see also Miyake & Friedman, 2004, 2012) stressed the need to develop a theory of the organization and inter-relation of executive functions and their role in complex cognition. They followed a structural equation modeling approach to show that it might be useful to view executive functions as both unitary and diverse in nature. Using a latent variable analysis, they identified that despite their unity (indicated by shared features), three different executive control functions termed *executive functions* (EFs), emerged from performing a variety of tasks, namely, switching, inhibitory control, and updating. As a result, this modeling study revealed that due to their correlations, all three EFs were part of the same underlying construct and were not fully independent of each other. Nevertheless, they were clearly separable from each other, and they contributed somewhat differently to complex executive tasks (N. P. Friedman & Miyake, 2004; Miyake & Friedman, 2012; Miyake et al., 2000).

Within the three-factor model of EFs, *switching* involves shifting flexibly between tasks or mental sets. It has also been referred to as “attention switching” or “task switching,” like the ability to shift back and forth between multiple tasks, operations, or mental sets (Kiesel et al., 2010; Strobach, Salminen, Karbach, & Schubert, 2014). Evidence of optimized shifting derives from studies using task-switching practices that involve disengagement from irrelevant information (such as the task set of a previous task) and/or active engagement in relevant information (such as the task set of an upcoming task) (Berryhill & Hughes, 2009; Karbach & Kray, 2009; Strobach, Liepelt, Schubert, & Kiesel, 2012). These studies showed that the performance costs associated with shifting processes (such as larger reaction times in trials with switches between different tasks in contrast with trials with task repetitions) could be reduced with practice and, consequently, illustrate the optimization of the executive function of switching (Strobach et al., 2012, 2014).

Inhibitory control (IC) refers to deliberately overriding dominant, automatic, or prepotent responses when necessary. Inhibition implies the capacity to resist interference from internal representations as well as the complementary ability to inhibit a powerful response tendency (N. P. Friedman & Miyake, 2004). A prototypical inhibition task is the color Stroop task (Macleod, 1991), in which participants have to identify the ink color in which the words are written across trials, which can be congruent (GREEN in green ink) or incongruent (GREEN in black ink). Typically, reaction times in incongruent trials are larger than in congruent trails, indicating the requirement to override the tendency to produce a more dominant response in naming the color word. However, practice in the Stroop task can result in a reduction of the Stroop effect within the task itself, indicating a task-specific training effect through an increased reaction time reduction in congruent versus incongruent trials (Davidson, Zacks, & Williams, 2003; Dotson, Sozda, Marsiske, & Perlstein, 2013; Wilkinson & Yang, 2016). This effect suggests that practice facilitates interference processing by improving the suppression of reading processes in the Stroop task (Strobach et al., 2014).

Updating and monitoring information in working memory (WM) are an essential dimension of the executive functions proposed in Miyake's model (Miyake et al., 2000). They relate to the monitoring and coding of incoming information for the task at hand (Morris & Jones, 1990). Indeed, updating processes serve to revise items held in WM by replacing old information that is no longer relevant with newer, more relevant information (Miyake et al., 2000; Morris & Jones, 1990). For instance, updating plays a key role in tasks such as *n*-back type, in which participants are presented with a sequence of stimuli and are instructed to respond whenever the currently presented stimulus matches the one from *n* steps earlier in the sequence (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Smith & Jonides, 1997; Wilhelm, Hildebrandt, & Oberauer, 2013). The nature of this updating task involves the progressive increase of memory load (*n*-back level) and simultaneous updating, which also involves multiple EFs such as shifting between different stimuli modalities as well as the inhibition of previous irrelevant items (Jaeggi et al., 2008; 2010). Because of high executive control demands, practicing challenging tasks such as the *n*-back could lead to broad cognitive changes.

Within traditional models of WM, executive functions are often conceptualized as a system involved in coordinating and controlling the processing and storage of information in WM. Thus, WM simultaneously allows for the temporary storing and processing of information in a controlled manner in order to undertake complex cognitive tasks (Baddeley, 1996, 2003; Smith & Jonides, 1997). There are different theoretical models of WM, although most assume that it acts as a form of mental workspace (for reviews, see Baddeley, 2012; Wilhelm et al., 2013). Indeed, most models agree that WM usually acts at the interplay between memory and attention and that its capacity is limited (Baddeley, 2012; Oberauer, 2009). Reliable individual differences exist regarding how much information people can maintain in WM as well as how readily they do it in the face of distraction. Thus, individual differences in working memory capacity (WMC) place constraints on performing a wide range of other cognitive abilities (Engle, Kane, & Tuholski, 1999; Kane & Engle, 2002).

Different theoretical models emphasize the essential role of working memory updating. Miyake highlights updating as the EF in charge of monitoring and refreshing the information that is temporarily held in WM (Miyake et al., 2000, 2004, 2012). Oberauer (2009) defines WM as a system made of two dynamically interconnected parts: one in charge of temporally organizing information and another that dynamically binds this information to allow or inhibit responses (see also Wilhelm et al., 2013). In the multicomponent model of WM proposed by Baddeley and Hitch (1974; 2000), the *central executive* component represents an attentional limited capacity system that provides control for selecting and manipulating material in the rest of the subsystems (the phonological loop, visual sketchpad, and episodic buffer) (Baddeley & Hitch, 1974, 2000). WMC is the functional limit on how many, how well, and how quickly memory representations can become available in the face of interference and conscious shifts of focus in the service of ongoing cognitive activities (Baddeley, 2012). Thus, different functions need to be coordinated, such as the processing of task-relevant information, retrieval from long-term memory, attending to relevant information, inhibiting irrelevant information, as well as the scheduling of multiple tasks. Baddeley identifies the linkage between his influential model and others that relate more to the study of attention and underlines that the central executive has major similarities with the supervisory attentional system in the information processing model proposed by Norman and Shallice (1986). Along these lines, for Cowan (1988, 2010), the central executive also has a prominent position in WM, which is linked to attentional control, proposing that information is viewed as long-term memories held in the focus of attention. Cowan further stresses that the central executive should be seen as equivalent to the control processes of limited capacity or the effortful processing system described by Shiffrin and

Schneider (1977) and Kahneman (1975). Engle underlines that all EF tasks are constricted by a common executive attention construct (Engle, 1996; Unsworth, Redick, Heitz, Broadway, & Engle, 2009). Moreover, these authors emphasize the role of WM in inhibiting potentially distracting material and facilitating retrieval from long-term memory (Engle, 1996). In particular, they propose that performance on a complex WM task such as the operation span is made difficult by the need to protect memory of the presented items from *proactive interference*. This is the tendency for earlier items to be recalled by hindering access to more recent ones. In comparison, *retroactive interference* refers to the tendency for more recently acquired information to impede the retrieval of similar older memories (Kane & Engle, 2000, 2002).

Although the different theoretical frameworks might differ in the assumed underlying structure of the WM and executive control system, taken together, they all agree that WM allows for the simultaneous maintenance and processing of information. Because of this fundamental function, executive control has been shown to be a central determinant of higher-order cognitive functions that are highly relevant in daily life. On the basis of the previous and upcoming theoretical models, we place the focus of this dissertation on the functional properties of the cognitive processes that fall under the umbrella of EFs – namely, WM, IC, and cognitive flexibility – in an attempt to enhance them through practice and training.

As mentioned, executive control is one of the most important human psychological functions for success in a complex and rapidly changing world, and individual differences in how these functions perform seem to predict real-world outcomes. Thus, although there is some disagreement regarding the exact nature of EFs and their precise neural substrates (Banich, 2009; Braver & Cohen, 2001; Jurado & Rosselli, 2007; Kane & Engle, 2002; Miyake & Friedman, 2012), substantial evidence supports that executive control in fact plays an essential role in learning and academic achievement (Bull & Scerif, 2001; St. Clair-Thompson & Gathercole, 2006), knowledge acquisition (Blair & Razza, 2007; Danielsson, Henry, Rönnberg, & Nilsson, 2010), metacognition (Fernandez-Duque, Baird, & Posner, 2000), as well as emotional and self-regulation (Barkley, 2001; Hofmann, Schmeichel, & Baddeley, 2012).

Similarly, executive control is essential in memory retrieval. EFs have been shown to be involved in episodic memory tasks that require elaborate rehearsal, remembering the source of information, and when appropriate strategies for encoding and retrieval have to be generated (Anderson, 2003; Dobbins & Han, 2006; Román, Soriano, Gómez-Ariza, & Bajo, 2009). Indeed, patients with prefrontal cortex damage show substantial recall difficulty due to the disruption of control processes that support retrieval (Cabeza, Ciaramelli, Olson, & Moscovitch, 2009; Wagner, Maril, Bjork, & Schacter, 2001). Imagine that you intentionally want to retrieve what you had for dinner last night. Cognitive control might be necessary to focus the search on memory processes, carefully specifying what you are trying to remember, which may also include a retrieval strategy. Moreover, the cue to retrieving the specific meal you had (i.e., veggies in case you ate mushrooms) might need to be maintained in WM; in addition, control processes would help you to overcome interference from competing memories (i.e., peas); moreover, after retrieval, monitoring the search products would allow you to decide and evaluate whether the information you have retrieved was what you were actually looking for (Anderson, 2003; Baddeley, Eysenck, & Anderson, 2015). Indeed, damage to the prefrontal cortex disrupts many of these memory processes that rely on executive control (Szczepanski & Knight, 2014).

Furthermore, the need for executive control is especially strong in conflict situations when competing actions are activated; however, only one is appropriate and should be selected. Researchers have tried to transfer these situations to experimental tasks where cognitive control mechanisms can be rigorously tested in the lab. These tasks try to create scenarios in which reciprocal interactions between top-down and bottom-up processes are essential for solving a conflict situation within the experimental tasks. In these scenarios, relevant stimuli for successfully performing the task bias the selection toward the most appropriate response. Additionally, such stimuli may actively represent the task context in WM. These representations may bias attention to task-relevant information and trigger executive processes toward conflict resolution. Such goal-oriented executive processes might promote the inhibition of task-irrelevant information as well as the maintenance and retrieval of task-relevant information from working and long-term memory. The final result of this interaction would support the planning and execution of adaptive goal-directed actions and behavior (Braver, 2012; Chiew & Braver, 2017).

An additional and influential theory of cognitive control is the dual mechanisms of control account (DMC framework, Braver, 2012). According to this theory, cognitive control can be understood as operating in two primary modes, namely, *proactive* and *reactive*, which may be flexibly deployed to prompt goal-directed actions or thoughts and suppress inappropriate ones. In this way, it is proposed that the proactive control mode acts by actively maintaining task-relevant information in a sustained manner so as to be aware of impending interference and bias behavior in a goal-driven manner. From this perspective, proactive control may be understood to encompass early selection to prevent interference from cognitively demanding events and is characterized by the active maintenance of contextual representations in the prefrontal cortex (Braver, 2012; Braver, Paxton, Locke, & Barch, 2009). By comparison, the reactive control mode is thought to act by detecting and resolving interference at the time it occurs and may be conceptualized as a "late corrective" function to deal with already triggered conflicts (Braver et al., 2009). Additionally, reactive control may be implemented as a transient mechanism, which occurs in response to changing environmental demands or stimulus-triggered associative retrieval.

A very well-validated experimental task that provides sensitive and reliable individual differences in the use of proactive and reactive control strategies is the AX version of the Continuous Performance Task (AX-CPT). This is a delayed-response task requiring context maintenance and updating for successful performance (see Figure 1.1). On each experimental trial of the AX-CPT, participants must respond to pairs of letters (cue-probe) presented sequentially. They are required to respond "yes" when they are presented with the cue letter "A" followed by the probe letter "X." All other possible combinations of cues and probes require the non-target response ("no"). AX represents target trials, which usually occur at a higher frequency (70%), biasing participants' response toward "yes" throughout the task. Of the remaining three conditions – occurring at 10% of each trial – two of them represent the conflict trials (AY and BX), while BY trials constitute the baseline condition. In AY trials (target cue "A" – non-target probe "Y"), the contextual cue leads to a bias toward a proactive strategy to maintain the target response "yes," which must be overridden when the non-target probe "Y" appears. As for BX trials (non-target cue "B" – target probe "X"), there is also a need to maintain the contextual information – that the response should be "no," but it must be used to engage a reactive strategy and inhibit the tendency to respond "yes" at the moment that the target-probe is presented. Finally, BY trials (non-target cue "B" – non-target probe ("Y") also occur at a low frequency (10%) and are considered the control condition (Braver et al., 2009; Chiew & Braver, 2017; Morales, Gómez-Ariza, & Bajo, 2013).

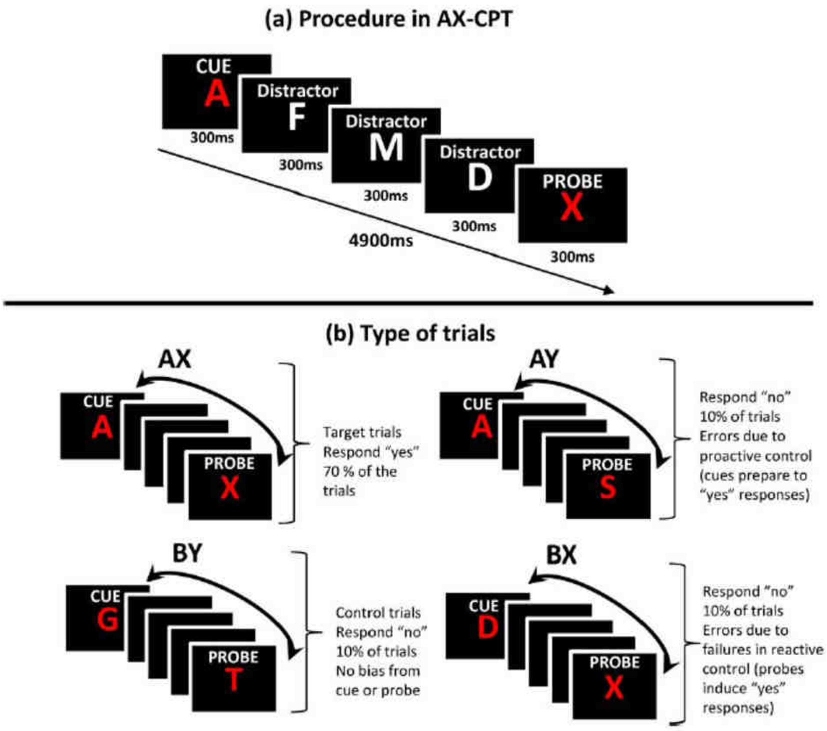


Figure 1.1. Schematic procedure of the AX-CPT paradigm (taken from Morales et al., 2013). (a) The series of stimuli in a typical target trial. (b) The four different types of trials, the correct response for each of them, and the proportion of a given trial during the task. AX are target trials ("yes" response, 70% of the trials). AY trials (10%) share the cue with the target trials and erroneously bias participants to expect the target probe. BX trials (10%) share the probe with the target trials, but the cues signal "no" responses. Finally, BY are control trials in which both the cue and probe differ from the target trials ("no" response, 10% of the trials).

Therefore, both types of conflict trials (AY and BX) reflect the adjustment between two modes of cognitive control: proactive and reactive. On one hand, errors in BX trials are thought to reflect a higher reliance on reactive control, revealing failures to maintain the "no" response after seeing the non-target B cue and to suppress a "yes" response to the target X-probe. On the other hand, errors in AY trials suggest greater reliance on proactive control, indicating the maintenance of context information and the preparation of the "yes" response, as well as a failure to reactively suppress the incorrect response when the non-target probe is presented. Thus, the extent to which interference is experienced in AY and BX trial conditions during task performance may serve as an indicator of relative tendencies toward proactive versus reactive control, since cognitive control during the AX-CPT task can be understood as operating in these two primary modes (Chiew & Braver, 2017).

The optimized balance between both modes of control is thought to be the basis of effective cognitive flexibility (Chiew & Braver, 2017). While both strategies are equally likely to lead to the correct performance on a cognitive control task, there are some situations in which one or the other might be more appropriate depending on factors such as individual characteristics or task demands.

Neural Basis of Executive Control

There is broad agreement that executive control is linked to the *frontal lobes*. The selection of strategies, conflict resolution, and the coordination and manipulation of cognitive operations – as the essential functions of executive control – appear to be related to the neuromodulator, dopamine (Bäckman & Nyberg, 2013; Colzato, Slagter, de Rover, & Hommel, 2011; Jongkees, Hommel, & Colzato, 2014; Wimber et al., 2011), and to involve the *prefrontal cortical regions* (PFC) such as the anterior cingulate (Botvinick et al., 2004; Bush et al., 2000; Carter, 1998; Posner et al., 2007). Many sources of evidence support this neural substrate of cognitive control (Braver et al., 2009; Burgess et al., 2011; Nelson et al., 2009; Roberts, 1998; Wiecki & Frank, 2013). Thus, for example, individual differences in prefrontal activity have been related to difficulty detecting and solving conflict during childhood development (Rothbart & Rueda, 2005), aging (Paxton et al., 2008), or pathological conditions such as schizophrenia (Edwards, Barch, & Braver, 2009; Lesh et al., 2013).

Although there is no doubt that the frontal lobes play a key role in executive control, there is much less agreement on the particular neural location of specific executive capacities. The prefrontal cortex is the cortical brain region that develops evolutionarily later across the lifespan

(Stokes et al., 2017). In particular, what may give the prefrontal cortex its special role in cognitive flexibility might be its connection throughout the brain. The prefrontal cortex is especially well situated anatomically to play a controlling role in cognition and act as a "central executive" (Cabeza et al., 1997; Della-Maggiore et al., 2000; Glabus et al., 2003). Subregions within the prefrontal cortex are densely interconnected within and across hemispheres; and also with many other cortical regions, with especially prominent connections to the temporal, parietal, and cingulate cortexes (Della-Maggiore et al., 2000). Moreover, the prefrontal cortex is closely interconnected with subcortical regions such as the basal ganglia, via the striatum, or the hippocampus (Stokes et al., 2017). Thus, given the anatomical position of the prefrontal cortex within the broader network of brain structures, it has been proposed as a sufficiently flexible neural structure, critically important for planning and executing sequences of actions, guiding activity throughout the brain in a way that accomplishes current tasks (Smith et al., 2001). However, structural anatomy is necessary but not sufficient to determine the role of the prefrontal cortex in cognition, and it highlights the necessity of considering how these network properties are functionally modulated by different task contexts (Stokes et al., 2017).

Duncan and Miller (2002) propose that prefrontal cortex neurons represent information in a highly dynamic manner, adapting rapidly and dynamically to the current task-relevant information, according to the principle of adaptive coding. This means that the prefrontal cortex constitutes a flexible pool of neural resources that can be recruited online (while performing the cognitive control task) to represent whatever information is currently most relevant for achieving behavioral goals (Duncan & Miller, 2002). In particular, neurophysiological studies demonstrate that, independently of the nature of the task, neurons from the prefrontal cortex can represent the relevant information (including what the task is), hold it "in mind," and then use this task-relevant information to plan future actions and guide current behavior (Stokes et al., 2017). According to Stokes et al. (2017), any mechanism of cognitive control must be able to selectively boost the relevant neural representations to accomplish the current task, while also suppressing undesired representations. However, this selection cannot be absolute, given that behavior in the real world is highly dynamic and continuously changing. Thus, cognitive control mechanisms must be sufficiently flexible to allow for rapid changes between behaviors (Stokes et al., 2017). Along these lines, the DMC account

(Braver et al., 2009; Braver, 2012; Chiew & Braver, 2017) postulates that the same lateral prefrontal cortex regions may implement different cognitive control modes on the basis of temporal activity dynamics, which would be modulated in response to external or internal conditions (Braver, 2012). For instance, proactive control is expected to be associated primarily with anticipatory and sustained activation of the lateral prefrontal cortex, which would reflect goal-maintenance activity; however, reactive control would entail the rapid engagement of transient activity in the lateral prefrontal cortex (in addition to activity in other brain regions) on an as-needed basis, which would reflect detection and/or resolution of interference only at specific times immediately preceding a response (Braver et al., 2009; Chiew & Braver, 2017). Along these lines, it has been found that maintaining and biasing task-relevant sets during task preparation is specifically associated with activity changes in the dorsolateral prefrontal cortex, while the processing of response conflict during task execution is specifically associated with activity in the anterior cingulate cortex (Botvinick et al., 2004). Furthermore, Niendam et al. (2012) have also provided evidence of the prefrontal neuronal substrate for executive functions. They conducted a meta-analysis based on neuroimaging studies in which they examined switching, planning, WM, and vigilance and determined common as well as specific brain-activation patterns in the prefrontal regions across these functions. In particular, they proposed a general activation network comprising the activation of prefrontal, dorsal anterior cingulated, and parietal cortices, supporting the idea of a higher-order common control system. However, at the same time, they also found evidence of specific activation patterns, depending on the executive task involved in the anterior prefrontal, anterior, midcingulate, and subcortical brain regions (Niendam et al., 2012).

Electroencephalography (EEG) is a widely applicable method for studying the working brain in real time. It involves recording the ongoing electrical activity of the human brain by means of the analysis of electrical voltage changes on the surface of the brain. The study of *event-related potentials* (ERPs, average brain responses to similar stimuli presented repeatedly) is a precise way of evaluating the brain's response to specific cognitive activities by time-linking an event to a specific component of the EEG (Czernochowski, 2015; Lopez-Calderón & Luck, 2014). A remarkable feature of this inexpensive and non-invasive technique is its temporal resolution. It allows for the monitoring of the effects of cognitive processing over a period of milliseconds, providing a picture of the way in which the brain reacts to specific events. Despite its high temporal resolution, EEG compromises its spatial resolution since the location of evoked responses is typically imprecise, and it is sometimes difficult to separate the influence of different components. However, the study of brain activity using EEG recording provides a useful tool to identify the role of the brain areas involved in successive processes of particular cognitive tasks (Lopez-Calderon & Luck, 2014). Studies focusing on the temporal dynamics of cognitive control using ERPs have also observed dual dissociations between distinct negative medial components associated with proactive control compared to greater medial posterior negativity associated with reactive control (West & Bailey, 2012).

Moreover, the study of *brain oscillations* – the analysis of oscillatory neural activity in different frequency bands – have a particularly high potential to shed light on the mechanisms underlying executive control. Specifically, oscillations provide temporal windows for neural firing and shape synaptic plasticity by synchronizing and desynchronizing neural assemblies (Simon Hanslmayr, Staresina, & Bowman, 2016). Increased synchrony between neuronal assemblies is reflected by increased power, whereas desynchronization is the result of decreased power at particular frequency bands (Simon Hanslmayr, Staudigl, & Fellner, 2012). This latter desynchronized activity has been proposed to reflect efficient information encoding, and in particular, power decreases in alpha and beta frequencies (8–20 Hz) might represent more richly encoded and more efficiently retrieved memory traces (Hanslmayr et al., 2012, 2016). Regarding the brain mechanisms proposed to detect conflict, the anterior cingulate cortex constitutes the brain structure that acts as an early developed conflict detector (Cohen, 2014). This cortical region, together with the dorsolateral prefrontal cortex, has been proposed as a network of frontoparietal regions related to conflict monitoring and response inhibition (Barch et al., 2001; Cohen, 2014; Garavan, Hester, Murphy, Fassbender, & Kelly, 2006). Furthermore, time-frequency-based data analyses of EEG allow for inferences regarding neural oscillations and have revealed that the neural response to conflict detection is an increase in theta band (4–8 Hz) power over midfrontal electrodes (Cohen, 2014).

The neural activation patterns that support executive functions can differ across a wide variety of tasks, context situations, and especially across individuals. Therefore, considering individual differences in executive control functions has become essential in an attempt to enhance cognitive functions.

Individual Differences in Executive Control

Individual differences might influence performance in executive control tasks and become relevant predictors and moderators of performance on a wide variety of cognitively demanding tasks, including reasoning, problem solving, episodic retrieval, reading comprehension, and overall academic performance (Engle et al., 1999). The literature regarding the manner in which individual differences impact cognition is vast, as many factors can be considered sources of "individual differences," such as age, baseline performance, gender, personality traits, or motivation (Katz, Jones, Shah, Buschkuehl, & Jaeggi, 2016). To begin with, in this section, differences in age and baseline performance would be considered important modulators of executive control functioning.

The limits of WMC have been associated with prefrontal functions and are of interest as a factor accounting for individual differences in cognitive performance (Kane & Engle, 2002). Because the WM system allows for information maintenance in the presence of interference, its variability across individuals predicts such important skills as reading comprehension (Daneman & Carpenter, 1980; McVay & Kane, 2012), learning programming and logic skills (Kyllonen & Stephens, 1990; Shute, 1995), multitasking (Bühner, König, Pick, & Krumm, 2006; Hambrick & Oswald, 2007), and solving novel problems (A. R. a. Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle et al., 1999; Kane, Conway, Hambrick, & Engle, 2007; Martinez & Colom, 2009). Furthermore, individual variability in WM has also been associated with goal maintenance and context processing ability and may thus act as a potentially important determinant of proactive control (Unsworth et al., 2009). Recent studies using adaptations of the AX-CPT paradigm suggest that task performance in high WM individuals tends toward proactive control (L. Richmond, Redick, & Braver, 2015). In addition to WM, related cognitive dimensions such as fluid intelligence might also interact with other task factors to modulate cognitive control shifts between proactive and reactive control modes. Burgess and Braver (2010) found that individuals with lower fluid intelligence (low Gf) showed increased tendency toward reactive control – rather than a shift toward proactive control – under conditions of high interference expectancy in WM paradigms. By contrast, high Gf individuals evidenced an increased tendency toward proactive control, with reduced interference and a shift of prefrontal cortex dynamics (Burgess & Braver, 2010). Following the relationship between WM and IC, Kane and Engle (2000) demonstrated that interference effects are reliably greater in low WM participants, suggesting that resistance to interference from previous information held in WM is a critical factor (Kane & Engle, 2000). In a similar vein, Conway (2001) also showed that low-span WM participants were less able to inhibit irrelevant material (Kane, Bleckley, Conway, & Engle, 2001). These and other studies suggest that there is an essential link between WMC and the ability to resist interference. However, it is entirely reasonable to assume that both reflect some more general executive capacity that plays an equally important role in cognitive functions.

In addition to individual differences regarding cognitive capacities, age-related differences have also been reported in the adjustment of proactive and reactive control mechanisms (Zanto & Gazzaley, 2017). While the typical pattern of healthy young adults reveals a greater reliance on proactive control (Braver et al., 2009; Braver, 2012; Morales, Gómez-Ariza, et al., 2013; Morales, Yudes, Gómez-Ariza, & Bajo, 2015), older adults tend to employ more of a reactive control mode (Braver, Satpute, Rush, Racine, & Barch, 2005; Paxton et al., 2008; Zanto & Gazzaley, 2017). Rather than a generic deficit in cognitive control functions, this tendency in older adults seems to reflect a shift from proactive to reactive control, presumably because proactive control is cognitively more demanding (Braver, 2012). More recently, Xiang et al. (2016) proposed that age-related differences in cognitive control mainly relate to reactive control mechanisms rather than proactive ones. Specifically, older adults seem to experience lower processing of contextual information and lower levels of effectiveness in IC, thus rendering them less proficient at reducing interference (Xiang et al., 2016; for a similar interpretation based on findings with non-invasive brain stimulation, see Gómez-Ariza, Martin, & Morales, 2017). While this will be addressed in greater detail in upcoming sections, this fact further supports the hypothesis that a reduction in inhibition efficiency is an important component of age-related cognitive changes (L Hasher, Stoltzfus, Zacks, & Rypma, 1991).

In summary, in this chapter, we have discussed the critical role of executive control in controlling internal processes and behavior. We have also tried to evidence the complexity of cognitive control processes in behavioral and neural terms and the manner in which their functioning is influenced by individual differences. However, in spite of its complexity and because of the essential role of executive control in successful adaptive behavior, recent research has focused efforts on the promising question of how executive control might best be improved.

CHAPTER II
Training Executive Control

Brain Plasticity

Throughout the lifespan, people need to adapt to the demands of changing contexts and dynamic social environments. Indeed, this capacity to be almost infinitely adaptable to different circumstances is what makes humans such a successful species. As the previous chapter demonstrated, there is general agreement that executive control plays a paramount role in achieving such adaptive goals and that executive-related deficits could be a major handicap (Diamond, 2013; Jolles & Crone, 2012; Roberts, 1998).

The term *plasticity* has been used in brain science to refer to the modifiability of the neural organization, which may account for changes in a person's cognitive functioning in response to either short or long-lasting adaptation (Berlucchi & Buchtel, 2009; Demarin, Morovic, & Bene, 2014). A classical definition of *brain plasticity* describes it as our "brain's ability to change, remodel and reorganize its structure and function for better ability to adapt to new situations" (James, 1890; Ramón & Cajal, 1911). The fact that the human brain is capable of continuous functional changes is based on the principle that the neural network is not fixed and that, as a result of experiences, changes occur and disappear dynamically throughout our lives (Diamond, 1996; James, 1890). While we repeatedly practice one activity, such as a sequence of movements or a mathematical problem, neuronal circuits are being formed, leading to a better ability to perform the practiced task with less waste of energy. Once we stop practicing a certain activity, the brain will redirect these neuronal circuits through a much known "use it or lose it" principle. Thus, brain plasticity could lead to many different neuronal effects such as habituation, sensitization to a certain position, or even recovery following brain injury (Berlucchi & Buchtel, 2009; Demarin et al., 2014; Diamond, 1996).

One way to understand plasticity is to observe the effect of applying training interventions and to measure their impact in an attempt to identify the mechanisms underlying changes in cognitive functioning as well as in the brain (for reviews, see Hertzog et al., 2009; Karbach & Verhaeghen, 2014; Morrison & Chein, 2011; Schubert et al., 2014). Therefore, brain plasticity is the basis of the proposal that cognitive functioning can be enhanced by means of training. The typical training study is designed as a pre-post longitudinal experiment in which subjects are assessed on some cognitive capacity immediately before and after an extensive intervention. Classical empirical studies have attempted to enhance human cognition by considering a wide range of targeted functions and training procedures. For example, Chase and Ericsson (1982) trained a subject in digit span, enabling him to expand his digit span from an average of 7 to 88 after 44 weeks of practice (Chase & Ericsson, 1982). Unfortunately, the participant was not able to use this enhanced skill for anything other than digits.

Training implies that participants will improve their performance by working across several regular sessions over an extended period. The basic idea is that during cognitive training, participants repeatedly activate the neural regions involved in dealing with the training tasks (Buschkuehl, Jaeggi, & Jonides, 2012; Hsu, Novick, & Jaeggi, 2014; Hussey & Novick, 2012; Olesen, Westerberg, & Klingberg, 2004), which enhances the cognitive function supported by the specific neural region. Indeed, systematic practice of a particular task could establish new anatomical pathways or strengthen existing ones that are optimized for repeated scenarios and cognitive routines (Stokes et al., 2017). As a consequence, training effects would generalize and transfer to non-trained tasks, which also involve the targeted training domain, and the underlying trained brain areas (*near transfer*) (Beauchamp, Kahn, & Berkman, 2016; Erika Borella, Carretti, Riboldi, & De Beni, 2010; Lee, Lu, & Ko, 2007; Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009; Woodworth & Thorndike, 1901). In support of this, by using fMRI, Klingberg and colleagues (2004) found that five weeks of practice on WM training led to increased activation in the frontal and parietal cortical regions, which have widely been related to WM (Olesen et al., 2004). Furthermore, training effects could go beyond the trained domain and show benefits in measures that are considerably different from the training task, as long as they are associated with the trained process and share comparable neural circuits (*far transfer*) (Borella et al., 2010; Dahlin, 2013; Jaeggi et al., 2008). Most views regarding transfer suggest that the likelihood and strength of far transfer vary as a function of the similarity in processing demands between the training and transfer tasks. Thus, one would expect that at the behavioral level, transfer effects could be expected in potentially related cognitive functions, thus enhancing performance in a variety tasks that, although untrained, and share the same cognitive mechanism as the targeted trained processes (Morrison & Chein, 2011). Von Bastian and Oberauer (2013) propose two different mechanisms to explain transfer effects – on one hand, enhanced capacity, and on the other, enhanced efficiency – using available capacities (von Bastian & Oberauer, 2013). Enhanced efficiency has been proposed to act at a general level, such as faster encoding or attentional processes that, when improved, would generalize to different contexts (von Bastian & Oberauer, 2013). However, enhancing capacity, especially when referred to WM, remains the most widespread focus of most training studies (Klingberg, 2010).

An additional and complementary framework for the study of plasticity is the mismatch model proposed by Lövdén (2010). According to Lövdén, plasticity denotes the capacity for change in the brain structure, induced by a mismatch between the demands of the environment and the current functional supply that the brain can momentarily offer (Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010). Thus, if training is challenging but manageable with a high degree of effort, it could promote a prolonged imbalance between cognitive resources and situational demands. Such a mismatch would be triggered at the limits of individual cognitive capacities and foster functional and structural brain changes in the possible ranges of individual cognitive performance (Lövdén et al., 2010). However, if the system is capable of responding to the task requirements due to its existing flexibility and can afford the training tasks within the existing limits of cognitive resources, no mismatch would arise, no plastic change would be necessary, and no transfer would be induced (Lövdén et al., 2010). In other words, according to Lövdén (2010), the system needs to experience mismatch, which means that the new environmental requirement needs to lie within the limit of task difficulty, being too high or too low to promote experience-dependent plastic changes. As a result, executive control training needs to maintain adaptive task-difficulty conditions to foster plastic changes by permanently keeping executive demands at the individual limit and, therefore, enabling adaptation and generalization to new circumstances (Lövdén et al., 2010; Strobach & Karbach, 2016).

Cognitive Training as a Tool in the Study of Brain Plasticity

Given the essential role that executive control seems to play in efficient cognition and successful behavior regulation, a large and growing body of empirical work is being conducted in an attempt to enhance it. Thus, different types of training interventions have sought to better understand whether, how, and under what conditions different training interventions produce desirable improvements, even in the short term. Last decade has seen an explosion in the development of cognitive training research, resulting on a large body of published and unpublished results. Training effects are typically operationalized as increases in performing certain cognitive tasks between pre- and post-training, compared to performance changes in *passive* (with no instructed activities) or *active* control groups (with an instructed activity by clearly differentiating the targeted trained cognitive processes (Clark, Lawlor-Savage, & Goghari, 2017; Shipstead, Redick, & Engle, 2012). A substantial number of studies have found near transfer effects after training WM, IC, or attentional control, even though far transfer effects remain limited and inconclusive (Enge et al., 2014; Melby-Lervåg, Redick, & Hulme, 2016; Morrison & Chein, 2011; Schwaighofer, Fischer, & Bühner, 2015; Spierer, Chavan, & Manuel, 2013; Sprenger et al., 2013; Thorell et al., 2009).

Training studies may differ in terms of the type of executive control process targeted by the training activities. WM is perhaps the EF domain that has attracted the largest number of training studies because of its well-known central role in cognition and its relationship with high-level abilities (Jaeggi, Buschkuehl, Shah, & Jonides, 2013; Klingberg et al., 2005; Morrison & Chein, 2011). Most studies involve the use of computer-based programs that require participants to practice, through increasing levels of difficulty, the monitoring, updating, and manipulation of information in memory. Several studies have demonstrated the positive effects of WM training in different age groups (Erika Borella, Carbone, Pastore, De Beni, & Carretti, 2017; Söderqvist, Nutley, Ottersen, Grill, & Klingberg, 2012; Stephenson & Halpern, 2013), with transfers to trained and untrained domains such as mathematical performance (Bergman-Nutley & Klingberg, 2014; Dahlin, 2013), reading abilities (Chein & Morrison, 2010; Dahlin, 2013; Karbach, Strobach, & Schubert, 2014;

Loosli et al., 2012), or reasoning and fluid intelligence (Au et al., 2014; Borella et al., 2010; Jaušovec & Jaušovec, 2012; Klingberg et al., 2005; see also Harrison et al., 2013; Chooi & Thompson, 2012; Redick et al., 2013 regarding failure to find far transfer effects after WM training; for reviews, see Dougherty et al., 2016; Bogg & Lasecki, 2015; Schwaighofer et al., 2015; Melby-Lervåg & Hulme, 2013; Melby-Lervåg et al., 2016).

Some other studies have focused on training IC processes (Spierer et al., 2013). Although several of these studies have failed to find behavioral transfer effects after training IC (Berkman, Kahn, & Merchant, 2014; Enge et al., 2014; Thorell et al., 2009), others have found positive near and far transfer effects after task-switching training across the lifespan of healthy individuals (Julia Karbach, & Kray, 2009), training-related benefits in fluid intelligence scores in children after executive control training (Liu, Zhu, Ziegler, & Shi, 2015; Rueda, Checa, & Cómbita, 2012; Rueda, Rothbart, Mccandliss, Saccomanno, & Posner, 2005), and near transfer effects in normal developing children (Dowsett & Livesey, 2000) and those with executive control deficits (Kray, Karbach, Haenig, & Freitag, 2012). In addition to the behavioral effects, brain activity studies have reported different activation patterns in the brain network associated with IC: namely, increased activation in the right inferior frontal gyrus after training response inhibition in young adults (Berkman et al., 2014) or a more adult-like pattern of EEG markers (dorsoprefrontal negativity linked to the anterior cingulate gyrus) in six-year-old children after a five-day training with tasks involving conflict resolution (Rueda et al., 2005).

While studies (with some exceptions) focusing on either WM or IC training show transfer effects (for a meta-analysis of studies that trained WM, switching, and IC in older adults, see Karbach & Verhaeghen, 2014), to date, very few studies have directly compared the effects of WM and IC training across tasks (for a comparison between WM and IC training in preschoolers, see Thorell et al., 2009). Thus, this question is interesting from an empirical point of view. The direct comparison of these two types of programs is also theoretically interesting since, according to some proposals, WM and IC seem to represent two separate executive functions and may, therefore, have separate effects (Miyake et al., 2000).

As mentioned earlier, despite the studies showing positive results after training in different populations, their effectiveness remains controversial, and far transfer effects are not always obtained (Clark et al., 2017; Melby-Lervåg et al., 2016; Schwaighofer et al., 2015; Simons et al., 2016). Melby-Lervåg and Hulme (2013) conducted a meta-analysis and concluded that there was good evidence of short-term gains that generalize to tasks other than those studied, although the maintenance of such effects was less encouraging and provided very little evidence of generalization beyond the laboratory. Since this publication, a considerable number of reviews and meta-analyses employing different methodological approaches have tried to answer the question of whether or not training succeeds. However, despite the pessimism of some publications – as stated by Gathercole and colleagues (2012) – the great practical value of enhancing executive control makes worthwhile empirical attempts to study brain plasticity by means of cognitive training (Gathercole, Dunning, & Holmes, 2012).

Taking into account such heterogeneity in the literature, the results stemming from different training studies need to be carefully interpreted, with special attention to methodological differences that could account for the significant variance and diversity of findings across studies. Thus, for example, the presence and nature of control groups is an essential requirement in dissociating the effectiveness of training (Clark et al., 2017; Dougherty et al., 2016; Melby-Lervåg et al., 2016). For example, there are *passive control* groups – no-contact controls – whose use in training studies has repeatedly been criticized, considering that the potential training benefits of experimental groups, when compared to untrained controls, could be driven mainly by simple practice effects (Clark et al., 2017). In comparison, *active control* groups refer to participants who are treated with a no-targeted intervention. These controls use less demanding regimes that are not expected to be effective, such as training activities that are similar to the experimental condition, but operate at a lower difficulty level (Jaeggi et al., 2008; Karbach & Verhaeghen, 2014), or activities that involve no executive control demands, such as processing speed (Lawlor-Savage & Goghari, 2016; Peng, Wen, Wang, & Gao, 2012; Takeuchi & Kawashima, 2012). In this context, active controls may enable researchers to uncover the specificity of different cognitive training procedures by maintaining similar levels of motivation and reducing the possibility of placebo effects – guarding against gains simply being the result of receiving more attention (Boot, Simons, Stothart, & Stutts, 2013; Dougherty et al., 2016).

Moreover, training procedures targeting specific cognitive abilities (such as WM or IC) allow for more restricted attributions on training-derived transfer effects (Erika Borella et al., 2010; Jaeggi et al., 2013; Rueda, Checa, & Cómbita, 2012) than complex procedures that include multiple cognitive domains (memory, attention, IC, reasoning, etc), which seem to be less specific and often yield more limited transfer effects (Baniqued et al., 2014, 2015; Dovis, Van Der Oord, Wiers, & Prins, 2015; Hardy et al., 2015; S.-C. Li et al., 2008). In addition, although many studies have used single training tasks (Carretti, Borella, Zavagnin, & De Beni, 2013; Jaeggi et al., 2008; Loosli et al., 2012a; Rueda et al., 2005), the potential generalization of the training might be enhanced by the use of different tasks in recruiting the particular targeted process. Switching between multiple tasks that target the same process during training might promote cognitive flexibility by adapting general processes and strategies. In this sense, using more than one training task would prevent the use of very specific task-strategies that would more likely be implemented when training is based on a single task (Bherer et al., 2005; Dahlin, Nyberg, Ba, & Neely, 2008; Schmidt & Bjork, 1992; Schwaighofer et al., 2015). The effectiveness of training has also been attributed to the fact that participants work with adaptive procedures that adjust the demands of the task to individual performance. The adaptiveness of the training procedures means that they remain constantly novel and challenging and promote participants' interest and motivation during the entire training procedure (García-Madruga, Gómez-Veiga, & Vila, 2016; Shin, Lee, Yoo, & Chong, 2015). In sum, executive control training interventions frequently engage different processes that include encoding, maintaining, and inhibiting information, simultaneously managing two tasks, sustaining and shifting attention, and reducing interference. Taken together, these aspects are believed to promote learning and, in particular, enable the training to favor transfer effects (Erika Borella et al., 2017).

Individual Differences in Cognitive Training

There is considerable evidence to suggest that cognitive training is not equally effective for all participants across studies. When examining the transfer of executive control training for untrained tasks, it is not always clear why some seem to benefit more from training than others. It is likely that certain individual differences, such as baseline capacities and biomarkers, training performance, age, or even motivation, among many others, can determine the extent to which participants can improve during the training and, afterward, transfer to the untrained tasks (Benjamin Katz, Jaeggi, Buschkuehl, Stegman, & Shah, 2014; Könen & Karbach, 2015; Taya, Sun, Babiloni, Thakor, & Bezerianos, 2015). These differences have significant implications not only for our ability to improve our theoretical understanding of cognitive plasticity, but also for the real-world efficacy of any individual intervention (Katz et al., 2016).

In most of the recent training studies, positive effects of executive control training over cognitive functions have been analyzed on the group level. However, because individual differences in training-derived gains are often very large, the pattern of results concerning its role in training-related performance gains and transfer effects is rather mixed. This is particularly critical in children and older adults because they are likely to differ more from each other than young adults, and simple between-group comparisons might not be sufficiently fair to account for individuals' strengths and weaknesses.

To begin with, individual differences in cognitive resources related to baseline performance might predict training outcomes (see Jaeggi et al., 2014, for evidence in young adults and Borella et al., 2017, for older adults). Analyzing this potential predictor will enable us to test the two proposed theoretical explanations for individual differences in training-related performance gains, namely, those about the *compensation* and *magnification* effects of process-based training on cognition (Karbach & Kray, 2016). On one hand, if there is a *magnification* effect (also called the Matthew or scissors effect), then individuals who already perform well will benefit the most from executive control training. In other words, "the rich may get richer," since high-performing participants may have more efficient cognitive resources and, therefore, be in a better position to learn and implement new abilities. Thus, baseline cognitive performance should be positively associated with training-related gains, and the training should result in a magnification of age and individual differences (Jaeggi et al., 2013). In fact, there are some earlier studies supporting this account, most of which are from the field of memory-strategy training (for a review, see Rebok et al., 2007).

On the other hand, if there is a *compensation* effect, training might be helpful for those who needed it most. High-performing individuals will benefit less from the training because they are already functioning at their optimal level, close to their ceiling, and may thus have less room for improvement. In this case, age-related and individual differences should be reduced after the training, and baseline cognitive performance should be negatively associated with training-induced gains (Carretti, Borella, Elosúa, Gómez-Veiga, & García-Madruga, 2017). Evidence supporting this account comes from studies focusing on EF training, revealing that training-induced benefits are larger in children and older adults than in younger adults (Karbach & Unger, 2014; Strobach & Karbach, 2016; Zinke et al., 2014; Zinke, Zeintl, Eschen, Herzog, & Kliegel, 2011). Figure 2.1 illustrates the compensation effect after executive control training.

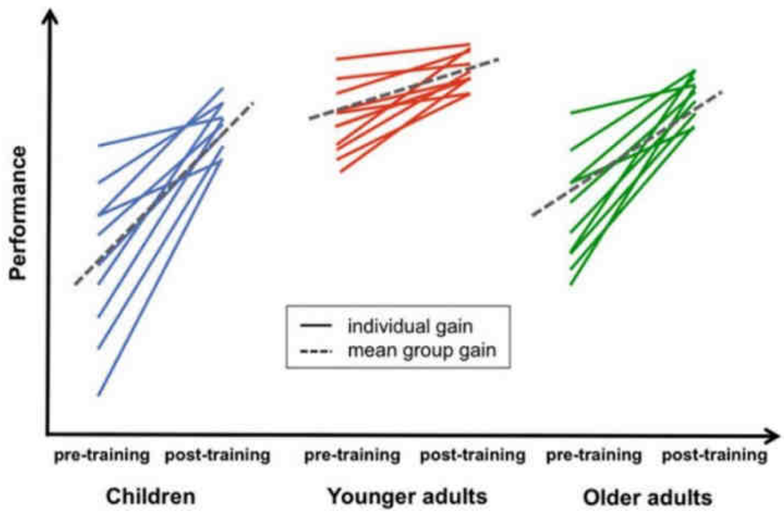


Figure 2.1. Compensation effects after EF training. Taken from Karbach and Kray in Strobach and Karbach (2016). Illustration of the compensation effects after EF training. The figure reveals the reduction in inter-individual differences in performance after the training, the reduction in age group differences after the training, and the negative correlation between the baseline cognitive performance at the pre-test and training gains.

Although few studies have specifically looked at how pre-test performance on transfer tasks may influence transfer gains, a recent study found that individuals who performed worse at the pre-test on transfer tasks showed greater improvement in these tasks following training (Hardy et al., 2015). This is also consistent with the results of the ACTIVE training project with older adults, which found that lower baseline performers recorded greater improvement after a period of cognitive training (Ball et al., 2002; Willis & Caskie, 2013).

Studies have also revealed a close relationship between training improvement and the extent of transfer and have found that the amount of improvement in the training task does contribute to a number of transfer gains in certain executive control and verbal WM tasks (Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Morrison & Chein, 2011; Schmiedek, Lövdén, & Lindenberger, 2010). However, it is worth keeping in mind that the source of individual differences in baseline performance may differ across studies. In some studies, lower baseline individuals may have less experience or even be younger or older (Katz et al., 2016). It is also possible that different training paradigms may result in different patterns of performance across individuals with high and low baseline capacities. For example, process-based training often results in higher gains for individuals with low baseline performance, whereas strategy-based training paradigms generally result in greater gains for high baseline individuals (Karbach & Unger, 2014). Thus, it becomes essential to consider not only individual differences that may influence baseline performance, but also training paradigm characteristics. While most of the previously described studies provide some evidence that low-performing individuals may stand to benefit more from training than those with higher baseline capacities, the relationship between baseline ability and transfer seems to be fairly complex and might also be influenced by methodological differences such as the design of the intervention and the sensitivity of the outcome measures.

Another relevant factor that has been proposed as a potential modulator of training and transfer effects across studies is age, independently of other factors. Several studies have found that improvements in untrained tasks are smaller for older adults than for younger adults (Brehmer, Westerberg, & Bäckman, 2012; Schmiedek et al., 2010; Zinke et al., 2014) and even smaller for old-older adults when compared to young-older adults (Erika Borella et al., 2014). However, in this field, results are also inconsistent across studies. For example, while one meta-analysis found no difference between younger and older adults in transfer improvement (Karbach & Verhaeghen, 2014), another found that younger adults improved more in these tasks than older adults (Wass, Scerif, & Johnson, 2012).

Finally, variables such as motivation, engagement, and beliefs about the potential benefits of cognitive training heavily influence training improvement and transfer. Some studies reporting positive transfer effects informed participants that they were conducting an intervention that could improve their cognitive functions during the study (Jaeggi et al., 2008, 2013; Klingberg et al., 2005), whereas others, actually reporting null effects, simply mentioned to participants that they were going to practice computerized tasks (Redick et al., 2013). Jaeggi et al. (2013) suggest that personal beliefs about the malleability of cognitive functions may contribute to the amount of transfer in the sense that those who believed that cognitive capacities could be improved experienced larger transfer gains following training. Regarding motivation during the training, the inclusion of "game-like" elements in training paradigms could also impact participants' engagement. There is some evidence that game elements – such as feedback, scoring, or animations – may influence performance on the tasks involved and that adding excessive game-like features may undermine training and transfer if they distract participants from the core task (Katz, Jaeggi, Buschkuehl, Stegman, & Shah, 2014).

Taking this into account, the training studies included in this dissertation made use of the Cognitive Training Program of the University of Granada (PEC-UGR)[1] (Maraver, Bajo, & Gomez-Ariza, 2016). This program includes a battery of EF training activities that could be adapted to the specific target population and combined according to the methodological constraints of the training design. We designed these batteries and considered both the neural basis of the cognitive processes underlying the activities and the logic of the experimental procedures traditionally used to evaluate executive control. As an example of the IC activities, the training included versions of i) the Stroop task, in which participants had to select coins/numbers contained in congruently or incongruently

[1] The Cognitive Training Program (PEC-UGR) was developed collaboratively between professors M. Teresa Bajo and M. Rosario Rueda from the Department of Experimental Psychology, the University of Granada.

sized bags; ii) a conflict resolution task, where a sample of animals was presented, and participants were asked to search for a target match from a set of distractors displaying congruent/incongruent shaped/colored animals; and iii) the Go/No-Go and Stop-Signal tasks, in which participants had to respond to matching shapes (a robot and a screw) and stop their response when faced with a rusted-looking shape; iv) or switching tasks, based on the Wisconsin Card Sorting Test, in which pictorial stimuli (cards with geometrical figures) had to be sorted according to a particular rule that changed after a certain time, thus requiring flexibility to shift the categorization criteria. Regarding WM training, the tasks represented versions of i) the *n*-back task, in which participants had to monitor sequences of open/closed windows from a six-window display presentation and press a key whenever the open window was the same as the window *n* trials back; ii) WM updating, which consisted of the serial presentation of objects of different sizes that were introduced in boxes. The participants were asked to recall the two to six largest/smallest elements from the series; and iii) dual span tasks, in which participants were asked to recall the shape and color of an increasing number of animals; they were then asked to select the animal that matched one of the study animals, from a set of distractors, while searching for the items maintained in memory. Finally, this cognitive training program also allowed us to create non-executive control demanding activities in which the active control groups could participate, involving only processing speed, without any requirement for executive control.

Despite the large body of literature that seeks to evidence enhanced cognition after executive control training in healthy populations, there is also a growing body of research that attempts to show the potential benefits of training in populations that, across the lifespan, suffer from deficits in executive control-related functions (Brehmer et al., 2012; Dahlin, 2010; Kueider, Parisi, Gross, & Rebok, 2012; Weicker, Villringer, & Thöne-Otto, 2016). Cognitive control abilities enable most activities of daily living, such as safely and effectively navigating our environment, and the consequence of impaired cognitive control can severely alter quality of life. Here – and in addition to a population of young, healthy adults – two different group conditions were addressed, in particular, healthy older adults and children with reading difficulties.

Executive Control Functions and Training in Aging

Becoming older is associated with impairments in cognitive performance and declines in prefrontal cortex functioning (Denise C Park et al., 2002). When a cognitive task involves a high level of cognitive control, such as an interference task, deficits in cognitive control also become evident among healthy older adults (Nessler, Friedman, Johnson, & Bersick, 2007; West & Bailey, 2012). Older adults have been shown to have not only difficulties in inhibition – a mechanism for solving interference – but also in detecting interference, for example, in memory recall and selection. Compared to younger adults, older adults exhibit lower grey and white matter volumes, particularly in the prefrontal and parietal cortices (Gordon et al., 2008; Raz, Ghisletta, Rodrigue, Kennedy, & Lindenberger, 2010). Given the prominent role of the prefrontal cortex in cognitive control (Paxton et al., 2008; Roberts, 1998; a D. Wagner et al., 2001), many theories of cognitive aging consider alterations of the prefrontal cortex as a primary contributor to the age-related declines in cognitive control (Dempster & Vegas, 1992; L Hasher et al., 1991; Cindy Lustig, Hasher, & Zacks, 2007; Reuter-Lorenz & Cappell, 2008; Reuter-Lorenz & Lustig, 2005).

In response to these anatomical changes, compensatory neural activity may serve to maximize inefficient neural resources, especially in the prefrontal cortex, to uphold behavioral performance. Evidence now exists to support the age-related compensation of both sensorial impairments (visual or auditory deficits) and reduced neural resources by engaging greater cognitive control. In particular, the cognitive reserve hypothesis (Stern, 2002), the compensation-related utilization of neural circuit hypothesis (Reuter-Lorenz & Cappell, 2008; Reuter-Lorenz & Lustig, 2005), and the scaffolding theory of aging and cognition (Denise C. Park & Reuter-Lorenz, 2009) all suggest that compensatory mechanisms may be successfully engaged, but only until a capacity limit is reached. Thus, these compensatory mechanisms might not always be engaged (if the task exceeds the capacity limits), or they may be engaged but fail to sufficiently compensate (Zanto & Gazzaley, 2017). Therefore, although older adults may use and benefit from compensatory mechanisms during tasks with low demands, they might exhibit performance declines as the task demands increase, in which case, age-related deficits become evident in multiple cognitive control domains, such as IC, WM, task switching, and multitasking (Zanto & Gazzaley, 2017). Fortunately, the brain remains plastic throughout the lifespan, and many age-related declines in cognitive control may be reversed through stimulation demand such as cognitive training (Dahlin et al., 2008; Karbach & Verhaeghen, 2014; Lampit, Hallock, Suo, Naismith, & Valenzuela, 2015).

In accordance with the hypothesis of specific age-related cognitive deficits during high task demands, older adult's exhibit slowed neural processing associated with attentional selection (Wang, Fu, Greenwood, Luo, & Parasuraman, 2012). In addition, whereas younger adults recruit additional prefrontal cortex and parietal regions under high task demands, older adults seem to be unable to recruit these additional neural resources (Prakash et al., 2009), and in high task demands, they exhibit similar network activity during low task demands as younger adults (Prakash et al., 2009). This provides evidence that older adults engage all available resources during low-demand tasks, which prevents the recruitment of additional compensatory mechanisms during high-demand tasks. Thus, these results support theories and hypotheses that suggest that the use of compensatory mechanisms in aging is limited by cognitive resources, which may become unavailable with increased task demands.

An additional general deficit observed during aging is a general slowing down of neural processes that impact stimuli detection, a fact that has been taken as evidence for theories that suggest that age-related declines in cognitive control stem from slowed processing speed (Salthouse, 1996, 2007). The consequence of such generalized slowing of neural processing is the increased computational time required for a particular process, making less information available for higher-level functions in a set amount of time (Zanto & Gazzaley, 2017).

Furthermore, as for the age-related deficits in cognitive control, efficient performance does not decline globally with aging. Rather, older adults demonstrate a steeper decline in proactive control mechanisms relative to reactive control mechanisms (Chiew & Braver, 2017). Braver et al., (2017) propose that in cognitive control tasks, context information could be actively maintained in the prefrontal cortex, remain protected against interference, though flexible to updating, and used to bias action responses in the service of goal-oriented behavior (Chiew & Braver, 2017). According to Braver et al. (2017), impaired cognitive control performance in older adults relative to young adults is especially characterized by selective impairments in specific components of context processing. Specifically regarding the AX-CPT, healthy older adults tend to show worse BX performance and better AY performance relative to healthy young adults, a pattern that is consistent with a specific impairment in context maintenance (Paxton, Barch, Storandt, & Braver, 2006; Rush, Barch, & Braver, 2006). Specifically, Paxton et al. (2008) revealed decreased neural activity using fMRI during the cue/delay period and increased activity during the probe period in older relative to young adults, providing neural evidence of decreased proactive control with aging (Paxton et al., 2008).

In addition to the age-related deficits observed in context maintenance, subjective changes in one's memory functioning is a frequently voiced concern for older adults. Both verbal and visual span tend to decline with age, although this effect is far from dramatic (Baddeley et al., 2015; Grady & Craik, 2000; Park et al., 2002; Parkinson & Dannenbaum, 1985). However, a crucial difference emerges between younger and older adults when the WM task requires them to simultaneously hold and manipulate the material. May, Hasher, and Kane (1999) propose that the age-related impairment in WM might reflect a problem with inhibiting irrelevant material rather than combining storage and processing.

Thus, older adults seem to be more sensitive to interference and suffer a greater negative impact of distractors compared to young adults (Zanto & Gazzaley, 2017). This also supports theories that attribute declines in cognitive control to deficient inhibitory abilities that arise from the anatomical and functional brain changes that occur during aging (Dempster & Vegas, 1992; Hasher et al., 1991; Lustig et al., 2007; West, 1998). Thus, another possible way to explain these age-related executive control deficits has been proposed through inhibitory deficit theory, which posits that cognitive failures related to normal aging are due to a deficit in inhibitory mechanisms (Hasher et al., 1991; Lustig et al., 2007). Specifically, authors in this tradition argue that age-related deficits in attention, language, or memory could be due to a common underlying mechanism: a decline in inhibitory function with increased age. According to the inhibitory hypothesis, older adults cannot suppress or inhibit unwanted information from entering WM.

Apart from the inhibitory deficits observed during aging in speed processing, cognitive control, and WM tasks, such age-related impairments have also been observed in selective memory retrieval (Umanath & Marsh, 2014). Age-related deficits in episodic memory have an array of different sources (Bäckman, 1989). Deficient retrieval mechanisms alone or impaired encoding and retrieval mechanisms could just as well play a role in attentional deficits (Cabeza et al., 2004; Nyberg, Nilsson, Olofsson, & Bäckman, 1997). As memory deficits accompanying the aging process have several origins, efforts to alleviate these deficits should ideally be multifactorial. Training of encoding operations to provide effective strategies for the organization and visualization of the material could then be combined with the training of attentional skills targeted to improve the focus of attention and vigilance, essential functions for meeting the attentional demands of remembering (Banducci et al., 2017; Dahlin et al., 2008).

A paradigm commonly used to investigate inhibitory function in memory is the *retrieval practice* paradigm (Anderson, Bjork, & Bjork, 1994). Here, participants first study pairs of words belonging to a given category (i.e., FRUIT – apple; FRUIT – orange; ANIMAL – elephant). In a subsequent retrieval practice phase, upon presentation of a cue (i.e., FRUIT – ap___), they are then asked to retrieve half of the words from half of the categories. When presented with the category cue ("FRUIT"), all the related previously studied items might become active in memory ("apple, orange, banana…"), competing with the specific memory trace that needs to be retrieved. In such a situation, and according to the inhibition hypothesis (Anderson, Bjork, & Bjork, 2000; Anderson et al., 1994), to overcome interference during retrieval, an IC mechanism is triggered. It suppresses the competing memory representations ("orange") and then promotes the recall of the target memory ("apple"). Inhibition is especially required to suppress strong competing responses to allow the expression of weaker but appropriate ones (Anderson, 2003; Levy & Anderson, 2002). Importantly, this framework implicates at least two mechanisms: (i) a mechanism that detects interference and (ii) a mechanism that reduces interference by inhibiting competing memories. Behaviorally, this paradigm typically shows that the recall of unpracticed items from practiced categories ("orange") is significantly impaired in comparison with control items (items that were neither studied nor did they belong to studied categories, such as "elephant") in the final recall test. This effect has been named *retrieval-induced forgetting* (RIF) (Anderson et al., 1994). Additionally, and unsurprisingly, a facilitation effect is observed, in which retrieval practice enhances the recall of practiced items ("apple") compared to unpracticed control items from baseline categories for which there was no practice. Research on RIF suggests that selective retrieval imposes demands on attentional control processes (i.e., inhibition) to overcome interference from competing memory traces. In particular, the RIF effect is absent if people cannot devote all the resources needed to suppress distracting memories, such as in some divided attention situations (Román et al., 2009).

In a similar vein, because the RIF effect is executive-control dependent, individual differences in IC during selected retrieval could be expected as a function of age. Aslan and Bäuml (2012) and Marful et al. (2015) showed that younger-old adults exhibit an IC induced-forgetting effect similar to that of young adults, but that this effect disappears in older-old adults (Aslan & Bäuml, 2012; Marful, Amado, Ferreira, & Bajo, 2015). In addition, Ortega et al. (2012) and Aguirre et al. (2014) seemed to indicate that older adults are capable of performing inhibitory tasks when there is a sufficient availability of cognitive resources; however, when retrieval is made difficult as cognitive demands increase, the inhibitory effects become impaired (Aguirre, Gómez-Ariza, Bajo, Andrés, & Mazzoni, 2014; Ortega et al., 2012). Thus, as the discussion in this section has shown, many age-related deficits in performance may stem from a lack of cognitive resources that compensate for the age-related deficits in WM, context processing, or IC, as in the case of selective retrieval.

At the neural level, several electrophysiological and neuroimaging studies have demonstrated that the inhibitory mechanism triggered during selective retrieval practice depends on the prefrontal structures involved in interference detection (such as the anterior cingulate cortex; Ferreira, Marful, Staudigl, Bajo, & Hanslmayr, 2014; Staudigl, Hanslmayr, & Bauml, 2010) and its resolution (as the ventrolateral prefrontal cortex; Dudukovic & Kuhl, 2017; Kuhl, Dudukovic, Kahn, & Wagner, 2007; Wimber et al., 2008; Wimber, Rutschmann, Greenlee, & Bäuml, 2009). Electrophysiological studies investigating retrieval practice effects and their dynamics have provided evidence to suggest that the IC mechanism recruited during selective retrieval can be traced by mid-frontal theta (~4-8 Hz) and alpha/beta oscillations (~8-20 Hz). These studies explore how these neural markers of the retrieval-related IC function in the elderly may shed light on whether aging-related deficits rely on impaired prefrontal cortex resources. Thus, anatomical declines associated with aging contribute to inhibitory deficits and slow processing speed, both of which underlie deficient cognitive control in older adults.

In sum, we have so far summarized some of the behavioral and neural functional changes that accompany normal aging. Although many aspects of cognitive control decline with age, there is considerable evidence that the adult brain is capable of significant plastic changes. Following the transfer scope of Lövdén et al. (2010), brain plasticity is the result of a substantial and prolonged imbalance between environmental demands during training and actual brain supply. Because of their less efficient prefrontal lobe system (Cabeza et al., 2004; Park & Bischof, 2013; Park & Reuter-Lorenz, 2009; Raz et al., 2010), older adults might experience this mismatch more frequently than younger adults, and they would benefit more from such functional and structural brain-induced training interventions targeting executive functions (Brehmer et al., 2012; Dahlin et al., 2008; Lampit et al., 2015).

In contrast to earlier accounts that assumed that basic processing capacities could not be improved by training after early adulthood (Wiesel & Hubel, 1965), recent work has clearly established that the brain of older adults can still be plastic and that cognitive control abilities can be maintained or even enhanced through practice and training (Hertzog et al., 2009; Karbach & Verhaeghen, 2014). As per the discussion in this chapter, because WM and executive control processes are cognitive functions that clearly decline with age (Erika Borella, Carretti, & De Beni, 2008; Denise C Park et al., 2002; Paxton et al., 2008), executive control has repeatedly been targeted by the new generation of process-based cognitive training programs. As mentioned earlier, the assumption that executive functions can be trained is based on evidence of the plasticity of our cognitive system throughout the lifespan (Lustig et al., 2009). For older adults, the aim of executive control training is thus to counteract age-related decline in various cognitive control abilities (Bürki, Ludwig, Chicherio, & de Ribaupierre, 2014; Zinke et al., 2011) in order to sustain their cognitive functioning for active aging (for reviews, see Brehmer, Kalpouzos, Wenger, & Lövdén, 2014; Lampit et al., 2015; Lövdén, Wenger, Mårtensson, Lindenberger, & Bäckman, 2013; Lustig et al., 2009). The idea is that training can change the way in which individuals process information, enabling them to make more flexible use of their resources. The recent meta-analysis of aging by Karbach and Verhaeghen (2014) showed that executive control training can promote significant gains, both in trained tasks and in other similar tasks (near transfer effects). In that meta-analysis, there also seemed to be some improvement in untrained tasks that shared some cognitive processes with the task used in training (far transfer effects), though they were usually small in terms of effect size.

Cognitive training appears to be potentially beneficial for many cognitive domains in which it is targeted, and IC decline in older adults is often in need of improvement. Age-related decline in multitasking performance has also been targeted through cognitive training in older adults, with the result that improved performance occurs alongside prefrontal cortex activity profiles that become more similar to those of younger adults (Anguera et al., 2013; Bherer et al., 2005). Moreover, multitasking training has been shown to yield positive transfers to WM and attention (Anguera et al., 2013; Ball et al., 2002; Schmiedek et al., 2010; Willis & Caskie, 2013). However, there have been mixed reports regarding the efficacy of training in aging since transfer effects are not always observed. In sum, it is promising to explore whether conflict detection and interference resolution mechanisms could be enhanced by means of an executive control training intervention in aging. Our focus will be on the behavioral performance of older adults before and after training in conflict resolution, WM, and reasoning tasks. However, we are also interested in analyzing the neural dynamics of cognitive control and interference detection during selective memory retrieval during healthy aging.

Executive Control Training and Transfer to Reading Comprehension

As discussed throughout this section, executive control is essential for many cognitive processes such as language comprehension, planning, or problem solving in everyday life and especially during children development (Cowan et al., 2005; Miyake & Friedman, 2012; St. Clair-Thompson & Gathercole, 2006). We have already reported that there is considerable evidence that shows major differences among individuals in relation to age and baseline capacities in executive functioning (Cowan, 2001; Cowan et al., 2005; Gathercole, 1999; St Clair-Thompson & Gathercole, 2006). Individual differences in the capacity of executive control may arise for several reasons, including limited capacity per se (Cowan, 2005) or limitations in the cognitive control mechanisms supporting executive control (Lustig et al., 2007; May et al., 1999).

It has been argued that executive control and WM capacity are crucial for children to acquire knowledge and new skills (Alloway et al., 2005; Gathercole & Pickering, 2004; Gathercole, Alloway, Willis, & Adams, 2006; St Clair-Thompson & Gathercole, 2006). There is also evidence to suggest that WMC is directly related to scholastic achievement (Hsu et al., 2014; Rapport, Scanlan, & Denney, 1999), for example, to mathematical skills (Alloway et al., 2005; Bull & Scerif, 2001; Mayringer & Wimmer, 2000; McLean & Hitch, 1999), vocabulary (Daneman & Green, 1986), language comprehension (Nation, Adams, Bowyer-Crane, & Snowling, 1999; Seigneuric, Ehrlich, Oakhill, & Yuill, 2000; Seigneuric & Ehrlich, 2005), and reading ability (de Jong, 1998; Gathercole & Pickering, 2004; Swanson & Berninger, 1995).

Reading comprehension is a higher-level skill that requires the reader to engage in multiple cognitive processes: lexical-semantic access, phonological decoding and syntactic analysis, articulatory planning, context processing, and to some degree, even their coordination into higher-order functions that determine efficient language comprehension. WM, which is assumed to be a system for the short-term storage and active manipulation of information (Baddeley & Hitch, 2000), is highly involved in both word reading and reading comprehension. Daneman and Carpenter (1980) showed that the WM span in the reading span task was able to predict comprehension capacity in students. Daneman and Merikle (1986) further evidenced a high correlation between WM span and language comprehension (see also Daneman & Merikle, 1996; Daneman & Carpenter, 1980; Daneman & Green, 1986). There is a large body of research specifically focused on the relationship between reading processes and WM. In particular, it has been shown in adults that reading comprehension relies on the executive component of WM (Daneman & Carpenter, 1980; Daneman & Merikle, 1996). However, de Jong and de Jong (1998) have demonstrated that both executive processing and simple storage are equally related to reading comprehension in typically developing children and that both are related to reading speed. At the word, sentence, and text level, efficient reading comprehension involves WM-dependent cognitive processes that must be engaged and coordinated. Thus, one might expect that a reader with poor WMC might struggle with reading comprehension (Carretti, Borella, Cornoldi, & De Beni, 2009; Gathercole et al., 2006; Swanson & Berninger, 1995).

In this line, much evidence suggests that low WMC is correlated with reading disorders (Carretti et al., 2009; Chiappe, Hasher, & Siegel, 2000; de Jong, 1998; Gathercole et al., 2006). In particular, further evidence of an association between WM and reading comprehension comes from studies with children with reading disabilities, which often show phonological deficits (Goulandris, 2003) and poor performance in complex WM span tasks relative to typically developing children (Reiter, Tucha, & Lange, 2005). For example, Carretti et al. (2004) found that good comprehenders had higher WMC than poor comprehenders; they were also better at recalling words and made fewer intrusion errors. Furthermore, low comprehenders have low attention spans, are easily distracted, and tend to forget instructions (Alloway, Gathercole, Kirkwood, & Elliott, 2009). There is also evidence to suggest that children with low WMC need additional classroom support in school to achieve appropriate goals. Taking these results into account, low WMC seems to be a high-risk factor for poor scholastic achievement (Alloway et al., 2009). Comprehension of narrative texts requires building a situation model where the characters, their interactions, and the context of the story are represented. In particular, an essential part of text comprehension is the ability to infer information that has not been explicitly described (Cain & Oakhill, 1999). Poor reading comprehension has also been related to difficulty inhibiting irrelevant information. In this sense, problems with text comprehension can be due to difficulty integrating new information with previous knowledge, as well as with the previous mental model of the text, as a result of an inefficient inhibition of irrelevant information (Cain, Oakhill, & Bryant, 2004; Gernsbacher & Faust, 1991). Thus, the capacity to make inferences and to update the situation model are ongoing processes that are engaged during text reading, which become essential for successful comprehension (Palladino & Cornoldi, 2001; Pérez, Cain, Castellanos, & Bajo, 2015; Pérez, Joseph, Bajo, & Nation, 2016; Rapp & Kendeou, 2007). These processes are both highly dependent on WM – to maintain the current representation of the situation model and to update the new information – and executive function – to efficiently inhibit no-longer-relevant information (Palladino &

Cornoldi, 2001; Pérez et al., 2015; Pérez, Paolieri, Macizo, & Bajo, 2014; Rapp & Kendeou, 2007; Zwaan, Langston, & Graesser, 1995). As a result, these facts seem to support that readers with good WM may be better able to update and regulate their situation model than those with poor WM because the former are more efficient at inhibiting no-longer-relevant information, an essential process for constructing an accurate and coherent situation model.

Because children's academic learning is supported by cognitive abilities such as executive control and WM, the usefulness of training interventions that attempt to promote children's cognitive capacities might become an important complement during their development. On a typical WM exercise, children have to retain series of visuospatial or verbal stimuli in memory and repeat them after a brief delay. Using these types of exercises for training, several studies have demonstrated WMC enhancements in typically developing children (Alloway, Bibile, & Lau, 2013). Moreover, training gains in cognitive functions have also been reported in child populations that present with WM and executive control deficits. It is well known that children diagnosed with attention-deficit/hyperactivity disorder (ADHD) show poor WM performance (Dunning, Holmes, & Gathercole, 2013; Holmes et al., 2015; Klingberg et al., 2005). Thus, it might be expected that WM training may help children with such disabilities. Klingberg et al. (2005) administered their Cogmed training program to ADHD children and compared them to matched active controls. They observed a clear improvement in performance in the trained group, which extended to both a novel WM test (near transfer) and to Raven's matrices (a far transfer measure of fluid intelligence). Furthermore, if Cogmed worked for ADHD children, some other areas of childhood disability might benefit from WM training, for example, in cases of children with poor reading comprehension abilities.

Recent work in the field of cognitive training has tried to establish a causal link between WM and reading ability. However, the nature of the training interventions employed to assess the potential transfer to reading comprehension is quite heterogeneous (Alloway et al., 2013; Carretti et al., 2017; Loosli et al., 2012). A significant difference across studies has to do with whether the training procedure involved domain-general WM and executive control activities or whether they engaged specific reading comprehension activities that require executive demands. A few studies have tested the generalization of WM training effects on measures of verbal competence and reading performance in typically developing children. For instance, Alloway et al. (2013) reported higher scores on measures of verbal competence and spelling after 32 sessions of WM training, which was maintained eight months after the intervention. Transfer to reading performance has also been reported with shorter interventions (Karbach et al., 2014; Loosli, Buschkuehl, Perrig, & Jaeggi, 2012), suggesting the possible enhancement of reading competence after WM training. Considering the strong relationship between WM and higher-order reading comprehension processes, a compelling research goal would be to explore the effectiveness of WM training in high-order processes engaged during reading comprehension, such as the processing of relative structures and updating the mental model during text reading comprehension.

CHAPTER III
Organization and Goals of the Experimental Series

The general goal of the present dissertation was to investigate the extent to which the cognitive processes that fall under the umbrella of executive function, namely WM, IC, and cognitive flexibility (Miyake & Friedman, 2012; Miyake et al., 2000), can be enhanced through cognitive training.

From the perspective of a unitary view of executive functions, we would expect to see the relatively broad transfer of executive control training to a large variety of other aspects of executive control. This would be the confirmation of the hypothesis that if executive control is a higher-order control system, its training should enhance a wide range of different related executive control functions. Taking a more modular perspective, the generalization of the training gains in one specific executive process (such as WM or IC) would necessarily result in benefits from different executive control tasks, tapping into the same trained executive function. Thus, the scope of transfer should depend on the degree of domain-specific overlap between the trained and transfer tasks, not only in terms of shared cognitive processes, but also in terms of neural substrates (Brehmer et al., 2014; Buschkuehl et al., 2012; Jaeggi et al., 2011; Lustig et al., 2009). In this sense, we would expect that the more sources are shared, the greater the likelihood of transfer. However, assuming both common and domain-specific aspects of executive control, we would expect to see a larger transfer if the neural network in charge of control, which includes the prefrontal, dorsal, and parietal cortical areas, are trained.

Thus, the first goal of this dissertation was to explore the specificity of executive control training in healthy young adults. Chapter IV describes Experiment 1, in which we used a procedure in an attempt to maximize generalization (by using multiple activities within each trained process) and to control for practice and motivation (by including active and passive control groups and by capturing motivational variables during training). Specifically, we compared a group of participants trained in WM memory to a group trained in IC, and we included passive and active control groups in the study. The active controls performed the same training protocol as their experimental counterparts, but they engaged in activities that relied on perceptual abilities and progressively increased their speed demands without increments in executive load (Lawlor-Savage & Goghari, 2016; Peng et al., 2012; Takeuchi & Kawashima, 2012). In this initial study, we analyzed the potential near transfer effects to WM and IC as well as far transfer effects to non-verbal reasoning. In addition, we included a far transfer task (AX-CPT) to explore whether WM and IC training might change the adjustment of distinct executive control strategies (proactive versus reactive), which have been proposed to support cognitive flexibility (Braver, 2012; Burgess et al., 2011; Braver et al., 2009).

Despite the executive impairments observed in older adults, there is general agreement that the brain remains plastic across the lifespan. Thus, the second aim of this dissertation was to explore whether conflict detection and interference resolution mechanisms can be enhanced during healthy aging by means of an executive control training intervention. In Experiment 2A, in Chapter V, we describe our second experiment on a healthy older adult population. Using a similar training procedure as that conducted in the previous experiment with young adults, we move our focus to the older adults' behavioral performance before and after the training in conflict resolution, WM, and reasoning tasks and compare this to an active control training group, which engaged in processing speed activities. Moreover, we were interested in analyzing the neural dynamics regarding the adjustment of cognitive control mechanisms and analyzed ERPs in the AX-CPT, comparing the older adults' performance before and after completing the executive control training.

Taking into account that older adults exhibit different cognitive deficits in relation to executive control and episodic memory, Chapter VI has two goals. First, an exploratory aim of this work was to characterize the aging-related deficits in interference detection and IC during selective memory retrieval. To do that, in Experiment 3, we used the retrieval practice paradigm and analyzed the age effect over the electroencephalographical activity, specifically, neural oscillations in theta band (~6-8 Hz) as neural markers of interference detection and IC during selective memory retrieval (Cohen, 2014; Ferreira et al., 2014). This first goal aimed to set the basis for the training study, which we also aimed to perform with older participants. Thus, the second goal of this chapter was to explore whether the resulting age-related differences in selective episodic retrieval (Experiment 3) could be influenced by an executive control training intervention. As a consequence, in Experiment 2B, we analyzed the differences in selective episodic retrieval using the retrieval practice paradigm between two groups of trained, healthy older adults: an experimental condition for executive control training and an active control group undergoing speed training. We expected to observe the differences in retrieval not only at the behavioral level in terms of modulated forgetting and practice effects, but also at the neural level through an analysis of brain oscillations in the theta and alpha/beta bands (~8-20 Hz) as markers of efficient encoding and retrieval.

Finally, considering the strong relationship between executive control, WM, and high-order reading comprehension processes, the final goal of this dissertation was to explore the effectiveness of a WM training in high-order processes engaged during reading comprehension, such as the processing of relative structures and updating the mental model during text reading comprehension. Chapter VII focuses on Experiment 4, in which we compared the performance of children who underwent a WM training program to an active condition that underwent processing speed training. We predicted transfer effects to text reading because proficient reading requires the simultaneous engagement of WM-related processes: information must be held in WM until it has been read to the end. As we trained WM and executive processes, we expected the transfer to those reading skills that place more demands on WM.

PART II

RESEARCH

"Reserve your right to think,
for even to think wrongly is better than not to think at all."

Hypatia of Alexandria.
370-415 CE

CHAPTER IV

Specificity of Executive Control Training: Training Working Memory and Inhibitory Control in Healthy Young Adults

Experiment 1*

Different types of interventions have focused on trying to improve Executive Functions (EF) due to their essential role in human cognition and behavior regulation. Although EF are thought to be diverse, most training studies have targeted cognitive processes related to working memory, and fewer have focused on training other control mechanisms, such as inhibitory control. In the present study, we aimed to investigate the differential impact of training working memory and inhibitory control as compared with control conditions performing non-executive control activities. Young adults were divided into two training (working memory/inhibitory control) and two (active/passive) control conditions. Over six sessions, the training groups engaged in three different computer-based adaptive activities (working memory or inhibitory control), whereas the active control group completed a program with low control-demanding activities that mainly involved processing speed. In addition, motivation and engagement were monitored through the training. The working memory-training activities required maintenance, updating and memory search processes, while those from the inhibitory control group engaged response inhibition, and interference control. All participants were pre- and post-tested in criterion tasks (n-back and Stroop), near transfer measures of working memory (Operation Span) and inhibitory control (Stop-Signal). Non-trained far transfer outcome measures included an abstract reasoning test (Raven's Advanced Progressive Matrices) and a well-validated experimental task (AX-CPT) that provides indices of cognitive flexibility considering proactive/reactive control. Training results revealed that strongly motivated participants reached higher levels of training improvements. Regarding transfer effects, results showed specific patterns of near transfer effects depending on the type of training. Interestingly, it was only the inhibitory control training group that showed far transfer to reasoning. Finally, all trained participants showed a shift towards a more proactive mode of cognitive control, highlighting a general effect of training on cognitive flexibility. The present results reveal specific and general modulations of executive control mechanisms after brief training intervention targeting either working memory or inhibitory control.

---

* This chapter correspond to the content of the paper published as Maraver, M.J., Bajo, M.T. & Gómez-Ariza, C.J. (2016). Training on Working Memory and Inhibitory Control in Young Adults. *Frontiers in Human Neuroscience*. 10:588.doi: 10.3389/fnhum.2016.00588

Executive Functions (EFs) refer to a variety of cognitive and brain mechanisms thought to be in charge of regulating the dynamics of human cognition and behavior in changing environments (Jurado & Rosselli, 2007; Miyake et al., 2000; Smith & Jonides, 1999). Although there is some disagreement over the exact nature of EFs and their precise neural substrates (Banich, 2009; Braver & Cohen, 2001; Kane & Engle, 2002; Miyake et al., 2000), substantial evidence supports the fact that EFs play an essential role in learning and academic achievement (Bull & Scerif, 2001; St. Clair-Thompson & Gathercole, 2006), knowledge acquisition (Blair & Razza, 2007; Danielsson et al., 2010), metacognition (Fernandez-Duque & Posner, 2000) as well as emotional and self-regulation (Barkley, 2001; Hofmann et al., 2012).

The large role that EF seem to play in efficient cognition and in successful behavior regulation has led researchers to develop interventions aimed at improving executive functioning, even in the short term. Brain plasticity is at the basis of the proposal that cognitive functioning can be enhanced by means of training. The basic idea is that during cognitive training, participants repeatedly activate neural regions involved in the training tasks (Hsu et al., 2014; Hussey & Novick, 2012; Buschkuehl, et al, 2012; Olesen et al., 2004) enhancing, thus, the cognitive function supported by the specific neural region. As a consequence, training effects would generalize and transfer to non-trained tasks that also involve the targeted training domain, and the underlying trained brain areas (*near transfer*) (Beauchamp et al., 2016; Borella et al., 2014; Lee et al., 2007; Thorell et al., 2009). Furthermore, training effects could go beyond the trained domain and show benefits in measures considerably different from the training task, as long as they were associated with the trained process and shared comparable neural circuits (*far transfer*) (Borella et al., 2010; Dahlin, 2013; Jaeggi et al., 2008; Loosli et al., 2012). Similarly, at the behavioral level, transfer effects could be expected in potentially related cognitive functions, and lead to enhanced performance in a variety tasks that, although untrained, share the same cognitive mechanism than the targeted train processes (Morrison & Chein, 2011). Although plenty of studies have found near transfer effects after training working memory, inhibitory control or attention, far transfer effects are still limited and inconclusive (Melby-Lervåg et al., 2016; Schwaighofer et al., 2015; Enge et al., 2014; Sprenger et al., 2013; Spierer et al., 2013; Thorell et al., 2009).

Training studies differ in the type of EF targeted by the training tasks. WM has traditionally been the target for many cognitive training programs due to its well-known central role in cognition and its relationship with high-level abilities (Jaeggi et al., 2013; Klingberg et al., 2005; Morrison & Chein, 2011). Several studies have demonstrated positive effects of WM training in different age groups (Borella et al., 2010; Jaeggi et al., 2013; Söderqvist et al., 2012) with transfer to trained and untrained domains such as mathematical performance (Bergman-Nutley & Klingberg, 2014; Dahlin, 2013), reading abilities (Karbach et al., 2015; Loosli et al., 2012; Dahlin, 2010; Chein & Morrison, 2010), or reasoning and fluid intelligence (Au et al., 2014; Borella et al., 2010; Jaušovec & Jaušovec, 2012; Klingberg et al., 2005; but see Harrison et al., 2013; Chooi & Thompson, 2012; Redick et al., 2013 for failures to find far transfer effects after WM training; and Dougherty et al., 2016; Bogg & Lasecki, 2015; Schwaighofer et al., 2015; Melby-Lervåg, & Hulme, 2013 for reviews).

Some other studies have focused on training inhibitory control processes (Spierer et al., 2013). Although several of these studies have failed to find behavioral transfer effects after training IC (Berkman et al., 2014; Enge et al., 2014; Thorell et al., 2009), others have found positive near and far transfer effects after task-switching training across the lifespan of healthy individuals (Karbach & Kray, 2009), training-related benefits in fluid intelligence scores in children after executive control training (Liu et al., 2015; Rueda et al., 2012; Rueda et al., 2005), and near transfer effects in normal developing children (Dowset & Livesen, 2000) or with executive control deficits (Kray et al., 2012). In addition to the behavioral effects, brain activity studies have reported different activation patterns in the brain network associated with IC: namely, increased activation in the right inferior frontal gyrus after training response inhibition in young adults (Berkman et al., 2014); or a more adult-like pattern of EEG markers (dorsoprefrontal negativity linked to the anterior cingulate gyrus) in 6 year-old children after a 5-day training with tasks involving conflict resolution (Rueda et al., 2005).

While, with some exceptions, studies focusing on either WM or executive control training show transfer effects (see Karbach & Verhaeghen, 2014 for a meta-analysis with studies that trained WM, switching and IC in older adults), to date very few studies have directly compared the effects of WM and IC training across tasks (see Thorell et al., 2009 for a comparison between WM and IC training in preschoolers). Thus, the main aim of the present study was to directly compare near and far transfer effects of two different training programs targeting either WM or IC processes. The direct comparison of these two types of programs is theoretically interesting since, according to some proposals, WM and IC seem to represent two separate executive functions and may therefore have separate effects (Miyake et al, 2000). In addition, we also aimed to carefully control some factors that have been subject to criticism in previous training studies.

As mentioned, despite the studies showing positive results after training in young adults, its effectiveness is still controversial and far transfer effects are not always obtained (Melby-Lervåg & Hulme, 2016; Schwaighofer et al., 2015). Results stemming from different training studies need to be carefully interpreted with special attention to methodological differences that could account for the diversity of findings. Thus, for example, training procedures targeting specific cognitive abilities (such as WM or IC) allow for more restricted attributions on training-derived transfer effects (Borella et al., 2010; Jaeggi et al., 2013; Rueda et al., 2012) than complex procedures that include multiple cognitive domains (memory, attention, inhibitory control, reasoning, etc), which seem to be less specific, and often yield more limited transfer effects (Baniqued et al., 2015, 2014; Dovis et al., 2015; Hardy et al., 2015; Schmiedek et al., 2010). Moreover, although many studies have used single training tasks (Carretti et al., 2013; Jaeggi et al., 2013; Loosli et al., 2012; Rueda et al., 2005), the potential generalization of the training might be enhanced by the use of different tasks recruiting the particular targeted process. Switching between multiple tasks targeting the same process during training might promote cognitive flexibility by adapting general processes and strategies, and thus, preventing the use of very specific task-strategies that would more likely be implemented when training is based on just one single task (Bherer et al., 2005; Dahlin et al., 2008; Schmidt & Bjork, 1992; Schwaighofer et al., 2015). Finally, the presence and type of control groups is an essential requirement to dissociate the effectiveness of training (Dougherty et al., 2016; Melby-Lervåg et al., 2016; Mohr et al., 2009). Thus, passive control groups (PC) may allow researchers to keep track of simple practice effects, while active control (AC) groups may enable them to uncover the specificity of different cognitive training procedures by maintaining similar levels of motivation and reducing the possibility of placebo effects (Boot et al., 2013; Dougherty et al., 2016).

Hence, in the present study we explored potential transfer effects of two executive-control training programs in young adults. We used a procedure that attempted to maximize generalization (by using multiple activities within each trained process) and to control for practice and motivation (by including active and passive control groups and by capturing motivational variables during training). Specifically, we compared a group of participants trained in working memory (WMT) to a group trained in inhibitory control (ICT). Both groups were trained with three different training activities during six sessions spread across two weeks. Importantly, the training procedures were adaptive and increased executive control demands. We included passive (PC) and active (AC) control groups in the study. AC performed the same training protocol as their experimental counterparts, but they engaged activities that relied on perceptual abilities and progressively increased their speed demands, without increments in executive load (Lawlor-Savage & Goghari, 2016; Peng et al., 2012; Takeuchi & Kawashima, 2012). The batteries of training activities used here were designed from the Cognitive Training Program of the University of Granada (PEC-UGR), which included a number of tasks that could be adapted and combined. We designed these batteries considering both the neural basis of the cognitive processes underlying the activities and the logic of the experimental procedures traditionally used to evaluate executive control. As for the ICT group, the training included versions of i) the Stroop task in which participants had to select coins/numbers contained in congruent or incongruently sized bags; ii) the Conflict resolution task, where a sample of animals was presented and participants were asked to search for a target match from a set of distractors displaying congruent/incongruent shaped/colored animals; and iii) the Go/No-Go and Stop-Signal tasks, in which participants had to respond to matching shapes (a robot and a screw), and stop their response when faced with a rusted-looking shape. Regarding WMT, participants performed versions of i) the *n*-back task, in which participants had to monitor sequences of open/closed windows from a six-window display presentation, and press a key whenever the open window was the same as the window *n* trials back; ii) WM updating, that consisted of the serial presentation of objects of different sizes that were introduced in boxes. Participants were asked to recall the 2 to 6 largest/smallest elements from the series; and iii) Dual Span tasks, in which participants were asked to recall the shape and color of an increasing number of animals and then ask to select the animal that matched one of the study animals from a set of distractors. Participants were evaluated before and after training with two criterion tasks (*n*-back and Stroop), with near transfer working memory (Operation Span) and inhibitory control (Stop-Signal) tasks, as well as with far transfer non-verbal reasoning (Raven's Advanced Progressive Matrices). In addition, we included a far transfer task (AX-CPT; the AX version of the Continuous Performance Test) to explore whether WM and IC training might change the adjustment of distinct executive control strategies (proactive versus reactive), which have been proposed to support cognitive flexibility[1] (Braver, 2012; Burgess et al., 2011; Braver et al., 2009).

Also of relevance, in the present study we also aimed to explore the role of individual differences on training and transfer performance. This represents a recent and unexplored issue that may be important in predicting the benefits of training (Könen & Karbach, 2015). In this sense, previous studies have already reported that at baseline, reasoning predicts training achievement (Bürki et al., 2014). Furthermore, individuals' improvement during training has been shown to be a relevant predictor of transfer effects in young adults (Jaeggi et al., 2011) as well as in children and older adults (Wang et al., 2014; Zinke et al., 2013). Thus, in order to explore the potential role of individual differences in training success, predictors of training improvement and transfer gains were analyzed (Könen & Karbach, 2015).

Based on the key assumption that generalization to non-trained tasks could occur whenever there is cognitive and neural overlap between the trained processes and those engaged in the outcome measures (Hussey & Novick, 2012; Persson & Reuter-Lorenz, 2008; Woodworth & Thorndike, 1901), we expected the two experimental groups to exhibit differential and specific enhanced post-training performance (for related findings see Chein & Morrison, 2010; Foy & Mann, 2014). Thus, we expected that, after training, the WMT group would outperform the ICT group on the *n*-back and Operation Span tasks, which involved WM maintenance demands. On the

[1] Proactive control refers to an "early selection" control mode that anticipates and prevents interference before it occurs, while reactive control implies a "late correction" strategy that detects and solves interferences once it is already present (Braver et al., 2009; Braver, 2012; Morales, Gómez-Ariza, & Bajo, 2013). The AX-CPT is a sensitive and reliable experimental task widely used to explore individual differences in the use of proactive and reactive control strategies (Braver, 2012; Chiew & Braver, 2014). Hence, we used it to assess whether the participants' control mode changes with training. While young adults tend to rely on a proactive control strategy while performing the AX-CPT (Braver et al., 2009; Morales et al., 2013), training could somehow modulate the way they faced the task, which systematically required goal maintenance, interference detection and conflict resolution.

other hand, due to the greater reliance on conflict resolution for the ICT group than for the WMT group, we predicted better performance after IC training in the Stroop and Stop-Signal tasks relative to the WMT group.

Regarding the active control group, which went through progressive response speed demands, we expected benefits in response times after training. Processing speed, even at a low processing demand level, may lead to changes in performance mainly driven by the fact that participants' responses could become faster after the training (Lawlor-Savage & Goghari, 2016; Peng, et al., 2012; Takeuchi & Kawashima, 2012).

As for the AX-CPT, which provided an index of the control strategy deployed by the participants, we hypothesized that the two executive control-training programs would make participants more dependent on proactive control relative to control conditions. This hypothesis is based on the assumption that the high executive control demands of both training programs would encourage participants to focus on contextual cues and, hence, to enhanced reliance on cue processing (rather than probe processing) on the AX-CPT task. If so, both types of training would lead to maximize the typical proactive strategy deployed by young healthy adults. However, we also expected the WM training, which specifically focuses on monitoring and maintenance, to have a stronger impact on proactivity than IC training.

Finally, on the basis of either the close relationship between matrix problem resolution, WM (Friedman, Naomi et al., 2006; Harrison, Shipstead, & Engle, 2015; Martinez & Colom, 2009; Martínez et al., 2011) and executive control (Dempster & Corkill, 1999; Engle & Kane, 2004; Jarosz & Wiley, 2012; Shipstead, Harrison, & Engle, 2015) and the results of some previous training studies (Au et al., 2014; Rueda et al., 2012; Jaeggi et al., 2008; Karbach & Kray, 2009), we expected to find better post-training performance in the reasoning test in the two experimental groups than in the active and passive control conditions.

METHODS

Participants

Participants were recruited via physical ads in the University of Granada requiring the fulfillment of the following conditions: i) be aged between 18 and 30 years old; ii) not to have any major medical or psychological condition; iii) be committed to undertake at least 4 experimental sessions in the lab, which could be extended to 10. One hundred and twelve undergraduate students were selected to take part in the present study (M_{age} = 20.51 years; SD_{age} = 1.74; range = 18 – 25; 83 females). After pre-testing, they were randomly assigned to one of the four groups making up the study: inhibitory control training, (ICT, N = 32; M_{age} = 20.41 years; SD_{age} = 1.88; 23 females), working memory training (WMT, N = 32; M_{age} = 20.31 years; SD_{age} = 1.57; 23 females), active control (AC, N = 24; M_{age} = 20.75 years; SD_{age} = 1.32; 18 females), or passive control (PC, N = 24; M_{age} = 20.67 years; SD_{age} = 2.16; 19 females). There was no significant difference either in age (p = 0.76; η^2_p = 0.01) or in gender distribution (p = 0.92; η^2_p = 0.00). At the end of the study, the participants were economically compensated for their involvement. None of the participants withdrew from the study although they were informed they could do so if they wished. This study was approved and carried out in accordance with the recommendations of the Research Ethics Committees of the University of Granada, with written informed consent from all subjects. All participants were provided with information about the study and gave written informed consent in accordance with the Declaration of Helsinki (World Medical Association, 2013).

Procedure

The cognitive training schedule consisted of two (pre and post-training) testing sessions and six training sessions distributed over two weeks, with three training sessions per week. Therefore, the total length of the study extended for approximately four weeks. In the testing sessions all of the participants were evaluated for: i) criterion tasks (*n*-back and Stroop); ii) working memory (Operation Span) and inhibitory control (Stop-Signal) as near transfer measures; and ii) adjustment of proactive/reactive cognitive control (AX-CPT) and abstract reasoning (Raven's Advanced Progressive Matrices) as far transfer measures. We created two random task orders for evaluation that were counterbalanced across participants. The training and active control groups engaged in three different activities during each session (twenty minutes per activity). The order of the activities in each training session was also counterbalanced over all participants. The resulting total training time for each activity was 120 minutes. The passive control group only performed the evaluation sessions and continued with their regular college activity during the two weeks between pre and post training.

Participants worked in individual cabins although an experimenter continuously supervised the procedure and was available to attend to any request. Every two training sessions participants were to complete a motivation questionnaire (Alonso-Tapia & de la Red Fadrique, 2007; Colom et al., 2013) in which they were asked for their: i) involvement in the program; ii) perceived difficulty of the activity levels; iii) perceived challenge of improving over the levels; and iv) expectations for their achievement. They had to rate each of the four statements on a scale ranging from 0 (very low) to 10 (very high). In the last training session, they were asked for a general evaluation of the training program and their satisfaction with the experimental procedure.

Training Procedures

We used the online training program from the University of Granada (PEC-UGR) that included different game-like activities organized in levels of increasing difficulty. Training difficulty was adaptive in order to maintain activities as a constant challenge (Brehmer et al., 2011; Karbach et al., 2015; Klingberg et al., 2005). Also, participants received feedback on whether their performance was correct or not (Katz et al., 2014). Activity levels were built up over runs of trials. Whenever participants succeeded in 3 runs they went forward to the next level and if they failed 2 runs, they went back to the previous level. Details of each of the three activities per training group are detailed below.

Inhibitory control training

Stroop-like

This activity was modeled on the Steinhauser & Hübner's (2009) complex Stroop task, which involved both conflict resolution and switching. The task was implemented in a scenario where bags of different sizes containing amounts of money had to be put into a treasure chest. Participants had to select the bag with the largest (gold in color) or the smallest (silver in color) number of items, with the number of bags increasing over the levels. The size of the bags could be either congruent or incongruent with the amount inside. An example of a congruent trial is one in which the stimuli were a big bag containing seven golden coins (correct choice) and a small bag containing five golden coins. In an example of an incongruent trial the stimuli could be a small bag containing six golden coins (correct choice) and a big bag containing three golden coins. Difficulty increased by changing the ratio of congruent/incongruent trials (0; 0.25; 0.50; 0.75), so that the larger the proportion of congruent trials, the harder the choice for incongruent trials. At higher levels, switching was manipulated by changing the color of the items from gold to silver between trials within the same round. Times to respond and inter-stimuli intervals were also progressively reduced with each level. The dependent variable was a relative index of conflict resolution [(RT in incongruent trials – RT in congruent trials)/ RT in congruent trials.

Conflict resolution task

The scenario of this activity was an ocean where a sample of sea animals was displayed in the upper part of the screen and a group of animal buttons was shown in the lower part. The buttons set size was always sample $n + 1$ and it was progressively increased over the levels from 2 to 6. Participants had to select, as fast as possible, the animal of the buttons that had the same shape and color as one of the animals in the sample (match trials). If there was an animal whose shape matched but the color did not, they had to click on the different button (no-match trials). An example of match trial could be one in which the sample stimuli included “blue turtle – yellow starfish – brown crab” and the button choices included “pink turtle – yellow starfish (correct choice) – red crab – grey dolphin”. On the other hand, a no-match trial could be one displaying as sample "blue turtle – yellow starfish – brown crab" and the button choices containing "pink turtle – green starfish – red crab – grey dolphin (correct choice)". The percentage of match trials was manipulated (0.25; 0.5; 0.75) so that the higher this ratio, the stronger the tendency to respond. Difficulty was also manipulated with the similarity of the color between the sample and the choice of the buttons. When colors were limited (a different color between the target and the possible options), the choice got harder since the color of the distractors had to be inhibited. The time to respond and inter-stimuli intervals were also reduced over the levels. The parameter distribution across the levels was manipulated following the procedures used in Rueda et al., (2005, 2012). As in the previous activity, the dependent variable was the score in the relative index of conflict.

Go/No Go-like

This was a matching-to-sample activity based on the shape of the items: a robot was the target and a screw was the sample. Participants had to respond when the shape of the robot and the screw matched (Go trials: i.e., a squared robot and a squared screw on its top) and inhibit their response when the shapes did not match (No-Go - shape trials: i.e., a circled robot and a squared screw on its top). At higher levels, there was an extra difficulty because the response had to be also inhibited when the screw was rusted (No-Go – color trials: i.e., a squared robot and a rusted squared screw on its top), even if its shape matched that of the robot. The proportion of Go trials (0.10; 0.20; 0.50; 0.80; 0.90) was manipulated together with the additional No-Go color trials ratio (from 0 to 0.30). The higher the proportion of Go trials, the stronger the tendency to respond with greater inhibitory control being required to succeed. The manipulation of the parameters was conducted following similar procedures regarding Go/No Go trials proportion (Benikos et al., 2013b) and reaction times deadlines (Benikos, Johnstone, & Roodenrys, 2013). As in the previous activities, the maximum time to respond was reduced when levels increased (Benikos et al., 2013). In this case, false alarms and omission errors were the dependent variables.

Working memory training

N-back

Participants had to monitor, maintain and continuously update the items throughout a sequence of elements. Participants were presented with a six-window house and had to detect coincidence between positions (opening/closing of the windows), sounds, or the combination of both modalities. They had to give their response pressing a button whenever the position of the opening window, its sound or both, matched the one that was presented as *n* positions-back in the sequence. Increments in *n*-back (from 1 to 8) were implemented after participants had completed the *n*-back level with single (position or sound) and dual (position plus sound) modality levels. As for the dependent variables, we considered the achieved *n*-back level and the sum of errors in each session.

Working Memory search

This was a matching-to-sample activity based on the shape and color of the items sequentially displayed: animals on one screen as the sample, and a group of animal buttons after a retention interval. Participants were presented with a matrix to be maintained in memory composed of animals with different shapes and colors displayed in an open field (i.e.: memory matrix, "brown bear – red eagle – purple snake"). After a retention time of 5000 ms, participants performed a memory test in which they had to select as fast as possible the animal on the buttons that had the same shape and color of one of the previously retained animals (i.e. button choices, "orange bear – red eagle (correct choice) – yellow snake – blank button"). If none of the animals on the buttons had the same shape and color, they had to select the blank button (i.e. button choices, "orange bear – green eagle– yellow snake – blank button (correct choice)"). The number of to-be-maintained items increased from 1 to 8 over the levels. The number of elements recalled (set size) was the dependent variable.

Working Memory updating

This task was adapted from the word updating task from Palladino & Cornoldi (2001). Participants were presented with a group of numbered boxes. Items of different categories (food, objects, animals or clothing) were sequentially displayed. For each trial, items from only one category were relevant and introduced into the boxes (i.e., animals). Participants were asked to recall the larger (or smaller) element(s) by selecting the box or boxes in which they were introduced (i.e., Rule*:* recall the smallest animal; Items presented*:* apple - cat - trousers - bee (correct choice) - chair - elephant). Maintenance and updating in WM were involved in this activity. The memory load was manipulated by increasing the number of elements to recall (from 1 to 7), the number of distractors that belong to the target category (from 1 to 7), and the number of distractors from different categories (from 2 to 20). The program randomly changed the rule from big to small keeping an equal proportion of the trials within a level. The dependent variable was the number of items successfully recalled.

Active Control (Speed Training)

Speeded comparison

In this matching-to-sample activity participants were presented with a group of sea animals in the upper half of the screen and another group of animals in the lower half, and they were asked to find as fast as possible which animal in the lower part was present in the upper part of the screen. In all of the trials, the target was presented in the sample, which increased from 2 to 6. Times were reduced within each sample size, so that whenever one element was added to the sample the time to respond started at a higher level at the beginning and was progressively reduced. Response time was the dependent variable.

Speeded visual search

For this speed of processing task, participants were presented with a plate of soup with 10 elements (digits and letters) and they had to find one element contained in the soup out of 4 different possible options. The number of elements to be found and the possible options remained constant so that the difficulty of the levels was only determined by the speed of the responses over the levels. Average reaction time per session was the dependent variable in this case.

Speeded categorization

This activity required participants to categorize groups of figures while progressively reducing the time to do so over the levels. Participants saw 3 groups of figures and 2 boxes to classify them according to different rules (size, color, shape or quantity). The rule to be applied for categorizing them was always displayed in the upper left corner of the screen so that it trained the response time throughout the levels. As in the two previous activities, we considered reaction time as the dependent variable.

Transfer tasks

Stroop

The scenario of this task was similar to the one used for training, where participants were presented with different-sized bags and they had to select one with the largest (or smallest) amount inside. The bags were either congruent or incongruent in size. The switching component was manipulated by changing the color of the coins and the consequent response rule from the largest (gold) to the smallest (silver). The number of bags presented (from 2 to 7), the proportion of incongruent trials (0, 0.25 or 0.50), the proportion of switching trials (0, 0.25, 0.50, 0.75), the inter-stimuli interval (from 1500 to 600 ms) and the maximum time to respond (from 3000 to 3600, this increased as a function of the number of bags) was manipulated across blocks of trials (levels). Inter-stimuli intervals were designed considering the average ITI used in the study by Steinhauser and Hübner (2009); the maximum and minimum intervals limited a wider range than the one parametrized for the training so that enough room was left to observe a possible benefit in response time. The dependent variable (conflict score) was calculated as a relative index from (Incongruent – Congruent)/Congruent trials RT (ms) for hits. Stimuli were presented randomly both in pre and post-training testing sessions.

N-back

In this WM task, participants had to retain the spatial position of a sequence of elements over 9 blocks of increasing memory load. Participants had to give a response any time an element matched the position of an element presented *n* (from 1 to 8) position-back. The length of the sequence in a block increased parallel to the memory load, from 6 to 20. The maximum time to respond and the inter-stimuli interval was respectively 2000 and 1000 for the first 4 blocks, and 1500 and 800 for the 4 last ones. *N*-back level and errors (omissions and commissions) were considered as dependent variables. The order of the stimuli in the sequence was randomized in pre and post-testing.

Stop-signal

We used this task of response inhibition with the standard parameters of the software STOP-IT (Verbruggen et al., 2008). Participants had to respond with the keyboard as fast as possible to two different stimuli (circles or square) presented in the center of the screen. In 25% of the trials, participants faced an auditory stop-signal (750 Hz, 75 ms) that was presented briefly after the visual stimuli onset and required the response to the current stimulus to be withdrawn. The task comprised of 32 practice trials and 3 blocks with 64 experimental trials each. The trials were displayed on a black screen and were composed of a 250 ms fixation point (white +), the stimuli presentation (a white square or circle) during 1250 ms and a fixed inter-stimuli interval of 2000 ms. Stimuli were randomized in pre and post-testing, and in all cases the stop signal was presented with a variable stop-signal delay (SSD). Although initially it was set to 250 ms, it was continuously adjusted. When the inhibition was successful it was reduced 50 ms and if not, increased in 50 ms, so that according to the performance the software tried to maintain a stopping probability of 50%. We considered the Stop-Signal Reaction Time (SSRT) as a measure of motor inhibition efficiency (Verbruggen & Logan 2008; Verbruggen et al., 2008; Morales et al., 2013).

Operation span (O-Span)

We used the Spanish adapted version of the procedure developed by Turner & Engle (1989) (Tokowicz et al., 2004; Redick et al., 2013; Turner & Engle, 1989). It was a dual memory span task that required participants to verify mathematical operations while trying to remember sets of words of increasing set sizes. Each trial was composed of a simple solved mathematical equation (i.e., (14/2) + 2 = 8) presented for 3750 ms that participants had to verify and mark as correct or not by pressing one out of two keys on the keyboard. Afterwards, a word was presented for 1250 ms to be maintained in memory. Operation-word pairs were presented in increasing set sizes from 2 to 6. After each set, participants had to recall and type the words. While the order of recall was not important, they were told to avoid writing the last word presented first in order to prevent recency effects. The task comprised of 18 trials (3 trials per set size) and the testing procedure was repeated until the end. We developed parallel versions of the task by randomizing the order of the stimuli presented that were counterbalanced across sessions and participants. Two parallel versions were created and counterbalanced for pre and post-testing by randomizing the equation-word pairing. Special care was taken to avoid a similar pairing set size distribution between the two versions.

AX-CPT

We used the same version of the task as Morales et al. (2013) did to explore the adjustment of proactive/reactive cognitive control. In each trial participants were presented with 5 letters for 300 ms each (cue – 3 distractors – probe) in the center of a black screen, with a fixed inter-stimuli interval of 1000 ms. Cue and probe stimuli were presented in red font while distractors were presented in white. Participants were instructed to respond “yes” whenever they saw an A in the first position (cue) followed by an X in the fifth position (probe). Participants were asked to respond “no” to any other cue- probe combination and to the distractors (items in positions 2 to 4). The task was composed of a 10 trials practice phase and an experimental block of 100 trials, which were presented randomly both in pre and post-testing. The target trials (AX) were the most frequent ones (70%) and the rest of the trials (cue – distractor: AY; distractor – probe; BX or neither cue nor probe: BY) occurred in a 10% of the remaining cases. Proactive and reactive control adjustment can be assessed by considering the proportion of errors in AY and BX type trials (Braver et al., 2009; Chiew & Braver, 2014; Morales et al., 2013).

Raven's Advanced Progressive Matrices (RAPM)

We used the computerized version of the set II of this test as a standardized measure of fluid intelligence (Raven, 1990). Participants had to solve visual analogy problems of increasing difficulty. A 3 × 3 matrix of patterns was presented and they had to a missing pattern of a matrix, from 8 different response alternatives. We counterbalanced two parallel versions of the test over sessions with 18 matrices for the pre- and post-testing as used by Jaeggi (2013). Participants had to complete the task as fast and accurately as possible with a 20 minutes time restriction. The dependent variable was the proportion of correct matrices answered and the reaction times of the hits.

RESULTS

Data were processed using Microsoft Excel and all statistical analyses reported were conducted in IBM SPSS Statistics 20, two-tailed, and alpha set to 0.05.

Training effects

To determine the significance of the training improvement in each activity, we compared the performance in the first training session with that of the final training session (sixth session). Thus, for all tasks mixed analyses of variance (ANOVAs) were conducted on the specific dependent variables for the task (conflict score, errors, reactions times or memory load) with training session (first vs. sixth) as the within-subject independent variable.

Inhibitory Control Training group

The ANOVA yielded a reliable difference in the relative conflict effect [(incongruent-congruent)/congruent hits RT] from the first to the last training session (M_{s1} = 0.52, SD_{s1} = 0.24; M_{s6} = 0.33, SD_{s6} = 0.19; F (1, 21) = 5.94; p = 0.02; n^2_p = 0.22). The conflict effect was also reduced from the first to the last training session in the Conflict resolution task, although the difference did not reach statistical significance (M_{s1} = 0.48, SD_{s1} = 0.34; M_{s6} = 0.39, SD_{s6} = 0.25; F (1, 31) = 1.71; p = 0.20; n^2_p = 0.05). For the Go/No-Go task we analyzed both omission errors and false alarms. The results of these analyses showed that participants reduced their average omission errors (M_{s1} = 3.50, SD_{s1} = 2.68; M_{s6} = 1.43, SD_{s6} = 2.01; F (1, 31) = 13.11; $p < 0.01$; $n^2_p = 0.30$), while the reduction of false alarms was not reliable (M_{s1} = 3.90, SD_{s1} = 3.50; M_{s6} = 3.25, SD_{s6} = 2.70; $F < 1$; $p = 0.40$; $n^2_p = 0.02$).

Working Memory Training group

For all the WM-training tasks (*n*-back, WM search and WM updating), we compared the memory set size recalled from the first to the last training sessions. The increment in set size recalled was statistically significant for all the three activities trained: *n*-back (M_{s1} = 1.13, SD_{s1} = 0.17; M_{s6} = 2.60, SD_{s6} = 0.57; F (1, 31) = 190.92; $p < 0.01$; $n^2_p = 0.75$); WM Search (M_{s1} = 2.21, SD_{s1} = 0.17; M_{s6} = 4.92, SD_{s6} = 1.07; F (1, 31) = 198.32; $p < 0.01$; $n^2_p = 0.76$) and WM Updating (M_{s1} = 1.00, SD_{s1} = 0.06; M_{s6} = 3.20, SD_{s6} = 0.63; F (1, 31) = 390.95; $p < 0.01$; $n^2_p = 0.86$).

Active Control group

Note that this group did not change the level of executive demands, which was held constant throughout the training sessions. Although, they went forward over levels, so their impression was that they were training, the changes from one level to the next were the progressive reduction of presentation speed and response-time. Hence, we compared the speed of the participants' responses (ms) from the first to the last session for the three activities. The results of this comparison yielded statistically significant differences for Speeded Comparison (M_{s1} = 5075.87, SD_{s1} = 437.75; M_{s6} = 3539.04, SD_{s6} = 656.75; F (1, 23) = 89.62; $p < 0.01$; $n^2_p = 0.66$); Speeded Visual Search (M_{s1} = 22555.57, SD_{s1} = 864.64; M_{s6} = 3585.23, SD_{s6} = 534.92; F (1, 23) = 8096.82; $p < 0.01$; $n^2_p = 0.99$) and Speeded Categorization (M_{s1} = 24987.26, SD_{s1} = 62.39; M_{s6} = 13731.60, SD_{s6} = 194.22; F (1, 23) = 374.22; $p < 0.01$; $n^2_p = 0.89$).

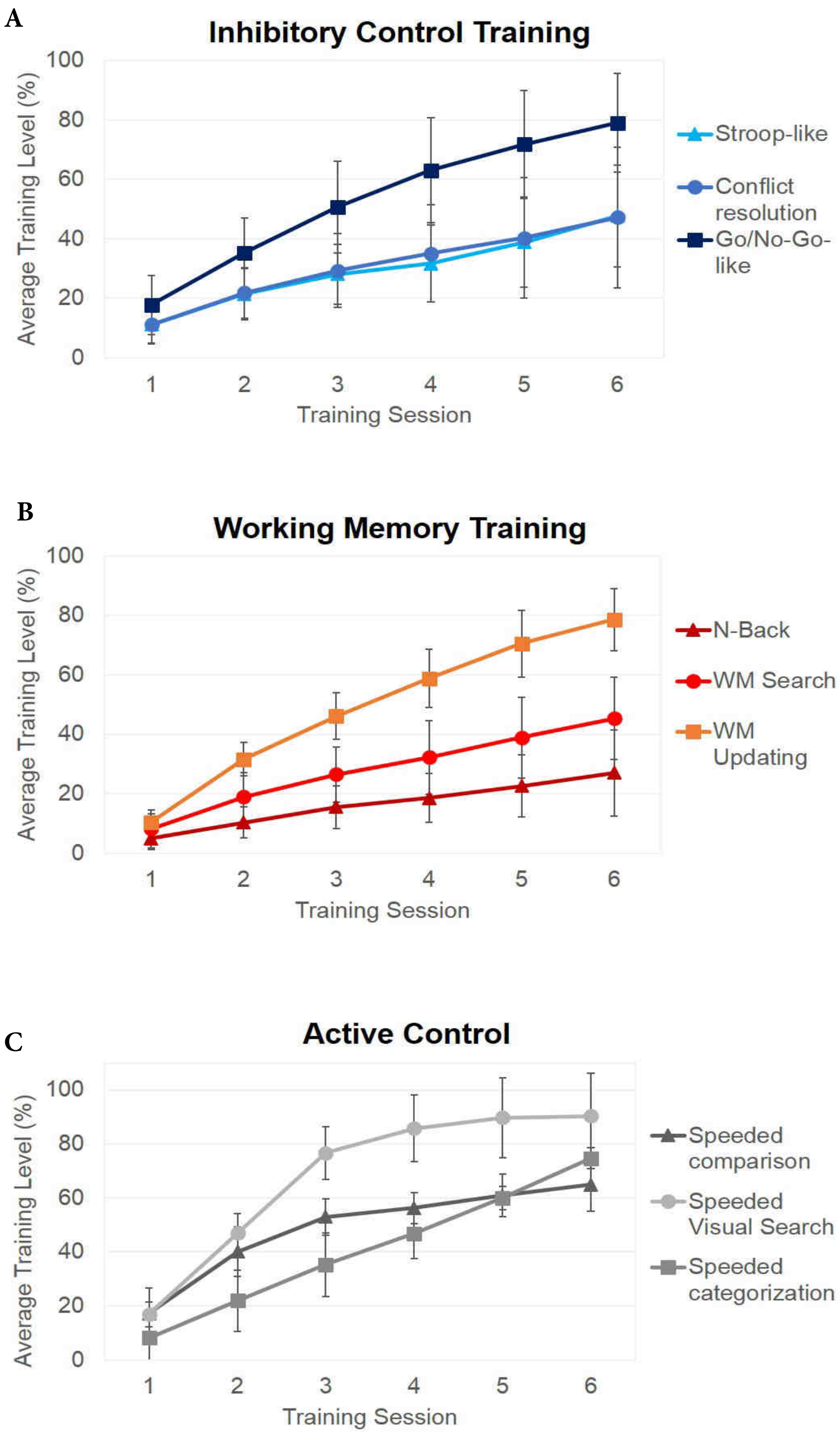
Training slopes

The training program PEC-UGR enabled us to create many training levels by using all possible combinations of task parameters (i.e., proportion of congruent/incongruent trials; target-distractor similarity; memory load; response times; etc.). Nonetheless, because the tasks differed in the number of to-be-manipulated parameters, the number of training levels varied across activities.

Consequently, in order to put together the trained activities and to compare how far participants from the different groups went in the training, we standardized the level of achievement for each participant by dividing the average level reached in a given activity by the number of levels possible in the activity. Thus, Figure 4.1 represents the relative level achieved in each activity and each training session for the three trained groups.

To quantify participants' training improvement over the six sessions of training, we calculated the slope of a linear regression model using the standardized average level in each training session and activity per participant (Katz et al., 2014; Wang et al., 2014). In order to compare the training achievements of the different groups (Figure 4.1), slopes of the three training tasks for each group were averaged. A one-way ANOVA showed a main effect of group (F (2, 85) = 16.26; p < 0.01; n^2_p = 0.27), as the average slope for the AC (M = 12.23; SD = 1.34) was significantly larger than the one for the ICT (M = 8.68; SD = 2.92; p < 0.01) and the WMT (M = 8.05; SD = 1.78; p < 0.01) groups. This is consistent with the fact that active control activities were significantly easier that the executive control ones, facilitating the advancement through the activity levels. The slopes of the two experimental training groups did not differ one from each other (p = 0.76).

Figure 4.1. Training improvement of healthy young adults. Training performance over the six training sessions for the three different groups that complete training procedures: **(A)** Inhibitory Control Training **(B)** Working Memory Training **(C)** Active Control. In all the cases, *y*-axes represent the average relative level achieved in each session and training activity. Error bars represent standard deviations.



Correlations at pre-test

To check for relationships between the cognitive functions tested at baseline, Pearson correlations were run on the pre-test scores for all the participating groups as a whole. As shown in Table 4.1, these analyses showed that WM-related measures were correlated: those participants with a higher combined score in the O-Span task showed fewer intrusions in the O-Span (r = -0.34; p < 0.01) and fewer errors in the n-back task (r = -0.19; p = 0.03). Additionally, participants with a larger BSI showed fewer intrusions in the O-Span task (r = -0.20; p = 0.03).

Finally, RAPM scores significantly correlated with errors in the n-back (r = -0.24; p = 0.01), conflict effect in the Stroop task (r = -0.21; p = 0.03) and with the combined score from the O-Span task (r = 0.31; p < 0.01).

Table 4.1. Pearson correlations between outcome measures at pre-test.

		Raven	BSI	SSRT	N-back level	N-back errors	Stroop Conflict	O-Span
BSI	Pearson *r*	-0.04	-					
	p-value	0.66						
SSRT	Pearson *r*	-0.07	0.12	-				
	p-value	0.40	0.17					
N-back level	Pearson *r*	0.00	0.06	-0.02	-			
	p-value	0.95	0.49	0.76				
N-back errors	Pearson *r*	**-0.24***	0.03	0.16	**0.53***	-		
	p-value	**0.01**	0.70	0.08	**0.00**			
Stroop Conflict	Pearson *r*	**-0.21***	0.04	0.05	0.03	-0.00	-	
	p-value	**0.03**	0.63	0.59	0.76	0.95		
O-Span	Pearson *r*	**0.31***	0.08	-0.14	-0.06	**-0.19***	-0.08	-
	p-value	**0.00**	0.39	0.11	0.52	**0.03**	0.43	
Intrusions (O-Span)	Pearson *r*	-0.12	**-0.20***	-0.12	0.15	0.14	-0.02	**-0.34***
	p-value	0.20	**0.03**	0.20	0.11	0.12	0.83	**0.00**

Transfer results

Table 4.2 summarizes the descriptive data of the outcome measures, including statistical comparisons for the session effects (pre vs. post) in each of the groups. We also calculated standardized gains subtracting the pre-test scores from the post-test (the opposite for reaction times) and divided by the standard deviation of the entire sample (Erika Borella et al., 2014; Colom et al., 2013; Jaeggi et al., 2013; Redick et al., 2013). One-way ANOVAs were performed for each variable in order to compare standardized gains between the groups. The participants who were excluded at pre-test due to missing data were also excluded from analyses of performance after the training.

Stroop

For the Stroop-like task, the reaction times from 20 participants (10 from ICT and 10 from WMT) were not registered due to a software coding error and consequently they could not be included in the analyses. We obtained a relative conflict score from the difference in reaction times between incongruent and congruent trials. There were no pre-test differences between the groups (F (3, 88) = 1.86; $p = 0.14$; $n^2_p = 0.05$). The ANOVA on the standardized gains failed to show a reliable effect of group, F (3, 88) = 1.76; $p = 0.16$; $n^2_p = 0.05$. As can be observed in Table 4.2, however, it was only the ICT group that was able to significantly reduce their conflict scores after completing the training.

N-back

The n-back level and the number of errors were considered in this task. There were no differences in the baseline n-back level before training (F (3, 108) = 1.39; $p = 0.24$; $n^2_p = 0.03$). However, a one-way ANOVA revealed differences in the number of errors at pre-test (F (3, 108) = 10.02; $p < 0.01$; $n^2_p = 0.21$), whereby the PC group committed significantly fewer errors than the other three groups (all ps < 0.01). Table 4.2 shows that only the WMT group showed a reliable increase in the number of items that could be maintained/updated in WM and a reduction in the number of errors committed after the training. The ANOVA performed on the standardized gains scores revealed a statistically significant effect of group for n-back level: (F (3, 108) = 4.06; $p < 0.01$;

$n^2_p = 0.10$). Post hoc comparisons for the *n*-back level indicated that the only reliable difference was between the PC and the WMT groups ($p < 0.01$) whereas the pairwise comparisons between the remaining groups were not significant (ICT-WMT: $p = 0.11$; ICT-AC: $p = 1.00$; ICT-CP: $p = 1.00$; WMT-AC: $p = 0.42$; PC-AC: $p = .89$). In the case of errors, and because we found differences between groups at pre-test, we checked whether there were group differences in the standardized gains as *n*-back errors committed at pre-test were introduced as a covariate. The analysis of covariance (ANCOVA) revealed a reliable effect of the covariate (F (3, 107) = 59.06; $p < 0.01$; n^2_p = 0.35) but also a significant effect of group (F (3, 107) = 5.28; $p < 0.01$; $n^2_p = 0.13$). Further analyses showed that there was a statistically significant difference between the AC and WMT groups (p = 0.01), and between the two control groups ($p < 0.01$). None of the other comparisons showed reliable differences (ICT-WMT: $p = 0.39$; ICT-AC: $p = 0.89$; ICT-CP: $p = 0.14$; WMT-CP: $p = 1.00$).

Stop-Signal

We used the software ANALYZE-IT provided by Verbruggen et al. (Verbruggen et al., 2008) to determine the impact of training on inhibition. The Stop-Signal Reaction Time (SSRT) is an index of pure response inhibition and the program calculates it by subtracting the Stop-Signal Delay (SSD) from the untrimmed RT mean. Following the criteria of Verbruggen, we removed 5 participants (1 ICT, 1 WMT, 1 AC and 2 PC participants) from the analysis, since they had an overall probability of responding on stop trials significantly below or above 50% in both pre and post-test. The groups did not differ in SSRT at pre-test (F (3, 104) = 1.85; $p = 0.14$; $n^2_p = 0.05$). As for response inhibition, while the corresponding ANOVA on the standardized gain did not reveal a reliable effect of group (F (3,104) = 0.52; $p = 0.66$; $n^2_p = 0.01$), the only reliable pre-post reduction of SSRT was in the ICT group (see Table 4.2). Note that there were training-related effects neither on hits nor on the RTs of Go trials[2]. Thus, training effects were only evident in the SSRT as an index of response inhibition, but not in the other variables that assess basic task performance. This is important since it shows that transfer is specific to the executive control trained process.

[2] No reliable differences in pre-post effects were observed on hits (ps > 0.33) or RTs (ps > 0.56) in Go trials for the ICT, WMT or AC groups. The PC group showed a worse performance with a lower hits rate ($M_{pre} = 95.71$, $SD_{pre} = 4.76$; M_{post} = 91.77, $SD_{post} = 4.56$; F (1, 21) = 8.06; $p = 0.01$; $n^2_p = 0.27$); and slower RTs ($M_{pre} = 753.21$, $SD_{pre} = 156.80$; $M_{post} = 832.54$, $SD_{post} = 168.07$; F (1, 21) = 11.75; $p = 0.00$; $n^2_p = 0.35$) in the post-test.

Operation-Span

For the O-Span task, we considered the number of words recalled (storage capacity) and the averaged accuracy of equations (ongoing processing) multiplied, and resulting as a combined index of dual processing. For the calculation, we used a partial credit load scoring approach (PCL, Conway et al., 2005), which considered the average proportion of correctly recalled words from all set sizes, regardless of whether the set size group was perfectly recalled or not.

A one-way ANOVA on the combined scores (words recalled and equations accuracy) showed that there were no differences between the groups at pre-test (F (3, 108) = 0.42; p = 0.73; n^2_p = 0.01). Particularly, there was a reliable pre-post enhancement in the three training groups, with the greatest effect size in the ICT group (see Table 4.2). The ANOVA comparing the groups' standardized gains failed to show reliable differences however, F (3,108) = 1.76; p = 0.15; n^2_p = 0.04.

Finally, intrusions were also considered as a measure of updating in WM (low intrusion corresponding to successful updating). In this case, only the WMT group was able to significantly reduce the number of intrusions in the dual task (Table 4.2). The one-way ANOVA on the standardized gain confirmed a reliable effect of group, F (3,108) = 2.73; p = 0.04; n^2_p = 0.07. The post-hoc comparisons showed that the only reliable difference involved the WMT and the PC groups (p = 0.03).

AX-CPT

To assess the tendency towards proactive/reactive control, we calculated the Behavioral Shift Index[3] introduced by Braver (BSI, Braver et al., 2009; Chiew & Braver, 2014). Larger BSIs stands for a greater tendency towards proactive control, whereas smaller BSIs indicate a tendency towards reactive control. Invalid trials, which included no responses and trials with responses times below 100 or above 1000 ms, were 6.1% out of the trial total. 8 participants were removed from the analysis because they had more than 10% of invalid trials in Pre and Post-test. The four groups were comparable in BSI at pre-test (F (3, 100) = 0.21; p = 0.88; n^2_p = 0.01).

[3] This index is based on the formula (AY-BX)/(AY+BX) for errors and reaction times. Trials where errors were equal to 0 were corrected [(errors + 0.5)/ frequency of trials + 1].

The one-way ANOVA on BSI standardized gains failed to show a group effect (F (3, 100) = 1.60; p = 0.19; n^2_p = 0.04). Nonetheless, the pre-post analyses only showed a reliable effect in both ICT and WMT groups, which exhibited larger BSI after the training (Table 4.2, ps ≤ 0.01).

Raven's Advanced Progressive Matrices

There were no differences between the groups at pre-test in either hit rates (F (3, 108) = 0.44; p = 0.72; n^2_p = 0.01), or reaction times (F (3, 108) = 1.47; p = 0.22; n^2_p = 0.03). As shown in Table 4.2, however, the ICT was the only group that exhibited a pre-post increase in hit rates. The one-way ANOVA confirmed an effect of group, F (3,108) = 2.63; p = 0.05; n^2_p = 0.06), which was mainly accounted for by the difference between the ICT and PC groups (post-hoc comparison with p = 0.04). No effects were found in hit reaction times.

Table 4.2. Descriptive statistics for outcome measures. Mean and standard deviations for the outcome measures in the Pre and Post-testing. Significance p values and effect sizes (Cohen's d) estimators are reported for the mixed ANOVAs including session as a within subject variable (Pre-test and Post-test values) and group as a between-subject effect in each of the four groups. Standardized gains mean (Post-Pre)/(SD Pre) for hits proportion variables and reversed for reaction times.

		Pre-test		Post-test		Pre-Post effects		Standardized Gain	
Variables	*n*	*M*	*SD*	*M*	*SD*	*p*	*d*	*M*	*SD*
Stroop: Conflict effect ((Incongruent - Congruent)/Congruent) hits RT (ms)									
IC Training	21	0.12	0.20	0.01	0.03	**0.02***	0.76	0.61	1.01
WM Training	22	0.14	0.21	0.09	0.14	0.32	0.28	0.25	0.99
Active Control	24	0.04	0.07	0.05	0.04	0.62	-0.17	-0.05	0.50
Passive Control	24	0.04	0.18	0.07	0.30	0.70	-0.12	-0.13	1.72
N-back: level									
IC Training	32	1.55	0.82	1.72	0.95	0.28	0.19	0.07	1.05
WM Training	32	1.78	0.83	2.43	0.75	**0.00***	0.82	0.75	1.23
Active Control	24	1.95	0.80	2.12	0.94	0.44	0.19	0.19	1.21
Passive Control	24	1.66	0.96	1.41	0.58	0.20	-0.31	-0.28	1.09
N-back: errors									
IC Training	32	8.51	4.77	8.51	5.48	1.00	0.00	0.12	1.28
WM Training	32	9.81	4.40	6.34	3.80	**0.00***	0.84	0.79	1.26
Active Control	24	9.95	3.74	9.70	2.64	0.76	0.07	0.05	0.93
Passive Control	24	4.62	1.78	4.20	1.44	0.38	0.25	0.09	0.53
Stop-Signal: SSRT (ms)									
IC Training	30	280.47	39.02	255.54	53.56	**0.00***	0.53	0.54	0.97
WM Training	31	266.29	51.68	254.66	36.19	0.28	0.26	0.25	1.30
Active Control	21	258.96	48.16	244.30	51.59	0.10	0.29	0.32	0.87
Passive Control	22	254.55	39.36	239.30	37.17	0.19	0.39	0.33	1.17
O-Span Index: Words recalled × Equations hits									
IC Training	32	0.59	0.10	0.66	0.12	**0.00***	0.63	0.52	0.68
WM Training	32	0.59	0.18	0.66	0.19	**0.00***	0.37	0.45	0.82
Active Control	24	0.55	0.13	0.60	0.13	**0.00***	0.38	0.19	0.28
Passive Control	24	0.58	0.12	0.61	0.10	0.24	0.27	0.18	0.77
O-Span: Intrusions									
IC Training	32	2.31	1.71	1.78	1.56	0.10	0.32	0.26	0.87
WM Training	32	2.46	1.81	1.34	1.42	**0.00***	0.69	0.55	0.92
Active Control	24	3.00	2.91	2.70	2.31	0.46	0.11	0.14	0.94
Passive Control	24	2.50	1.61	2.87	2.29	0.44	-0.18	-0.18	1.15
AX-CPT: BSI (AY-BX)/(AY+BX)									
IC Training	28	0.42	0.13	0.50	0.17	**0.01***	0.52	0.48	1.03
WM Training	30	0.39	0.17	0.51	0.14	**0.00***	0.77	0.66	1.26
Active Control	23	0.40	0.18	0.45	0.17	0.15	0.28	0.33	1.08
Passive Control	23	0.39	0.19	0.36	0.32	0.72	-0.11	-0.15	2.04

RAPM: Hits									
IC Training	32	0.44	0.18	0.51	0.18	**0.01***	0.38	0.36	0.77
WM Training	32	0.43	0.20	0.47	0.17	0.34	0.21	0.20	1.18
Active Control	24	0.47	0.20	0.49	0.18	0.44	0.10	0.14	0.91
Passive Control	24	0.48	0.15	0.42	0.17	0.06	-0.37	-0.32	0.76
RAPM: Hits RT (s)									
IC Training	32	35.75	12.94	33.87	15.50	0.49	0.13	0.12	0.98
WM Training	32	34.42	16.63	31.38	15.92	0.15	0.18	0.19	0.76
Active Control	24	42.32	17.13	40.51	15.27	0.55	0. 11	0.11	0.93
Passive Control	24	34.44	15.55	32.24	16.44	0.48	0.13	0.14	0.95

Predictors for training improvement and transfer

We were also interested in exploring which of the cognitive abilities tested at the baseline level predicted the magnitude of training improvement. We ran linear regression analyses with the average training slope as the outcome, and all the measures at the pre-testing stage as predictors. Only for the experimental training groups, RAPM scores significantly predicted the global training improvement ($R^2 = 0.12$; $p = 0.01$; $\beta = 0.86$). We also looked at whether pre-test performance on the reasoning test predicted transfer gains after training. However, there was not a reliable relationship between RAPM scores before training and any of the gain scores on the transfer tasks. Reasoning scores at pre-test only predicted reasoning scores at post-test ($R^2 = 0.24$; $p < 0.01$; $\beta = 0.45$).

Going a step further we also looked at whether the magnitude of training improvement predicted transfer gains. We ran linear regression analyses in each training group, setting the standardized gains in the different transfer tasks as the criterion and the average training slope as the predictor variable. In the ICT group, higher training improvements predicted larger gains in the relative conflict score of the Stroop task ($R^2 = 0.29$; $p < 0.01$; $\beta = 0.19$) and larger gains in the RAPM ($R^2 = 0.12$; $p = 0.04$; $\beta = 0.09$). No reliable regressions emerged for the WMT and the AC groups (all with ps > 0.15).

On the whole trained sample, the analyses showed that the level participants were able to achieve in the training activities only predicted performance in the criterion tasks; namely, conflict in Stroop ($R^2 = 0.12$; $p < 0.01$; $\beta = 0.13$) and errors in the *n*-back task ($R^2 = 0.05$; $p = 0.03$; $\beta = -0.10$).

Motivation results

In order to account for the motivational factors during training, every two sessions we asked participants about their: i) involvement in the program; ii) perceived difficulty of the activity levels; iii) perceived challenge of improving over the levels; iv) expectations for their achievement (Alonso-Tapia & de la Red Fadrique, 2007; Colom et al., 2013). We averaged all the variables across the three measurement points and explored their distribution across groups. One-way ANOVAs failed to show group differences in any of the four motivational variables: implication [(AC: M =

9.09; *SD* = 0.85; ICT: *M* = 9.03; *SD* = 0.94; WMT: *M* = 8.98; *SD* = 0.92); $F < 1$; $p = 0.90$, $n^2_p = 0.00$]; perceived difficulty [(AC: *M* = 6.31; *SD* = 1.46; ICT: *M* = 6.11; *SD* = 1.76; WMT: *M* = 6.25; *SD* = 1.49); $F < 1$; $p = 0.8$, $n^2_p = 0.00$]; perceived challenge to improve [(AC: *M* = 7.15; *SD* = 1.46; ICT: *M* = 7.31; *SD* = 1.47; WMT: *M* = 7.28; *SD* = 1.52); $F < 1$; $p = 0.91$, $n^2_p = 0.00$] and expectations to improve [(AC: *M* = 7.28; *SD* = 1.58; ICT: *M* = 7.76; *SD* = 1.20; WMT: *M* = 7.94; *SD* = 1.07); F (2, 85) = 1.91; $p = 0.15$; $n^2_p = 0.04$]. Then, we calculated partial correlations controlling for group between the four motivation variables and the global training slope. We only found a modest correlation between the training slope and the perceived challenge ($r = 0.25$; $p = 0.04$), so that those participants who perceived the training as more challenging were the ones who tended to improve the most.

In order to explore whether participant's motivation modulated training improvement, we averaged the four motivation variables and calculated a global motivation score (AC: *M* = 6.81; *SD* = 0.69; ICT: *M* = 6.99; *SD* = 0.75; WMT: *M* = 6.99; *SD* = 0.54). A one-way ANOVA showed no differences between the groups in general motivation, $F < 1$; $p = 0.54$; $n^2_p = 0.01$. However, because we wanted to more precisely examine whether the motivation level was related to the participants' training achievement, we split all the executive control trained participants by the median of the global score (*Md* = 6.95) to differentiate between high and low motivated participants. A one-way ANOVA with motivation (high and low) as the factor and global training slope of ICT and WMT participants as the dependent variable showed motivation levels to be statistically significant, $F(1, 62) = 5.55$; $p = 0.02$; $n^2_p = 0.08$); with high motivated participants exhibiting a higher training slope (*M* = 9.39; *SD* = 2.65) than less motivated participants (*M* = 7.82; *SD* = 2.66).

To explore whether motivation predicted transfer, multiple linear regression models were run setting the standardized gains in the transfer tasks as criterion variables, the four motivational variables measured during training as predictor variables, and considering the two training groups as a whole. The level of motivation predicted transfer to the O-Span task in the two experimental training groups ($R^2 = 0.15$; $p = 0.03$), so that those who felt more involved ($\beta = 0.28$; $p = 0.03$) and those who perceived the training as less difficult ($\beta = -0.31$; $p = 0.02$) had larger gains after training.

Lastly, we compared the transfer gains in those participants who were highly motivated from the experimental groups (ICT: $n = 17$; WMT: $n = 15$) with those who were highly motivated in the active control group (*n* = 12). Most likely due to the small sample sizes, only a marginal statistical effect was found on the standardized gains of one of the two criterion tasks. Specifically, in the *n*-back task the WMT participants had larger gains (*M* = 0.92; *SD* = 0.99) than the ICT (*M* = 0.13; *SD* = 1.07) and the AC participants (*M* = 0.19; *SD* = 0.96), [F (2, 31) = 2.80; p = 0.07; n^2_p = 0.12].

Discussion

The main goal of the present study was to directly compare the effectiveness of two specific process-based EF training programs (WM and IC) in young adults. These two programs were based on the assumption of the highly influential "Unity and Diversity" model of executive functions proposed by Miyake et al., (2000). The main feature of this model is that the executive function system could be partitioned into overlapping (unity) and yet distinct (diversity) components (inhibition, shifting, and WM updating). A logical conclusion drawn from the assumption of diversity is that EF training could specifically be targeted to one of these functions with transfer effects showing some degree of specificity and commonality. The results of the present experiment generally support this assumption.

Thus, regarding the improvement in the criterion tasks – structurally similar to the trained ones – our results support the specificity of EF training on the basis of the specific benefits observed at post-test. Only the WMT group showed pre-post enhancement in the *n*-back task (*n*-back level and errors) and only the ICT group exhibited reduced conflict scores in the Stroop task after training. Even though some previous studies have shown benefits in the Stroop task following WM training (Erika Borella et al., 2010; Chein & Morrison, 2010; Schweizer, Hampshire, & Dalgleish, 2011), we failed to observe a reliable effect of working memory training over conflict resolution. Hence, the results concerning the criterion tasks point to straightforward training-specific effects.

In relation to near transfer effects, we also observed specific training benefits for the WMT group in the non-trained WM task (O-Span). Particularly, for the O-Span task only the WMT group showed a benefit in suppressing memory intrusions; consistent with previous studies showing the relationship between high WMC and more efficient intrusions suppression in span tasks (Borella et al., 2008; Rosen & Engle, 1998; Turley-Ames & Whitfield, 2003). Similarly, the ICT group was the only group that specifically showed a benefit in response inhibition (SSRT), indicating that adaptive training in conflict resolution tasks improves performance in other tasks also thought to require conflict resolution mechanisms (for related results see Dovis et al., 2015; Berkman et al., 2014; Enge et al., 2014; Manuel, Bernasconi, & Spierer, 2013). Together with the results found with the criterion tasks, the near transfer results also support the idea that training on either WM or IC leads to specific performance benefits in tasks related to the training (Simons et al., 2016).

However, and despite this specificity, the two EF-trained groups also showed some common features regarding near transfer effects. Thus, both WMT and ICT groups improved dual performance (Equations accuracy × Words recalled) in the O-Span task [related findings of improved complex span scores have been reported after simple, complex span and visual search training, (Harrison et al., 2013); rehearsal strategy training (Turley-Ames & Whitfield, 2003) or task-switching training (Karbach & Kray, 2009)] , suggesting that dual tasking may require both WM capacity and IC mechanisms (Chein et al., 2011; Smith et al., 2001; Towse et al., 2000; Unsworth, 2010). Hence, inhibitory control seem to be demanded not only in the training activities practiced by our ICT group but also in the WM updating tasks that required suppression of irrelevant information and that were extensively practiced by the WMT group. This might be indicating the relationship between working memory and inhibitory control at the behavioral level, and be suggestive of the degree to which trained and transfer processes may overlap in their underlying neurocognitive networks. Kane & Engle (2002) proposed that dorsolateral prefrontal cortex could play a role in WM capacity in contexts providing potential interference (and requiring attentional control), and it has also been proposed that in WM span tasks, regions in the prefrontal cortex are activated when an executive control mechanism is recruited to reduce interference during the maintenance and manipulation of information (Conway, Kane, & Engle, 2003; Gray, Chabris, & Braver, 2003).

It is however puzzling that we also observed a training effect for the active control group in the O-Span task, which did not differ from that obtained by the WMT group. Note that, although the AC group did not increase the cognitive load over the training levels, we used activities that involved increasing difficulty by augmenting the speed of processing. Thus, as also predicted, it is possible that the positive effect for this control group stemmed from the overarching time-limited nature of the tasks. Increasing speed of processing could have led to more efficient processing and maintenance in working memory that would result in better performance in the O-Span task. Unsworth et al., (2009) reported a negative correlation between processing speed and WM maintenance, suggesting that participants who processed quickly recalled more items that those who worked slowly. Similarly, faster speed processing has been proposed to reduce the possibility of items being forgotten, and less time for rehearsing or refreshing processes (Hudjetz & Oberauer, 2007; Towse et al., 2000; Unsworth et al., 2009).

Regarding far transfer effects, we also found common and diverse features in our trained groups. We included two tasks (AX-CPT and RAPM) that did not directly capture WM or IC: the AX-CPT was used to explore whether training effects might change the control strategy used by the participants, and Raven's matrices to explore whether WM and IC training transferred to a more general complex domain such as abstract reasoning. The AX-CPT is widely used to explore the dynamic adjustment of cognitive control strategies and it has shown to be very sensitive to individual differences in cognitive control (Braver et al., 2009; Braver, 2012; Burgess et al., 2011). Proactive control requires goal maintenance and is related to paying attention to contextual cues in order to effectively solve interference while keeping the monitored cues in mind (Rush, 2006). In this version of the task, the use of a proactive control strategy was encouraged since the context was highly predictive (the A cue precedes the X target in 70% of the trials); hence, a control mode that involves sustained maintenance of task-relevant information would lead to a high success rate, albeit it would lead to errors in trials where the cue was A but the probe was not X (AY trials; 10% of the trials). Thus, enhanced proactive control is expected to increase AY errors and reduce BX errors, with the BSI tending to larger values since the cue in BX trials does not signal a "yes" response. Usually, because it is the most efficient strategy, young adults exhibit behavioral performance and brain activity (sustained lateral PFC activation) consistent with a predominant proactive control strategy (Braver, 2012; Morales et al., 2013).

Interestingly, results from our experiment regarding the BSI (an index signaling changes toward proactive control) in the AX-CPT suggested a higher reliance on proactive control for WM and IC trained participants compared to active and passive control groups. Previous studies have already reported the malleability of cognitive control mechanisms engaged in the AX-CPT due to transcraneal electric brain stimulation (Gómez-Ariza, Martin & Morales, 2017), experience-based conditions such as bilingualism (Morales et al., 2013; Morales et al., 2015) or different kinds of training interventions: task-strategy training made older adults (Paxton et al., 2006) and people with schizophrenia (Braver et al., 2009; Edwards et al., 2010) more prone to engage in proactive control; indeed, more similar to adults-like performance than before training. Previous studies have also reported proactive shifts in cortical regions as the lateral PFC after strategy (Braver et al., 2009) and IC training (Berkman et al., 2014), suggesting the possibility that the lateral PFC might serve to anticipate upcoming control demands across a range of executive control domains. Our results replicate and extend these findings by showing behavioral shifts toward proactive processing in both ICT and WMT (even though numerically larger in the WMT group), suggesting again some common executive resources for inhibitory and WM processes.

In contrast, the results of the non-verbal reasoning (RAPM) task showed, some degree of specificity. Specifically, we observed a benefit for the ICT group but not for the WMT group. The question of whether cognitive training could improve fluid intelligence is a recurrent controversial area of research with considerable number of studies reporting data against (Melby-Lervåg & Hulme, 2013; Shipstead et al., 2012) and in favor of it (Au et al. 2014; Morrison & Chein, 2011). Results of our ICT group join others showing better reasoning performance after training. Karbach & Kray (2009) reported improved performance in a composite measure of reasoning after 4 sessions of task-switching training in children, young and older adults compared to an active control group (Karbach & Kray, 2009). Similarly, Rueda and collaborators found benefits in a measure of reasoning after 5 (Rueda et al., 2005) and 10 days (Rueda et al., 2012) of executive-control training in pre-school children when compared to control groups (but see Enge et al., 2014 and Thorell et al., 2009 for failures to show such positive effects).

However, our WMT group did not show benefits in abstract reasoning. Although fluid intelligence and WM share common variance (Colom, 2004; Friedman et al., 2006; Harrison et al., 2015; Oberauer et al., 2005) and executive functions have been related to reasoning operations (Dempster & Corkill, 1999; Engle & Kane, 2004; Jarosz & Wiley, 2012; Shipstead et al., 2015) it is possible that our participants did not reach the level of difficulty needed to show far transfer. In support of this interpretation, the results of the regression analyses showed that training improvement only predicted transfer to abstract reasoning for the ICT group, which suggests that the training levels achieved by the WMT group did not reach high enough demand levels to promote transfer. Previous studies reporting positive training effects have normally used single but highly demanding tasks, such as the dual *n*-back task (Jaeggi et al., 2008, 2010, 2013) and/or participants attained high levels of performance over training, such as *n*-back levels of over 3 (Jaeggi et al., 2008, 2013). Note that, in average, our WMT participants reached an *n*-back level below three and performed a single *n*-back task. Hence, and considering the fact that we trained more than one task, it is possible that the level of difficulty was below that needed to show far transfer effects with WM training.

Together, the observed transfer effects allow us to claim that it was the ICT group that showed the most consistent pattern of enhanced performance across tasks. While there might be more than a single reason behind this finding, we favor the idea that the benefit for the ICT group is not related to differences in cognitive demands or motivational aspects between the two training programs. As previously noted, the training levels achieved by the WMT group could have not been demanding enough to lead to stronger overall transfer.

An additional and interesting point addressed in the present work was to look at individual differences regarding training and transfer effects. This is an issue that remains to be explored in deep (Könen & Karbach, 2015). In line with previously reported studies (Bürki et al., 2014), we have found that abstract reasoning was a meaningful predictor of training improvement, indicating that people with higher reasoning scores benefitted more from training. Furthermore, training improvement constituted a relevant predictor of transfer to the criterion tasks for the two experimental trained groups, and particularly in the case of the ICT group a predictor for transfer to reasoning and conflict reduction. This pattern of results highlights the importance of considering individual differences before training because they might influence how well they do during training and how much benefit they can take from it (Könen & Karbach, 2015).

In addition to the more important theoretical issues related to brain plasticity and transfer, a secondary aim of our study was methodological in nature. Previous training studies have been criticized for the suitability of the control conditions, for not considering motivational factors, or for the use of single training tasks (Jaeggi et al., 2013; Melby-Lervåg et al., 2016; Redick et al., 2013). In our study, we took these factors into account by using different tasks to train the target processes (and to increase the probability of generalization), by introducing two different control conditions (active and passive), and by considering motivational variables associated with training. Thus, the active control group engaged in tasks essentially requiring processing speed (for related approaches see Lawlor-Savage & Goghari, 2016; Goldin et al., 2014), in order to keep participants' motivation and engagement similar to those from the experimental groups. Importantly, all trained participants (including the AC group) showed a meaningful improvement in the specifically trained process (inhibitory control, working memory and processing speed). In fact, the AC group showed larger training slopes than the two experimental groups (see Figure 4.1). Note again that control activities were mainly perceptual and successive levels did not engage greater executive load but only faster responses with a low constant cognitive effort.

Also of relevance, the motivation questionnaire revealed similar levels of implication, perceived difficulty, perceived challenge and expectations during training for the three trained groups, indicating that transfer differences among the groups were not due to differences in motivation or perceived difficulty. Interestingly, while motivation cannot easily account for the differences between the training and control groups, it was a factor that predicted training improvement in the experimental groups, so that highly motivated participants – those that were more involved and perceived the training as less difficult - showed larger improvements across the training sessions than less-motivated participants. Thus, and consistent with previous studies, motivation this result highlights the importance of considering individual motivation through training, since it is related to greater improvements that could result in greater transfer effects

(Jaeggi et al., 2013; Katz et al., 2014; Mather & Carstensen, 2005). Apart from motivation, it would be of interest in future studies the inclusion of additional self-reporting assessments regarding individual differences in beliefs about the fixed or malleable nature of cognition (Jaeggi et al., 2013), expectancy and perceived improvement (Boot, Blakely, & Simons, 2011).

It must be noted that the present research is not without limitations. First, and despite the specific benefits found in the within-group comparisons, the lack of group effects in some of the standardized gain measures suggests caution in the interpretation of the results. Null effects in the gain comparisons may reflect the lack of statistical power but also inflated variability among groups. In a recent meta-analysis, Melby-Lervåg, et al., (2016) established that training studies with large effect sizes normally included small sample sizes (less than 20 participants per training condition) and untreated (passive) control groups, which produces biases towards significant – but low powered – results. (Melby-Lervåg et al., 2016; Enge et al., 2014). In the present study we used samples that were all over 20 participants per condition and we included a passive control group as well as an active control group. Second, the present training schedule covered two weeks, which is in the lower end of the range of the current training studies (from 2 to 14 weeks; Morrison & Chein, 2011). Hence, it is yet to be explored the magnitude of the transfer effects when training is extended over a longer period of time. Similarly, our study is blind regarding possible long-term effects since we did not follow them up in time. Future studies should address this issue because the value of training interventions essentially relies on the durability of training-induced results. Finally, we recognize that transfer effects in studies with young healthy samples are limited as long as they might be optimally functioning at pre-testing, leaving not enough room for meaningful improvements with training. Hence, studies with children and older adults could be more sensitive to training-related changes than studies with young people (M. E. Kelly et al., 2014; Spencer-Smith & Klingberg, 2015; Weicker et al., 2016).

In closing, and despite the existing limitations, our results lead us to suggest that executive-control training may modulate cognitive abilities in young people. The malleability of EFs challenges the long-standing assumption that cognitive abilities remain fixed over time. Training cognition is not a new concept (Boot & Kramer, 2014; Jolles & Crone, 2012; Schubert et al., 2014), but the idea that training and experience can generalize to tasks and domains beyond those trained is still controversial. In this sense, our results, while being modest and at the task level – rather than at the construct level – are promising and support substantial plasticity of cognitive control mechanisms by means of training. Interestingly, the results also suggest that there is some specificity in the consequences of the trained processes so that transfer occurs only when the specific trained process is tapped by the transfer task and domain. This opens the possibility that training in applied settings may be specific to the process needed for a specific domain, or to the impaired process due to deficient brain functioning. Also, this is suggestive of setting the ambitious goal of exploring the potential benefit of executive control training for everyday activities (Simons et al., 2016). Before this, further research would need to address the potential effects of executive-control training over brain structure and dynamics. Analyzing structural and functional brain profiles may provide further insight into why specific interventions may be more successful for certain individuals, and help characterize the overlap between training tasks and tests that show training-related transfer.

CHAPTER V

Training Executive Control during Healthy Aging

Experiment 2A*

Normal aging involves a progressive prefrontal decline that normally comes with cognitive impairments in memory as well as in executive control functions. Thus, it is not surprising that in the latest decades a wide variety of cognitive interventions have been carried out aiming to compensate or at least maintain the functioning level of older adults. Enhancing cognitive capacities by means of cognitive training is an ambitious research goal that becomes of paramount importance when it concerns older adults. Thus, in the next experiment we compare the potential impact of an executive control based cognitive training intervention to a non-demanding speed training intervention that acted as an active control condition. We assessed several transfer domains including working memory, inhibitory control, processing speed, reasoning, and the adjustment between cognitive control strategies – looking also in this latter case at the effects of cognitive training at the neural level. Moreover, we controlled for relevant modulator factors during the training such as baseline capacities prior to the training, motivational level and training location, since participants decided where to conduct the training either at home or in the lab. Our results showed significant gains for those participants who engaged in executive control training in comparison to those who underwent speed-processing training. Moreover, they also suggested the importance of considering individual differences when examining training-related gains and, overall, support the existence of cognitive and neural plasticity during healthy aging.

---

* The content of this chapter is in preparation for publication and is co-authored by Maraver, M.J., Gómez-Ariza, C.J., Borella, E., Cerrutti, C., Franzese, E. & Bajo, M.T.

As people grow older individual differences in cognition become progressively more evident. Aging is typically related to changes in brain and cognition, normally associated with a progressive impairment of prefrontal cortex functioning (Grady, 2012; Park et al., 2002). However, the aging process is heterogeneous and differs between individuals (Brehmer et al., 2014). A critical factor that is associated to neurocognitive age-related declines is the general impairment in health that many people suffers with age, that in turn, is linked to both genetic and lifestyle differences. Although an active and healthy lifestyle has been related to better cognitive performance (Hertzog et al., 2009; Kramer, Erickson, & Colcombe, 2006; Whalley, Deary, Appleton, & Starr, 2004), although much research is still needed to establish the impact of lifestyle on aging.

A growing body of research suggests that executive-control related functions decline with aging. Many older adults feel that their memory systems do not serve them as faithfully as when they were younger and, indeed, impairments in episodic memory and retrieval have been repeatedly reported in the aging literature (Lars Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012; Souchay, Isingrini, & Espagnet, 2000). Furthermore, evidence has also shown impaired performance of older adults in tasks that require a high degree of cognitive control. These include tasks in which older adults struggle when information has to be maintained in working memory (Daigneault & Braun, 1993; Holtzer, Stern, & Rakitin, 2004; Denise C Park et al., 2002; Stine, 1995), when attention has to be focused while facing distraction and interference of irrelevant information (Duchek et al., 1998), and when prepotent response tendencies, and even irrelevant memory traces, have to be inhibited (Aguirre et al., 2014; May et al., 1999; Ortega et al., 2012; R. T. Zacks & Hasher, 1997). As for the range of mechanisms that could be responsible of such age-related declines in cognitive control tasks, different proposals suggest a generalized slower processing (Cerella, 1985; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Salthouse, 1996), reduced cognitive resources and reduced working memory capacity (Salthouse, 1991; Park, 2000, 2002), inhibitory deficits (Biss, Campbell, & Hasher, 2013; Bojko, Kramer, & Peterson, 2004; Butler & Zacks, 2006; Gazzaley, Cooney, Rissman, & D'Esposito, 2005), disturbed attentional control (Madden, 2007), and also a deficit in the ability to actively represent and maintain task goals (Braver et al., 2005; Rush et al., 2006; Paxton et al., 2006, 2008).

The neural substrates of the cognitive deficits observed in older adults share the common denominator of an altered prefrontal activity (Raz et al., 2010). However, a variety of studies indicate that older adults tend to show pattern of either reduced or enhanced recruitment of prefrontal regions (Cabeza et al., 1997; Logan, Sanders, Snyder, Morris, & Buckner, 2002; Park et al., 2004; Rypma & D'Esposito, 2000). Thus, while some findings show reduced activity in frontal regions, including lateral prefrontal areas, when compared to young adults (Milham et al., 2002; Persson et al., 2004), other studies suggest enhanced activity in older adults in a number of prefrontal cortical and subcortical regions during performance on a range of cognitive tasks (R. Cabeza et al., 2004; Colcombe, Kramer, Erickson, & Scalf, 2005). This mixed pattern has been interpreted as deficit in executive control (reduced activity in frontal areas), that some people can compensate through larger engagement of this same frontal areas (Nelson et al., 2009; Reuter-Lorenz & Cappell, 2008; Reuter-Lorenz & Lustig, 2005; Turner & Spreng, 2012).

A promising attempt to prevent and counteract cognitive declines during aging is cognitive training. Indeed, a number of research efforts have focused on training older adults so that they can maintain an efficient cognitive functioning into later life (Borella et al., 2017; Karbach & Verhaeghen, 2014; Kelly et al., 2014; Lampit, Hallock, & Valenzuela, 2014; Tardif & Simard, 2011,for reviews). As we concluded in the previous chapter, training either working memory or inhibitory control in healthy young adults could lead to improvements in executive functions. Therefore, our next focus will be placed on exploring whether a similar executive control based intervention might be potentially helpful for a population of older adults in which cognitive deficits have been systematically reported. To do that two experimental series were conducted. First, in Experiment 2A, we compared an executive control training intervention in healthy older adults with a control condition that did not demand executive control. We considered relevant predictors for training improvement, such as baseline capacities and motivation, and explored the scope of transfer to a variety of cognitive functions including working memory, inhibitory control, speed processing as well as the adjustment of cognitive control mechanisms. Second, taking into account that impairment in episodic memory has been frequently reported in older adults, Experiment 3 was conducted to analyze the differences in selective memory retrieval between young and older adults by using the retrieval practice paradigm. Finally, in Experiment 2B we explore whether executive control training may modulate the memory mechanisms involved in selective retrieval in older adults.

The heterogeneity of the results and methods reported in the literature on cognitive training has been repeatedly addressed along this work. However, this becomes even more evident when dealing with aging, since studies differ substantially in a multitude of aspects (i.e., design, inclusion criteria, and age of participants or training setting). Taking all these factors into account, we outline below the most recent findings regarding the benefits of cognitive training in healthy older adults.

Selecting the appropriate control groups is also an essential methodological issue to consider when it comes to training older adults. Karbach & Verhaeghen (2014) conducted a meta-analysis on processes-based cognitive training in older adults and reported that, when compared to passive control groups, older adults showed training gains of 0.9 *SD*. In a different meta-analysis, Kelly et al. (2014) also demonstrated the effectiveness of cognitive training interventions in improving memory and subjective measures of cognitive performance compared to passive controls. However, while positive effects have also been shown for composite measures of executive functions relative to active controls (Kelly et al., 2014), some reports have revealed reduced (Karbach & Verhaeghen, 2014) or even null effects (Martin, Clare, Altgassen, Cameron, & Zehnder, 2011). Studies have also shown that most process-based cognitive training interventions lead to successful near transfer effects when the intervention is adaptive and of longer duration (Kelly et al., 2014).

The type of training intervention is also a determining factor of the variability of results across studies. Cognitive interventions focused on training a specific strategy (such as mental rotation or the method of loci) have reported little or even null transfer effects (Martin et al., 2011). On the contrary, the effects of process-based training (such as working memory or inhibitory control) would seem to be more prone to induce transfer to other cognitive tasks sharing the same process as the one targeted during the intervention (Karbach & Verhaeghen, 2014; Li et al., 2016; Shipstead et al., 2012). Specifically, substantial training gains have been reported for older adults after completing training programs targeting working memory (Borella et al., 2014, 2010, 2017; Buschkuehl et al., 2008; Dahlin et al., 2008; Richmond, Morrison, Chein, & Olson, 2011) and executive functions such as inhibition, dual-tasking or switching (Ball et al., 2002; Bherer et al., 2006; Mahncke et al., 2006; Schmiedek et al., 2010). However, in older age far transfer effects following process-specific training are often much smaller and less broad (Brehmer et al., 2012; Karbach & Verhaeghen, 2014, Kelly et al., 2014; Buschkuehl et al., 2008; Richmond et al., 2011; Schmiedek et al., 2010; but see Bherer et al., 2006; Borella et al., 2010; Karbach & Kray, 2009) or even absent (Borella et al., 2013; Dahlin et al., 2008; Li et al., 2008; Zinke et al., 2011).

Furthermore, training interventions that include different cognitive processes (such as working memory, processing speed, inhibitory control within a similar training program) have also reported positive transfer effects. Thus, multi-domain training interventions including cognitively complex group activities (Park et al., 2014), problem-solving (Stine-Morrow, Parisi, Morrow, & Park, 2008) or even video games (Anguera et al., 2013) have also shown small to moderate transfer effects to some cognitive functions, including executive control, processing speed or episodic memory.

An additional modulator of cognitive training and transfer gains is training location. Recent studies suggested that lab settings show greater effects than home-based training interventions (Kelly et al., 2014; Lampit et al., 2014). However, it remains unclear whether these differences emerge from receiving formal instruction in the lab but not at home, or whether they are related to the social environment provided by the lab setting in comparison to being alone during the training at home.

In addition, current research is focusing on identifying the brain mechanisms underlying training-related behavioral changes, generally using functional and structural magnetic resonance imaging techniques as well as electrophysiological recordings that reflect the oscillations of neural activity (Brehmer et al., 2012). Theoretically, short-term interventions could result in increased or decreased activation patterns of either similar brain regions or new neural networks that were not engaged before the intervention (Kelly, Foxe, & Garavan, 2006). So far, however, no consistent pattern of activation changes following short-term intervention has been observed for older adults. Results vary substantially depending especially on the type of intervention. However, generally increases in activation following training have been discussed as an indicator of individuals' latent potential for recruiting additional brain regions. Thus, the activation of additional cortical connections or the increase of activity within specific ones are sometimes interpreted as correlates of shifts in strategies or processes involved in solving the tasks (Lövdén et al., 2010). In contrast, activity decreases have been seen as indications for improvements in processing efficiency - as a result of practice in a specific task, a lesser degree of activation will be required in a region in response to that task (see Kelly et al., 2006; Lustig et al., 2009). In other words, the task might become easier in some aspects and this would be reflected in reduced activity in neurally-dependent brain regions.

In this sense, a growing number of studies in healthy older adults provide evidence for beneficial effects of cognitive training on brain activity. In process-specific interventions, studies of brain function have associated training effects with both cortical activity decreases (Brehmer et al., 2011; Dahlin et al., 2008)and increases (Erickson et al., 2007). Erickson et al. (2007) revealed near transfer effects of dual-task training with increased bilateral prefrontal activity for the trained older adults, and reduced age-related differences between younger and older adults in prefrontal regions. In two different studies, Brehmer et al. (2011, 2012) showed evidence of near transfer effects of working memory training on the basis of reduced fronto-parietal activity, being the decrease larger for the experimental training condition. In a similar vein, Dahlin et al., (2008) also revealed training-related cortical decreases in prefrontal regions in older adults after updating training. Along these lines, studies recording EEG before and after perceptual discrimination training have revealed facilitative effects of training that predicted post-training behavioral gains on working memory capacity (Berry et al., 2010). Also looking at the effects of training on brain oscillations, Anguera et al. (2013) revealed significant gains after dual-task training in the efficiency of reducing dual-task costs. These training gains transferred to behavioral measures of sustained attention, working memory, and were supported by increased theta power in prefrontal regions and frontal-posterior theta coherence as neural markers of enhanced cognitive control (Anguera et al., 2013). This discrepancy of neural patterns might be due to the different neural mechanisms recruited by the different training interventions. In any case, these findings reflect processes of neuroplasticity that might counteract the brain dysfunctions normally observed with aging. Again, however, most of these studies used passive control groups, which renders their results hard to interpret. Hence, the inclusion of active control groups would help to shed light on the specificity of such training effects.

In the present study, we aimed to explore the effects of an executive control training intervention in healthy older adults. Thus, a group of older adults completed six 1 h training sessions distributed across two weeks. We employed the training procedure used in Maraver et al. (2016), which combined executive control activities that included working memory (updating and maintenance) as well as inhibitory control and switching processes. As a comparison, we included an active control condition that worked with no-demanding perceptual tasks that only required progressive speeded responses. The active control group only differed from the experimental group in the process to be trained, but they were identical in many other factors that could potentially influence the scope of the training effect. This allows for a fine-grained evaluation of unique training effects.

We examined the potential transfer effects of training by using a number of experimental laboratory tasks that tapped into working memory (Operation-Span), inhibitory control (Stop-Signal), processing speed (Symbol comparison), reasoning (Raven's Matrices and Cattell Culture Fair Test), and the adjustment of proactive/reactive cognitive control mechanisms (AX-CPT). The AX-CPT provides an experimental paradigm that operationalizes representation, maintenance and updating of task goals in terms of the effects of contextual cues on task performance (Braver & Cohen, 2000; Braver et al., 2005, Paxton et al., 2006). Task-goals maintenance – also referred to as context processing - is a critical component in cognitive control and behavior planning, and is also an important cognitive mechanism that declines with aging (Braver et al., 2001; Braver & Barch, 2002; Paxton et al., 2006). Previous studies have suggested that goal representations are located within lateral regions of the prefrontal cortex and actively maintained (Braver & Cohen, 2001; O'Reilly & Frank, 2006; Paxton et al., 2008) Thus, if goal maintenance and context processing deficits in older adults result from altered function in prefrontal regions, we could expect a potential benefit of executive control training at the behavioral but at also at the neural level since they share cognitive and neural sources.

Effectiveness of training interventions is typically examined at the group level. However, because there is also evidence indicating that individual differences in baseline capacities and motivation may modulate training and transfer effects (Katz et al., 2016; Könen & Karbach, 2015; Borella et al., 2017), we decided to take these variables into account in our study. To date few studies have addressed how individual differences may impact on training effects in older adults. In addition, a remarkable feature of our experimental design is the inclusion of training location as a potential modulator of training effects. Our sample of older adults voluntarily chose where they wanted to complete the training (either at home or in the lab) so that we could explore whether location had a specific role in the effectiveness of training beyond participants' preferences.

Finally, a relevant consideration regarding sample sizes needs to be pointed out before describing the study, since the sample size is at the moment below recommended for training studies. Recent meta-analysis propose training studies must have at least 20 participants per condition to conclude significant training and transfer effects (Melby-Lervåg et al., 2016). In addition, in order to keep a complete distribution of participants across the versions of counterbalance of the paradigm used in Experiments 2B and 3 (Ferreira, Maraver, Hanslmayr & Bajo, *submitted)*, our expected sample size is 24 participants per training condition. Thus, at the moment, the sample sizes per group in the current study are at the limit of the criteria of Melby-Lervag & Hulme (2016) and under our expected sample size. Hence, simple session effects in each training condition would be analyzed and the significance of the results would be discussed considering effect sizes in order to outweigh the costs of low statistical power.

Methods

Participants

Healthy adults older than 60 years participated in the study. Our sample was in relatively good health and had a high level of education as well as an active lifestyle, thus reducing the likelihood of having a sample with a high proportion of disease-related conditions associated with secondary aging.

Prior to data collection, we conducted a pre-screening to explore the potential availability of the participants. A large sample of 200 older adults from Granada was contacted via email. This large sample was part of a research database of older people who had replied to advertisements for participation in previous projects. They were provided with an online form with a brief description of the structure of the study and asked for: i) contact information (name, phone, email) and socio-demographic variables such as educational level, occupation, date of birth and sex; ii) cognitive health: possible cognitive impairment (existent diagnose or pre-diagnose of dementia) and possible visual impairment (visual loss, color blindness, etc.); iii) training setting: preferred training location (home or laboratory) and quality of their home technological equipment (computer and internet connection); iv) beliefs about the potential benefits of cognitive training programs in the aging; v) availability to attend the testing sessions (see Appendix 1 for the questionnaire data). Out of the total sample, over 80 people replied and filled out the questionnaire from Appendix 1.

The question referring to the training setting revealed a homogenous distribution since half of the respondents preferred to do the training at home (49.4%) and the other half preferred the lab (50.6%). Thus, we contacted older adults by phone and recruited them keeping their preferences when selecting them into the home and lab training groups.

Our final sample included 40 older adults (M_{age} = 64.97, SD_{age} = 3.50; 10 females), 20 of them voluntarily chose to complete the training procedure at home and the other 20 preferred to train in the lab. After pre-test participants were randomly assigned to one of the two training conditions. At the end of the study the participants were economically compensated for their involvement. None of the participants withdrew from the study although they were informed they could do so if they wished. This study was approved and carried out in accordance with the recommendations of the Research Ethics Committees of the University of Granada, with written informed consent from all subjects. All participants were provided with information about the study and gave written informed consent in accordance with the Declaration of Helsinki (World Health Organisation, 2013).

Table 5.1 summarizes data comparing training conditions (executive control vs. active control) and split by training location. As reported in the tables, no differences were found between any of the training groups in either age, gender distribution, years of study, vocabulary or cognitive impairment (mental state score from the Mini-Mental Scale Examination, Folstein and Lobo, 1979). The distribution of participants regarding training setting was balanced.

Table 5.1. Descriptive and demographic data of healthy older adults. Means and standard deviations (in brackets) of the four experimental conditions as a function of training group (speed training vs. executive control training) and training location (home vs. lab) Between-group comparisons statistics are the result of a bilateral independent sample *t*-test including training group as the independent variable. For both training groups no statistical differences were observed in any of the variables between home and lab setting (all *p*s > 0.05).

	Speed Training (Active Control)			Executive Control Training			t (40)	p	Cohen's d
	Home	Lab	**Total**	Home	Lab	**Total**			
Age	64.10 (2.85)	65.40 (3.17)	**64.75 (3.01)**	65.20 (3.82)	65.20 (4.39)	**65.20 (4.01)**	0.08	0.93	0.02
Gender (M/F)	6/4	8/2	**14/6**	8/2	8/2	**16/4**	-0.85	0.39	-0.27
Years of education	17.78 (6.40)	15.78 (5.29)	**16.78 (5.79)**	16.90 (6.69)	18.70 (4.30)	**17.80 (5.55)**	0.54	0.59	0.17
Vocabulary	95.50 (4.78)	97.33 (4.17)	**96.42 (4.47)**	97.83 (3.52)	91.83 (14.48)	**94.83 (10.70)**	-0.76	0.44	-0.23
MiniMental State (MMSE)	29.30 (0.67)	29.10 (0.88)	**29.20 (0.77)**	29.70 (0.67)	29.10 (1.20)	**29.40 (0.99)**	0.46	0.64	1.37

General Procedure

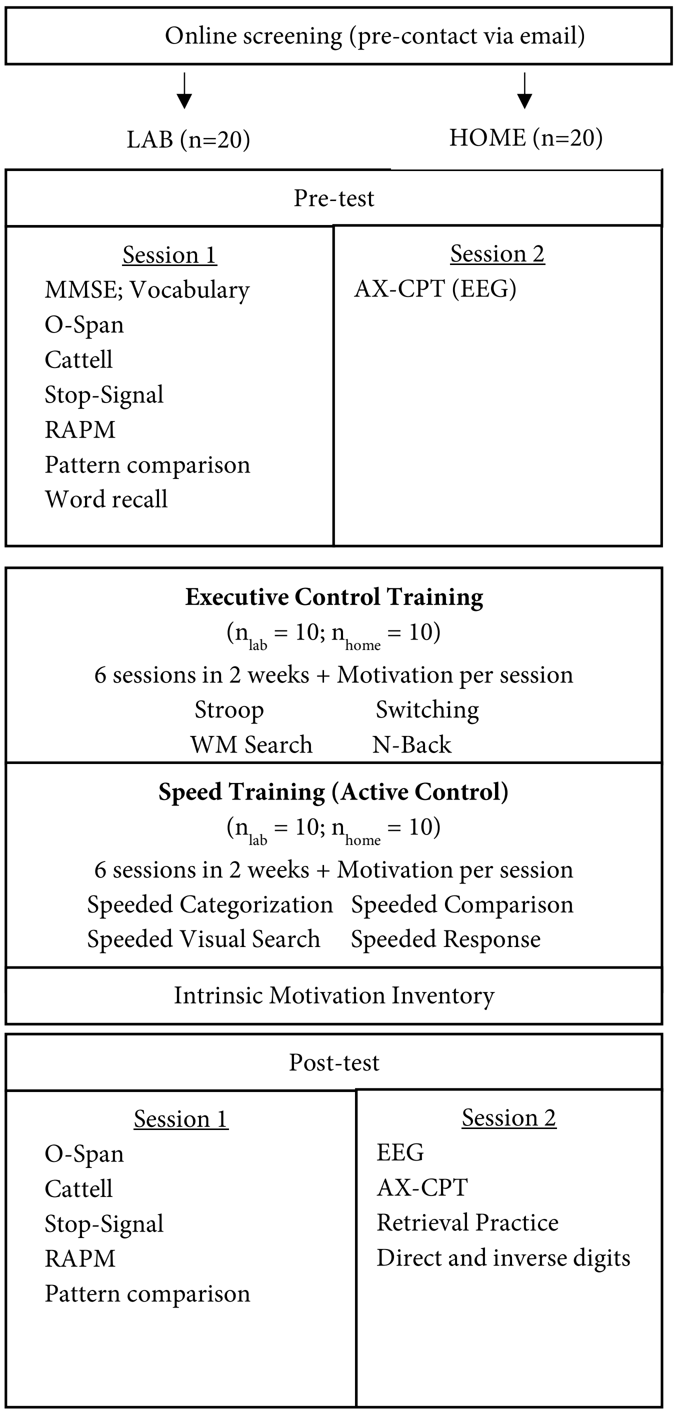
The experimental design consisted of 10 sessions distributed across four weeks: two pre-test sessions on the first week, six training sessions distributed across two weeks, with three sessions per week, and two post-test sessions on a final week. In the pre and post testing sessions all the participants were evaluated for: i) *near transfer*: working memory (Operation Span), inhibitory control (Stop-Signal) and speed processing (pattern comparison); and ii) *far transfer*: abstract reasoning (Raven's Advanced Progressive Matrices and Cattell Culture Fair Test); adjustment of proactive/reactive cognitive control (AX-CPT) and episodic memory (retrieval practice[1]). The two last far transfer tasks (AX-CPT and retrieval practice) included also the electrophysiological recording of brain activity (EEG) while performing the behavioral tasks. We created two random task orders for evaluation that were counterbalanced across participants.

The training and active control groups engaged in four different activities during each session (fifteen minutes per activity). The order of the activities in each training session was also counterbalanced across all participants. The resulting total training time for each activity was 90 minutes. Participants who trained in the lab worked in individual cabins although an experimenter continuously supervised the procedure and was available to attend to any request. In the meantime, participants who trained at home were required to complete the training sessions three specific days of the week, at the same time every day, and in a quiet place. They were asked to complete all the activities without interruptions in each of the sessions. The experimenters tracked the progress of the training online, and contacted the participant by phone once they completed the session to discuss their progress and to solve any possible technical inconveniences or task difficulties that they might have. All participants were provided with a paper booklet in which they had a previously randomized task order of the training activities for each training session. Thus, the order of the training activities was randomized across the sessions but all participants completed the activities in the same order each day. They were also provided with a blank space in which they could write all their comments and suggestions about the procedure. In the booklet they also had six questions of a

[1] The materials and results of the retrieval practice task are detailed in the next chapter as part of Experiment 2B.

motivation questionnaire that they were to complete once they had finished the training session (Alonso-Tapia & de la Red Fadrique, 2007; Colom et al., 2013). In such a questionnaire, participants were asked for their: i) involvement in the program; ii) perceived difficulty of the activity levels; iii) perceived challenge of improving the levels; iv) expectations for their achievement, v) effort during the session and vi) usefulness of the trained activities. They had to rate the four statements on a scale ranging from 0 (very low) to 10 (very high) and the two last on a 5 points scale from 0 (nothing) to 5 (a lot). Appendixes 2A and 2B include the training booklets of training and control groups. Figure 5.1 represents a diagram of the training procedure. In the last training session, they were asked for a general evaluation of the training program and their satisfaction with the experimental procedure by means of the Intrinsic Motivation Inventory (Deci, Eghrari, Patrick, & Leone, 1994) The Intrinsic Motivation Inventory (IMI) is a multidimensional measurement tool to assess participants' subjective experience with a target activity in laboratory experiments. It has been used in several experiments related to intrinsic motivation and self-regulation (Deci et al., 1994; R. M. Ryan, Connell, & Plant, 1990; R. M. Ryan, Koestner, & Deci, 1991). The instrument assesses participants' interest/enjoyment, perceived competence, effort, comfort, perceived choice (felt pressure and tension), value/usefulness and relatedness to the investigators, while performing a given activity, thus yielding six subscale scores. In this particular study, it was administered online at the end of the last training session. Although items were presented randomly, Appendix 3 includes the list of items of the different subscales.

Figure 5.1 Diagram of the experimental procedure of Experiments 2A and 2B.



Training Procedures

We used the online training program from the University of Granada (PEC-UGR, (Maraver, Bajo, & Gómez-Ariza, 2016) that included different game-like activities organized in levels of increasing difficulty. Training difficulty was adaptive in order to maintain activities as a constant challenge (Brehmer et al., 2011; Karbach et al., 2015; Klingberg et al., 2005). Also, participants received feedback on whether their performance was correct or not (Katz et al., 2014). Activity levels were built up over runs of trials. Whenever participants succeeded in 3 runs they went forward to the next level and if they failed 2 runs, they went back to the previous level. Details of each of the four activities per training group are detailed below.

Executive Control Training

Stroop-like

This activity was modeled on the Steinhauser and Hübner's (2009) complex Stroop task, which involved both conflict resolution and switching. The task was implemented in a scenario where bags of different sizes containing amounts of money had to be put into a treasure chest. Participants had to select the bag with the largest (gold in color) or the smallest (silver in color) number of items, with the number of bags increasing over the levels. The size of the bags could be either congruent or incongruent with the amount inside. An example of a congruent trial is one in which the stimuli were a big bag containing seven golden coins (correct choice) and a small bag containing five golden coins. In an example of an incongruent trial, the stimuli could be a small bag containing six golden coins (correct choice) and a big bag containing three golden coins. Difficulty increased by changing the ratio of congruent/incongruent trials (0; 0.25; 0.50; 0.75) so that the larger the proportion of congruent trials, the harder the choice for incongruent trials. At higher levels, switching was manipulated by changing the color of the items from gold to silver between trials within the same round. Times to respond and inter-stimuli intervals were also progressively reduced with each level. The dependent variable was a relative index of conflict resolution ((RT incongruent trials – RT congruent trials)/ RT congruent trials.

Switching

This activity is a categorization task with sorting rule changes based on the Wisconsin Card Sorting Test (Nyhus & Barceló, 2009). Participants had to sort pictorial cards with geometrical figures by one of the following perceptual dimensions: shape, color, size or number. In the first eight levels of the tasks, participants had the sorting rule displayed in the upper left corner of the screen, and their task was to drag the cards into the boxes following the sorting rule, only increasing the response speed across the levels. After level eight, the classification principle was no longer displayed and participants had to guess it. The new categorization rule was valid for a certain number of trials until the rule changed without warning. Then, they needed to switch to different sorting criteria to find the new rule by trial and error and the task feedback, remembering the invalid previous one in order to not perseverate in it. Once the subject chose the correct rule they were to maintain this sorting principle across changing stimulus conditions while ignoring the other – now irrelevant – stimulus dimensions until the next sorting rule changed. Difficulty increased across the levels by i) the number of required correct trials (4, 6 or 8); ii) the number of perceptual dimensions available (2, 3 or 4) iii) number of classification rule changes (2, 3 or 4); iv) number of errors permitted after the rule change (5, 4 or 3). The dependent variable was the percentage of errors.

Working Memory search

This is a matching-to-sample activity based on the shape and color of the items sequentially displayed: animals on one screen as the sample, and a group of animal buttons after a retention interval. Participants were presented with a matrix to be maintained in memory composed of animals with different shapes and colors displayed in an open field (i.e.: memory matrix, "*brown bear – red eagle – purple snake*"). After a retention time of 5000 ms, participants performed a memory test in which they had to select as fast as possible the animal on the buttons that had the same shape and color of one of the previously retained animals (i.e. button choices: "*orange bear – red eagle* (correct choice) – *yellow snake – blank button*"). If none of the animals on the buttons had the same shape and color, they had to select the blank button (i.e. button choices: "*orange bear – green eagle– yellow snake – blank button* (correct choice)"). The number of to-be-maintained items increased from 1 to 8 over the levels. The number of elements recalled (set size) was the dependent variable.

N-back

Participants had to monitor, maintain and continuously update the items throughout a sequence of elements. Participants were presented with a six-window house and had to detect coincidence between positions (opening/closing of the windows), sounds, or the combination of both modalities. They had to give their response pressing a button whenever the position of the opening window, its sound or both, matched the one that was presented as *n* positions-back in the sequence. Increments in *n*-back (from 1 to 8) were implemented after participants had completed the *n*-back level with a single (position or sound) and dual (position plus sound) modality levels. As for the dependent variables, we considered the achieved *n*-back level and the sum of errors in each session.

Active Control (Speed Training)

Speeded categorization

This activity had the same scenario as the Stroop-like task from the experimental group, but without executive control demands and only requiring processing speed. Participant's task was to select the bigger (when the color inside the bag was gold) or the smaller (when the color was silver), but bag size and amount were always consistent and the stimuli color never changed within a particular level. Thus, in this version only processing speed was required since there was not incongruencies or switches and, therefore, inhibitory control and switching were not required. The levels had four bags to select that were always congruent (the bag size is always consistent with the amount contained inside of it) and there was no switching rule within the same round. Participants' task was to select the biggest amount when the stimuli were in golden color and the smallest amount when they were silver. The difficulty across the level was only increased by progressively reducing the maximum time to respond from 4000 to 500 ms.

Speeded comparison

In this matching-to-sample activity participants were presented with a group of sea animals in the upper half of the screen and another group of animals in the lower half, and they were asked to find as fast as possible which animal in the lower part was present in the upper part of the screen. In all the trials, the target was presented in the sample, which increased from 2 to 6. Times were reduced in each sample size, so that whenever one element was added to the sample the time to respond started at a higher level at the beginning and was progressively reduced.

Speeded visual search

For this task participants were presented with a plate of soup with 10 elements (digits and letters) and they had to find one element contained in the soup out of 4 different possible options. The number of elements to be found and the possible options remained constant so that the difficulty of the levels was only determined by the speed of the responses over the levels.

Speeded response

This is a Go version of a Go/No-Go task in which all trials are Go. Participants are presented with a robot of a certain shape (square, round or triangle) with a screw on their top whose shape is always consistent with the robot's. Thus, participants' task is to press the spacebar as fast as possible when the robot and the screw appeared on the screen. Therefore, this task only requires speed processing considering that only two parameters are manipulated through the levels: i) the number of robots to respond in a round (from 3 to 60), ii) and the maximum time to respond (from 2000 to 500 ms). As with the four training activities of the control condition, reaction time per session was the dependent variable.

Neuropsychological assessment

Cognitive Functioning

The Mini-Mental Scale Examination (Folstein, Folstein, & McHugh, 1975) was administered as a brief screening battery to assess healthy cognitive performance. It is composed of 30 questions organized in several subscales including: spatial (5 points) and temporal (5 points) orientation; attention and calculation (5 points); immediate (3 points) and delayed recall (3 points); and language (9 points). The maximum score is 30, and score above 24 are considered as normal cognitive functioning.

Vocabulary

To measure proficiency in Spanish, we used the the Lextale-Esp vocabulary measure (Izura, Cuetos, & Brysbaert, 2013). In this brief test, participants are provided with a list of 90 strings of letters, half of them being non-words and the others real words in Spanish. Participants' task is to recognize and point out the real words in Spanish, even if they did not know the correct meaning of the word. The percentage of correctly identified words as Spanish was considered as the measure of vocabulary proficiency.

Transfer tasks

Stop-Signal

We used this task of response inhibition with the standard parameters of the software STOP-IT (Verbruggen et al., 2008). Participants had to respond on the keyboard as fast as possible to two different stimuli (circles or square) presented in the center of the screen. In 25% of the trials, participants faced an auditory stop-signal (750 Hz, 75 ms) that was presented briefly after the visual stimuli onset and required the response to the current stimulus to be withdrawn. The task comprised of 32 practice trials and 3 blocks with 64 experimental trials each. The trials were displayed on a black screen and were composed of a 250 ms fixation point (white +), the stimuli presentation (a white square or circle) during 1250 ms and a fixed inter-stimuli interval of 2000 ms.

Stimuli were randomized in pre and post-testing, and in all cases, the stop signal was presented with a variable stop-signal delay (SSD). Although initially set to 250 ms, the task was continuously adjusted. When the inhibition was successful it was reduced 50 ms and if not then it was increased in 50 ms, so that according to the performance the software tried to maintain a stopping probability of 50%. We considered the Stop-Signal Reaction Time (SSRT) as a measure of motor inhibition efficiency (Verbruggen and Logan 2008; Verbruggen et al., 2008; Morales et al., 2013).

Pattern Comparison

This paper-pencil task was used to measure perceptual comparison speed (Salthouse & Mitchell, 1990; Salthouse, 1991). Older adults were presented with two pages of pairs of drawings patterns composed of three, six or nine lines segments that required the decision of being the same or different. Participant's task was to write and S ("Si", yes in Spanish) when the pattern was similar and N ("No"), when it was different. An index of efficiency was calculated by dividing the percentage of correct responses by the time spent in completing each page.

Operation Span (O-Span)

We used the Spanish adapted version of the procedure developed by Turner and Engle (1989) (Tokowicz et al., 2004; Redick et al., 2012; Turner and Engle, 1989). It was a dual memory span task that required participants to verify mathematical operations while trying to remember sets of words of increasing set sizes. Each trial was composed of a simple solved mathematical equation (i.e., (14/2) + 2 = 8) presented for 3750 ms that participants had to verify and mark as correct or not by pressing one out of two keys on the keyboard. Afterward, a word was presented for 1250 ms to be maintained in memory. Operation-word pairs were presented in increasing set sizes from 2 to 6. After each set, participants had to recall and type the words. While the order of recall was not important, they were told to avoid writing the last word presented first in order to prevent recency effects. The task comprised of 18 trials (3 trials per set size) and the testing procedure was repeated until the end. We developed parallel versions of the task by randomizing the order of the stimuli presented that were counterbalanced across sessions and participants. Two parallel versions were created and counterbalanced for pre and post-testing by randomizing the equation-word pairing. Special care was taken to avoid a similar pairing set size distribution between the two versions.

Raven's Advanced Progressive Matrices (RAPM)

We used the computerized version of the set II of this test as a standardized measure of fluid intelligence (Raven, 1990). Participants had to solve visual analogy problems of increasing difficulty. A 3×3 matrix of patterns was presented and participants had to select the missing pattern of a matrix from 8 different response alternatives. We counterbalanced two parallel versions of the test over sessions with 18 matrices for the pre- and post-testing as used by Jaeggi (2013). Participants were told to complete the task as fast and accurately as possible with a 20 minutes time restriction. The dependent variable was the proportion of correct matrices answered and the reaction times of the hits.

Cattell's Culture Fair Test

The Scale III of the Cattell's Culture Fair Test was used as a measure of non-verbal intelligence that minimizes cultural and educational biases (Cattell & Cattell, 1963). This scale is composed of four abstract reasoning subtests: i) series (3 minutes length, 13 items), participants had to finish an incomplete sequence of elements choosing from 6 different and possible options; ii) classifications (4 minutes, 14 items), participants were asked to extract from a display of 5 elements, the 2 that shared a feature that made them different from the 3 elements left; iii) matrices (3 minutes, 13 items), participants needed to select the item missing on an incomplete matrix from 6 possible options; iv) conditioning (2.5 minutes, 10 items), participants had to follow a sample in which a dot was placed on a certain location between geometrical features, and select from a display with 6 different possibilities the location where the dot would be located in a position similar to that of the riginal display. Two parallels versions were used and counterbalanced across participants for pre and post-test. The maximum score of the whole test was 50 points, and the dependent variable considered was the average of correct responses.

AX-CPT

We used a similar procedure to that described in Morales et al. (2015). Participants were presented with pairs of capital letters composed by cues and probes, and they were instructed to respond “yes” whenever they saw an X-probe preceded by an A-cue (AX trials), and to respond “no” in any other possible cue-probe combination (AY, BX or BY trials). Cues could be any letter but “X”, “K” or “Y”, because of their perceptual similarity with “X”; whereas probes could be any letter but “A”, “K” or “Y”. AX trials were considerably more frequent since they constituted 70% of the task trials compared to AY, BX and BY that occurred in only 10% of the trials. Morales and colleagues manipulated cue-probe delays, but we employed only their long delay condition since longer cue-probe delays require higher context maintenance, and individual differences in proactive control might be better observed in this more demanding condition (Morales et al., 2015). Therefore, each cue appeared for 250 ms on a black screen with a white font (Courier New 60 points), followed by a long blank interval of 2000 ms and, afterward, the probe appeared for 250 ms followed by and inter-trial 1000 ms. blank screen. Participants were told to respond by pressing the keyboard within 800 ms after the probe appearance. If they failed to do so, a beep sound indicated that no response was given and the trial was marked as “no response”. Prior to the task, participants completed a practice block of 10 trials including all four possible experimental conditions: AX (“A” cue followed by an “X” probe); AY (“A” cue followed by any non-“X” probe); BX (any non-“A” cue followed by “X” probe); BY (any cue but “A” and any probe but “X”). During practice, participants were provided with feedback regarding thier accuracy and RT after each trial. After practice, two experimental blocks of 180 trials each were completed. Response buttons were counterbalanced across participants. Since this measure is content-free, the same exact version of the task was employed for pre and post-test.

EEG data acquisition

A continuous electroencephalogram (EEG) was recorded from 40 scalp electrodes mounted on an elastic cap (Quick-Cap, Neuroscan Inc.) on the standard 10-20 system at the pre and post-test for the AX-CPT.

The electrodes were referenced to the linked mastoids (A1 and A2) and the grounding electrode was mounted on the forehead (GND). Four additional electrodes were used to control for blink and horizontal movement ocular artifacts: two set above and below the left eye (controlling for vertical movement, VEOG) and another two set at the outer side of each eye, to control for horizontal movement (HEOG). The electrical signal was amplified with Neuroscan Nuamps, using a band pass of 0.01-100 Hz and digitized at a 500 Hz sampling rate, keeping electrode impedances were kept below 10 kΩ. Digital tags were obtained for the stimuli of interest in each of the tasks. Event-related potentials from the AX-CPT were analyzed using the open-source toolbox ERPLab (Lopez-Calderón & Luck, 2014). Ocular artifacts were identified by means of independent component analysis (ICA) and rejected by a careful visual inspection of the recordings.

Results

As outlined in the introduction, simple session effects in each training condition were analyzed and the significance of the results is discussed considering effect sizes in order to outweigh the costs of low statistical power.

Training effects

First, we aimed to determine the significance of the training improvement in each activity and contrast the achievement between the training settings. Thus, for all the individual tasks, 2 × 2 mixed analyses of variance (ANOVAs) were conducted on the specific dependent variables in each task (conflict score, errors, reactions times or memory load) with training session (first vs. sixth) as the within-subject independent variable and training setting (home vs. lab) as the between-subjects factor. Table 5.2 summarizes the results of the statistical comparisons.

Executive Control Training

This experimental condition trained four different executive activities, with two of them engaging mainly working memory (N-back and WM Search), one activity requiring inhibitory control (Stroop) and other cognitive flexibility (Switching). For the N-back task, we observed a main effect of session (F (1, 18) = 68.29; p = 0.00; $n^2{}_p$ = 0.79) indicating that older adults were able to maintain and update a larger memory load in the last training session compared to the first one, as shown in Table 5.2. We failed to observe either a main effect of training location (F (1, 18) = 2.70; p = 0.11; $n^2{}_p$ = 0.13) or a significant interaction between session and training setting (F (1, 18) = 0.63; p = 0.43; $n^2{}_p$ = 0.03). A similar pattern of results was observed for the WM Search task, revealing that older adults increased their (recalled) set size from the first to the sixth training session (F (1, 18) = 68.72; p = 0.00; $n^2{}_p$ = 0.80), but that the difference between training locations (F (1, 18) = 3.16; p = 0.09; $n^2{}_p$ = 0.15) and the training session × setting interaction was not significant (F (1, 18) = 0.52; p = 0.48; $n^2{}_p$ = 0.03). In the case of the Stroop task we looked at the conflict effect obtained in each training session by comparing the hits reaction times of the incongruent – congruent trials and then dividing by the speed on correct congruent trials. Consistent with the previous activities, older adults benefited from the training and reduced their conflict effect in the Stroop task (F (1, 18) = 4.54; p = 0.04; $n^2{}_p$ = 0.20), being this effect independent of the training location [(main effect of setting: F (1, 18) = 0.60; p = 0.44; $n^2{}_p$ = 0.03); interaction session × setting (F (1, 18) = 1.32; p = 0.26; $n^2{}_p$ = 0.06)]. Finally, when comparing the proportion of errors in the Switching task, we also observed a decreased error rate in the sixth session compared to the first one (F (1, 18) = 5.84; p = 0.02; $n^2{}_p$ = 0.25), with no effect of the training location (F (1, 18) = 0.16; p = 0.90; $n^2{}_p$ = 0.01) nor a significant session × training setting interaction (F (1, 18) = 1.61; p = 0.22; $n^2{}_p$ = 0.08). Taken together, the absence of main effects of training setting as well as the lack of significant session × location interactions suggest that training improvement was similar for all the trained older adults, no matter whether they completed their executive control activities at home or in the lab.

Speed Training (Active Control)

Before going into the analyses is worth mentioning that training for this group was not base in changes in the level of executive demands, but only in changes in speed of presentation and responding, and therefore, the training program conformed a placebo condition. Similar to their experimental counterparts, older adults went forward across the levels so that their impression was that they were training, although the changes from one level to the next were the progressive reduction of presentation speed and response-time. Hence, we compared the speed of the participants' responses (ms) from the first to the last session for the four activities. In all the cases, as shown in Table 5.2, we observed significant main effects of session revealing faster responses by the end of the intervention with independence of the training location [main effects of session: Speeded Categorization (F (1, 18) = 4.20; p = 0.05; $n^2{}_p$ = 0.18); Speeded Comparison (F (1, 18) = 60.99; p = 0.00; $n^2{}_p$ = 0.77); Speeded Response (F (1, 18) = 97.75; p = 0.00; $n^2{}_p$ = 0.84); Speeded Visual Search (F (1, 18) = 20.33; p = 0.00; $n^2{}_p$ = 0.54); (all main effects of training setting and session × setting interactions ps > 0.05).

Table 5.2. Descriptive statistics of the training performance. Mean and standard deviations for the training activities in the first and last (sixth) training sessions. Significance p values and effect sizes (Cohen's d) estimates are reported for the Repeated-Measures ANOVAs including session as a within subject variable (first and sixth training session values values) for each training location (home vs. lab) group. Standardized gains mean (Post-Pre)/(SD Pre) for hits proportion variables and reversed for conflict effect and reaction times.

	First Session		Sixth Session		Training session effect		Standardized gain	
	M	*SD*	*M*	*SD*	*p*	Cohen's *d*	*M*	*SD*
Executive Control Training								
N-*back (set size)*	0.97	0.23	1.68	0.39	**0.00***	2.22	3.03	1.62
Home	1.03	0.06	1.80	0.36	**0.00***	2.97	3.32	1.80
Lab	0.91	0.32	1.55	0.38	**0.00***	1.81	2.74	1.46
WM Search (set size)	1.92	0.47	3.32	0.66	**0.00***	2.43	3.21	1.89
Home	2.04	0.12	3.56	0.67	**0.00***	3.04	3.71	1.97
Lab	1.82	0.64	3.10	0.57	**0.01***	2.12	2.70	1.76
Stroop (conflict effect)	0.07	0.06	0.03	0.04	**0.05***	0.69	0.04	0.08
Home	0.05	0.05	0.04	0.05	0.52	0.32	0.03	0.08
Lab	0.08	0.07	0.03	0.20	**0.04***	0.37	0.05	0.07
Switching (errors)	0.79	0.35	0.55	0.16	**0.03***	0.88	1.28	2.93
Home	0.79	0.41	0.61	0.21	**0.05***	0.56	0.27	3.55
Lab	0.86	0.30	0.49	0.09	**0.01***	1.62	2.30	1.80
Speed Training (Active Control)								
Speeded Categorization(ms)	3072.40	531.63	2750.10	284.23	**0.05***	0.76	0.62	1.27
Home	3141.50	505.48	2811.60	330.98	0.17	0.772	0.65	1.27
Lab	3003.30	574.94	2688.60	229.35	0.19	0.718	0.59	1.33
Speeded Comparison (ms)	1974.16	160.47	1704.75	143.67	**0.00***	1.768	1.68	1.09
Home	1920.00	173.31	1737.41	153.05	**0.01***	1.116	1.14	0.76
Lab	2028.32	133.44	1672.08	133.35	**0.00***	2.670	2.22	1.12
Speeded Response (ms)	598.23	150.55	298.99	93.67	**0.00***	2.386	1.99	0.87
Home	578.33	148.60	278.13	103.45	**0.00***	2.344	1.99	0.97
Lab	618.13	157.76	319.86	82.78	**0.00***	2.367	1.98	0.82
Speeded Visual Search (ms)	5049.57	1486.20	3572.06	490.51	**0.00***	1.335	0.94	0.93
Home	4983.97	1670.83	3530.95	575.58	**0.01***	1.162	0.88	0.94
Lab	5108.62	1388.50	3609.07	428.38	**0.01***	1.459	1.01	0.97

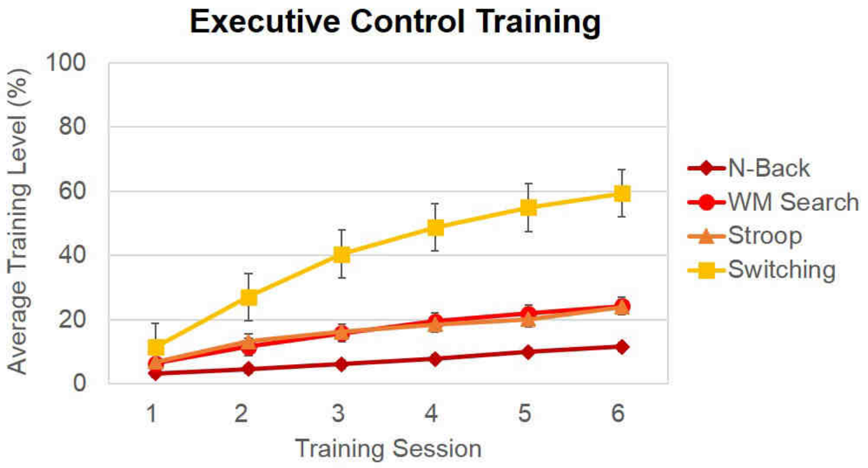
Training slopes

As in the procedure followed for the younger adults in the previous chapter, we standardized the level of achievement for each participant by dividing the average level reached in a given activity by the number of levels possible in the activity. Because the tasks differed in the number of to-be-manipulated parameters (i.e., proportion of congruent/incongruent trials; target-distractor similarity; memory load; response times; etc.), the number of training levels varied across activities. Thus, this statistical approach enabled us to put together the trained activities and to compare how far participants from the different groups and settings went in the training. Figure 5.2 represents the relative average level for each training activity across the intervention sessions in the two different training conditions.

With the intention of quantifying participants' training improvement over the six sessions of training and comparing training performance between the two settings, we calculated the slope of a linear regression model using the standardized average level in each training session and activity per participant (Katz et al., 2014; Wang et al., 2014). Table 5.3 displays the training slopes of each training task as a function of training setting (home vs. lab). As can be observed in the columns reporting the statistics, there were no significant improvement differences in any of the four training tasks of older adults that completed the executive control training at home and in the lab, nor in their global training improvements (all *p*s > 0.05). As for the case of the speed training control group, we only observed a significant difference in the slope between settings for the Speeded Response task. However, this difference could be related to the fact that this task was the one with the highest speed requirements; namely, while participants in the lab always used a wired mouse, older adults' training at home sometimes reported technical difficulties with this particular task if they had to use their touchpad and were not able to access to a wired mouse.

Figure 5.2. Training improvement of older adults. Data represent training performance over the six training sessions for the two different groups of older adults: **(A)** Executive Control Training **(B)** Speed Training (Active Control). In all the cases, *y*-axes represent the average relative level achieved in each session and training activity. Error bars represent standard deviations.

A



B

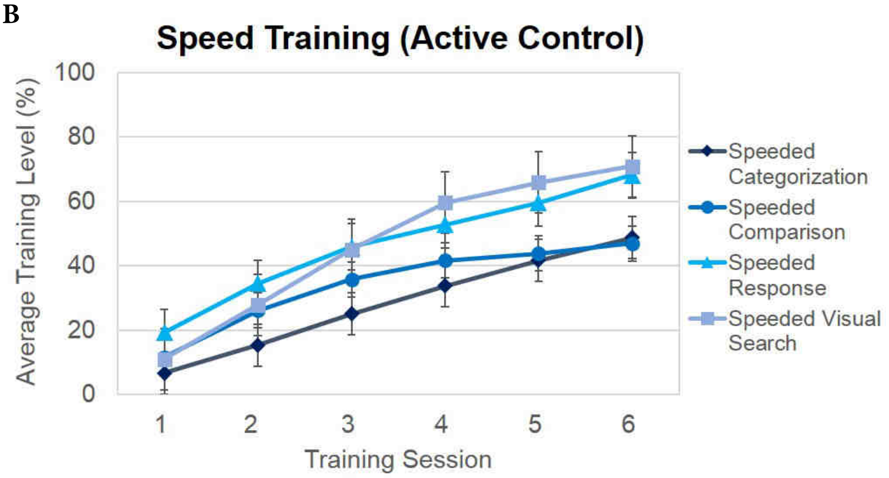


Table 5.3. Training slopes as a function of training setting and task. Mean and standard deviations of the training slopes as a function of training setting (home vs. lab). Values were calculated by the slope of a linear regression model using the standardized average level per training session. Significance *p* values and effect sizes (Cohen's *d*) estimates are reported for the one-way ANOVAs including slope in each activity as the dependent variable and training location (home vs. lab) group as the between-subjects factor. The two final columns represent the descriptives for the slope per training task of the total of participants in each training condition (collapsing home and lab).

	Home		Lab		Setting effect		Total training group	
	M	*SD*	*M*	*SD*	*p*	Cohen's *d*	*M*	*SD*
Executive Control Training	**0.28**	**0.08**	**0.38**	**0.20**	**0.18**	**0.62**	**0.33**	**0.16**
N-back	0.47	0.20	0.78	0.49	0.08	0.82	0.62	0.40
WM Search	0.24	0.06	0.36	0.30	0.22	0.56	0.30	0.22
Stroop	0.32	0.16	0.28	0.08	0.52	0.29	0.30	0.13
Switching	0.10	0.05	0.09	0.02	0.34	0.44	0.106	0.04
Active Control	**0.11**	**0.01**	**0.12**	**0.02**	**0.64**	**0.39**	**0.11**	**0.02**
Speeded Categorization	0.11	0.04	0.13	0.05	0.50	0.30	0.12	0.04
Speeded Comparison	0.15	0.07	0.14	0.05	0.70	0.17	0.14	0.06
Speeded Response	0.09	0.02	0.12	0.03	0.03	1.08	0.10	0.03
Speeded Visual Search	0.08	0.02	0.08	0.02	0.68	0.15	0.08	0.02

Motivation effects

Motivation during training

At the end of every single training session, participants had to rate their level of motivation in six different dimensions: involvement in the program; perceived difficulty of the activity levels; perceived challenge of improving the levels; expectations for their achievement, effort during the session and usefulness of the trained activities. Figure 5.3 represent the motivation progression across the training sessions for the two different training conditions as a function of their location. As observed in the figure, there were no general differences between the four training conditions. However, it must be noted that, at the beginning of the training, participants who trained at home tended to perceive the activities as less difficult (top middle panel) and the improvement across the levels as less challenging than those who trained at the lab (top right panel).

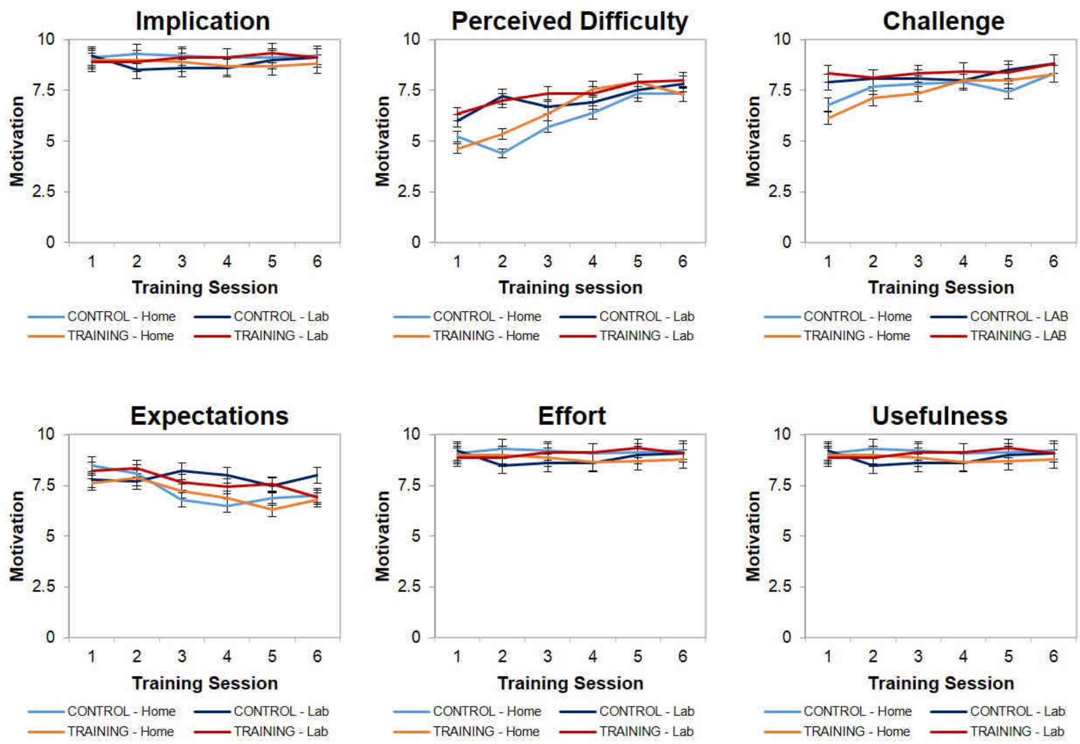
To determine if participants differed in motivation in terms of the type of training and where they had completed the intervention, we collapsed the values of all the training sessions to get a general score of each of the six different motivation variables. Table 5.4 summarizes the general scores of all the motivational variables measured during as well as after the training as a function of training setting and condition. We conducted 2 × 2 ANOVAs including the six motivational measures as dependent variables and two between subjects factors (training condition and training setting). In none of the six motivational measures we observed a reliable training condition × setting interaction (all *p*s > 0.05)[2], or significant main effects of training group (all *p*s > 0.05)[3]. However, we observed that those older adults that trained in the lab perceived the training as more useful (M_{lab} = 4.38, SD_{lab} = 0.55) and more difficult (M_{lab} = 7.24, SD_{lab} = 1.38) than their counterparts that trained at home [usefulness: M_{home} = 3.83, SD_{home} = 0.77, F (1, 36) = 6.39; p = 0.01; n^2_p = 0.15; perceived difficulty: M_{home} = 6.29, SD_{home} = 1.25, F (1, 36) = 5.04; p = 0.03; n^2_p = 0.12][4].

[2] No reliable training condition × setting interaction emerged in the motivational variables measured during training: implication (p = 0.23), perceived difficulty (p = 0.79), perceived challenge (p = 0.72), expectations (p = 0.94), effort (p = 0.73), usefulness (p = 0.65).

[3] No significant main effect of training group (executive control vs. speed training) emerged in the motivational variables measured during training: implication (p = 0.97), perceived difficulty (p = 0.19), perceived challenge (p = 0.66), expectations (p = 0.63), effort (p = 0.81), usefulness (p = 0.64).

[4] The remaining main effects of setting did not reach statistical significance [Implication: F (1, 36) = 0.02; p = 0.88; n^2_p = 0.01; Perceived challenge F (1, 36) = 3.74; p = 0.06; n^2_p = 0.09; Expectations F (1, 36) = 1.82; p = 0.18; n^2_p = 0.14; Effort: F (1, 36) = 0.33; p = 0.56; n^2_p = 0.10; Average of motivation during training: F (1, 36) = 0.78; p = 0.38; n^2_p = 0.02]

Figure 5.3. Motivation during the training. Progression of the six motivational variables measured each day during the training procedure as a function of setting (home vs. lab) and training condition (training refers to the executive control training condition and control to the speed training active control group). In all the cases, *y*-axes represent the motivation score rated by older adults. Error bars represent standard deviations.



Motivation after training

With the aim of analyzing the existence of differences in motivation after completing the training, we conducted 2 × 2 ANOVAs on the average of the seven subscales of the IMI as the dependent variable and two between-subjects factors: training condition and training setting. After collapsing the seven subscales we did not observe a main effect of group (F (1, 36) = 0.29; p = 0.59; n^2_p = 0.00) nor a reliable interaction (F (1, 36) = 0.32; p = 0.57; n^2_p = 0.00). However, there was a significant main effect of setting that leads us to conclude that older adults who trained in the lab had a greater level of motivation at the end of the training than those who trained at home [M_{lab} = 7.96, SD_{lab} = 0.68; M_{home} = 7.44, SD_{home} = 0.76; F (1, 36) = 4.93; p = 0.03; n^2_p = 0.12]. Table 5.4

summarizes the descriptive statistics of the six IMI subscales as a function of training setting and condition and Appendix 4 details the statistical comparisons on the individual motivational scales.

Taking into account that there were no significant differences in training improvements between the training settings (previous section), and that we did not observe any significant training condition × setting interaction, hereafter results will be presented after collapsing data from the two different settings. As a result, in the next sections we will not make the distinction between training at home or in the lab, in order to increase statistical power for the upcoming transfer effects analyses.

Table 5.4. Motivation measurements during and after the training. Mean and standard deviations (in brackets) of the different motivational variables measured across the intervention as a function of training setting (home vs. lab) and training condition (speed training as the active control and executive control training). The measures of motivation during training represent the average of the six training sessions in which older adults rated their implication, perceived difficulty, challenge, expectations, effort and usefulness. The measures of motivation after the training correspond to the seven different scales of the Intrinsic Motivation Inventory (IMI, Deci et al., 1994).

	Home Setting		Total Home	Lab Setting		Total Lab
	Speed Training	Executive Control		Speed Training	Executive Control	
Motivation during Training	**6.07 (0.57)**	**5.89 (0.43)**	**5.98 (0.50)**	**6.09 (0.39)**	**6.12 (0.42)**	**6.11 (0.39)**
Implication	9.18 (0.53)	8.88 (0.86)	9.03 (0.72)	8.83 (0.93)	9.15 (0.81)	8.99 (0.86)
Perceived difficulty	5.96 (1.59)	6.64 (0.75)	6.30 (1.26)	7.02 (1.45)	7.47 (1.36)	7.24 (1.39)
Perceived challenge	7.64 (1.15)	7.68 (1.20)	7.66 (1.15)	8.23 (1.39)	8.54 (0.95)	8.38 (1.17)
Expectations	7.34 (1.50)	7.10 (1.08)	7.22 (1.28)	7.87 (0.84)	7.70 (1.68)	7.78 (1.29)
Effort	4.39 (0.47)	4.48 (0.56)	4.43 (0.51)	4.35 (0.47)	4.33 (0.45)	4.34 (0.45)
Usefulness	3.83 (0.83)	3.83 (0.76)	3.83 (0.78)	4.28 (0.61)	4.48 (0.51)	4.38 (0.56)
Motivation after Training	**7.58 (0.69)**	**7.32 (0.84)**	**7.45 (0.76)**	**7.96 (0.52)**	**7.97 (0.85)**	**7.97 (0.69)**
Interest/Enjoyment	7.55 (1.32)	7.41 (1.22)	7.48 (1.24)	8.18 (0.71)	8.47 (1.54)	8.33 (1.17)
Perceived Competence	5.81 (0.99)	4.67 (0.95)	5.24 (1.11)	6.17 (1.14)	5.76 (1.72)	5.97 (1.44)
Effort/Importance	9.34 (0.54)	8.86 (1.02)	9.10 (0.83)	9.09 (1.01)	9.09 (1.07)	9.09 (1.02)
Comfortability	5.43 (1.12)	5.37 (1.84)	5.40 (1.50)	6.14 (1.41)	5.83 (1.73)	5.99 (1.54)
Perceived Choice	7.69 (0.66)	7.45 (1.29)	7.57 (1.01)	7.71 (0.99)	8.18 (1.36)	7.95 (1.19)
Value/Usefulness	8.16 (1.93)	8.70 (0.96)	8.429 (1.51)	9.03 (0.83)	9.33 (1.01)	9.18 (0.91)
Relatedness	9.05 (0.75)	8.77 (0.91)	8.91 (0.83)	9.41 (0.85)	9.12 (0.78)	9.27 (0.80)

Predictors for training improvement

In the previous analyses we explored whether the two different setting differ in terms of the motivational level created in the participants. However, an additional goal of this study was to explore whether individual differences in motivation during and after the training as well as baseline capacities predicted the magnitude of training improvement. Hence, the next set of analyses address the relation between motivation, baseline capacities and training improvements.

Motivation during training

As an exploratory approach, we first ran multiple forward linear regression models for each training task and training condition. Individual training slopes were included as the outcomes and the six motivation variables measured during the training were introduced as predictors (implication, difficulty, challenge, expectations, effort and usefulness). For the executive control training group only one model with two reliable predictors emerged. Older adults that reported greater effort and perceived the training experience as more challenging achieved a higher level of performance in the switching training task (R^2 = 0.50; p < 0.01; Effort: β = 0.67, p < 0.01; Perceived challenge: β = 0.56, p < 0.01). As for the speed training two models with one relevant predictor in each model were observed. Effort during training predicted performance in the speeded categorization task (R^2 = 0.30; p = 0.01; β = 0.55) and those who perceived the training as more difficult improved less in the speeded comparison task (R^2 = 0.20; p = 0.04; β = -0.45). The remaining models of the individual training tasks did not reach statistical significance. Moreover, we did not observe a general effect of motivation – considering the average motivational score during training - over the global training improvement – represented by the average slope of the whole training procedure.

Motivation after training

Following a similar statistical approach to explore the modulator effect of motivation over training improvement, we ran multiple forward linear regression models using the IMI's indexes. We introduced the individual training slopes as outcome measures and the seven motivation scales obtained from the IMI as predictors (interest/enjoyment, perceived competence, effort, comfort, perceived choice (felt pressure and tension), value/usefulness and relatedness to the investigators). For the executive control training group, participants who reported greater interest and enjoyment of the procedure improved more in the *n*-back task (R^2 = 0.22; p = 0.03; β = 0.47) and those who perceived themselves as more competent achieved higher levels of difficulty in the WM search training activity (R^2 = 0.26; p = 0.02; β = 0.51). In contrast, none of the variables measured by the IMI after the training predicted training performance in any of the tasks completed by the active control group.

When collapsing the slopes of the four training activities to obtain a general training improvement measure, we observed that it was only for the executive control training group that motivation was statistically significant. The older adults that completed the executive control training and reported greater interest and enjoyment reached higher levels of performance during the training (R^2 = 0.27; p = 0.02; β = 0.52). In the case of the active control speed training group, none of the IMI's subscales predicted global training performance and were not introduced in the model. Finally, we averaged all the IMI's subscales in order to calculate a general after-training motivation score and introduced it at the only predictor in a simple linear regression model with the average training slope as the outcome. This final analysis leads us to conclude that motivation after training was a reliable predictor of the general training improvement only for the executive control training group (R^2 = 0.28; p = 0.02; β = 0.53; active control group: R^2 = 0.01; p = 0.58; β = -0.13).

Baseline capacities

We were also interested in exploring which of the cognitive abilities tested at the baseline level predicted[1] the magnitude of training improvement. Thus, we first looked at the effect over training performance in the individual tasks by running multiple forward linear regression analyses with the average training slope as the outcome, and the measures at the pre-testing stage as predictors [fluid intelligence (average performance of Raven's matrices and Cattell); working memory (average between the n-back, WM Search setsizes and Operation-span score); inhibitory

[1] Appendix 5 includes the Pearson correlations between the baseline cognitive capacities measured at pre-test.

control (conflict effect from the Stroop task; hits in the Go/No-Go task and Stop-Signal Reaction Time); processing speed (efficiency in the symbol comparison task); and cognitive control (Behavioral Shift Index calculated from the AX-CPT). For the executive-control training group, working memory capacity at pre-test significantly predicted training performance in the *n*-back task ($R^2 = 0.27$; $p = 0.02$; $\beta = -0.52$), so that the lower working memory, the greater improvement. And conflict effect at pre-test predicted training improvement in the Stroop task ($R^2 = 0.35$; $p < 0.01$; $\beta = 0.59$), so that the more conflict at pre-test, the larger the gain in the Stroop task. None of the predictors was related to the performance in the Switching or WM Search tasks. Interestingly, for the speed-training active control group we only observed a reliable effect for the Speeded response task, by which processing speed significantly predicted how much older adults improved in this task ($R^2 = 0.22$; $p = 0.03$; $\beta = -0.47$). This effect was not consistent across the rest of speed training tasks.

To further explore the effect of baseline capacities over the general training performance, we conducted similar analyses maintaining the same previous predictors but introduced the average training slope as the outcome measure. For the executive control training group, fluid intelligence at pre-test predicted the overall training performance ($R^2 = 0.25$; $p = 0.02$; $\beta = -0.50$), indicating that older adults with lower reasoning ability at pre-test were the ones that improved the most during training. As for the control group, processing speed at the baseline level predicted their improvement during training ($R^2 = 0.27$; $p = 0.02$; $\beta = -0.52$), indicating that the slower older adults were at pre-test, the more they benefited from the speed training.

Transfer results

Table 5.5 summarizes the descriptive data of the outcome measures, including statistical comparisons for the session effects (pre vs. post by repeated-measures ANOVAs) in each of the two training groups. Standardized gains were calculated by subtracting the pre-test scores from the post-test (the opposite for reaction times) and dividing by the standard deviation of the entire sample (Borella et al., 2014; Colom et al., 2013; Jaeggi, Buschkuehl, Shah, & Jonides, 2013; Maraver et al., 2016; Redick et al., 2013). One-way ANOVAs were performed for each variable in order to compare standardized gains between the groups.

Stop-Signal

For this near transfer task we used the software ANALYZE-IT provided by Verbruggen et al. (Verbruggen et al., 2008) and looked at the Stop-Signal Reaction Time (SSRT) to explore the impact of training on inhibitory control. The SSRT is thought to be an index of pure response inhibition and the program calculates it by subtracting the Stop-Signal Delay (SSD) from the untrimmed RT mean. Verbruggen et al. (2008) recommended excluding from the analyses those participants with overall probability of responding on stop trials significantly below or above 50%. Importantly, all participants in the present study exhibited response rates that were in accordance with Verbruggen's criteria both at pre-test (M = 46.67, SD = 12.46) and at post-test (M = 44.45, SD = 3.87). The two training groups were comparable in their SSRT at pre-test (F (1, 38) = 0.13; p = 0.71; n^2_p = 0.00). As for the training effect on response inhibition, the repeated-measures ANOVA did not reveal effects of session (F (1, 38) = 0.83; p = 0.36; n^2_p = 0.02), group (F (1, 38) = 0.54; p = 0.46; n^2_p = 0.01), or interaction between both factors (F (1, 38) = 2.08; p = 0.15; n^2_p = 0.05). To increase statistical power, however, we looked at the groups separately (see Table 5.5). Analyses showed a reliable and considerably large effect of session for the executive control training group (p = 0.02; Cohen's d = 0.67), but a null effect for the speed training control group (p = 0.77; Cohen's d = -0.09). While the standardized gains on the SSRT also suggested that executive control training tended to improve response inhibition in older adults ($M_{training}$ = 0.41, $SD_{training}$ = 0.71; $M_{control}$= -0.09, $SD_{control}$ = 1.38), the one-way ANOVA revealed that the effect was not reliable (F (1, 38) = 2.08; p = 0.15; n^2_p = 0.05).

Speed processing (Symbol comparison)

This measure was used to assess older adults' speed processing. We created an index of efficiency by dividing the average proportion of hits by the time each participant took to complete the task. At pre-test, the groups did not differ in their speed processing (F (1, 38) = 1.99; p = 0.16; n^2_p = 0.05). The corresponding ANOVA revealed significant main effects of session (F (1, 38) = 5.79; p = 0.02; n^2_p = 0.13) and group (F (1, 38) = 5.04; p = 0.03; n^2_p = 0.11). The interaction did not reach statistical significance (F (1, 38) = 1.18; p = 0.28; n^2_p = 0.03). As shown in the table, although the comparison between the standardized gains in speed processing was not reliable (F (1, 38) = 1.18; p

= 0.28; n^2_p = 0.03), planned comparison showed that it was only the executive control group – and not the speed training group - the one that improved their processing speed.

Operation Span

For this near transfer dual span task we considered two different dependent variables. First, we calculated a general index by combining the average proportion of equations correctly solved and the total proportion of correctly recalled words. There was no difference between the groups at pre-test (F (1, 38) = 0.40; p = 0.53; n^2_p = 0.01). The ANOVA on this index did not show a main effect of group (F (1, 38) = 0.13; p = 0.71; n^2_p = 0.00), but revealed reliable effects of session (F (1, 38) = 15.77; p < 0.01; n^2_p = 0.29) and session × group interaction (F (1, 38) = 6.65; p = 0.01; n^2_p = 0.15). Consistent with the individual session effects reported in Table 5.5, the comparison between the standardized gains confirmed that only the executive control training group obtained a reliable gain in the O-Span task (F (1, 38) = 6.65; p = 0.01; n^2_p = 0.15).

Fluid intelligence

To explore the potential far transfer effects of executive control training in older adults, we calculated a composite score of fluid intelligence by averaging the proportion of hits in the Raven's Advanced Progressive Matrices and in the Cattell's Culture Fair Test. At pre-test, both groups were comparable in this measure (F (1, 38) = 0.24; p = 0.62; n^2_p = 0.00). When looking at the training effect, the repeated-measures ANOVA did not yield significant main effects of either session (F (1, 38) = 1.78; p = 0.19; n^2_p = 0.04) or training group (F (1, 38) = 0.03; p = 0.85; n^2_p = 0.00). However, the interaction between both factors was marginally significant (F (1, 38) = 3.25; p = 0.08; n^2_p = 0.08). Table 5.5 shows that only executive control training group tended to improve across sessions, with the comparison between the standardized gains also approaching statistical significance (F (1, 38) = 3.25; p = 0.08; n^2_p = 0.08).

Table 5.5. Descriptive statistics of transfer effects. Mean and standard deviations for the outcome measures in the Pre and Post-testing. Significance p values and effect sizes (Cohen's d) estimators are reported for the mixed ANOVAs including session as a within subject variable (Pre-test and Post-test values) and group as a between-subject effect in each of the four groups. Standardized gains mean (Post-Pre)/(SD Pre) for hits proportion variables and reversed for reaction times.

	Pre-test		Post-test		Pre-Post effect		Standardized gain	
Variables	*M*	*SD*	*M*	*SD*	*p*	Cohen's *d*	*M*	*SD*
Stop-Signal: SSRT (ms)								
Speed Training (Active Control)	276.21	97.97	283.38	36.54	0.77	-0.096	-0.09	1.38
Executive Control Training	285.27	53.01	253.32	40.77	**0.02***	0.675	0.41	0.71
Speed Processing (efficiency in symbols comparison)								
Speed Training (Active Control)	1.17	0.32	1.22	0.28	0.36	0.16	0.17	0.81
Executive Control Training	1.30	0.24	1.43	0.19	**0.02***	0.59	0.45	0.83
O-Span: Words recalled × Equations hits								
Speed Training (Active Control)	0.44	0.18	0.47	0.20	0.37	0.19	0.17	0.81
Executive Control Training	0.39	0.24	0.56	0.22	**0.00***	0.72	0.79	0.71
Gf (RAPM + Cattell)								
Speed Training (Active Control)	0.39	0.11	0.38	0.10	0.74	-0.05	-0.05	0.72
Executive Control Training	0.37	0.14	0.41	0.13	**0.04***	0.34	0.37	0.75
AX-CPT: Errors in A cues								
Speed Training (Active Control)	0.03	0.16	0.01	0.12	0.12	-0.08	-0.42	1.14
Executive Control Training	0.03	0.17	0.05	0.22	0.30	0.11	0.91	3.85
AX-CPT: Hits RT in A cues (ms)								
Speed Training (Active Control)	450.15	106.39	439.98	105.14	0.06	0.10	0.24	0.84
Executive Control Training	454.30	108.08	427.53	98.63	**0.00***	0.26	0.24	0.78
AX-CPT: Errors in B cues								
Speed Training (Active Control)	0.04	0.20	0.02	0.13	0.21	0.16	0.23	0.52
Executive Control Training	0.03	0.17	0.01	0.08	0.18	0.17	0.53	0.66

AX-CPT: Hits RT in B cues (ms)								
Speed Training (Active Control)	387.40	110.53	383.87	114.22	0.19	0.03	0.22	0.74
Executive Control Training	385.44	107.11	377.50	103.95	0.39	0.07	0.21	1.08
AX-CPT: BSI (AY-BX)/(AY+BX)								
Speed Training (Active Control)	0.20	0.11	0.22	0.08	0.25	0.19	0.14	0.53
Executive Control Training	0.26	0.15	0.25	0.09	0.94	-0.01	-0.02	1.05

AX-CPT

Behavioral data

To assess the tendency towards proactive/reactive control at the behavioral level, we calculated the Behavioral Shift Index introduced by Braver (BSI, Braver et al., 2009; Chiew and Braver, 2014). This index is based on the formula (AY-BX)/(AY+BX) for errors and reaction times. Trials with errors equal to 0 were corrected [(errors + 0.5)/ frequency of trials + 1]. Larger BSIs stands for a greater tendency towards proactive control, whereas smaller BSIs indicate a tendency towards reactive control. Invalid trials, which included no responses and trials with responses times below 100 or above 1000 ms, were 2.6% out of the total of trials. The two groups of older adults were comparable in BSI at pre-test (F (1, 38) = 1.89; p = 0.17; n^2_p = 0.04).

Previous research has shown that older adults tend to rely more on reactive control than younger adults (Paxton et al., 2008; Zanto & Gazzaley, 2017). Our data are in line with these previous findings since our participants exhibited lower BSI scores (which is usually interpreted in terms of reliance on reactive control) compared to young adults (see Table 5.5 for older adults and Table 4.2 for young adults). However, at the behavioral level, we did not observe a significant effect of training in the adjustment of cognitive control strategies (see Table 5.5). The repeated-measures ANOVA on the BSI score failed to show significant effects of either session (F (1, 38) = 0.22; p = 0.63; n^2_p = 0.00), group (F (1, 38) = 2.36; p = 0.13; n^2_p = 0.06) or the interaction (F (1, 38) = 0.36; p =

0.55; $n^2_p = 0.00$). The one-way ANOVA on the BSI standardized gains also revealed that there was not a reliable effect (F (1, 38) = 0.34; $p = 0.55$; $n^2_p = 0.00$).

Despite the lack of training effect on the adjustment of cognitive control strategies during aging, we further explored the effect of training over context processing, given that older adults also normally show deficits related to the processing and maintenance of contextual information (Paxton et al., 2008; Zanto & Gazzaley, 2017). Thus, the AX-CPT allows for the observation of differences in context processing by looking at performance as a function of the type of cue. In particular, while B cues demand less cognitive sources since they trigger the no-response, A cues are more demanding in terms of processing and maintaining contextual information since both types of responses have to be maintained until the presentation of the probe. As a result, we compared performance (errors and hits reaction times) in A and B cues as a function of training session and training group. As for the proportion of errors in the processing of A cues, results from the mixed ANOVA did not reveal a main effect of session (F (1, 38) = 0.23; $p = 0.59$; $n^2_p = 0.00$), nor an interaction between session and group (F (1, 38) = 2.18; $p = 0.15$; $n^2_p = 0.05$), although the main effect of group (F (1, 38) = 3.33; $p = 0.07$; $n^2_p = 0.08$) remained close to statistical significance. As observed in Table 5.5, older adults from the executive control training group tended to show more errors in A cues after the training, although the simple effects were not reliable in any of the groups. Regarding the analysis over the reaction times in successful A-cue trials, results from the ANOVA revealed a significant main effect of session (F (1, 38) = 16.51; $p < 0.01$; $n^2_p = 0.30$) but not of group (F (1, 38) = 2.43; $p = 0.13$; $n^2_p = 0.06$), nor their interaction (F (1, 38) = 0.56; $p = 0.81$; $n^2_p = 0.00$). However, as shown in Table 5.9, when looking at the main effect of session in each of the training groups, it was only participants from the executive control group who significantly reduced their response times in correct A-cue trials.

Despite this individual benefit on context processing of the executive control training group, the one-way ANOVA on the standardized gains of both training conditions was not reliable for the proportion of errors (F (1, 38) = 2.18; $p = 0.15$; $n^2_p = 0.05$), nor for the reaction times of correctly responded A-cue trials (F (1, 38) = 2.42; $p = 0.13$; $n^2_p = 0.06$).

In relation to the performance on B-cue trials, none of the statistical comparisons regarding errors or hits reaction times yielded significant results (see Table 5.5 for a summary of the descriptive statistics).

EEG data

During the AX-CPT, the continuous EEG was recorded with a 40 electrodes system (Neuroscan Synamps2). The analysis of the event-related potentials was performed using the open-source toolbox EEG/ERPLab (Lopez-Calderón & Luck, 2014).

We based our ERP segmentation and analyses on previous studies that looked at ERPs during the AX-CPT (Beste et al., 2011; Van Wouve et al., 2011; Morales et al., 2015). As a result, we averaged epochs individually for each participant, training session, training condition and trial type, and took only epochs of correct responses into account. We applied two procedures for artifact rejection on the resulting epochs: semi-automatically by using independent component analyses (ICA) by the automatic rejection tool "adjust" and visual inspection; and automatically with an amplitude threshold of ± 50 μV. Data was re-referenced to the linked mastoids and epochs ranged from -200 prior to the stimuli (cue/probe) presentation until 1000 ms. The resulting epochs were grouped into grand mean averages across groups (executive control vs. speed training) and session (pre vs. post training). Due to physical problems with the recording system, data from two older adults (1 from the executive control training and 1 from the speed training active control group) were not properly recorded and therefore not introduced in the analyses.

To obtain the target components, EEGs were filtered off-line from 0.01 (high-pass filter) and 30 Hz (low-pass filter), slope 24 db/octave at the corresponding electrode site of interest. The analyses for each of the AX-CPT processes as a function of session and training group are detailed below. First, we report the components associated with the processing of the cue and then the effects related to the probe processing.

Cue processing

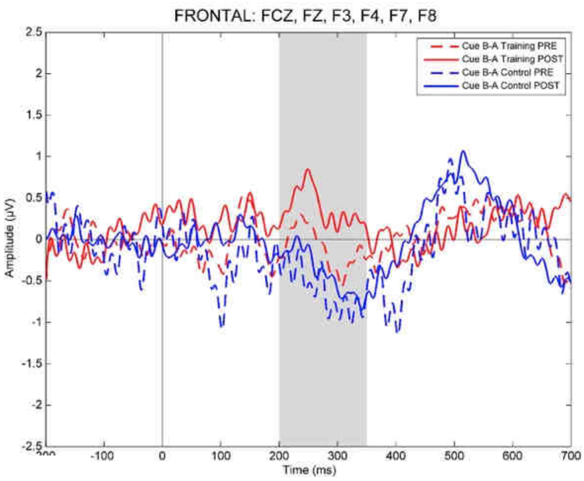
Following the analytical approach by Morales et al. (2015), EEG signal was aligned to a baseline of -200 ms until the presentation of the cue (A and B). In order to compare the differential neural activation between A and B cues, we calculated an index of cue processing by substracting the activation to B cue minus the one to A cues. A priori regions of interests were defined by grouping electrodes as a function of their location. In particular we defined frontal (FCZ, FZ, F3, F4, F7, F8), central (FCZ, FC3, FC4, CZ, C3, C4) and parieto-temporal (CPz, Pz, P3, P4, TP7, TP8) clusters by including all the electrodes of such particular cap section. Mixed ANOVAs were conducted with session (pre vs. post) as the within-subject factor, training condition (executive control vs. speed training) as the between-groups factor and amplitude differences between B and A cues as the dependent variables. As shown in Figure 5.4, in the frontal ROI we observed a main effect of group in the time window ranging from 200 to 350 after the cue presentation (F (1, 36) = 4.84; p = 0.03; n^2_p = 0.12), although the main effect of session (F (1, 36) = 0.19; p = 0.66; n^2_p = 0.00), and the session × group interaction did not reach statistical significance (F (1, 36) = 1.35; p = 0.25; n^2_p = 0.03). Following the same analytical approach as in the behavioral data, however, we looked at the session effect in the groups separately with the idea of gaining statistical power. Planned comparisons revealed that it was only for the executive control training group that differences in amplitude between cues B and A increased after the training in the frontal region (M_{pre} = -0.10, SD_{pre} = 0.80; M_{post} = 0.38, SD_{post} = 0.79 ; F (1, 18) = 5.02; p = 0.04; n^2_p = 0.22, Figure 5.4 panels A1 and A2). There was no change in between-cues amplitude for the control group (M_{pre} = -0.39, SD_{pre} = 0.93; M_{post} = -0.61, SD_{post} = 2.14; F (1, 18) = 0.15; p = 0.70; n^2_p = 0.00). No other statistical comparisons yielded reliable effects in the central or parietotemporal ROIs, as seen in Figure 5.4 panels B and C.

Probe processing components

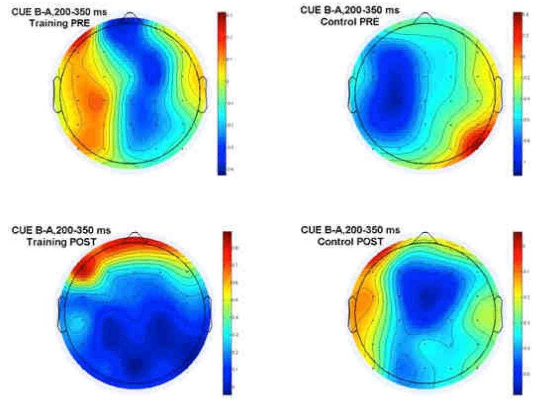
Probe-related potentials were also analyzed as a function of training session and group, although we did not observe any significant effects (all ps > 0.05). For the sake of simplicity, statistical comparisons are not reported here.

Figure 5.4. Cue processing components in older adults after executive control training. Grand average waveforms elicited by the difference in amplitude between cues B-A before (dashed lines) and after (solid lines) the training in frontal (A1), central (B) and parieto-temporal (C) regions of interest defined a priori. Red lines represent the executive control training condition whereas blue lines belong to the speed training control group. Shaded area indicates the window of analysis. Panel A2 represent the mean amplitude between the limits of the region of analysis (200-350 ms) in the frontal region.

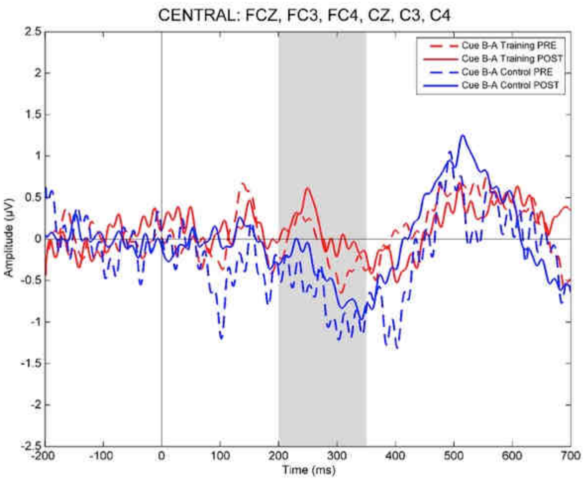
A1



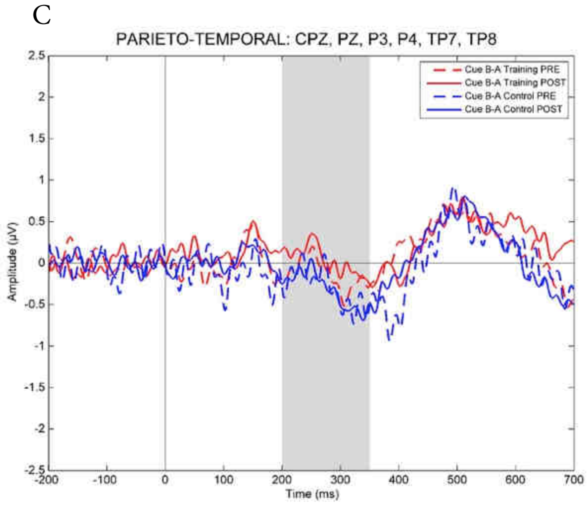
A2



B



C



Predictors for transfer

To further explore whether individual differences can predict the magnitude of transfer effects, we conducted multiple forward linear regression models in each training group by including baseline capacities, training improvement, motivation during and after the training and training location as predictors, and the standardized gains as the criterion.

Regarding baseline capacities, the general trend was a compensation effect in most outcome measures, by which older adults with lower abilities at pre-test were those who gained more after the training (Borella et al., 2017; Weicker et al., 2015). First, we observed that reasoning at pre-test (Gf as an average score from Cattell and RAPM tests) predicted the magnitude of transfer to Gf for the speed training group ($R^2 = 0.27$; $p = 0.02$; $\beta = -0.52$), even though this group did not improved their performance in Gf after the training (see Table 5.5). As for the executive control group, those participants with lower reasoning abilities at pre-test were the ones who obtained larger gains in Gf after the training ($R^2 = 0.22$; $p = 0.04$; $\beta = -0.46$). A similar compensation effect was observed regarding transfer to the Operation-Span task; namely there was not reliable effect for the speed training group ($R^2 = 0.16$; $p = 0.22$), working memory and reasoning capacities predicted transfer gains for the executive control group ($R^2 = 0.43$; $p < 0.01$; $\beta_{wm} = -1.05$, $p_{wm} < 0.01$; $\beta_{Gf} = 0.76$, $p_{Gf} = 0.02$). In processing speed as well as in inhibitory control, we also observed compensation since, for the executive control group, lower efficiency in symbols comparison predicted larger gains after the training ($R^2 = 0.43$; $p < 0.01$; $\beta = -0.66$), and slower stop-signal reaction times predicted greater gains in inhibitory control ($R^2 = 0.51$; $p < 0.01$; $\beta = 0.72$). Finally, and regarding the index of adjustment between proactive and reactive control (BSI), though we failed to observe reliable pre-post effects for any of the groups (see Table 5.5), it became evident that the more reactive older adults were at pre-test (lower BSI scores), the more they tended towards a proactive control mode after the training (by greater standardized gains, $R^2 = 0.66$; $p < 0.01$; $\beta = -0.81$)[2].

[2] Because the (speed training) control group did not show reliable pre-post effects, statistics of the regression models are not reported in the main text, although similar compensation effects were observed for the efficiency in processing speed ($R^2 = 0.29$; $p = 0.01$; $\beta = -0.54$), SSRT($R^2 = 0.88$; $p < 0.01$; $\beta = 0.94$) and BSI ($R^2 = 0.45$; $p < 0.01$; $\beta = -0.67$).

Motivation during the training also had a modulator effect on the transfer to working memory capacity, but only for the executive control training group. Again, we ran a multiple forward linear regression analysis introducing all the motivation variables measured during the training as predictors, and all the outcome measures as criterion. Whereas no variables were introduced in the regression model for the speed training active control group ($R^2 = 0.37$; $p = 0.33$), those who perceived the training as more challenging got greater standardized gains in the Operation-Span task ($R^2 = 0.20$; $p = 0.04$; $\beta = 0.45$). As for motivation and setting during the training, only for executive control participants that trained in the lab effort during the training predicted the gain in the Operation-Span task ($R^2 = 0.56$; $p = 0.01$; $\beta = 0.75$). No reliable model emerged for those trained at home ($R^2 = 0.00$; $p = 0.99$), or those from the speed training control group ($R^2 = 0.00$; $p = 0.98$).

Discussion

Aging is characterized by decline in cognitive performance and by structural and functional brain changes (Grady, 2012). As a result, and because life expectancy is progressively increasing in western societies, the development of interventions that attempt to enhance, or at least maintain, cognitive functioning in older adults is a challenging issue in current research (Chapman et al., 2016; Hertzog et al., 2009)

In the present study, we compared the effectiveness of two different adaptive process-based training procedures. One engaged executive control processes such as updating, inhibitory control and switching, and the other – that served as an active control condition - only required progressive speed in giving the responses without any demand on executive control. To date, the use of active control groups in training studies with older adults is not a common practice (Kelly et al., 2014). Studies using only passive control groups only allow for the control of test-retest effects, while the presence of an active control group permits controlling for motivational and expectancy that may drive training improvements. An additional novelty of our experimental design was the comparison between training locations since so far not many studies have directly compared the performance of older adults training at home versus those training in the lab including an active control condition. The participants in this study were healthy, well-educated and cognitively intact older adults as measured by extensive neuropsychological testing. In the current aging literature a wide number of studies have employed groups of older adults with mid-cognitive impairment and even dementia to study the potential benefits of cognitive training on declining aging population (Barnes, Yaffe, & Belfor, 2009; Rosen, Sugiura, Kramer, Whitfield-Gabrieli, & Gabrieli, 2011) Therefore, the fact that we employed a healthy aging sample allows us to generalize our findings to normal cognitive aging.

In fact, we did not observe differences in training improvement as a function of training location. This is in agreement with previous findings showing that training at home leads to positive benefits (Wadley et al., 2006), although not directly compared to a lab location as in our study.

Thus, our data suggest that with a controlled supervision and track of the participant's training, older adults can benefit from these activities even when they work at home. Note however that all our participants trained in their preferred setting, and it is possible that when participants perform their training in a non-preferred setting, their level of performance might suffer. The interaction between setting and preference should be explored in further studies given the importance of this factor when designing interventions for older adults.

Previous reports have already outlined that training do not benefit all individuals in a similar way, so that it is essential to consider factors such as motivation or baseline capacities that could account for individual differences in training and transfer (Katz et al., 2016). In our study, we controlled for motivation during each session and also after completing the training intervention by using the Intrinsic Motivation Inventory. Thus, we observed that motivation was only a significant modulator of training improvement for the older adults in the executive control training condition, and that those who perceived themselves as more competent and reported greater interest and enjoyment reached higher levels of performance in the working memory activities (*n*-back and WM Search) during the training. This highlights the importance of considering motivational factors when exploring the effects of training, especially in the case of older adults where it can significantly influence training improvement. As for baseline capacities, and consistent with previous reports (Carretti et al., 2017; Karbach & Kray, 2016), we observed a compensation effect during the training for both training conditions. In the case of the active control, older adults with lower processing speed were the ones who gained more during the training. Similarly, those with the lower score on fluid intelligence at pre-test were who improved the most during the executive control training (Carretti et al., 2017; Karbach & Kray, 2016; Karbach & Unger 2014; Zinke et al., 2014).

Despite the relatively small sample sizes used here, the executive control group tended to outperform the speed training group in most of the transfer measures. Although only two session × group interactions reached statistical significance (O-Span and the composite measure of fluid intelligence), the analysis on the individual effects revealed enhanced performance on the Stop-Signal, O-Span, Symbol Comparison and fluid intelligence tasks only for the executive control group. Because training regimes and results are considerably heterogeneous, some authors have proposed that the evidence for the generalizability of training gains to untrained tasks and ability domains is relatively rare (Noack, Lövdén, Schmiedek, & Lindenberger, 2009, 2013). However, our results are in line with previous empirical reports that have supported the effectiveness of cognitive training in older adults as measured by behavioral indices (Borella et al., 2014; Bhremer et al., 2011; Buschkuehl et al., 2008; Carretti et al., 2017; Dahlin et al., 2008, 2010; Karbach & Verhaeghen, 2014; Richmond, 2011; Wilkinson et al., 2016).

In addition to the behavioral measures, we also used the AX-CPT to look at training-derived effects in the adjustment of cognitive control as well as in the processing on contextual information. While training did not modulate the typical older adults' reactive pattern of control as consiering the Behavioral Shift Index (Paxton et al., 2008; Braver et al., 2012), we observed an effect over the processing of contextual information at the behavioral and at the neural levels. The AX-CPT provides a measure that allows one to disentangle different control processes that may contribute to task resolution. Thus, by looking at the processing of the cue we are able to determine whether training may affect the maintenance of contextual information until the time the response has to be given upon the presentation of the probe. In our study, we observed that only the executive control group became more efficient in reducing the time to correctly respond to A cues after the training. Previous behavioral studies with the AX-CPT have observed a pattern of performance that is suggestive of a selective deficit in goal maintenance and context processing in older adults (Braver et al., 2001; Braver et al., 2005; Paxton et al., 2006). At the neural level, prior research has suggested that the use of task-related information provided by the contextual cue is associated with sustained brain activity in prefrontal regions (Braver & Cohen, 2001; MacDonald III & Carter, 2003). In particular, some studies with the AX-CPT have revealed that older adults show decreased cue-related activity due to their impairment in context processing and their reduction in the utilization and maintenance of task-goal information (Paxton et al., 2008). Hence, the present study provides new insights on how to dampen the decifits that aging brings in goal maintenance and context processing. In particular, the analysis of event-related potentials (ERPs) revealed training-related enhanced activity upon the presentation of the cues (calculated by a difference between the amplitude of B and A cues). This increase in amplitude after training is consistent with results from studies in which behavioral gains and increased ERPs amplitudes have been reported after training in visual search (Wild-Wall, Falkenstein, & Gajewski, 2012), selective attention (O'Brien et al., 2013) or task-switching (Gaál & Czigler, 2017; Gajewski & Falkenstein, 2012). In sum, this training-derived increase in amplitude suggests that executive control training could represent a tool to compensate some of the cognitive deficits observed during aging.

Despite the promising applications of the current results, the study is not exempt from limitations. As is the case of our experiment, low statistical power due to small sample sizes is a big issue in training studies, which is especially pronounced with older adults (Kelly et al., 2014). Hence, we recognize the exploratory nature of the present study and the need of increasing the sample sizes in order to accurately estimate the effectiveness of executive control training interventions in older adults. In addition, without follow-up assessments it is not possible to precisely know how long these putative training effects may last.

One of the most desired applications of training is its potential transfer to everyday life. The majority of training studies have focused primarily on laboratory-based measures when examining cognitive abilities in older age. However, in order to appropriately assess the effectiveness of a training intervention in older adults it would also important to include measures of daily life functioning. While transfer to everyday functioning immediately after the training has not been a consistent result, some studies suggest that, at the long-term, trained individuals could experience less impairment in their lives (Ball, Edwards, Ross, & McGwin, 2010; Willis et al., 2006). Some authors have proposed that a possible way to go from lab to life would be to use training interventions with video games or serious game scenarios such as the ones used in our intervention. The idea is to make older adults work with tasks that tend to match everyday challenges (Binder et al., 2016) or engage in novel and cognitively demanding activities.

Because successful performance in everyday tasks is critically dependent on executive control functions (Cahn-Weiner, Boyle, & Malloy, 2002; Pharo, Sim, Graham, Gross, & Hayne, 2011), the ultimate goal of cognitive training interventions in older adults is to enhance cognitive abilities that are essential in daily life. In this sense, to ensure that training and transfer effects reflect changes in the underlying cognitive abilities and no particular task-specific skills, it is necessary to demonstrate transfer at the level of abilities rather than at the single tasks (Noack et al., 2009). Future research using larger sample sizes and latent variable analyses would provide an advantage to evaluate training-derived changes by increasing measurement validity. Finally, it is evident that cognitive training intervention often lacks ecological validity. Future research should make an attempt to join forces between training and aging experts in order to develop comprehensive, reliable and valid test batteries for assessing training-related improvements outside laboratory. This would help to shed light on the effects of older adults' environment on cognition and overall functioning, and to design better training interventions that transfer to all the dimensions of older adults' lives.

So far we have explored the potential transfer of an executive control training to different executive-related functions in healthy older adults, including working memory, inhibitory control, speed of processing, cognitive flexibility and context processing. In addition, because normal aging is also associated to a decline in episodic memory, our next goal is to focus on episodic encoding and selective retrieval during aging. First, we tried to characterize the behavioral and neural indices of selective retrieval in healthy aging to later explore whether executive control training could benefit cognitive processes that come into play during episodic selective retrieval.

CHAPTER VI

Episodic Memory in Healthy Aging

Experiment 3: Theta oscillations show impaired interference detection in the elderly during selective memory retrieval*

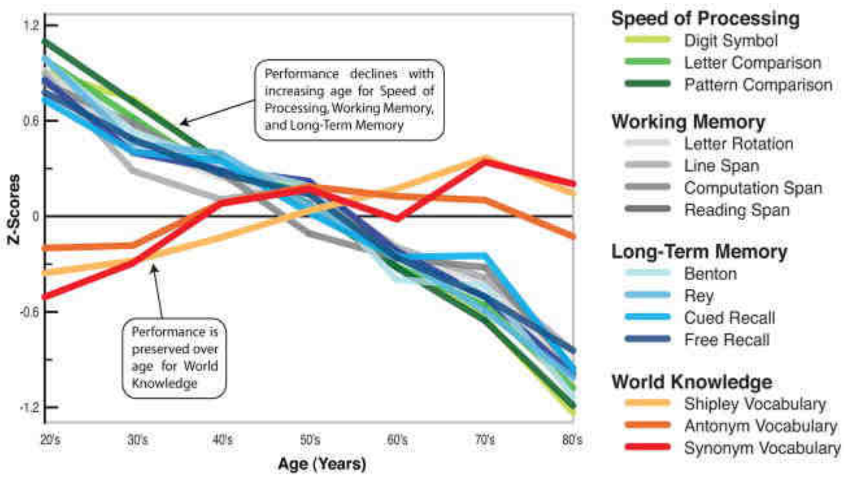
Becoming older involves progressive impairment in executive control and memory-related functions. One of the most frequently cognitive failures reported by older adults arises in naming difficulties. A possible mechanism that could explain naming difficulties lies in the concurrent activation of related competitors at the moment a particular memory trace has to be retrieved from memory. To investigate this hypothesis, we used the Retrieval Practice (RP) paradigm, which has been repeatedly shown to elicit interference between stimuli, while recording electrophysiological activity from a group of young and older adults. In this study, participants performed three retrieval cycles by using semantic material. The study ended with a surprising memory test. Behaviorally, young participants showed a typical Retrieval-Induced Forgetting (RIF) effect, whereas older did not. At a neural level, young adults exhibited an increase in theta power (~4-8Hz) upon presentation of a category cue compared to older adults. Moreover, young participants significantly reduced theta power across retrieval cycles. No such reduction was found for the elderly. Thus, young adults would seem to be more sensitive to interference than older people, as traced by mid-prefrontal theta oscillations. This more efficient detection of interference would lead younger adults to recruit inhibitory mechanisms to overcome competition, as reflected by the theta power decrease across retrieval cycles and by the behavioral RIF effect. However, the deficient interference detection by the elderly would render them unable to recruit memory selection mechanisms, which would prevent RIF from appearing.

---

* This section correspond to the second experiment of the paper submitted to *Neuroimage* as Ferreira, C.S., Maraver, M.J., Hanslmayr, S. & Bajo, M.T. Theta oscillations show impaired interference detection in the elderly during selective memory retrieval.

As we mentioned in the previous chapter, the goal of the next study was to identify memory processes that may underlie the difficulties of older people for episodic remembering. That aging entails a general decline in cognitive functioning, with memory being one of the most affected functions, is a well-established fact (Park et al., 2002; Park & Reuter-Lorenz, 2009, see Figure 6.1). As people get older, they seem to have greater difficulty in remembering and finding words that they easily did in their youth (Craik, 1994) and become more vulnerable to everyday forgetfulness.

Figure 6.1. Life-span performance on cognitive measures. Taken from Park & Reuter-Lorenz, (2009). Cross-sectional aging data adapted from Park et al. (2002) showing behavioral performance on measures of speed of processing, working memory, long-term memory, and world knowledge. Almost all measures of cognitive function show decline with age, except world knowledge, which may even show some improvement.



There is considerable evidence that performance on tasks involving episodic memory declines steadly through the adults' years. Moreover, not only do adults over 60 report more memory problems in everyday life situations (Cutler & Grams, 1988; Montejo, Montenegro, Fernández, & Maestú, 2012; Ryan, 1992), but they also perceive themselves as having less control over their own memory than their younger counterparts (Dixon & Hultsch, 1983). Additionally to these subjective reports, more objective measures have similarly shown that older adults perform worse in free recall and recognition tests (Craik & Jennings, 1992; Light, 1991, 1996) as well as in neuropsychological tests tapping into memory (LaRue, 1992).

One possible way to explain these age related changes has been proposed by Hasher and Zacks and their Inhibitory Deficit Theory (IDT), which postulates that cognitive failures related to normal aging are due to a deficit in inhibitory mechanisms (Hasher et al., 1991; Hasher & Zacks, 1988). According to the IDT, older adults do not have the ability to suppress or inhibit unwanted or irrelevant information from entering working memory. Thus, for example, older people's naming difficulties could be due to an inability to suppress irrelevant-competing representations (such as someone's name) making it harder to access and choose the desired information (Lustig, Hasher, & Zacks, 2007).

Corroborating this idea, several studies have found age-related impairments when testing participants with inhibitory paradigms (i.e. Stop Signal and Go/No go: Bedard et al., 2002; Think/No Think: Anderson, Reinholz, Kuhl, & Mayr, 2011, but see Murray, Anderson, & Kensinger, 2015). An fMRI study by Gazzaley, Cooney, Rissman and D'Esposito (2005), for instance, compared young and older adults in a task wherein they were asked to remember, ignore or passively view the stimuli presented. Young adults showed significantly less activation within a scene-selective region of interest in the left parahippocampal/lingual gyrus during the ignore condition in comparison to the condition where they passively view the stimuli (Gazzeley et al., 2005). In contrast, older adults showed similar levels of activation under both conditions. Importantly, there were no age differences when it came to increasing activation during the remember condition. Thus, older adults would seem to have a specific deficit in preventing irrelevant information from interfering. Furthermore, the degree of reduced activation selectively predicted memory performance, whereas the activation increase (under the attending instructions) did not.

Another paradigm commonly used to investigate inhibitory control is the retrieval practice paradigm (Anderson, Björk & Björk, 2004). In this paradigm, participants first study pairs of words belonging to a given category (i.e., FRUIT - apple; FRUIT - orange; ANIMAL - elephant). On a second memory phase, participants complete several retrieval practice cycles (usually three) in which they are asked to repeatedly retrieve half of the words from half of the categories upon presentation of a cue (i.e., FRUIT – ap___). The idea is that when presented with the category cue (i.e., FRUIT), all the related previously studied items become active in memory (i.e., apple, orange, banana…), so that an interference situation arises from the competition between related memory representations. In order to promote the retrieval of the target memory (i.e. apple), an inhibitory control mechanism is triggered to suppress the interference of the competing memory representations (i.e., orange). According to an inhibitory account of the processes involved during selective retrieval (Anderson, Bjork, & Bjork, 1994), inhibition is especially required to reduce activation of strong competing traces so that the retrieval of weaker but appropriate memories would be facilitated (Anderson, 2003; Levy & Anderson, 2002). Importantly, this process involves at least two mechanisms: first, a mechanism that detects conflict/interference between the competing memory representations and, second, a mechanism that reduces interference by inhibiting competing memories. Behaviorally, the retrieval practice paradigm typically shows two different effects in a final memory test. On the one hand, the recall of unpracticed items from practiced categories (i.e., orange) is normally significantly impaired in comparison to that for control items (i.e. items that were neither practiced nor belonged to practiced categories), then inducing *forgetting*. This retrieval-induced forgetting effect (RIF) is assumed to be the behavioral consequence of competitors inhibition that results in reduced accessibility for the unpracticed items from the practiced categories (Anderson et al., 1994). Thus, the RIF effect results from the very act of remembering (Anderson, 2003). On the other hand a *practice* effect emerges from the fact that practiced items (i.e. apple) are recalled significantly better than control items.

Though different theories have been proposed to explain RIF effects (Jonker, Seli, & MacLeod, 2015; Mensink & Raaijmakers, 1988), there is overwhelming support for an inhibitory account of such effects (Gómez-Ariza et al., 2017; Levy & Anderson, 2002; Román et al., 2009; Storm & Levy, 2012; Weller, Anderson, Gómez-Ariza, & Bajo, 2013). Several electrophysiological and neuroimaging studies have shown that RIF strongly depends on prefrontal structures involved in conflict/interference detection, such as the anterior cingulate cortex (ACC; Ferreira et al., 2014; Kuhl, et al., 2007; Staudigl et al., 2010), and its resolution, such as the ventro-lateral prefrontal cortex (Kuhl et al., 2007; Wimber et al., 2008, 2009). Importantly, these studies have shown that does the RIF effect depend on prefrontal control structures but also that it involves downregulation of the competing items themselves rather than the modulation of their associations to the retrieval cue (Waldhauser, Johansson, & Hanslmayr, 2012; Wimber, Alink, Charest, Kriegeskorte, & Anderson, 2015).

Of particular relevance for the current study are findings showing that the behavioral effect of RIF is gradually impaired in older adults, and that this impairement is modulated by factors such as the aging process itself (Aslan & Bäuml, 2012; Marful, Gómez-Amado, Ferreira, & Bajo, 2015) or the degree of cognitive resources imposed by the task (Ortega, Gómez-Ariza, Román, & Bajo, 2012). To our knowledge, however, there are not EEG studies specifically investigating the brain mechanisms underlying the age-related changes in RIF, and whether the possible deficits are related to interference detection, interference resolution or both. Due to its superb temporal resolution, the EEG signal might allow for the dissociation between the two neural signatures that mediate RIF (interference detection and inhibition), which would be difficult to separate with purely behavioral methods. This should enable us to identify the source of the RIF deficit in older adults.

Electrophysiological studies investigating RIF provide evidence that the effect can be traced by mid-frontal theta (~4-8 Hz) and alpha/beta oscillations (~8-12 Hz). These studies (Simon Hanslmayr, Staudigl, Aslan, & Bäuml, 2010; Staudigl et al., 2010) typically compare a competitive condition (standard retrieval practice) with a non-competitive one (i.e., relearning condition). In the latter, participants are simply re-exposed to the material without requirements to retrieve any information. While the standard retrieval practice should lead to interference between stimuli and, consequently, inhibition of competitors, relearning should not induce interference since participants do not need to retrieve any items. Accordingly, not only does the behavioral RIF effect fail to appear in the relearning condition (Anderson, Bjork, & Bjork, 2000), but there is also an increment in theta power when comparing retrieval to relearning (Hanslmayr et al., 2010; Staudigl et al., 2010). This increment is localized in medial prefrontal brain regions (such as the anterior cingulate cortex) and predicts later forgetting (Staudigl et al., 2010).

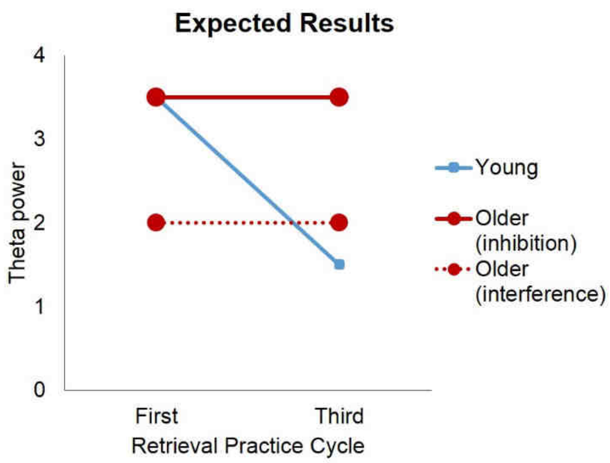
In a previous study aimed to experimentally disentangle the neural correlates of interference and inhibitory mechansisms (Ferreira, Marful, Staudigl et al., 2014), Ferreira et al., (2014) used the pre-cuing retrieval practice paradigm with professional categories and faces as cues to retrieve people names. The pre-cuing paradigm (Bajo, Gómez-Ariza, Fernandez, & Marful, 2006) consists in separating in time the presentation of the category cue (i.e. Fruit) from the retrieval-specific cue (the name of a specific fruit). The underlying reasoning is that whenever participants see the category cue, all the previously studied items belonging to that category (i.e. Fruit) become active and generate competition (interference) among memory representations, which should be solved by inhibitory mechanisms upon presentation of the retrieval specific cue (i.e. the word "apple"). Therefore, this design allowed the authors to track the time course of interference detection specifically, by looking at category cue presentation. Results showed that the category cue in the competitive condition led to a greater increase in theta power than in the non-competitive condition, which was interpreted as a marker of interference detection. Moreover, in the competitive condition theta power decreased from the presentation of the category cue to the presentation of the retrieval cue, reflecting a decrease in interference due to its resolution. Importantly, the amount of theta power decrease correlated with later forgetting. This paradigm, in combination with electrophysiology, is therefore ideally suited to reveal the mechanism potentially impaired in older adults: interference detection or its resolution by means of inhibition.

The following experiment uses a similar procedure to that of Ferreira et al (2014), but using semantic material. We opted to eliminate the non-competitive condition and compare the neural correlates of RIF throughout subsequent cycles of retrieval practice between age groups. Previous studies have shown a reduction in BOLD signal (Kuhl et al., 2007; Wimber et al., 2008) as well as a decrease in theta power (Staudigl et al., 2010) from one retrieval practice cycle to the next, which is suggestive of interference resolution across cycles. The first time that retrieval cues are presented – in the first practice cycle - conflict might be at its highest level and, therefore, theta power as its neural correlate should be high. By the time competitors are inhibited across the practice cycles, interference becomes solved and theta power might start decreasing across the practice cycles. Thus, by using this pre-cuing procedure, consecutive practice cycles (Bajo, et al., 2006; Ferreira, Marful, Staudigl et al., 2014) and assessing theta oscillations upon presentation of the cue, we would be able to disentangle interference detection (first presentation of the cue, when interference should be at its highest level) from inhibition or interference resolution (difference between first and last presentation of the cue).

Our hypotheses were as follows. On the one hand, if the elderly's difficulties in selective retrieval were due to poor interference detection, we would expect theta power upon presentation of the category cue during the first retrieval practice cycle to be lower for older adults compared to younger participants (see Figure 6.2). Our expectation is supported by studies showing that low forgetters exhibit on the first retrieval cycle lower levels of theta (Staudigl et al., 2010) and lower ACC activity (Kuhl et al., 2007) than high forgetters. In this case, theta power should remain constant across cycles since, if interference is not detected, the inhibitory mechanism in charge of resolving it should not be called into play (Anderson et al., 2003).

If, on the other hand, the problem lies in interference resolution, theta power upon the first presentation of the category retrieval cue should be equivalent for young and older participants since both will detect interference to a similar level. However, while in the elderly theta power would remain constant (at high levels, in this case) across cycles because of their difficulties to engage inhibitory mechanism to reduce interference, younger people would show a reduction in theta power from one cycle to another indicating reduced interference across cycles.

Figure 6.2. Expected results for theta power during retrieval practice as a function of age. Expected neural results in theta power as a function of practice cycle and age group. The blue line represents the expected results in theta power for the young participants, replicating previous studies. The red lines represent the expected results for the elderly. The solid line represents the expected results if older participants suffer from a deficit in interference detection, whereas the dashed line depicts what could be expected if the elderly's struggle was in solving interference.



Thus, by combining behavioral and electrophysiological procedures in young and older adults, our study aims to better understand the neural substrates underlying age-related changes in the RIF paradigm, specifically whether the elderly difficulties in naming are due to interference detection or interference resolution.

Methods

Participants

24 students from the University of Granada (17 female; M_{age} = 21.12; SD = 3.51) and 24 older adults[1] (8 female; M_{age} = 64.73; SD = 3.50; range 60-75) participated in this study. Older participants were recruited from an advert published in local newspaper and in the University of Granada webpage. Inclusion criteria specifically stated that older adults should have a minimum of 12 years of education and the mean years of education for this sample was of 15.46 (SD = 2.25). Participants completed the Mini Mental State Exam (MMSE; Lobo et al., 1979), scoring 28.15/30 (SD = 0.99). No differences were found between groups as to working memory capacity, as measured by the digits span test from the WAIS III (see Table 5.1. in the results section, M_{young} = 15.87; SD_{young} = 3.51; M_{older}=14.82; SD_{older} = 2.98; F (1, 46) = 1.67, p = 0.20, η_p^2 = 0.03).

All participants were Spanish or had been living in Spain for at least 15 years and were thus native or very fluent speakers. All reported normal or corrected-to-normal vision. Participants were given all the information about the study and signed an informed consent prior to its beginning. Young participants received course-credits and older adults were monetarily rewarded for their participation in the study.

Material

A total of 64 target words plus six fillers were used. The words belonged to eight different categories (animals, fruits, tools, vehicles, insects, trees, clothes and furniture) with eight exemplars each. Filler items belonged to two extra categories (drinks and toys, with three exemplars each). Within the same category, no items shared the first two letters. Moreover, in order to maximize

[1] The sample size was determined on the basis of the minimum number of participants per condition used in Ferreira et al., (2014) but increased in order to keep a complete counterbalance of the task material.

competition between items, within each category four items were chosen for being highly representative (by reporting higher frequency of word use) of their categories, while other four were poor representatives (less frequent). The poor representatives were used as practiced items and their baseline, whereas high representative words were used as unpracticed ones and their respective baseline. This was done this way because literature has shown that the more representative of its category an item is, the more it will compete with the to-be retrieved ones. Thus, interference is thought to be boosted by doing this manipulation (Anderson et al., 1994; Anderson, 2003). Four counterbalance versions of the practice status of the items were created and participants were randomly assigned to each version. Indices of frequency and rank for each item respective to its category were taken from Marful, Díez, & Fernández (2015), using the NIPE database (Norms and Indices for Experimental Psychology; (Díez, Fernández, & Alonso, 2006). Mean frequency was of 4.70 (*SD* = 6.21) for practice items and 208.30 (*SD* = 52.78) for competitors. Rank scores were on average 8.53 (*SD* = 2.20) and 4.43 (*SD* = 1.51) for practice and competitor items respectively. The words were presented in the centre of the screen in a black font (Courier New, 18 pts) on a white background. Category cues were always presented in uppercase letters, whereas the specific items and their stems were presented in a capitalized fashion.

Procedure

The experiment consisted of a version of the retrieval practice paradigm (depicted in Figure 6.3) thus comprising an initial study phase, a retrieval practice and a final test. Details of the different phases are detailed below.

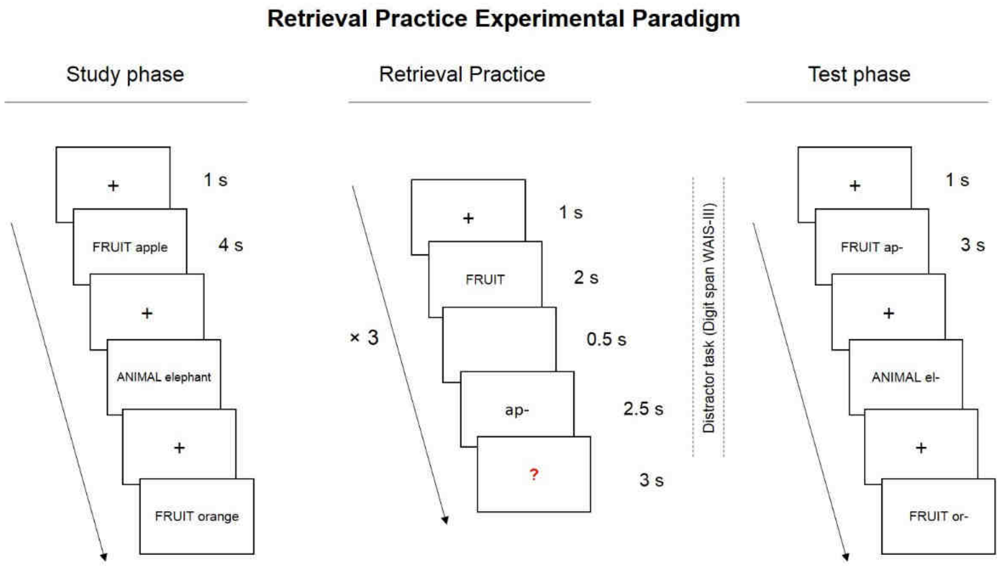
The experiment started with a *study phase*, in which participants were sequentially shown 64 pairs of category-exemplar (i.e. FRUIT- apple), but blocked in 8 groups of one exemplar per category. Presentation was randomized except that the first and last two items were always filler items, to soften primacy and recency effects. After a 1000 ms fixation cross the category and item pair appeared on the screen for 4000 ms (i.e.: FRUT – apple). The participants' task consisted of pressing a number from 1 to 5 on the keyboard according to how familiar the presented pair of words was for them (1- very unfamiliar; 5- very familiar). This was done not only to control for possible differences in item familiarity between participants, but also to make sure that participants were attending to and processing the stimuli. Furthermore, they were instructed to pay close attention to the words since they would be asked about them later.

During the *retrieval practice* phase, which occurred right after study, participants were asked to retrieve half the exemplars from six of the eight categories, in which the pre-cuing procedure was maintained across the three cycles of retrieval practice. Thus, participants first saw a fixation point for 1000 ms, followed by the category cue (p.e. FRUIT) for 2000 ms, a blank screen for 500 ms, and the two first letters of the specific target exemplar (p.e. ap-) during 2500 ms. Then a red question mark appeared on the screen during 3000 ms and participants were instructed to give their response (name the exemplar) at that moment. Participants were explicitly instructed to refrain from responding up until the moment the question mark was presented on screen, to avoid speech artefacts. Exemplars were presented in a pseudo-random order, so that a whole set would be presented before repeating itself on the subsequent retrieval practice cycle. As in the study phase, the first and last two exemplar were filler items used to control for primacy and recency effects. Crucially, there were three cycles of retrieval practice so that each of the 24 exemplars used during this part of the experiment was repeated three times in order to allow for comparisons between first and third cycles, similarly to what has been done in previous studies (Kuhl et al., 2007; Staudigl et al., 2010; Wimber et al., 2009).

Note that after retrieval practice, three types of items can be distinguished: practiced items, unpracticed items from practiced categories, and control items (i.e. non-practiced items from non-practiced categories), which serve as baseline items. A 5 minute distracter task followed retrieval practice (the direct and inverse digits span test from the WAIS III).

Thereafter, a final memory test occurred wherein each studied exemplar was presented again for naming. After a fixation cross (1000 ms), a retrieval cue consisting of the category cue and the two first letters of the target exemplar (FRUIT - ap-) appeared on the screen for 3000 ms. and participants were asked to retrieve the corresponding word as soon as possible. The order of presentation was randomized, such that all unpracticed items and half of the control items were presented first, followed by practiced items and the other half of the baseline-items. This was done this way to prevent possible confounds with the forgetting effect, since retrieval of practiced items first could block access to the unpracticed ones

Figure 6.3. Experimental procedure followed during the retrieval practice task. Adaptation of the competing condition of the retrieval practice paradigm from Ferreira et al., (2014). Three differentiated phases comprised the paradigm: a first study phase (left), a three cycle retrieval practice phase where the EEG was recorded (center), and a final memory test at the end of the task (right). The digit span task was used before the final test phase as a distractor task.



EEG Recording

The EEG was recorded from 64 scalp electrodes mounted on an elastic standard 10-20 system cap. Four additional electrodes were used to control for eye movements: two set above and below the left eye (controlling for vertical movement) and another two set at the outer side of each eye, to control for horizontal movement.

Continuous activity was recorded using Neuroscan Synamps2 amplifiers (El Paso, TX) and was first recorded using a midline electrode (half-way between Cz and CPz) as reference. The data was then re-referenced offline against a common average reference. Each channel was amplified with a band pass of 0.01-100 Hz and digitized at a 500 Hz sampling rate. Impedances were kept below 5kΩ. Prior to analysing the data, a high-pass filter (at 1Hz) was applied and artefacts (such as eye movements and EKG) were removed using independent component analyses (ICA). Remaining artefacts after ICA were manually removed by carefully inspecting the data.

EEG pre-processing

For EEG analyses we used the Fieldtrip toolbox (Oostenveld, Fries, Maris, & Schoffelen, 2011) on Matlab (The MathWorks, Munich, Germany). The EEG data were cut into segments ranging from 2000 ms before stimulus presentation to 4000 ms after, around both the category cue and the retrieval specific cue (i.e. the word stem; first, second, and third cycle in both cases). These large segments were chosen to avoid filter artefacts after wavelet transformation at the beginning and end of each period. Data analysis was restricted to a smaller time window from -500 ms to 2000 ms, both on the first and third cycle trials.

Analyses of Oscillatory Power

For time-frequency analyses, a Morlet wavelet transformation (7 cycles) was applied to the data. Data were filtered in a frequency range from 1-30 Hz and exported in bins of 50ms and 1Hz. As in previous experiments (Ferreira et al., 2014), power changes were calculated in relation to a prestimulus baseline (from -500 to 0ms before category cue onset).

Given our a-priori hypotheses, analyses were restricted to the theta frequency range (4-8Hz) and on the time window around cue presentation. A region of interest analysis was applied on a set of 9 fronto-central electrodes (Fcz, F1, Fz, F2, Fc1, Fc2, C1, Cz, C2) based on our previous study (Ferreira et al., 2014) and on a plethora of other studies showing that mid-frontal theta oscillations are typically recorded at these locations (Cohen, 2014). Power differences over this ROI were used to define the exact time-frequency windows for subsequent analyses.

Results

Behavioral results

Table 6.2 summarizes the descriptive data of the retrieval practice paradigm. As shown in the table, for the intermediate retrieval practice phase no differences in mean recall were found for the two age groups (M_{young} = 0.565; SD_{young} = 0.13; M_{old} = 0.57; SD_{old} = 0.10; F (1,46) = 0.13, p = 0.71, η_p^2 = 0.00), and also no differences were observed in any of the three consecutive practice cycles (all ps > 0.05, see Table 6.1).

To examine forgetting and practice effects, two 2 × 2 mixed ANOVAs were performed with type of item (unpracticed/practiced *vs.* control) as a within subject factor and group (young *vs.* older) as a between subjects factor. Planned comparisons were then conducted for each group separately with one-tailed paired-sample t-tests.

Forgetting

The ANOVA conducted to assess forgetting (type of item × age group) revealed no significant effect of item type (F (1, 46) = 2.46, p = 0.12, η_p^2 = 0.05) or age group (F (1, 46) = 1.16, p = 0.28, η_p^2 = 0.02), but did yield a significant item × group interaction (F (1, 46) = 4.60, p = 0.04, η_p^2 = 0.09). As can be seen in the table, follow-up analyses showed a significant difference between unpracticed items (M = 0.67, SD = 0.15) and their respective controls (M = 0.78, SD = 0.14) for the younger adults (F (1, 23) = 10.14, p < 0.01, η_p^2 = 0.30). No such a difference was found however in the older group ($M_{unpracticed}$ = 0.70, SD = 0.10; $M_{control}$= 0.68; SD = 0.20; F (1, 23) = 0.12, p = 0.73, η_p^2 = 0.00).

Practice

Concerning the practice effect (see Table 6.1), a significant main effect of item type was obtained (F (1, 46) = 62.65, p < 0.01, η_p^2 = 0.58) so that practiced items were recalled significantly better than their controls ($M_{practiced}$ = 0.56, SD = 0.13; $M_{control}$ = 0.31; SD = 0.20). No significant main effect for group F (1, 46) = 0.30, p = 0.58, η_p^2 = 0.00 nor item × group interaction F (1, 46) = 0.88, p =

0.35, $\eta_p^2 = 0.02$ were obtained. Further analyses revealed that practice effects were present in both groups (young: $F\,(1, 23) = 52.30$, $p < 0.01$, $\eta_p^2 = 0.69$; older: $F\,(1, 23) = 19.13$, $p < 0.01$, $\eta_p^2 = 0.46$).

Table 6.1. Descriptive behavioral data of the retrieval practice paradigm. Mean and standard deviations for the outcome measures in the retrieval practice task. Significance p values and effect sizes (Cohen's d) estimates are reported for bilateral independent samples t-test (46) as a function of age group. Forgetting effect is calculated by the difference between control and unpracticed items, whereas practice is the result of the substraction between practiced and control items.

	Young		Old		Group effect	
Variables	*M*	*SD*	*M*	*SD*	*P*	*Cohen's d*
Age	21.12	3.52	64.74	3.51	**0.00***	-12.42
Working Memory (Digits WAIS-III)	15.87	2.58	14.83	2.98	0.20	0.38
Retrieval Practice (overall recall)	0.56	0.13	0.58	0.10	0.71	-0.11
Practice cycle 1	0.52	0.13	0.52	0.13	0.94	-0.01
Practice cycle 2	0.58	0.14	0.58	0.11	0.93	-0.03
Practice cycle 3	0.59	0.13	0.63	0.10	0.36	-0.27
Final memory test (overall recall)	0.58	0.10	0.57	0.08	0.79	0.09
Control	0.79	0.14	0.68	0.209	**0.05***	0.59
Unpracticed	0.67	0.15	0.70	0.10	0.40	-0.25
Forgetting	0.12	0.18	-0.02	0.25	**0.04***	0.62
Control	0.29	0.17	0.34	0.22	0.39	-0.25
Practiced	0.58	0.14	0.56	0.10	0.76	0.09
Practice	0.29	0.20	0.23	0.25	0.35	0.28

Theta Power Analyses

Differences in theta power upon presentation of the cue on the first and third cycles were computed for each participant in the young and older group. The first step was to look at group differences in theta power upon presentation of the first cue, as an index of initial levels of sensitivity to interference detection, and then perform an interaction analysis (cue cycle 1 minus cue cycle 3 × age group). Thus, differences in theta power upon presentation of the cue between the first and third cycle were calculated for each participant, at the previously mentioned mid-frontal ROI. These differences were then subjected to a *t*-test comparing the two age groups. Analyses of oscillatory power upon word stem presentation were also performed in a similar fashion to the analyses of category cue.

In order to control for multiple comparisons, Monte Carlo randomization was used (see details on this method in Maris and Oostenveld, 2007). From this procedure, clusters of electrodes that significantly differed from one cycle to the other were obtained (p_{corr}<.05). Planned comparisons were then made for each group (young and older) separately, comparing first cue and word stem presentations and third ones over the time, and significant frequency windows in the interaction analysis.

Cue

We first report the analysis for the first cycle (Cue 1; interference detection index) and then the difference between the first and third cycles (Cue 1 vs. 3; interference resolution).

Interference detection (Cue 1: Younger vs. Older)

For the first cue presentation a significant difference in theta power was found between younger and older adults (F (1, 46) = 10.81, p_{corr} < 0.01, η_p^2 = 0.20), such that younger adults showed greater theta power (7-8 Hz) compared to older adults over frontal and parietal areas, in a time window ranging from 200 to 500 ms (Figure 6.4A and 6.4C1).

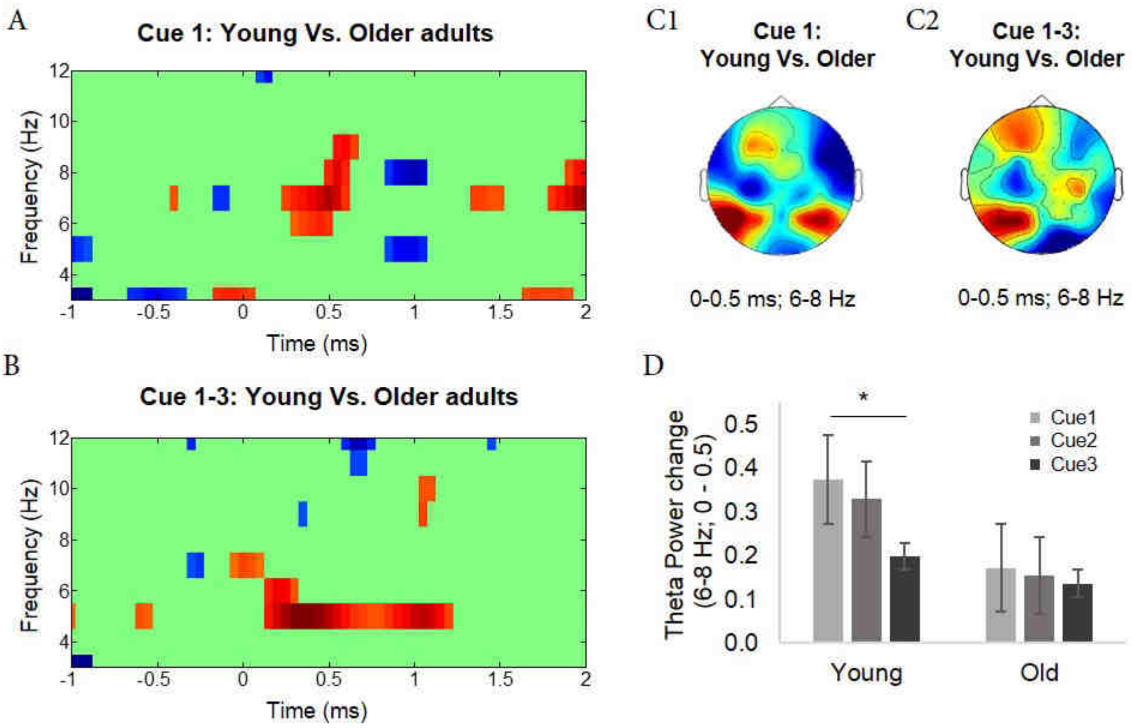
Inhibition interaction (Cue 1 vs. 3: Younger vs. Older)

The interaction analysis (first cue minus third cue × age group) yielded a significant difference over a time window ranging from 200 to 500 ms, at 7 Hz (F (1, 46) = 4.50, $p_{corr} < 0.05$, η_p^2 = 0.04; see Figure 6.4B and 6.4C2). Over the mid-frontal ROI, theta power was higher for younger compared to older adults. Planned comparisons on this effect are described next.

Inhibition main effects (Cue 1 vs. 3 in each age group)

For young adults, mid-frontal theta power decreased at 7 Hz upon cue presentation from the first to the third retrieval practice (F (1, 23) = 6.96, $p_{corr} < 0.02$, $\eta_p^2 = 0.24$) from 200 to 500 ms. Theta power gradually decreased from the first to the third cycle (Figure 6.4D). For older participants, however, no significant difference was found between the first and the third cue (F (1, 23) = 0.60, $p_{corr} > 0.05$, $\eta_p^2 = 0.00$).

Figure 6.4. Theta power as a function of the retrieval practice cycle and age group. A) Difference in the presentation of the first category cue (cue 1) between young and older adults. B) Interaction analysis: differences between younger (cue1 – cue3) and older adults (cue1 – cue3). The time-frequency plots on the left shows the significant time-frequency window (over a central ROI comprising 9 mid-frontal electrodes, depicted in black circles) used for subsequent analyses and the topography on the right (C) shows the distribution of this effect. D) Percentage signal changes in theta power (6-8 Hz), from 0 to 500 ms upon presentation of the category cue in each cycle for young (left) and older (right) participants. Note how theta power decreases across retrieval cycles for the younger participants but not for the elderly.



Discussion

In this experiment, we aimed to explore individual differences as a function of adult age in selective memory retrieval. Specifically, we focused on the behavioral performance and the brain activity that has been previously linked to the retrieval practice paradigm. At the behavioral level, the RIF effect was absent in a sample of older adults, whereas it was present in younger adults. According to the inhibitory account (Anderson, 2003; Levy & Anderson, 2002; Román et al., 2009; Storm & Levy, 2012), RIF is the consequence of the competition experienced when presented with a category cue for retrieval of a specific item (i.e. FRUIT to retrieve orange). The presentation of the cue activates in memory several of the previously studied exemplars, which leads to competition between the stimuli. This conflict is assumed to trigger inhibitory mechanisms in charge of supressing the competing items and promote the correct recall of the target memory trace. While younger adults seemed to involve these processes, our data suggest that older adults did not recruit these mechanisms during selective retrieval.

Thus, at a neural level, our results show that, at the moment of the first category cue presentation, mid-frontal theta power was higher for younger than older participants, in a time-frequency window ranging from 7-8 Hz and 0 to 500 ms. The increment in theta power in this time-frequency window for younger adults is in good agreement with previous results (Ferreira et al., 2014; Hanslmayr et al., 2010; Staudigl et al., 2010). Mid-frontal theta has been interpreted as a fine-grained marker of conflict/interference detection (Cohen, 2014), and the fact that older adults showed lower levels of theta power than younger participants parallels results showing that lower forgetters exhibit less theta power during the first retrieval cycle (Staudigl et al., 2010) and less activity in frontal regions such as the anterior cingulate cortex (Kuhl et al., 2007). Moreover, it is well known that prefrontal structures seem to suffer with aging to a great extent and that age-related decline in frontal lobes has been closely linked to a decrement in cognitive functioning (Nielson, Langenecker, & Garavan, 2002; Raz et al., 2010). Thus, the fact that older participants show less theta power upon cue presentation seems to indicate that older adults do not efficiently engage the brain mechanism in charge of detecting and reacting to interference, which is in line with studies showing that this population is more susceptible to interference (Friedman & Castel, 2013; Solesio-Jofre et al., 2012; Tays, Dywan, Mathewson, & Segalowitz, 2008).

For the young adults, however, we observed a significant reduction in theta power from the first to the third retrieval cycle. Theta power decreased gradually from one cycle to the next, which arguably reflects the successful down-regulation of interference and is thought to be a marker of how well inhibition operates (Kuhl et al., 2007; Staudigl et al., 2010; Wimber et al., 2011). The more effective detection of interference by younger adults could have allowed them to trigger the necessary inhibitory mechanisms to suppress activation of competing items and therefore to resolve interference. This successful suppression of competing items (Wimber et al., 2015) is revealed by the behavioral forgetting effect displayed by younger participants.

Remarkably, no such theta power reduction through practice cycles was found for the older group, in which theta power was constant across retrieval cycles. It thus seems that the elderly are not capable of recruiting the necessary mechanisms to detect interference in the first place, which supports the interference detection deficit hypothesis (see Figure 6.2). As shown in Anderson et al. (2000), inhibition is interference-dependent. Accordingly, if the elderly do not detect interference, inhibition should not be called into play. Again, this is evidenced not only by the fact that theta power does not decrease across cycles, but also by the fact that no RIF effect was found for the elderly. Notably, our results are consistent with the Inhibitory Deficit Theory (IDT; Hasher & Zacks, 1988) in that they show an impairment for older adults in a task that requires inhibition. Our results advance this theory by identifying one of a possible reason for this inhibition impairment, which might lie in an early stage of interference detection.

Previous research has also pointed to this same direction. For instance, ERP studies in young adults showed that during incongruent trials of a Stroop task (interference inducing trials), a medial frontal negativity component occurs between 400 and 500 ms (N450; (Rebai, Bernard, & Lannou, 1997; West & Alain, 1999), with several studies showing medial prefrontal brain regions as the source of this medial frontal negativity (Simon Hanslmayr et al., 2008; Liotti, Woldorff, Perez, & Mayberg, 2000; West & Alain, 2000). Crucially, the medial frontal negativity generated by older adults has been shown to be attenuated during different variants of the Stroop task (West & Schwarb, 2006; West, 2004). Similarly, Tays et al. (2008) found that in a Sternberg-like task, older adults showed a large frontal positivity instead of the medial frontal negativity, and that this unique pattern of frontal positivity is associated with poorer behavioral performance, rather than with compensatory mechanisms. The fact that a component that is consistently found in interference-related trials (such as the medial frontal negativity) is attenuated in older adults agrees with our results and with the idea that older adults have a harder time in detecting interference.

Our results could help explaining discrepant findings in the aging literature. Kramer, Humphrey, Larish, & Logan (1994) showed that age-related inhibitory deficits were only present in some of the tested inhibitory tasks. Similarly, studies using RIF (Aslan, Bäuml, & Pastötter, 2007, Aslan & Bäuml, 2012; Gómez-Ariza, Pelegrina, Lechuga, Suárez, & Bajo, 2009; Hogge, Adam, & Collette, 2008; Marful et al., 2015; Ortega et al., 2012), directed forgetting (Aguirre et al., 2014; Sahakyan, Delaney, & Goodmon, 2008; Sego, Golding, & Gottlob, 2006) and Think/No-Think paradigms (Anderson et al., 2011; Murray et al., 2015)have shown both preserved and impaired effects in the elderly. Altogether, these experiments point to the idea that several different factors (such as the nature of the task itself, the age of the participants or the availability of cognitive resources) might modulate how inhibition affects performance by impairing interference detection, and/or subsequent inhibitory control. Regarding the age-related modulation, Aslan and Bäuml (2012) and Marful et al. (2015) showed that younger-old adults exhibit a similar RIF effect to that of young adults, but that this effect does not show up in older-old adults. Moreover, Ortega et al. (2012) showed that RIF is maintained in older people but easily disrupted when another concurrent task is added. Taking the present results into account, one possibility is that RIF only appears if a task is simple enough, as when older adults can make use of all their available cognitive resources. In this case older participants can easily detect interference and trigger appropriate inhibitory mechanisms. However, if the task turns out to be more demanding (see Ortega et al., (2012) for dual-tasking, Koessler (2009; 2012) for situational stress – and such as it could happen in an EEG recording scenario like that used here–), it could make the task harder for older adults who would have less resources available to detect interference. If so, there would not be need of inhibitory mechanisms and RIF would not be expected. Similarly, Aguirre et al. (2014) showed that while older adults have similar directed forgetting effects as compared to young adults, making directed forgetting more demanding (selective; Delaney, Nghiem, & Waldum, 2009) reduces the ability of the elderly to voluntarily forget. These studies seem to indicate that older adults are capable of performing inhibitory tasks when enough cognitive resources are available, but that as cognitive demands increase this capacity becomes impaired. Finally, studies with Directed Forgetting and Think/No-Think paradigms (Sahakyan et al., 2008; Murray et al., 2015) show that inhibitory deficits may be overcome when participants are provided with a precise guided strategy on how to perform the task, which is also suggestive of how sensitive their ability to inhibit may be.

In the present work, we aimed to further understand the neural dynamics underlying selective memory retrieval and to identify executive control differences as a function of age. We aimed to disentangle whether cognitive aging affects interference detection or interference resolution mechanisms, especially in the context of selective memory retrieval. Our results support the age-related inhibitory deficit largely described in the literature, and suggest that it might be due to a missing interference signal, with the elderly not detecting interference and thus not recruiting the inhibitory mechanisms necessary to overcome it.

In contrast, we also observed that older adults do benefit equally from repeated retrieval, given that there were no performance differences between young and older participants regarding performance during the retrieval practice and the practice effect was similar in both groups.

Our next goal was to explore whether the previously observed episodic memory effects (forgetting and practice) could be enhanced by an executive control intervention during healthy aging.

Experiment 2B: Training Executive Control in Healthy Aging and Transfer to Episodic Memory*

The retrieval practice paradigm provides two different behavioral indexes of selective memory retrieval; namely, one that concerns the repeatedly retrieved items (practice index), and other that concerns those items which were not practiced but are related to the practice ones (inhibition/forgetting index). In relation to the practice effect, at the neural level, the study of brain oscillations has shown a decrease in alpha/beta power (α/β: ~8-20 Hz) that is associated with efficient encoding and retrieval from long-term memory. As for the forgetting index, electrophysiological studies have revealed that the mechanisms recruited during selective retrieval can be traced by mid-frontal theta brain oscillations (~4-8 Hz). In the previous experiment we reported a specific older adults' impairment in detecting interference in the retrieval practice paradigm that was linked to an absent forgetting effect. At the neural level, such deficit corresponds to a significantly reduced mid-frontal theta power compared to young adults. Fortunately, because the brain remains plastic throughout the lifespan, age-related declines could be compensated through cognitive training. In the present work, we investigated the potential transfer effect of executive control training to the practice and forgetting effects, as measured through the retrieval practice task, relative to an active control condition that only involved processing speed. After the training, both groups performed the retrieval practice paradigm while their electrophysiological brain activity was recorded. At the behavioral level we observed a enhanced practice effect only in the experimental group, although none of the groups showed forgetting. At the neural level, time-frequency analyses over theta and alpha/beta bands suggest that executive control training could benefit older adults' retrieval by virtue of a potentiated practice effect, supporting training-induced cognitive plasticity during healthy aging.

---

* The sample of this experiment is the same as for experiment 2A: "Training Executive Control during Healthy Aging".

Throughout the lifespan, episodic memory functioning continuously undergoes extensive change with rapid increases during childhood, decreases in adulthood and progressive decline in very old age (Burke & Light, 1981; Horn, Donaldson, & Engstrom, 1981; Noack et al., 2013; Shing et al., 2010; Wagner, Shannon, Kahn, & Buckner, 2005). Given the important role that episodic memory plays in our daily lives, the idea of enhancing this cognitive function by means of cognitive training has become a stimulating research goal. Especially in the case of older adults, many training interventions have focused on improving episodic memory ability (Gross et al., 2012), given that subjective changes in one's memory functioning are a frequent concern to older adults that can seriously affect their well-being.

Training interventions designed to enhance memory have grown over the past decades and they differ in terms of the type of training program as well as in the target memory process to be enhanced (Lustig et al., 2009; Verhaeghen, Marcoen, & Goossens, 1992). Episodic memory can be trained by instructing people to use specific strategies, such as the method of loci or organization (categorization, chunking, associations, imaginery), optimizing basic processes like rehearsal or concentration, or even strategies making the best use of external memory cues (see Gross et al., 2012 for a review). All these previous interventions share a common feature: they train episodic memory via strategy instruction. Indeed, studies have shown that older adults benefit from strategy training, although to a lesser extent than younger adults and children (Brehmer, Li, Müller, von Oertzen, & Lindenberger, 2007; Kliegl, Smith, & Baltes, 1990; Kliegl, Smith, Heckhausen, & Baltes, 1987; Singer, Lindenberger, & Baltes, 2003). Thus, consistent findings indicate that cognitively healthy older adults are able to acquire and make use of memory strategies, even up to their 80s (Brehmer et al., 2012; Gross et al., 2012)Moreover, when directly compared to young adults after memory strategy training, older adults can indeed improve their memory performance even achieving performance levels that are similar to those exhibited by young adults before training (Brehmer, Shing, Heekeren, Lindenberger, & Bäckman, 2016)

Furthermore, there have also been attempts to enhance memory without strategy instruction. By training recollection processes, for example, Jennings and Jacoby (2003) provided participants with trials of a continuous recognition task in which they had to recollect from memory items to be repeatedly identified. After each trial, the number of intervening items between repetitions increased gradually. This adaptive approach in which difficulty was incremented gradually showed to enhance the ability to recollect information across increasing delayed intervals and to even transfer to working memory tasks (Jennings & Jacoby, 2003). Of special relevance here, transfer effects to untrained tasks have not been commonly observed after memory training (Gross et al., 2012; Rebok et al., 2007; Verhaeghen et al., 1992). A possible reason for the lack of positive transfer might be the specificity of the strategies in which participants were instructed and the limited applicability of these strategies to most other ability-related situations (Brehmer et al., 2012).

Parallel with the improvements in episodic memory observed behaviorally, studies have also found changes in brain activation after memory training. After a training intervention using the method of loci, some studies have revealed more efficient encoding after the intervention supported by increased activity in frontal areas and fusiform gyrus (Kondo et al., 2005) and also in media partial cortex and right posterior hippocampus (Maguire, Valentine, Wilding, & Kapur, 2002). Particularly in the context of aging, Nyberg et al. (2003) demonstrated that while young adults showed increased activity during memory encoding in occipital-parietal and frontal regions, only the older adults who benefited from the memory strategy training exhibited increased occipital-parietal activity, but not changes in frontal activity (Nyberg et al., 2003). Kirchhoff et al., (2012) also trained older adults to use semantic encoding strategies and investigated the effects of training on brain activity during an intentional encoding task. After training, older adults showed more efficient semantic encoding strategies, their performance on a recognition task significantly increased, and training gains in recognition memory were positively correlated with activity increases in prefrontal and left lateral temporal regions (Kirchhoff, Anderson, Smith, Barch, & Jacoby, 2012) Moreover, a recent study also revealed similar training-induced neural activation changes as well as enhanced performance in young and older adults after training (Brehmer et al., 2016). Altogether, these results show that older adults are actually capable of implementing and benefiting from memory training and that related cortical activation increases are functionally relevant in promoting enhanced memory performance.

In the current study, we explored the potential benefits of executive control training over the memory processes that come into play during the retrieval practice paradigm. As described in the previous experiment, this paradigm provides information about the cognitive processes engaged during encoding and selective retrieval, including practice and forgetting effects. During the retrieval practice phase, participants have to repeatedly retrieve half of the exemplars (i.e., practiced items: *fruit* – *apple*) from half of a list of previously studied list of semantic categories (i.e., unpracticed items: *fruit* – *orange;* control items: *animal* – *elephant).* Consistent evidence suggests that the repeated retrieval of some items leads to two different memory effects. On the one hand, the effects of *practice* as shown by the recall benefit of repeatedly retrieving some items (*apple*), as compared to controls (*elephant*), which indicates that retrieval practice is a powerful encoding strategy to enhance memory accessibility. On the other hand, *forgetting* of related but competing items (*orange*), relative to control items (*elephant*), which is thought to be an aftereffect of their inhibition (to overcome interference) by an executive mechanism (Anderson, 2003; Ortega et al., 2012; Román et al., 2009).

Here, our focus was placed in exploring the effects of executive-control training on practice and forgetting effects after repeated retrieval at the behavioral and neural levels. Recent studies on episodic memory encoding and retrieval have analyzed brain oscillations to signal successful encoding and difficulty of retrieval. Brain oscillations are important for long-term memory because they induce synchronized firing between neural assembles that shape synaptic plasticity (for reviews, Axmacher, Mormann, Fernández, Elger, & Fell, 2006; Düzel, Penny, & Burgess, 2010; Nyhus & Curran, 2010). A recent hypothesis derived from the information theory gives a mechanistic explanation of how neural desynchronization facilitates memory encoding and retrieval (Hanslmayr et al., 2012). This desynchronization hypothesis proposes that low-frequency (below 20 Hz) power decreases reflect the active engagement of cortical modules during encoding and retrieval of memories (Hanslmayr et al, 2016). In particular, oscillatory power in low frequency bands decrease specially during the encoding of items that are later remembered as compared with not remembered ones (Burke et al., 2014; Hanslmayr et al., 2011; Noh, Herzmann, Curran, & De Sa, 2014). In particular, during encoding of verbal material decreases in alpha/beta power (~8-20 Hz) are evident in the left inferior prefrontal cortex (Hanslmayr et al., 2011; Long, Burke, & Kahana, 2014). Moreover, decreases in alpha/beta power have been reported during encoding and memory retrieval (Hanslmayr et al., 2016). Alpha/beta power decreases have also been proposed to indicate memory reactivation (Burgess & Gruzelier, 2000; Khader & Rösler, 2011). Hence in our experiment we will analyze brain oscillations to capture possible changes in encoding and retrieval as a consequence of training.

To do so, we evaluated the potential benefits of executive-control training in healthy older adults by the comparison to an active control condition that underwent processing speed training. In order to analyze transfer effects to such an untrained domain, episodic memory measures were introduced before and after training. Before training, participants completed a word recall task to obtain a pre-test baseline measure of episodic retrieval. After training, participants were asked to perform the retrieval practice paradigm to provide post-test measures of episodic retrieval (recall of non-practiced control items), the effect of repeated retrieval (recall of practiced items) and interference control (recall of competing items at retrieval practice). Only at post-test and during the retrieval practice phase, electrophysiological activity was recorded and brain oscillations were analyzed at different frequency ranges: differences in theta oscillations were considered a measure of interference detection, whereas differences in alpha/beta bands provided the neural marker of encoding and retrieval from episodic memory.

Methods

Participants

The groups of participants were those from Experiment 2A. In particular, 40 healthy older adults divided in two different training conditions: executive control training and speed training – without executive control demands and only engaging processing speed – as an active control condition. At pre-test, groups did not differ in age, years of education, vocabulary, working memory or cognitive functioning assessed by the MMSE (see Table 5.1 for descriptive data of the groups).

Procedure

The methodological description of the training intervention is detailed in Experiment 2A (pages 115-121). Episodic Memory measures were introduced before and after training. Before training, participants were administered a word recall task to obtain a pre-test baseline measure of episodic retrieval. After training, participants were asked to perform a retrieval practice test to provide post-test measures of basic episodic retrieval (recall of non-practiced items), of the effect of repeated encoding (recall of practiced items) and interference control (recall of competing items at retrieval practice). Similar to Experiment 3, EEG recording during retrieval practice phase was also obtained. The retrieval practice task was only administered at post-test in order to prevent the participants from undertaking a particular memory strategy after knowing that the task would end up with a surprise memory test. Despite this, the between-group comparison could provide reliable markers of the impact of training intervention in encoding and retrieval. Similarly, the comparison concerning the pretest recall task with the control items in the retrieval practice task could provide and overall index of transfer of training to memory retrieval.

Transfer Tasks

Word recall

As a baseline measure of episodic memory, we used a task in which participants had to remember a list of random 64 words. On a first study phase after a fixation point (+) of 1000 ms and each of the words was presented on a white screen in black font (Courier New 18 points) during 4000 ms (p.e.: "teacher") and participants were told to rate their familiarity from 1 (very unfamiliar) to 5 (very familiar). After the study phase, the direct and inverse digit span scale of the WAIS-III was administered as a distractor task. On a final cued-recall memory test, the two first letters of the words were presented (p.e.: "te-") for 1000 ms and participants had to say the word out loud as soon as they remembered. The percentage of correctly recalled words was the dependent variable for the episodic memory task at the pre-test.

Retrieval Practice

The materials and procedure of this task were exactly the same as the one used in Experiment 3.

EEG Data acquisition and analysis

A continuous electroencephalogram (EEG) was recorded from 40 scalp electrodes mounted on an elastic cap (Quick-Cap, Neuroscan Inc.) on the standard 10-20 system at the pre and post-test for the AX-CPT task, and only at post-test during the Retrieval Practice task.

The electrodes were referenced to the linked mastoids (A1 and A2) and the grounding electrode was mounted on the forehead (GND). Four additional electrodes were used to control for blink and horizontal movement ocular artifacts: two set above and below the left eye (controlling for vertical movement, VEOG) and another two set at the outer side of each eye, to control for horizontal movement (HEOG). The electrical signal was amplified with Neuroscan Nuamps, using a band pass of 0.01-100 Hz and digitized at a 500 Hz sampling rate, keeping electrode impedances were kept below 10 kΩ. Digital tags were obtained for the stimuli of interest in each of the tasks.

Event-related potentials from the AX-CPT task were analyzed using the open-source toolbox ERPLab (Lopez-Calderón & Luck, 2014), whereas brain oscillations for the Retrieval Practice task were analyzed with the toolbox Fieldtrip, following an identical procedure as in Experiment 2. In both measures, ocular artifacts were identified by means of independent component analysis (ICA) and rejected by a careful visual inspection of the recordings.

RESULTS

Behavioral results

Table 6.2 summarizes the descriptive data of the performance on the retrieval practice task. As we mentioned, since the retrieval practice task was only administered at post-test, we also included at pre-test a word recall task (without retrieval practice) to obtain an episodic memory index that worked as baseline. We conducted one-way ANOVAs for all the behavioral measures included in the table. Regarding the recall level at pre-test, and as observed in the table, the two groups of older adults were comparable in their baseline memory recall (F (1, 38) = 0.14; p = 0.70; $n^2_p = 0.00$).

Importantly, however, we did observe a benefit for the executive control training group in their recall during the retrieval practice phase. Specifically, they were more efficient in retrieving the correct exemplars during the first practice cycle than participants from the control group (F (1, 38) = 5.35; p = 0.03; n^2_p = 0.12; see Table 6.2). Nevertheless, when conducting a mixed ANOVA introducing the pre-test memory recall and the recall in the first practice cycle (session) as within-subjects factor and training group as the between-group factor, the analysis did not yield significant main effects of session (F (1, 38) = 1.28; p = 0.26; $n^2_p = 0.03$), group (F (1, 38) = 0.30; p = 0.58; n^2_p = 0.01). nor interaction between the factors (F (1, 38) = 1.81; p = 0.18; $n^2_p = 0.04$).

Forgetting

As was the case in Experiment 3, none of the two groups of trained older adults showed a reliable forgetting effect (see Table 6.2). The ANOVA with item type (unpracticed and control) as the within-subject factor and training group as the between-groups factor failed to yield significant effects of either item type (F (1, 38) = 0.14; p = 0.70; n^2_p = 0.00), training group (F (1, 38) = 0.95; p = 0.33; n^2_p = 0.02), or the interaction (F (1, 38) = 0.29; p = 0.59; n^2_p = 0.01). Moreover, and as it can be observed in the table, executive control training did not have any impact over the retrieval of either unpracticed or control items, since both groups were comparable in their recall.

Practice effect

Executive control training seemed, however, to optimize the processes older adults' engaged during practice. Compared to older adults who trained only with speeded tasks, participants who trained with tasks demanding executive control showed an enhanced practice effect (see Table 6.2). The comparison between practiced and control items as a function of training group revealed a main effect of item type (F (1, 38) = 41.53; p < 0.01; n^2_p = 0.52), the group effect was not reliable (F (1, 38) = 0.51; p = 0.47; n^2_p = 0.01, but item × group interaction was significant (F (1, 38) = 4.98; p = 0.03; n^2_p = 0.11), While the comparison between practiced and control items was significant for both executive control training (F (1, 38) = 32.71; p < 0.01; n^2_p = 0.63) and speed training active control group (F (1, 38) = 10.44; p < 0.01; n^2_p = 0.35), it must be noted that the effect size for the executive control training condition was significantly larger. As can be observed in the table, the training groups did not differ in their recall of control items, but the executive control training outperformed the speed training condition in the recall of practiced items.

Table 6.2. Descriptive behavioral data of the retrieval practice paradigm. Mean and standard deviations for the outcome measures in the retrieval practice task. Significance *p* values and effect sizes (Cohen's d) estimates are reported for one-way ANOVAs as a function of training group. The forgetting effect is calculated by the difference between control and unpracticed items, whereas the practice effect is the result of the substraction between practiced and control items.

	Executive Control Training		Speed Training Active Control		Group effect	
Variables	*M*	*SD*	*M*	*SD*	*p*	Cohen's *d*
Working Memory (Digits WAIS-III)	14.95	3.49	15.20	3.36	0.82	-0.07
Recall at pre-test	0.44	0.29	0.48	0.34	0.70	-0.12
Retrieval Practice (overall recall)	0.60	0.16	0.52	0.12	0.08	0.57
Practice cycle 1	0.58	0.15	0.48	0.12	**0.03***	0.73
Practice cycle 2	0.62	0.15	0.54	0.12	0.08	0.57
Practice cycle 3	0.64	0.16	0.58	0.13	0.21	0.41
Final memory test (overall recall)	0.58	0.10	0.55	0.09	0.29	0.33
Control	0.70	0.19	0.64	0.23	0.41	0.26
Unpracticed	0.69	0.11	0.68	0.10	0.67	0.24
Forgetting	0.01	0.23	-0.03	0.26	0.59	0.17
Control	0.33	0.17	0.37	0.18	0.43	-0.25
Practiced	0.61	0.17	0.51	0.13	**0.04***	0.66
Practice	0.28	0.22	0.14	0.19	**0.03***	0.70

Power Analyses

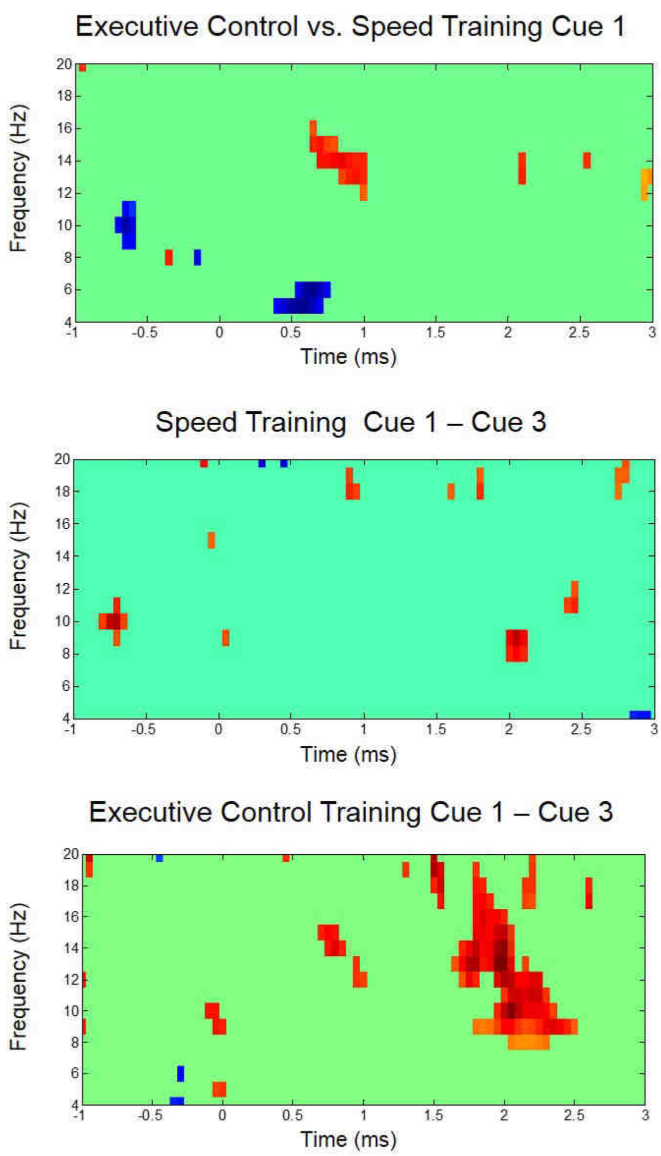
Consistent with Experiment 3, we explored the neural correlates during the retrieval practice paradigm by looking at brain oscillations based on an a priori defined mid-frontal ROI (FCZ, FP1, FZ, FP2, F3, F4, FC3, CZ, FC4). In particular, we looked at differences at the presentation of the first category cue as well as the difference between the first and the third practice cycle in two different frequency bands: i) theta (6-8 Hz) as a measure of interference detection (Ferreira et al., 2014; Cohen et al., 2014; Staudigl et al., 2010); ii) alpha/beta (8-20 Hz) as a measure of encoding and retrieval (Hanslmayr et al., 2012; 2016). Figure 6.5 represents the difference in power spectrum at the first retrieval practice cycle between both training groups (panel A), the comparison between the first and the third practice cycle for the executive control training (panel B) and for the speed training active control group (panel C).

Theta band

As detailed in Experiment 3, activity in theta band upon the presentation of the category cue has been proposed as a neural marker on interference detection (first cycle) and a measure of inhibitory control (difference between first and third cycle). As observed in Figure 6.5, there were no significant differences in the presentation of the first category cue between the two training groups (Figure 6.5A). However, when looking at the 1st - 3rd cycles comparison in theta band activation we observed an effect around 6-8 Hz over the presentation of the category cue for the executive control training group (Figure 6.5B), which was not evident for the speed training group (Figure 6.5C). Figure 6.6 represents the topographical distribution of the effects as well as the linear representation of frequency values across the practice cycles. The numerical values of theta power were obtained for the time window between 0 and 500 ms after the presentation of the category cue within a frequency band ranging 6-8 Hz. We conducted a mixed ANOVA with theta power as the dependent variable and two factors: practice cycle (first vs. third; within-subjects) and training group (executive control vs. speed training; between groups). Despite the observed tendency (see Figure 6.6A) for the executive control training group to show greater theta power over the first practice cycle relative to the second and third cycles, the effects of practice cycle (F (1,36) = 0.40; p =

0.52; $\eta^2_p = 0.01$), training group (F (1,36) = 0.46; $p = 0.50$; $\eta^2_p = 0.01$), and the interaction (F (1,36) = 0.58; $p = 0.45$; $\eta^2_p = 0.01$) were not significant. Panels B2 and B3 (Figure 5.9) represent the topographical distribution of the difference between cycles for the executive control group (B2) and the speed training group (Figure 6.6B3). These graphs show a tendency for the executive control group to reduce theta from cycle 1 to 3 that it is not present in the speed training group. As mentioned, however, this tendency was not reliable.

Figure 6.5. Power spectrum differences between executive control and speed training. A) Differences upon the presentation of the first category cue; B) between the first and the third practice cycle for the executive control training group; and C) between the first and third practice cycle for the speed training active control. *X* axis represent the time in ms where 0 belongs to the category cue, and *y* axis represent the frequency in Hz.



Alpha/Beta band

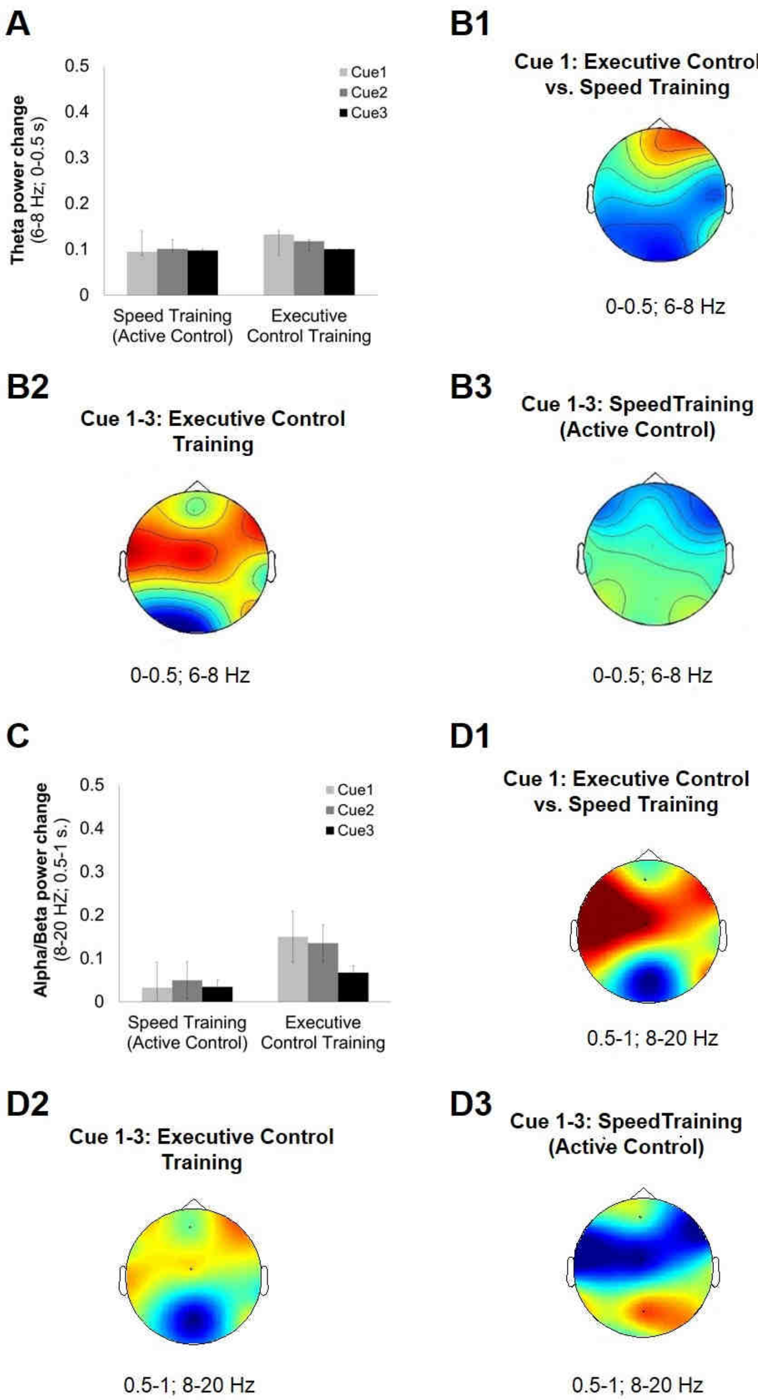
Activity in alpha and beta bands has been related to a wide variety of cognitive functions such as memory processes. In particular, decreases in alpha/beta power have been proposed to support efficient encoding and retrieval from long-term memory (Hanslmayr 2012, 2016). Figure 6.5A depicts a difference in activation between the training groups in 12 -16 Hz around 500 and 1000 ms after the presentation of the first category cue. When extracting the alpha/beta values (ranging from 12 to 16 Hz) between 500 ms and 1000 ms after the category cue, the one-way ANOVA revealed a main effect of group by which the group trained in executive control showed a larger alpha/beta power in the first practice cycle compared to the speed training condition (F (1, 36) = 4.90; p = 0.03; η^2_p = 0.12).

Panels 6.5B and C represent the difference in frequency activation between the first and the third practice cycle for each training condition. As can be observed in figure 6.5B, older adults trained in executive control show a difference in alpha/beta band between 500 and 1000 ms after the cue, followed by a great activation in alpha/beta bands between 1500 and 2500 ms, while such pattern is absent for the speed training control group (Figure 6.5C). A mixed ANOVA on alpha/beta power (12-16 Hz) between 500 and 1000 after the presentation of the category cue was conducted, introducing practice cycle (first vs. third) as the within subjects-factor and training condition as the between groups factors. Results revealed neither significant main effects [practice cycle: (F (1, 36) = 1.01; p = 0.32; η^2_p = 0.02); training group (F (1, 36) = 1.94; .p = 0.17; η^2_p = 0.05)] nor a reliable interaction between the factors (F (1, 36) = 1.09; p = 0.30; η^2_p = 0.03). Since at the behavioral level we found a reliable practice effect after executive control training, we divided the interaction by looking at the alpha/beta bands between the first and the third cycle individually for each training group. However, although the practice cycle effect was clearly inexistent for the control group (F (1, 18) = 0.00; p = 0.97; η^2_p = 0.00), the comparison did not reach significance in the executive control group (F (1, 18) = 2.30; p = 0.14; η^2_p = 0.11). D panels represent the topographical distribution of the differences in alpha/beta activation between practice cycles.

Finally, and because it is remarkably evident in Figure 6.5B, we compared the difference of activation between the first and the third practice cycles on a delay time window between 1500 and

2500 ms in alpha/beta (12-16 Hz), only for the executive control group. Results revealed a statistical significant decrease in alpha/beta power from the first (M = 0.87, SD = 0.18) to the third (M = 0.69, SD = 0.14) practice cycle (F (1, 18) = 9.26; $p < 0.01$; $\eta^2_p = 0.34$). This result is consistent with the fact that such a delayed window is very previous to the moment in which participants had to retrieve the target exemplar and with the behavioral results, which suggests enhanced retrieval for the older adults who were trained in executive control.

Figure 6.6. Neural activation during the retrieval practice paradigm in theta and alpha/beta frequency bands. A) Extracted theta values (6-8 Hz) from the time window of interest (0 – 0.5 s) across the practice cycles (first to third) and as a function of training condition. B) Between group comparisons of theta values (6-8 Hz) from 0-500 ms between executive and control training in the first practice cycle (B1), between first and third cycle for the executive control training group (B2) and between first and third cycle for the speed training (active control) group (B3). C) Same as A) but for alpha/beta frequency bands (8-20 Hz) from 500-1000 ms after the presentation of the category cue. D1) same as B1); D2) same as B2; D3) same as B3) but for alpha /beta frequency bands (8-20 Hz) from 0.5 – 1s.



Discussion

In this chapter we explored whether executive-control training may transfer to an untrained domain such as episodic retrieval in a healthy sample of older adults. It is well-known that aging brings a progressive decline in variety of processes related to episodic memory (encoding, and retrieval of information (Reuter-Lorenz & Lustig, 2005; Zacks, Hasher, Lynn, & Karen, 2000). Extensive behavioral and neurophychological research have highlighted the relevant role that executive control plays in episodic memory (Dobbins, Foley, Schacter, & Wagner, 2002; Shimamura & Squire, 1991). Thus, our hypothesis relied on the fact that an adaptive training protocol that directly challenged executive control networks could lead to benefits that extended to untrained but related abilities, including episodic memory. We approached such a goal by making use of the retrieval practice paradigm (Anderson, Bjork & Bjork, 1994), which is a suitable tool to look at two different processes: namely, forgetting and practice effects. In addition to the behavioral analysis of selective retrieval, we recorded and analyzed the electrophysiological differences in theta and alpha/beta frequency bands as neural markers of interference in episodic memory.

As for forgetting, none of the groups of older adults showed a reliable effect with no differences between both training conditions. This suggests that executive-control training did not modulate the mechanisms underlying the forgetting effect. As also discussed in Experiment 3, the lack of forgetting in older adults might be driven by the inhibitory deficits usually observed in the elderly (Gazzaley et al., 2005, Lustig, Hasher & Zacks, 2007). On the contrary, we observed an enhancement in episodic memory revealed by an increased practice effect after the executive control training intervention. Along these lines, many studies have demonstrated that older adults can profit from strategy memory instruction (Wenger & Shing, 2016). And also, previous findings have already reported in older adults benefits in memory performance after cognitive training. In particular, Dahlin et al. (2008) trained participants for 11.25 h on updating tasks and found episodic memory enhancement exclusively in young old adults, whereas Buschkuehl et al. (2008) trained participants for 17.25 h on similar updating tasks and also observed an increase in episodic memory in old-old adults. Our training procedure included not only updating tasks but also highly demanding switching and inhibitory control tasks. A recent study revealed that combining training over executive control and memory was even more effective than only training memory strategies by themselves (Li et al., 2016). Thus, it seems that training executive control made older adults capable of enhancing the memory strategies they practiced during selective retrieval, which in turn improved their recall after completing the intervention.

At the neural level, our results are consistent with previous findings indicating that prefrontal functioning is impaired with aging (Buckner, 2004). First, although previous studies have identified activity in theta band as a marker of effective interference detection (Cohen et al., 2014; Ferreira et al., 2014; Hanlsmayr et al., 2010), we did not observe a difference between both training conditions in older adults. Together with the absence of behavioral forgetting effect, these results seem to support the idea that interference detection and inhibitory control are compromised in older adults. Second, as the neural substrate of the enhanced practice effect, we observed a significant reduction in alpha/beta power across the practice cycles that was reliable only for the executive control group. In an attempt to clarify the nature of the prefrontal activation patterns in older adults, our findings are consistent with the synchronization/desynchronization hypothesis, since a progressive reduction in alpha/beta power has been related to more efficient encoding and retrieval of information from long-term memory (Hanslmayr et al., 2012; 2016). Given that only those participants who were trained in executive control showed an enhanced practice effect, it seems that training made older adults able to benefit from what they practiced.

Previous work on functional brain activity has suggested that most of the enhanced task-related activity found in older adults reflects compensatory activation in response to reduced efficiency (Cabeza et al., 2002; Mattay et al., 2006; Park et al., 2004). In this sense, although executive control training did not benefit interference detection nor inhibitory control as revealed by theta activity, the increased activation of alpha/beta frequencies might be the compensation of aging-related reduced activation in theta band.

In sum, our results go a step further and demonstrate that also process-based executive control training can enhance episodic memory. Despite the deficits observed in interference detection and inhibition, performance gains in the practice effect suggest that training reflects cognitive flexibility in memory, revealed by the adaptive potentiation of the existing cognitive and functional memory strategies. Moreover, this effect seems to be neurally supported by mid-frontal cortical regions.

General discussion

The results of the current series of studies contribute to the growing literature on healthy aging by both replicating and extending previous findings. Research has shown that the persistent view of an adult brain incapable of change is too pessimistic: many brain mechanisms seem to remain flexible throughout the lifespan and can adjust to new experiences and challenges, even during old age (Lövdén et al., 2013). In particular, our results support the conclusion that episodic memory can be enhanced by training. Moreover, the results of the current chapter add to the literature on the role of brain activation changes in older adults and their relationship to cognitive decline during aging.

In two consecutive experiments using the retrieval practice paradigm, we first explored the differences between young and older adults in selective episodic retrieval. To later attempt to enhance such memory processes in older adults by means of executive control training. Experiment 3 served us as a first characterization of age-related differences in memory processes and we actually observed a dissociation between the two behavioral effects that provides the retrieval practice paradigm.

First, in relation to the retrieval induced forgetting effect, we observed that while young adults exhibited a reliable effect indicated by the progressive decrease in theta power for successive retrieval cycles, neither the behavioral nor the neural effects appeared in the group of healthy older adults. This absence of forgetting was confirmed in Experiment 2A, in which none of the groups of older adults showed reliable forgetting, not even after having completed an executive control training intervention. To explore the neural basis of the transfer of executive control training to selective retrieval, we compared the brain oscillatory activity in theta band between the executive control training and the speed training conditions across the practice cycles. Although in the first practice cycle the older adults trained on executive control showed a tendency towards an increased theta power, the comparison between the groups of older adults did not reach statistical significance. Taken together, these results point to an impairment in interference detection and suggest that, despite the fact that older adults improved their performance during executive control training, this benefit did not transfer to the executive control-dependent inhibitory processes underlying the forgetting effect.

Second, the retrieval practice paradigm also provides an index of the benefit of repeatedly retrieving information from long-term memory. While in Experiment 3 we observed reliable but similar practice effects for young and older adults, in Experiment 2A we observed a significant difference between the two groups of older adults. Indeed, training executive control made older adults able to enhance the memory processes through repeated practice, so that they showed stronger improvement of their recall performance in the final memory test. In relation to the neural basis of such an effect, though we did not observe a difference in alpha/beta power between young and older adults in Experiment 3, the comparison between speed training and executive control trained older adults confirmed the enhanced effect of repeated practice in episodic memory recall after the executive training.

Taken together, our results seem to suggest that executive control training benefits those memory processes that are repeatedly called into play when retrieving information from long-term memory. However, this particular intervention was not able to significantly compensate the previously reported impairments in interference detection of older adults – revealed by a lack of forgetting effect. Given that our transfer hypothesis is based on the shared cognitive and neural substrates of the trained (executive control) and untrained (episodic memory control) processes, a possible explanation of the lack of transfer to the forgetting effect could be that the amount of the improvement achieved by older adults was not enough to promote transfer.

Busckuehl et al., (2012) reviewed studies exploring the neural basis of executive control training and concluded that "there is currently no clear pattern of results that would single out a specific neural mechanism underlying training and transfer that would fit within one single framework" and that "the results suggest a dynamic pattern of functional and structural plasticity underlying experience and learning". This heterogeneity of neural patterns of transfer is even more evident in the case of older adults. However, von Bastian and Oberauer (2013) proposed a model that tries to explain the diversity of findings observed in relation to the neural basis of training and transfer effects. According to the authors, transfer induced after the training might be mediated by two general mechanisms: enhanced capacity or enhanced efficiency of the system. On the one hand, enhanced capacity could be the result of the persistent cognitive demands of the training that lead to an extension of the current capacity limits, for example by making it possible that more items may be held in working memory. On the other hand, enhanced efficiency would improve the functioning of cognitive mechanisms and operations, and result in a boosted performance. Thus, our results seem to point to the enhanced efficiency of the retrieval processes, given that after the training older adults benefited from what they actually practiced.

In any case, our results support the hypothesis that plasticity is present during aging, and that not only behavior but also brain activity can be modified by experience. Different hypotheses have been proposed on the potential ways of enhancing cognitive capacities in old age. One of the them is the famous "use it or lose it" hypothesis proposed by Marian C. Diamond (2013), according to which exercising one's cognitive functions by performing cognitively demanding activities stimulate the mind and preserves cognitive functioning. Based on the morphological study of human brains, Diamonds identified five essential factors for a healthy aging brain; namely, diet, exercise, challenge, newness and love (Diamond, 2013). This hypothesis has been extended to a more general approach that considers even broader classes of behavioral interventions that could enhance cognitive functioning in older adults. Thus, Hertzog, Kramer, Wilson and Lindenberger (2009) stated the cognitive enrichment hypothesis by which behaviors of an individual – including cognitive activity, social engagement, exercise and other behaviors – have a meaningful impact on the level of effective cognitive functioning in old age. In summary, many questions in relation to training and transfer effects in older adults remain unanswered, and therefore, more research is necessary to disentangle the impact of different cognitive interventions in episodic memory in older adults. In particular, further efforts should be made to explore the factors that could promote the greater benefit of training during aging.

CHAPTER VII

Executive Control Training and Transfer to Reading Comprehension

Experiment 4*

Reading comprehension represents a complex cognitive task that is crucial to success in formal education and in everyday life activities. In fact, working memory and associated executive processes have been shown to be strongly involved in reading comprehension. Given that working memory training may transfer to trained and non-trained but related domains, the aim of the present study was to assess the efficacy of a program for improving reading comprehension skills. The program comprised cognitive training activities that required working memory and related executive processes. We conducted a school-based intervention in which children trained with two different adaptive procedures: one involving working memory and executive control and the other engaging perceptual activities directed to only train processing speed without the involvement of executive demands. As potential moderators of training and transfer effects, we considered individual differences in relation to baseline performance as well as motivation and engagement during the training procedure. To analyze transfer effects, we focused on the potential benefits of working memory and executive control training on different processing levels of reading comprehension. Therefore, we included a general ability score that involved performance of the lexical, phonological, semantic and syntactical abilities as transfer measures. Furthermore, we were especially interested in exploring whether training could transfer to high order reading processing such as the capacity to generate inferences and update the cognitive representation of the situation model that is generated during text comprehension. Because these high order processes are highly dependent on working memory and executive control, we expected children trained in working memory to become more efficient in high order reading comprehension processes.

---

* The content of this chapter is part of a publication co-authored by Maraver, M.J., Jones, M.R., Gómez-Ariza, C.J., Buschkuehl, M., Bajo, M.T., and Jaeggi, S.M., which is now in preparation.

In previous chapters, we have evidenced that executive control functions can be enhanced by means of training working memory or inhibitory control. Our results have revealed that these training-related improvements can be observed not only in healthy young adults, but also in populations generally associated with executive control-related deficits, such as in healthy older adults. We have so far proposed that executive control training can transfer to cognitive domains similar to the trained processes such as working memory, inhibitory control and cognitive control mechanisms. But, moreover, we have also shown how executive training can transfer to untrained but related domains such as episodic memory in older adults. The next goal of this dissertation is to provide evidence for an additional condition in which executive control training could transfer to an untrained domain that is particularly relevant during childhood development, namely, reading comprehension.

Reading comprehension is a higher-level skill that requires the reader to engage in multiple cognitive processes, such as lexical-semantic access, phonological decoding and syntactic analysis, articulatory planning, and context processing, as well as the coordination of all these processes by higher-order functions, for an efficient language comprehension. From a cognitive perspective, performance on essential academic skills, such as reading comprehension relies on underlying cognitive and linguistic abilities and processes that develop during childhood (Alloway & Alloway, 2010; Alloway et al., 2005; Titz & Karbach, 2014). One essential cognitive function that develops during childhood is working memory, which is assumed to be a system for the temporarily storage and active manipulation of information (Baddeley, 2003; Kane & Engle, 2012) and multiple sources of evidence suggest that it is highly involved in both word reading and reading comprehension (Alloway et al., 2005; Bull & Scerif, 2001; Gathercole, 1999). Indeed, it has been repeatedly evidenced that working memory capacity is directly related to scholastic achievement skills (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Rapport, Scanlan, & Denney, 1999) such as mathematical processing or reading comprehension (Alloway et al., 2005; Bull & Scerif, 2001; Gathercole, 1999; Mayringer & Wimmer, 2000); and that executive control and working memory capacity are crucial for children's general ability to acquire knowledge and new skills (Alloway, Gathercole, Adams, & Willis, 2005; Gathercole, Lamont, & Packiam Alloway, 2006; Gathercole, Pickering, Knight, & Stegman, 2004).

Traditional research studies specifically dedicated to investigate the relationship between reading processes and working memory have normally used complex span tasks, in which readers are required to recall verbal information (i.e., digits or words) while completing an additional activity (i.e., comprehending sentences). In particular, Daneman and Carpenter (1980) showed that performance in the reading span task predicted comprehension capacity of students. Furthermore, Daneman and Merikle (1986) evidenced a high correlation between working memory span and language comprehension. Additionally, de Jonge and de Jong (1996) demonstrated that executive processing and simple storage were also related to reading comprehension in typically developing children (de Jonge & Jong, 1996). In this line, there is ample evidence that complex linguistic skills are highly dependent on executive control functions related to working memory such as inhibition, updating and monitoring, both in children and young adults (Arrington, Kulesz, Francis, Fletcher, & Barnes, 2014; Borella, Ghisletta, & Ribeaupierre, 2011). Contemporary neurobiological models of language processing have highlighted the importance of domain-general non-linguistic executive control functions (Cahana-Amitay & Albert, 2014) and proposed that linguistic and executive control abilities develop in close interdependence during childhood (for a review see Muller et al., 2009). Moreover, from a developmental perspective, research has shown that the emergence of cognitive flexibility (or set shifting) in the preschool years depends on the acquisition and flexible use of language skills (Deak, 2003; Jacques & Zelazo, 2005; Muller et al., 2009) and vice versa (Khanna & Boland, 2010; Woodard, Pozzan, & Trueswell, 2016).

Empirical support for the role of working memory on many processes involved in reading comprehension comes from studies of children and adults with poor text comprehension (Cain et al., 2004; Carretti et al., 2009; Chiappe et al., 2000; Gathercole et al., 2006; Nation et al., 1999). These studies have shown a relationship between poor performance at different comprehension levels and difficulties with working memory. Indeed, previous findings have suggested that most processing differences could be explained in terms of linguistic proficiency and capacity deficits in working memory (Horiba, 1996; Newman, Tremblay, Nichols, Neville, & Ullman, 2012). This has been interpreted as that less proficient readers need to allocate more cognitive resources to lower level processes (lexical processing), leaving less resources available for higher level processes (Horiba, 1996, 2015). Hence, available evidence have so far suggested that there is a large interrelationship between language, executive processing and working memory during development, and that this interrelation is critical for reading comprehension.

In sum, successful reading comprehension seems to require the efficient coordination and integration of different linguistic and non-linguistic executive-dependent abilities. From lower to higher level of processing, comprehension involves phonological and orthographic ability, morphological knowledge, as well as vocabulary and syntax comprehension, being all of them critical for both lexical reading skill and supra-lexical reading comprehension. And at higher levels of processing, efficient reading comprehension involves higher-order and supra-lexical reading processes such as updating or inference processes that rely greatly on working memory capacity and reasoning abilities (Bowers, Kirby, & Deacon, 2010; Cain et al., 2004; Cutting & Scarborough, 2006; Oakhill, Cain, & Bryant, 2003).

In this sense, text comprehension requires the construction of a mental representation or situation model that combines the information given in the text with the reader's prior knowledge, in order to accurately understand the text's meaning (van Dijk & Kintsch, 1983). Hence, information integration and updating are high-order comprehension abilities that enable the construction of a good mental representation (situation model) during text reading, and both abilities are highly dependent on efficient working memory and executive processes (van Dijk & Kintsch, 1983; Zwaan et al., 1995; Zwaan & Radvansky, 1998). Integration and updating have to be performed online during text comprehension since readers process words and sentences in real-time, and keep generating the text interpretation moment by moment as words and phrases are encountered (Altmann & Kamide, 1999; Tanenhaus & Hare, 2007). In this incremental process, working memory plays a central role in maintaining information, monitoring for inconsistencies, updating the situation model as new information comes along and supporting other processes such as inference making and revision (Cutting & Scarborough, 2006; Oakhill et al., 2003; R. A. Zwaan et al., 1995).

Given the importance of executive control and working memory for successful reading comprehension, even small increments in the efficiency of working memory and executive functioning might facilitate children's performance in the classroom and in their daily lives. Thus, training interventions based on executive control and working memory might be a promising and important complement for the development of language and other school related activities. Recent work on cognitive training has provided evidence of some degree of transfer from working memory training to reading abilities (Dahlin, 2010; Carretti et al., 2014; Karbach et al., 2014). However, the nature of the training interventions employed to assess the potential transfer to reading comprehension is quite heterogeneous (Loosli et al., 2012; Alloway et al., 2013; Carretti et al., 2017). A significant difference across studies has to do with whether the training procedure involved domain-general working memory and executive control activities or whether they engaged specific reading comprehension activities requiring executive demands. As part of the latter, Carretti et al. (2017) conducted a school-based training program focusing on working memory and executive control embedded in reading comprehension activities and compared it to an active (performing extra-school activities) and a passive control groups (attending regular classes). Their results showed that the training was effective in directly improving the children's reading comprehension and working memory, even with some degree of maintenance effects after 2 months (Carretti et al., 2017). Also, during regular classroom activities Carretti et al. (2014) presented tasks that focused on working memory but combined with other linguistic tasks directed toward the processes involved in the construction of a coherent mental representation of the text and the comprehension of its content. This combined training program was effective for improving reading comprehension performance of 9- to 11-year-old typically developing children as compared with an active control group, with this benefit in reading comprehension correlating with the improvement in working memory performance (Carretti et al., 2014).

Other studies, however, have employed typical working memory exercises in which children have to retain series of visuospatial or verbal stimuli in memory and repeat them after a brief delay, progressively increasing the difficulty of the task. Using this type of domain-general exercises for training, several studies have also demonstrated enhancements of working memory capacity and reading. Chein and Morrison (2010) trained students on a visual and a verbal complex span task for

4 weeks and observed transfer to a reading comprehension task. Alloway et al. (2013) reported higher scores on measures of verbal competence and spelling after 32 sessions of working memory training, which were still maintained 8 months after the intervention. Shorter adaptive interventions have also suggested the possible enhancement of reading competence after working memory training by transferring to reading single words and texts (Loosli et al., 2012) and standardized reading ability tests (Karbach et al., 2014). Also recently, Henry et al. (2014) tested the efficacy of a working memory training consisting of 18 short individual sessions in typically developing children, in terms of near transfer effects (to a series of working memory tasks) and far transfer effects (to word reading, spelling, reading comprehension, and mathematics). This training produced a general improvement in working memory tasks for the trained group relative to an active control group, but they did not show significantly greater gains over low-level reading processes (such as word reading or spelling). In contrast, in a measure of high-order reading comprehension the trained group exhibited an advantage over the control group that was maintained twelve months after finishing the intervention (Henry, Messer, & Nash, 2014).

Moreover, training gains in cognitive functions and reading comprehension have also been reported in child populations with working memory and executive control deficits. Dahlin (2010) observed positive transfer results on a reading comprehension measure in children with special needs after they had completed the computerized Cogmed working memory training program (Klingberg et al. 2005). The training used in Dahlin's (2010) work involved daily individual sessions for 5 weeks and included an active control group that attended other activities in small groups. However, this difference in the procedure with respect to the individual sessions of the trained group may have introduced some biases in the comparisons in favor of the training condition.

In the present study, we aimed to investigate the potential impact of working memory training over high-order reading comprehension, with a special focus on reading processing at the text level. We also aimed to assess the possible impact of this training on basic linguistic skills at the word and sentence level (phonological, lexical, semantic and syntactic) and cognitive skills such as inference making, updating and integration that usually occur at the text level of processing. For this, as we describe in the methods section, we used basic decoding, spelling and reading fluency tasks and a picture-sentence syntactic scale to assess linguistic skills. In addition, we used the inference-revision task developed by Pérez, Cain, Castellanos, and Bajo (2015) to assess the processes involved in high-order reading comprehension.

In the inference-revision task, participants are presented with short narrative texts (see Table 7.1 for an example). Each text contains an introduction of two sentences that facilitates an inference (i.e., '*baby*'). The experimental manipulation is implemented in the following sentence (sentence 3) wherein readers are presented with one of three conditions: a no update condition, which is consistent and maintains the previous inference primed in the introduction (i.e., '*The little family member always seemed to be hungry and cried often*'); an inference condition, which mismatches the inference primed in the introduction and facilitates the generation of a new inference (i.e., '*The little animal said "meow, meow" every time it was hungry*'); and an update condition, in which the new inference is literally presented and forces the updating of the previous inference (i.e., '*The little cat was always hungry and cried all the time*').

Table 7.1. Sample text of the children version of the situation model revision task.

The new addition *baby/cat*	
Mr. and Mrs. Jones were happy about their newborn. Mrs. Jones knew that she would have feed the new little family member every day.	Introduction (inference = *baby*)
The little family member always seemed to be hungry and cried often.	Sentence 3: No update
The little animal said "meow, meow" every time it was hungry.	Sentence 3: Inference
The little cat was always hungry and cried all the time.	Sentence 3: Update
Mrs. Jones sat on the chair, holding the small **cat** in her arms.	Sentence 4 with disambiguating word
Mrs. Jones would have feed the new little family member every __. a) Hours **b) Day** c) Minute	Reading comprehension question
Mrs. Jones had to feed the new _____. a) Dog b) Baby **c) Cat**	Updating in reading comprehension question

This procedure provides different measures that can be taken as indexing different processes. For example, overall reading times for the third sentence in the text can be taken as a measure of reading fluency. More importantly, two different indices can be calculated from these reading times. One, related to interference detection, can be calculated by looking at the difference between the reading times for the no-updated and the updated condition, assuming that greater reading times in the updated condition would be a marker of difficulties to update the previous inference. The second index refers to the difference between the no updated and inference conditions, and served us as a measure of the efficiency in generating a new inference. In addition, the final sentence (sentence 4) provides an index of updating ability since this sentence always presented a disambiguating word (i.e., '*cat*'), which can be either consistent or inconsistent with the inference primed in the update/non-updated conditions in the previous sentence ('*meow, meow*'). The difference between the inconsistent and consistent conditions of the final sentence signals the extent to which participants have updated the information. Finally, two multiple choice comprehension questions were presented to children, one referring to information presented in the introductory sentences – which was considered as a general measure of reading comprehension – and the other referring to the to-be-updated inference. These two questions were used to explore and assure children's accuracy and discard all those fast and careless responses to avoid contaminated effects.

Inference making and updating of the situation model may be supported by the interplay of different control modes. Inference generation requires the connection of information in the text and in long-term memory, which likely relies on working memory and maintenance of a strong task set (here, the situation model). Updating needs overriding the previous inference made and replace the content held in working memory by the alternative interpretation of the available information, which has been proposed to be highly dependent on executive control (see Pérez et al., 2015a, 2015b). We thus hypothesized that inference making and updating could be modulated by working memory training.

Our target population was children from 9 to 11 years old divided in two groups. The selected age is especially critical from a developmental perspective since it has been shown to be the starting point from which components of working memory begin to function and coordinate on an adult-like fashion (Gathercole & Pickering, 2004). Children were divided in two groups, one engaged in an adaptive working memory training procedure and the other trained with speed processing activities without executive control demands serving as an active control group. Training was conducted at their regular school setting and involved working with three different training activities across ten training sessions. As mentioned, we measured low-level reading abilities (lexical, phonological, semantic and syntactic processing) as well as high-order reading processes at the text level as transfer outcomes. To explore the potential transfer of training to reading comprehension at the text level, we considered three different indices of the situation model revision task (Pérez et al., 2015): 1) general efficiency in reading ability, calculated by the proportion of errors in the first comprehension that refers to the introduction and reading times of the two first introductory sentences; 2) inference making, by comparing reading times of the no update and inference conditions; and 3) updating, by comparing reading times between the update and no update condition of the third sentence.

In sum, the goal of the present study was to assess the potential effects of working memory training in reading comprehension with the aim of dissociating between high-level processes at the text level (inferring and updating) from more basic kills at the sentence or word level. We hypothesized that working memory training would improve the participants' working memory capacity and, by extension, the participants' reading ability, especially that involving text level processing. We further explored if some individual difference factors such as the participants' working memory and reading abilities at the baseline level, and engagement during the training procedure would modulate the potential benefits from training.

Method

Participants

A total of 68 4th and 5th grade students from three elementary schools in the Orange County Area (Southern California, United States) took part in the study. Data collection was conducted during school time and parents gave written consent for their children to participate in the study. Two of the schools were private and one was public. After pre-test, they were pseudorandomly assigned to either a working memory training (n = 33) or an active control condition (*n* = 35) after considering grade, gender, working memory (WM) and reading abilities as matching criteria. One child from the control group dropped out of the study before starting the training, and another child from the training group did it after the first training session. Once data collection was finished, data from 10 children (2 control and 8 training) were excluded from the analysis because they did not perform the transfer tasks either at pre or post-test and, therefore, we were missing the main outcome measures. The remaining dataset included 56 children aged between 9 and 11 (M = 9.76 years; SD = 0.86). Table 7.2 shows the descriptive data of the two training groups. No differences were found between the groups in age (t (52) = -0.33; p = 0.74), socioeconomic status (SES, based on the level of mother's education) (t (48) = -0.18; p = 0.85), pre-test scores in reading ability (t (52) = -0.13; p = 0.90), or working memory (t (54) = 0.86; p = 0.39).

Table 7.2. Demographics data as a function of training condition

	Working Memory Training	Active Control Training
N	24	32
Age $M(SD)$	9.69 (0.76)	9.77 (0.92)
Grade ($4^{th}/5^{th}$)	(13/11)	(15/17)
Gender (male/female)	(10/14)	(14/18)
SES (mother's education)	4.23 (1.80)	4.32 (1.84)
Reading ability $M(SD)$	0.44 (0.13)	0.45 (0.12)
Working Memory $M(SD)$	0.54 (0.12)	0.50 (0.13)

General procedure

Prior to the start of testing sessions, parents of all the fourth and fifth graders from the participating schools were provided with packets of information about the study. These packets included written consent forms and two surveys to collect data about demographic variables such as socioeconomic status (SES), home literacy and language practices. Parents gave written consent form in accordance with the Declaration of Helsinki (World Health Organisation, 2013). This study was approved and carried out in accordance with the recommendations of the Institutional Review Board of the University of California-Irvine.

Participants performed a total of 16 experimental sessions, all of them being conducted in their regular school setting. In 3 pre and 3 post-test sessions students were evaluated in WM and reading skills, which included the assessment of four different reading ability components: lexical; phonological; semantic and syntactic (detailed description of the tests are provided below).

After pre-test, children were assigned to a WM training (WMT) group or an active control group, with both being matched in grade, WM span, and reading abilities. In between testing sessions, participants were trained with three different adaptive activities (5 minutes per activity in each session) during 10 consecutive days, excluding weekends and holidays. The active control condition involved activities mainly relying on processing speed with no demands on executive control, whereas WMT required the engagement of updating, maintenance and interference resolution.

Materials

Demographic Questionnaire

Parents filled out a demographic questionnaire that included questions regarding SES and the child's language experience. Regarding SES, we considered the level of mother's education on a 6-points scale: 1 – Some High School Coursework; 2 – High School Diploma/GED; 3 – Some

College Coursework/Vocational Training; 4 – 2-year College Degree (Associates); 5 -4-year College Degree (BA/BS); 6 – Postgraduate or Professional degree (MA, PhD, MD, JD).

Training Procedures

The two training regimes included three different tasks organized in levels of increasing difficulty and adapted to individual performance. Children had to practice with each activity for five minutes in each session, and the order of the tasks was randomized across the ten training sessions. Two of the training tasks in each group belonged to the online training program of the University of Granada (PEC-UGR: http://pec-ugr.es/portal/; Maraver, Bajo, & Gomez-Ariza, 2016); and one was programmed and run in the psychology software Psychopy (Peirce, 2007). Children were trained individually on a laptop in their school classroom, and an experimenter was always available to solve the requirements or technical difficulties they might have.

Working Memory Training

Complex Span Task

This task was run offline and programmed in the software Psychopy (Pierce, 2007). It required participants to simultaneously perform two tasks (Loosli et al., 2012). The first task involved an encoding/processing phase in which a sequence of animal stimuli were presented on the center of a white screen for 2000 ms (except for in level 1, when stimuli were present for 5000 ms). Stimuli could be presented right side up or upside down and participants had to make a right or a left mouse click, respectively, to categorize the orientation of the stimuli. The number of presented animals started with 2 and was increased as a function of proficiency with the task. Three additional parameters were adjusted to define the difficulty of a level: the presence or absence of feedback (green frame for correct or red frame for incorrect), after level 8, the presence or absence of non-animal stimuli as distractors, and after level x, the presence of semantic and perceptual lures (i.e., a semantic lure for a tiger would be a lion as the two are similar in many meaningful aspects. A perceptual lure for a walking tiger would be a running tiger). For the second task, participants had to reproduce the sequence of animals (but not distractors) previously presented by recognizing them from a display of choices. At the end of each trial, participants received feedback on whether their recall was correct or not.

Working Memory Updating

This task was included in the online cognitive training software PEC-UGR and was adapted from the word updating task (Palladino & Cornoldi, 2001). It displayed a scenario with a group of numbered boxes. Items of different categories (food, objects, animals or clothing) were sequentially displayed. For each trial, items from only one category were relevant and introduced into the boxes (i.e., animals). Participants were asked to recall the largest (or smallest) element(s) by selecting the box or boxes in which they were introduced (i.e., Rule: recall the smallest animal; Items presented: apple - cat - trousers - bee (correct choice) - chair - elephant). Maintenance and updating in WM were involved in this activity. The series of elements to be retained must be updated every time a new image is displayed. The memory load was manipulated by increasing the number of elements to be recalled (from 1 to 7), the number of boxes (from 2 to 8), and the total number of stimuli including targets and distractors (from 1 to 24). Presentation and response times remained constant across levels: 500 ms of stimuli display; 800 ms of inter-stimuli display; 8000 ms of maximum time to respond. The program randomly changed the rule from big to small keeping an equal proportion of the trials within a level.

Working Memory Search

This was a matching-to-sample activity based on the shape and color of the items sequentially displayed: animals on one screen as the sample, and a group of animal buttons after a retention interval. Participants were presented with a matrix to be maintained in memory composed of animals with different shapes and colors displayed in an open field (i.e.: memory matrix, "brown bear – red eagle – purple snake"), that was displayed for 2500 ms. After a retention time of 1000 ms, participants performed a memory test in which they had to select as fast as possible the animal on the buttons that had the same shape and color of one of the previously retained animals (i.e. button choices, "orange bear – red eagle (correct choice) – yellow snake – blank button"). If none of the animals on the buttons had the same shape and color, they had to select the blank button (i.e.

button choices, "orange bear – green eagle– yellow snake – blank button (correct choice)"). This task involved maintenance and search in working memory, since it requires participants to briefly maintain a group of elements in memory then search in memory to select the matching target. The difficulty of the task relies on the memory load of the initial animal matrix (from 1 to 8) and response buttons (from 1 to 9), both of which increased throughout the levels. Presentation and response times remained constant throughout the levels.

Active Control Training

Speeded Categorization

In this speeded categorization task, ran offline and programmed in Psychopy software, participants were simultaneously presented with two clouds of dots each of which contained a random number of dots between 5 and 60. One cloud appeared on the left side of the computer screen and the other one of the right side. Participants' task was to indicate, as fast as they could, which of the two clouds contained more dots by pressing the "A" for the left or "L" key for the right cloud, respectively. In order to keep cognitive demands low, the dot clouds remained fully visible on the screen until children gave the response. Across the levels, the similarity between the numbers of dots between clouds, the size of the dots and the maximum times to respond were manipulated to create levels of increasing difficulty. As a result, this task only increased progressively the demands on processing speed. Feedback was provided on a trial-by-trial basis, with summary accuracy and reaction time scores presented by the end of each level. Each new training session began at the same level that the participant achieved at the end of the previous session.

Speeded Response

This activity was run in the online training program PEC-UGR and was adapted from a modified Go/No Go task, so that all trials were go trials. Participants were presented with a robot below a screw, and if the robot and the screw are the same shape (square, circle, or triangle), the participant had to press the space bar. Across the levels, the number of response items increases (from 3 to 60): the maximum response time decreased (from 2000 to 450 ms) and the inter-stimuli interval changed (500, 700, 1000 and 1500 ms).

Speeded Visual Search

For this speed of processing task, also run in the online program PEC-UGR, participants were presented with a plate of soup containing 4, 6, 8 or 10 elements (digits and letters). Children's task was to find one element contained in the soup out of 4 different possible options. The maximum response time was 20000 ms and the inter-trial interval was 1500 ms, remaining constant through levels. The number of elements to be found and the possible options remained constant so that the difficulty of the levels was determined by the speed of the responses over the levels.

Engagement Assessment

At the end of each training session children were asked to rate their motivation level after having completed the activities. We used an online Google form in which children were provided with a question asking "How happy are you today after playing the games?" and a smiley faces scales ranging from 1 (happiest face: very motivated) to 5 (angry face: very un-motivated). Participant's task was to select a face corresponding to their motivation level of the session. The direct scores of this scale were reversed for a positive relation with the rest of variables.

Once children had left the testing room, experimenters rated two more factors about children's behavior during the training session (supervision and attention). Supervision referred to the need of attention from the experimenters that children required during the training sessions. It included a scale ranging from 1 ("Not at all – helped only with computer set up") to 5 ("Completely – sat with child the entire time, closely monitoring responses and encouraging focus"). In order to make this variable comparable to other motivation scales, scores were reversed and considered as measure of "autonomy". On the other hand, the experimenters also rated the children's attention while performing the tasks on a five points scale beginning with 1 ("Not at all focused – completely unfocused, must be constantly monitored throughout the game") and ending in 5 ("Completely focused – plays games without distractions through all rounds").

Baseline Performance Assessment

Reading Abilities

Phonological ability

This was measured with a computerized version of the decoding task Auditory Word Attack, from the Woodcock-Johnson Test III (Mather & Schrank, 2001). A list of 30 non-words were auditory presented over headphones and children had to choose the correct spelling from two possible options. The percentage of correct responses was the dependent variable. Two parallel versions were counterbalanced across participants for pre and post testing.

Lexical ability

A computerized version of the WRAT-4 spelling test was used here (G. S. Wilkinson & Robertson, 2006). Children heard via headphones a list of 42 words of increasing difficulty (from one to five syllables) and had to spell them by typing on the keyboard. The stimuli sequence followed the auditory presentation of a word, a sentence including the word, and the word repeated again. After ten consecutive errors the task finished. The dependent variable was the percentage of correct responses. Two parallel lists were used for pre and post-test, which were counterbalanced across participants.

Semantic ability

To assess this component we used the reading fluency test from the Woodcock-Johnson III (N. Mather & Schrank, 2001). Children were asked to read as many simple sentences as they could in 3 min., to make a grammatical judgment on whether each statement was true or false (e. g., “the moon is in the sky”), and to write their answer in a dedicated booklet. Participants were provided with booklet containing 98 simple sentences and had to write their answers of the sentences being rated as true or false. The dependent variable was the percentage of correct responses obtained within a 3-min. time limit. Two parallel versions were counterbalanced across participants for pre and post testing.

Syntactic competence

Sentence-level comprehension was measured by means of a picture-sentence matching task. Materials were the ones used in Hansen et al. (2016), which were adapted from the syntax scale of the PROLEC-R test battery for reading processes in Spanish (Cuetos, Rodríguez, Ruano, & Arribas, 2007; Hansen et al., 2016), and translated into English. From the 30 sentences of the material, two parallel versions were constructed for pre and post-test, with half of the material in each version (matching the difficulty level of the sentences) that was counterbalanced across participants. In each testing moment, participants were presented with two blocks of 15 sentences including the same sentences to minimize the possibility of random responses. Sentences were presented in written form on the computer screen, alongside with 4 pictures from which children had to select the one matching the meaning of the sentence. Sentence types differed in syntactical complexity: simple active structures, active sentences containing a negation, passive structures, and sentences containing a focalized object, a split subject, a split object, a subject-subordinate relative clause or an object-subordinate relative clause. Table 7.3 describes examples of each of the sentence types and the distribution of parallel versions. This task is thought to measure the ability to interpret sentence meaning despite increased difficulty and increased working memory load because of the need to maintain a syntagma active while reading the rest of the sentence (Montgomery, Magimairaj, & O'Malley, 2008).

Table 7.3. Classification of the sentence types for the syntactical ability assessment.

Example	Syntactic type
The clown is watching TV.	Simple transitive
The drum is red.	Simple intransitive
The mouse does not eat cheese.	Simple transitive negative
The racket is bigger than the ball.	Comparative
The frog is inside the fish tank.	Locative
The singer who wears a skirt is blonde.	Relative simple
It is the wolf that catches the tiger.	Cleft simple
The car is followed by the bicycle.	Passive
It is the donkey that is followed by the horse.	Cleft passive

The soccer player who is pushed by the policeman is bald.	Relative passive
This is the prisoner that the ball is hitting.	Object relative

Working Memory

On a computerized version of the dot counting span task (Case, Kurland, & Goldberg, 1982), children were required to count the number of black dots presented in a series of arrays on a white background, and then to recall subsequently the dot tallies in the order that the arrays were presented. Children had to remember from 2 to 6 count totals for a later recall test where they had to type their response.

Transfer Tasks

The five measures used for the baseline assessment were also considered as transfer measures. Dot counting span was taken as a near transfer measure, whereas the four measures evaluating reading abilities represented far transfer task. Moreover, the following task was included to provide an additional far transfer measure. This would allow us to better analyze the potential effects of working memory training to higher-level comprehension processes.

Updating in Reading Comprehension

We used an adapted-to-children version of the situation model revision task (Pérez, Cain, Castellanos, & Bajo, 2015). We included 38 narrative texts (2 practice, 36 experimental) made up of four sentences, an example of which is presented in Table 6.1 in the introduction. Out of the total of 36 experimental texts, 18 texts were used in pre-test and the remaining 18 in post-test, counterbalancing the versions across participants.

As shown in the example text of Table 7.1, the 2 first introductory sentences of the text created a particular situation model and always supported a specific inference to be made (i.e., *Mr. and Mrs. Jones were happy about their newborn. Mrs. Jones knew that she would have feed the new little family member every day*. To-be made inference: *baby*). On the basis of the reading times of the two first introductory sentences and the accuracy in the first comprehension question that refers to the introduction (see below), we calculated an index of general reading efficiency by dividing the proportion of hits by the average reaction times in the introduction of the texts.

After the two-sentence introduction, a third sentence was presented with three possible conditions:: (a) *no update* condition, in which the new information was consistent with the original inference (*The little family member always seemed to be hungry and cried often*); (b) *inference* condition, wherein participants had to revise their original situation model so that only the alternative inference was supported rather than the original inference (*The little animal said "meow, meow" every time it was hungry*. New to-be made inference: *cat*); (c) *update* condition, in which children were literally presented with the new inference concept that required the updating of the previous and original inference as a proxy for processing time, is the dependent variable for this third sentence (*The little cat was always hungry and cried all the time*). In addition, two indices were calculated: one was a measure of inference generation based on the difference between the reading times for no updated – inference, and the other was a measure of updating on the basis of the difference in reading times between no updated – updated conditions.

Finally, a fourth sentence with the updated information was presented to all participants by a disambiguating word (*cat*), independently of the condition of the previous sentence (*Mrs. Jones sat on the chair, holding the small cat in her arms*). At the end of the text, participants were presented with two multiple choice comprehension questions with three possible response options. The first question referred to the two first introductory sentences (i.e., *Mrs. Jones would have feed the new little family member every* __) and the second question referred to the updated inference of the third sentence (i.e., *Mrs. Jones had to feed the new* __). Throughout this task, participants were encouraged to read silently at their own pace, pressing the spacebar to pass through the sentences and words of the text. We developed two parallel versions of the task that were counterbalanced across participants. In each of the versions, children read 20 texts (6 no update, 6 update, 6 inference and 2 practice).

Before the beginning of data collection, we performed a norming study to provide empirical confirmation of words of the situation model revision task. Eighteen US English-speaking children

(*M* = 9.61 years old, range 8 – 13) were recruited for pilot testing and read the introduction of 60 texts (sentences 1 – 2) followed by one of two versions of sentence 3, either the no update or the updated. Then they were presented with different options. They had to mark the word that fit with the sense of the story. It could be either the target word that was more strongly supported by the introduction (i.e., *baby*), the alternative word (i.e., *cat*) or two other different options (i.e., *bird, dog*). We chose the 36 texts in which the two following conditions were met: (a) the word inferred by the introduction was selected in more than the 80% of the cases in the no update condition and rejected in more than 80% of the cases of the update condition; and (b) the alternative word was selected in more than the 80% of the cases in the update condition and rejected in more than 80% of the cases of the no update condition. The sample used in the norming study did not take part in the training study.

RESULTS

Training curves

In order to explore how participants performed during the training procedure, we calculated the average achieved level per training session and training activity, for each of the training groups. One of the two activities run offline (Speeded Comparison for the CT group) employed a mathematical algorithm to define the levels of difficulty that, by combining the different parameters, could generate until an infinite number of training levels. Therefore, for ease of comparison between tasks and unlike the two previous training studies - in which the relative level was used - in this study we considered the average absolute level reached in each session and task. Thus, Figure 7.1 represent the training curves of the two training groups: experimental working memory training and the active control training group.

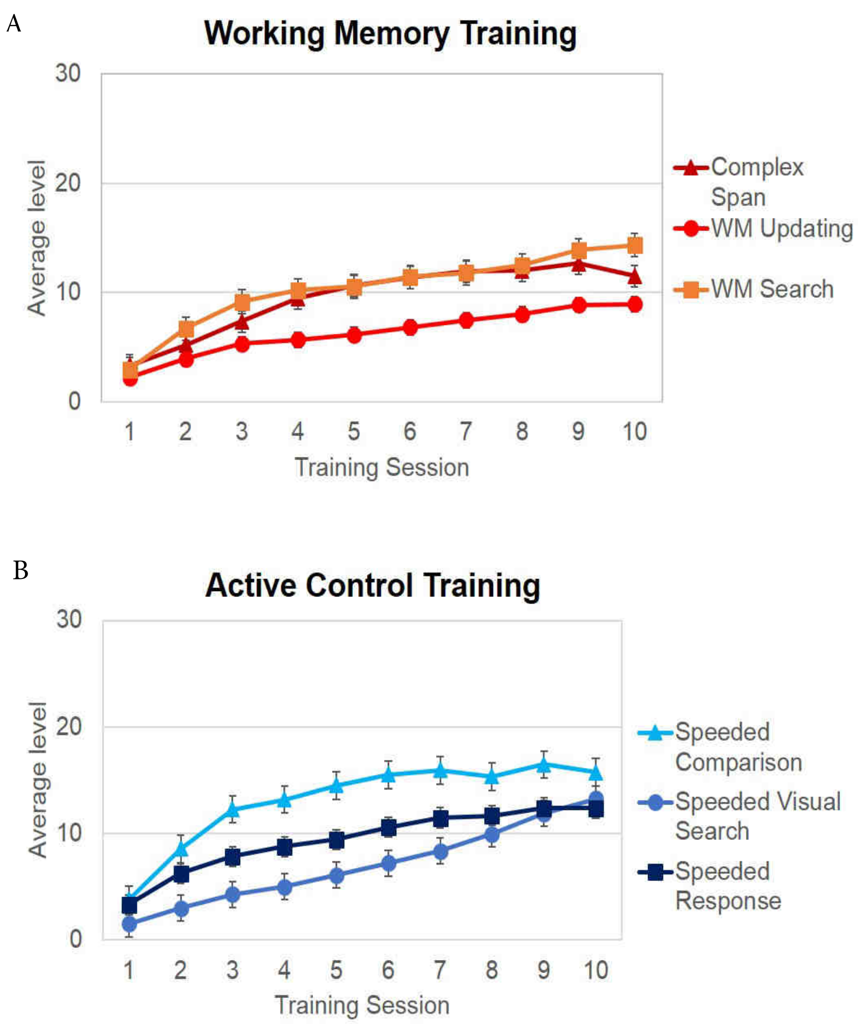
To determine the significance of the training improvement in each activity, we compared the performance in the first training session with that of the final (tenth) training session. Thus, for all tasks mixed analyses of variance (ANOVAs) were conducted on the specific dependent variables for the task (conflict score, errors, reactions times or memory load) with training session (first vs. tenth) as the within-subject independent variable.

Working Memory Training

We observed a positive effect of training in the three different activities trained by the WMT group. To begin with, on the complex span task children reached a significantly higher level in the last training session (M_{s10} = 10.78, SD_{s10} = 7.85, corresponding to a set size of 3 targets with 2 distractors) compared to the first session (M_{s1} = 3.26, SD_{s1} = 0.88, corresponding to a set size of 3 with no distractors), (F = 21.99 1; $p < 0.01$; n^2_p = 0.51). In relation to the WM updating task, children also increased their performance from the first session (M_{s1} = 2.01, SD_{s1} = 0.72, corresponding to a set size of 2 targets with 2 distractors) to the last training session (M_{s10} = 8.53, SD_{s10} = 3.50, corresponding to a set size of 3 with 6 distractors), (F = 74.09; $p < 0.01$; n^2_p = 0.77). Finally, as for the

WM Search task, participants also improved their memory performance from their level in the first session (M_{s1} = 2.92, SD_{s1} = 0.33, corresponding to a set size of 2 with 2 distractors) to the level on the last training day (M_{s10} = 14.00, SD_{s10} = 4.99, corresponding to a set size of 6 targets with 6 distractors), (F = 118.18; $p < 0.01$; n^2_p = 0.84).

Figure 7.1. Training improvement of children. Training performance across the sessions as a function of training condition. Panels depict the average achieved level (y-axis) across the ten training sessions (x-axis). Error bars represent standard errors of the mean. Panel A refers to the training curves of the three different working memory tasks trained by the experimental group, whereas panel B refers to the improvement in the three processing speed activities trained by the active control group.



Active control

Participants in the active control group trained with activities involving low executive control and with levels of training varying progressively in speed. Thus, on the tasks children significantly reduced their response speed from the first to the last session. In the speeded comparison task, children's speed decreased from the first session (M_{s1} = 628.31, SD_{s1} = 370.67) to the last one (M_{s10} = 552.73, SD_{s10} = 380.69; F = 354.22; p < 0.01; n^2_p = 0.95). A similar speed reduction was observed in the speeded visual search task (M_{s1} = 3325.23, SD_{s1} = 567.70; M_{s10} = 2672.18, SD_{s10} = 581.72; F = 168.40; p < 0.01; n^2_p = 0.86) as well as in the speeded response task (M_{s1} = 533.36, SD_{s1} = 298.60; M_{s10} = 196.09, SD_{s10} = 165.67; F = 446.70; p < 0.01; n^2_p = 0.94)

Predictors of training improvement

To quantify participants' training improvement over the ten sessions of training, we calculated the slope of a linear regression model using the standardized average level in each training session and activity per participant (Benjamin Katz et al., 2014; Z. Wang, Zhou, & Shah, 2014). To compare the training achievements of the different groups (Figure 7.1), the slopes of the three training tasks for each group were averaged.

To further explore if baseline capacities predicted training performance, linear regression models were conducted including the overall training slope as the dependent variable while reading ability and working memory were introduced as predictors (Söderqvist et al., 2012). Results showed that reading ability (as a composite measure) at pre-test and working memory capacity predicted improvements during training (R^2 = 0.28; p < 0.01; Reading ability: β = 0.93; p < 0.05; Working Memory: β = 0.67; p < 0.05). This indicates that participants with higher reading ability and working memory capacity were able to reach higher levels of performance during working memory training.

Afterwards, and with a similar analytical approach, we explored the predictors of the training slopes of the individual activities separately for the working memory training and the active control groups. In all the cases, individual training slopes were included in the regression model as the outcome variable, whereas reading ability and working memory were introduced as predictors.

First, for the active control group, the improvement in the Speeded Comparison and the Speeded Response task was not predicted by either reading ability or working memory (Speeded Comparison: $R^2 = 0.04$; $p > 0.05$; Speeded Response: $R^2 = 0.06$; $p > 0.01$). However, in the case of the Speeded Visual Search task, training improvement was significantly predicted by reading ability at the baseline level ($R^2 = 0.56$; $p < 0.01$; Reading ability: $\beta = 1.17$; $p = 0.07$; Working Memory: $\beta = 1.20$; $p < 0.01$). This task involved verbal material (numbers and digits) even if the activity did not require demands on working memory. However, the improvement was sensitive to the working memory capacity of the participants in comparison to the two others activities of the active control group, which only involved processing speed.

In contrast, for the working memory training group reading ability and working memory significantly predicted the magnitude of improvement during training in the Complex Span Task ($R^2 = 0.36$; $p < 0.01$; Reading ability: $\beta = 1.00$; $p > 0.05$; Working Memory: $\beta = 3.60$; $p < 0.01$); the WM Updating task ($R^2 = 0.44$; $p < 0.01$; Reading ability: $\beta = 1.14$; $p < 0.05$; Working Memory: $\beta = 0.99$; $p = 0.05$) and marginally in the WM Search task ($R^2 = 0.14$; $p = 0.07$; Reading ability: $\beta = 0.18$; $p > 0.05$; Working Memory: $\beta = 1.16$; $p = 0.05$). This different pattern is interesting since it makes evident that working memory capacity is only needed when participants have to deal with increments in executive control across training levels.

Training improvement and Engagement

Previous studies have reported the importance of motivation for training (Benjamin Katz et al., 2014, 2016). Therefore, we further explored whether children's engagement during training predicted their improvement in the activities. We calculated a composite score of engagement by averaging the three different motivational factors assessed in each training session; namely, attention, autonomy and motivation. This composite measure served as a predictor in a linear regression model that included training slope as the outcome variable, separately for both training and control groups. While we did not find a significant model for the control group ($R^2 = 0.01$; $p > 0.05$), engagement during training significantly predicted training performance only for the working memory training group ($R^2 = 0.27$; $p < 0.01$; Engagement: $\beta = 0.43$; $p < 0.01$).

Correlations between variables at pre-test

To check for relationships between the cognitive functions tested at baseline, Pearson correlations were run on the pre-test scores of the whole sample. As shown in Table 7.4, the four reading ability-related measures were strongly correlated. On the basis of these correlations, we calculated a composite measure of reading ability by considering the average scores of the lexical, phonological, semantic and syntactical ability.

Furthermore, all the four individual reading ability components significantly correlated with the dot counting span (a working memory measure, see Table 6.4). Consequently, when the four components were averaged to obtain a general reading ability score, it also showed a significant correlation with the WM dot counting span measure (r = 0.55; p < 0.01). Thus, the correlations among the four individual reading capacities as well as the correlation between the composite reading index and the WM measure provide further support to the strong relationship between both cognitive capacities.

Table 7.4. Bivariate Pearson correlations between variables at pre-test

	Spelling	Decoding	Semantic	Syntactic	Reading Ability	Working Memory
Spelling	-					
Decoding	**0.47***	-				
Semantic	**0.61***	**0.29***	-			
Syntactic	**0.71***	**0.29***	**0.50***	-		
Reading Ability	**0.87***	**0.68***	**0.84***	**0.64***	-	
Working Memory	**0.57***	**0.30***	**0.50***	**0.50***	**0.55***	-

Differences at pre-test

Table 7.5 summarizes the scores at pre-test as a function of the training group (working memory training vs. active control training). As shown in the table, there were no group differences at baseline in any task.

Table 7.5. Between groups differences at pre-test as a function of training condition

	WM Training (n =24)		Active Control (n = 31)		Between Groups Comparison		
	M	*SD*	*M*	*SD*	t (53)	p	*Cohen's d*
Reading ability	0.44	0.13	0.45	0.17	-0.13	0.90	-0.03
Lexical	0.42	0.18	0.40	0.16	0.25	0.80	0.07
Phonological	0.80	0.12	0.78	0.18	0.58	0.57	0.17
Semantic	0.49	0.24	0.51	0.21	-0.29	0.77	-0.08
Syntactic	0.09	0.03	0.10	0.03	-0.34	0.74	-0.09
Working Memory	0.80	0.13	0.73	0.21	1.63	0.11	0.44

Transfer Results

Table 7.6 summarizes the descriptive data of the different measures at pre and post-test as a function of training group. Hereafter, results from the transfer effects comparisons will be reported. In all the cases, mixed ANOVAs were conducted with the corresponding dependent variables in each task (% of hits, reaction times or indices of efficiency) and two different factors: session (pre vs. post), as the within participants variable, and training group (working memory training vs. active control) as the between participants factor.

Working Memory

Regarding the effects on the working memory measure (dot counting span), results from the ANOVA did not reveal main effects of training group (F (1, 52) = 0.30; $p > 0.05$; $\eta^2_p = 0.00$), nor session (F (1, 52) = 0.06; $p > 0.05$; $\eta^2_p = 0.00$). In addition, the interaction was not reliable (session × training group: (F (1, 52) = 3.93; $p > 0.05$; $\eta^2_p = 0.07$)), suggesting that working memory capacity was not affected by completing the cognitive training program.

General Reading Ability

We explored far transfer effects of working memory and executive control training to a general composite measure of reading ability, which included the average scores of four different tasks corresponding to four different components of reading skill: spelling task (lexical), decoding task (phonological), reading fluency task (semantic) and sentence comprehension task (syntactic). To do so, we introduced this composite measure into a mixed ANOVA including session (pre-post) as a within participants factor, and training group (training vs. control) as the between participant factor. Results failed to show significant main effects of training group (F (1, 53) = 0.00; $p > 0.05$; $\eta^2_p = 0.00$), or session (F (1, 53) = 3.16; $p > 0.05$; $\eta^2_p = 0.05$). Also the interaction was not statistically significant (session × training group: (F (1, 53) = 0.43; $p > 0.05$; $\eta^2_p = 0.00$). This null result seems to suggest that processes involved in reading might not be sensitive to the effects of cognitive training interventions in children.

Updating in Reading Comprehension

For this task we performed analyses considering different parts of the text and different dependent variables. Following Perez et al (2015), for this and the following analyses we filtered out the data from children with an overall accuracy below 60 % (7 control and 5 training participants) and average reading time below and above 2.5 standard deviations (2.3% of the data). These selection criteria were applied to discard participants with poorly comprehended texts, driven by either excessive failures in the comprehension questions or unreasonably fast or slow reading times.

First, we analyzed the combination of response times and errors corresponding to the introduction of the text (two first sentences), and computed an efficiency index by dividing the accuracy on the first question (regarding information of the two introductory sentences) and the average reaction times of the two first sentences of the text (Geva & Yaghoub Zadeh, 2006). These two introductory sentences can be considered as a text-reading baseline. We calculated a reading efficiency index (of the introduction) and entered it into a mixed ANOVA including session (pre vs. post training) and training group (control vs training) factors.

The results of this first analysis on reading times did not yield significant results. Thus, the effects of training group (F (1, 37) = 0.77; $p > 0.05$; $\eta^2_p = 0.02$); session (F (1, 37) = 1.06; $p > 0.05$; $\eta^2_p = 0.03$) and their interaction were not reliable (Session × Training Group: (F (1, 35) = 0.07; $p > 0.05$; $\eta^2_p = 0.00$)). This might suggest that the ability to efficiently comprehend general and consistent texts was not affected by training.

In order to assess whether inferring and updating improved with training, we calculated two indices: a) one of them is based on the comparison between the no update (control) and inference condition (inferring); b) the other relies on the difference between the reading times of the no update versus the update conditions (updating ability). For the first index (inferring) we did not observe any effect of session (F (1, 37) = 1.54; $p > 0.05$; $\eta^2_p = 0.04$), training group (F (1, 37) = 1.32; $p > 0.05$; $\eta^2_p = 0.03$), nor interaction between both variables (F (1, 37) = 0.69; $p > 0.05$; $\eta^2_p = 0.02$), suggesting that training did not impact the ability to make inferences. However, when analyzing the difference between the no update and the update condition, we found a marginal main effect of training group (F (1, 37) = 4.02; $p = 0.05$; $\eta^2_p = 0.08$), although not a main effect of session (F (1, 40) = 0.84; $p > 0.05$; $\eta^2_p = 0.02$). More relevant, the session by group interaction was reliable (F (1, 37) = 5.83; $p < 0.05$; $\eta^2_p = 0.12$). This interaction was accounted for by the fact that the control participants did not modify their speed to detect inconsistencies with training (no significant session effect (F (1, 22) = 1.34; $p > 0.05$; $\eta^2_p = 0.05$)), whereas trained participants were able to update their mental model and reduce interference from reading an inconsistent sentence (F (1, 17) = 4.64; $p < 0.05$; $\eta^2_p = 0.19$).

Lastly, we were also interested in exploring if the benefit in updating the situation model during text comprehension after the training was predicted by any of the baseline capacities or by the training improvement. Consistent with the analysis in the sentence comprehension task, we conducted linear regression models for both training groups. As the dependent variable we introduced a computed standardized gain measure of updating (pre-test - post-test /standard deviation of the entire sample at pre-test). As predictors, we introduced working memory capacity, reading ability at pre-test, average training slope and engagement during training. None of the variables significantly predicted reading gains for the speed training active control group ($R^2 = 0.00$; $p > 0.05$). In contrast, for the training group reading ability at the baseline level marginally predicted the gain in updating the text situation models ($R^2 = 0.13$; $p = 0.12$; Reading ability: $\beta = 0.83$; $p = 0.12$). This allows us to suggest that those working memory trainees that had a higher reading ability at baseline tended to better update their situation models after completing the training program.

Table 7.6. Descriptive statistics table of the transfer measures as a function of session and training condition. Mean and standard deviations for the outcome measures in the Pre and Post-testing. Significance p values and effect sizes (Cohen's d) estimates are reported for the Repeated-Measures ANOVAs including session as a within subject variable (Pre-test and Post-test values) and group as a between-subject effect in each of the four groups. Standardized gains mean (Post-Pre)/(SD Pre) for hits proportion variables and reversed for efficiency indices at the text comprehension level.

		Pre-Test		Post-Test		Pre-Post effects		Standardized Gain	
Variables	*n*	*M*	*SD*	*M*	*SD*	*p*	*Cohen's d*	*M*	*SD*
Working Memory (% Hits in Dot Counting Span)									
Active Control	31	0.73	0.21	0.76	0.20	0.13	0.13	0.15	0.54
Working Memory Training	24	0.80	0.13	0.76	0.15	0.23	-0.32	-0.34	1.15
Reading ability (% Hits Lexical + Phonological + Semantic + Syntactical)									
Active Control	31	0.45	0.12	0.42	0.09	0.07	-0.27	-0.19	0.57
Working Memory Training	24	0.44	0.13	0.43	0.09	0.38	-0.15	-0.11	0.85
Relative Sentences Comprehension: Reading efficiency (% Hits/Global RT)									
Active Control	32	0.08	0.04	0.08	0.03	0.58	0.10	0.10	1.00
Working Memory Training	23	0.08	0.03	0.09	0.04	0.02	0.32	0.26	0.49
Updating in Reading Comprehension *Reading efficiency in the Introduction (% Hits in Question 1/ Average RT of Sentences 1 and 2)*									
Active Control	22	0.19	0.06	0.20	0.07	0.33	0.19	0.16	0.75
Working Memory Training	17	0.17	0.07	0.18	0.07	0.61	0.08	0.06	0.53
Updating in Reading Comprehension *(Inferring: Inference - No Update reading times of sentence 3)*									
Active Control	22	0.01	0.15	-0.01	0.13	0.72	0.10	0.09	1.19
Working Memory Training	17	-0.01	0.22	-0.08	0.21	0.24	0.34	0.44	1.65
Updating in Reading Comprehension *(Updating: Update - No Update reading times of sentence 3)*									
Active Control	22	-0.01	0.13	0.04	0.14	0.26	-0.72	-1.22	0.84
Working Memory Training	17	-0.01	0.12	-0.11	0.25	**0.04***	0.54	1.15	1.33

Discussion

Reading comprehension is a highly demanding activity that involves different processes, and it is widely accepted that working memory and other executive functions play a key role in successful comprehension (K. Cain et al., 2004; Sesma, Mahone, Levine, Eason, & Cutting, 2009; Swanson & Berninger, 1995). In this study, we aimed to advance our understanding of the mechanisms driving the relationship between working memory and reading ability by attempting to provide a causal link between domain-general executive control processes and reading performance.

To do so, we conducted a school-based training intervention in which the performance of a group training working memory and executive control was compared to an active control group that engaged in perceptual activities requiring processing speed without executive demands. Previous studies have already reported the effectiveness of working memory training in improving reading comprehension in children (Carretti et al., 2014, 2017; García-Madruga et al., 2013; Henry et al., 2014; Karbach et al., 2015; Loosli et al., 2012). A first remarkable and suggestive finding was that working memory and reading ability at pretest predicted higher improvement during training. This suggests that training activities were particularly more effective in children who started from a higher level of performance at pre-test. This magnification effect contrasts with previous finding suggesting that children who start from lower levels of ability benefit more from training (Karbach 2014; Carretti et al. 2014, 2017; Cornoldi et al. 2015). However, the positive relation between baseline cognitive performance and our training gains could stem from the fact that, because the procedure used in our training program was highly demanding, it promoted that only those with higher baseline capacities were the ones able to reach and fulfill increased executive control demands.

Moreover, we also observed that engagement during the training procedure induced greater training gains but only for the working memory training group. Most training studies with children population have used no-contact control groups (Dahlin, 2010; Chein & Morrison, 2010; Loosli et al., 2012) or active control conditions in which children engaged in extracurricular activities (Karbach et al., 2014; García-Madruga et al., 2013; Carretti et al., 2017). Given that we included an active control group that completed a training procedure with an identical format to that from the experimental group, we kept similar motivational levels between the groups. As a result, the fact that engagement during the training was a relevant predictor of training improvement only for the working memory training group highlights the importance of considering individual differences during training. Thus, our results suggest that when training involves easy low-demanding activities, the level of engagement does not affect performance and that it is only when training involves high demanding and challenging activities, maintaining higher levels of engagement, that it results in larger gains (Katz et al., 2016; Maraver et al., 2016).

Regarding transfer effects, in contrast to previous studies (Dahlin, 2010; Chein & Morrison, 2010; Loosli et al., 2012; Karbach et al., 2014; Carretti et al., 2017) ours failed to observe near transfer to our measure of working memory capacity. This lack of effect could be partly explained by the features of the task itself. Despite the increase in performance observed in the working memory training activities, the use of a single measure to assess transfer that differed in several aspects from the ones trained, makes it difficult to disentangle the reasons why we did not find transfer to working memory. Future studies should consider the recommendation of using more than one outcome measures to analyze transfer effects (Colom et al., 2013; Shipstead et al., 2010). In addition, we also did not observe benefits of training over low-level reading processes involving lexical, phonological, semantic and syntactical abilities. This absence of transfer to low-level reading skills is consistent with previous findings such as those reported by Dahlin (2010), in which working memory training did not enhance word decoding nor performance on orthographic verification tests, even though it did enhance reading comprehension (Dahlin, 2010).

In contrast, more promising results emerged in relation to far transfer effects of working memory training over high-order reading comprehension processes, specifically at the text level. Using the situation model revision task we were able to obtain three different measures of successful text comprehension. First, we calculated a general index of comprehension efficiency with the reading times of the two introductory sentences and the accuracy in the first comprehension question that referred to the introduction. This measure, however, did not change for any of the groups after completing the training, which suggests that basic comprehension skills do not seem to be sensitive to the effects of working memory training. Second, by considering the difference in reading times between the inference and no update conditions of the third sentence we calculated a measure of inference generation, which was also not affected by training improvement. And third, by calculating an index subtracting reading times of the update and no update conditions of the third sentence, we observed that the children who completed the working memory procedure were more efficient in updating their previous situation model. Regarding the absence of effect on inference making, Pérez et al (2014) observed that individual differences in cognitive control predicted updating but not inference generation (Pérez, Paolieri, Macizo, & Bajo, 2014). Thus, the ability to generate new inferences might not have been sensitive to the gains from working memory training, in contrast to the updating process. When readers detect a mismatch between their current situation model and incoming text information, the updating process forces the activation of the newly encountered information as well as the reduction of activation from the no longer relevant information (Kendeou, Smith, & O'Brien, 2013 for review). Along these lines, although previous studies have reported that the ability to inhibit no longer relevant information in the situation model depends specifically on the verbal domain of working memory (Pérez et al., 2015a; 2015b), the ability to revise the working memory contents has been commonly defined as an executive function (Carretti et al., 2009; Palladino & Cornoldi, 2001). Therefore, our results suggest that only high level reading comprehension processes highly dependent on working memory, as it is the case of updating, are enhanced by working memory training

These results are in agreement with research on some incidental cognitive training conditions such as multilingual education (Bialystok & Martin, 2004; Carlson & Meltzoff, 2008; Morales, Calvo, & Bialystok, 2013) or musical training (Bergman-Nutley, Darki, & Klingberg, 2014; George & Coch, 2011), which also seem to lead to improvements in working memory and other executive functions. In this sense, a recent study by Hansen et al., (2016) investigated the relationship between bilingual education, reasoning and reading comprehension skills. Using principal component analysis, they categorized data from different tasks into two underlying subskills: "linguistic processing", similar to the general reading ability composite that we employed in the present study, and "memory and reasoning". The measures loading on the linguistic component required participants to process and pay attention to the lower-level units that form the basis of a written text (i.e., the speed or fluency of lexical access from written words or pictures). This general linguistic ability was related to purely linguistic processes and, seemed not to be sensitive to this natural cognitive training effect. However, “memory and reasoning” that included performance on measures related to sentence comprehension, long-term memory and fluid intelligence showed bilingual education effects. It is interesting that these functions are essential for treading comprehension and they reflect the capacity to learn and retain new information, which are needed to construct, maintain and update the mental representation of the text (Oakhill, Cain & Bryant, 2003). Along these lines, and because we only observed a benefit of working memory training on updating at the text comprehension level, our results suggest that training only affected those reading processes that demand a considerable amount of working memory and executive control.

Taken together, and consistent with previous findings, our data suggests that training children within school settings may improve skills related to reading comprehension (Henry et al. 2014). However, although our data are well in line with widely accepted theoretical assumptions regarding the relationship between working memory and reading performance (Dahlin, 2010; Chein & Morrison, 2010; Loosli et al., 2012; Alloway et al., 2010), our study has some limitations that have to be considered. The dissimilar number of participants in the groups and the small sample sizes go against straightforward conclusions from our findings. In addition, the use of single outcome measures to assess transfer effects makes us cautious regarding their interpretation. Despite these considerations, we think this research provides new evidence of the effectiveness of working memory training and is suggestive of plasticity across domains. Moreover, remarkable practical applications regarding the development of interventions at school could be derived from this work, since it seems it is possible to improve an ability that is key in everyday life and is related to scholastic achievement in school-aged children. This, in turn, supports the relevance of these interventions to enhance crucial abilities to success in daily life. Finally, the present findings are consistent with the idea that a training regime requiring participants to constantly perform at their individual limit of working memory capacity may be particularly effective in improving the efficiency of activities that largely rely on working memory, as it is the case of reading comprehension.

CHAPTER VIII

General Discussion

The training of executive functions as a way of increasing cognitive capacities has received a great deal of attention in recent years. Consequently, the studies included in this thesis aimed to investigate the extent to which training in executive functions could generalize not only to cognitive domains that are similar to the trained functions, but also to untrained domains. Thus, we focused on investigating training improvements and transfer effects of process-based training programs developed to target executive functions. With this purpose in mind, our training programs were based on the highly influential "Unity and Diversity" model of executive functions proposed by Miyake et al. (2000). The main feature of this model is that the executive function system could be partitioned into overlapping (unity) and yet distinct (diversity) components. A logical conclusion drawn from these assumptions of unity and diversity is that executive control training could specifically be targeted to one of these functions (diversity) or to the general executive mechanism (unity). If so, one would expect transfer effects with some degree of specificity and commonality across related cognitive domains. Consequently, our programs included training tasks designed to tap into inhibition, switching, and updating in order to broadly engage the executive system. We expected transfer effects based on the assumption that shared cognitive processes and common brain networks underpin performance in trained and untrained tasks (Miyake & Friedman, 2012; Miyake et al., 2000; Niendam et al., 2012). The results of the present set of experiments generally support the assumption of the unity and diversity of executive functions. Although not directly compared within the same study, the inclusion of children's and younger and older adult samples makes it possible to explore how modifiable executive functions are as a function of age. Therefore, the results of the current series of studies generate new insights into the contribution of cognitive training as a tool to enhance executive control and provide information on life-span changes in cognitive and neural plasticity.

Across a series of experiments, we challenged the assumption that cognitive processes remain fixed and static throughout the lifespan, by establishing specific goals along the studies. In Experiment 1, we attempted to analyze the specificity of executive control training by directly comparing a training program that relies on WM with another involving IC. Of relevance, we included a speed processing training group, which served as an active control condition and a passive control group. We assessed the potential benefits of executive control training over a variety of experimental tasks of related domains such as WM, IC, and adjustments between reactive and proactive modes of control (near transfer effects). We also analyzed far transfer effects, considering the generalization of executive control training to a measure of abstract reasoning and fluid intelligence. In Experiment 2A, we investigated the training and transfer effects of an executive control intervention in a group of healthy older adults. Since ample evidence suggests that aging entails a progressive decline in executive and cognitive control-related functions, we compared the potential benefits of an executive control intervention (combining activities of WM and IC) with a speed training condition that served as an active control. Similar to the study performed with younger adults, we considered WM, IC, processing speed, fluid intelligence, and reactive/proactive modes of control as transfer domains. Regarding reactive/proactive control, we were particularly interested in exploring the effects of training, both at the behavioral and neural levels. We paid special attention to possible training effects over task-goal maintenance and context processing, in which specific impairments have been repeatedly reported in older adults. Going a step further in the analysis of far transfer effects, and given that deficits in episodic memory are also frequent in the aging population, we conducted Experiment 3 as a first approach to the differences between young and older adults in selective retrieval. In this study, we explored the neural basis of episodic selective retrieval using the retrieval practice paradigm and by analyzing brain oscillations at different frequency bands. As previously stated, because failures in episodic memory are evident in older adults, we also aimed to explore the possibility of executive control training transfer to the untrained but strongly related domain of episodic memory. To this end, in Experiment 2B, we compared performance on the retrieval practice task (similar to Experiment 3) between older adults who completed executive control training and their counterparts undergoing speed training (who served as an active control condition). Finally, we explored the far transfer effects of WM training to reading comprehension in children because of the relevance of this and other executive-related functions in successful development. In fact, WM and associated executive processes are strongly involved in reading comprehension (Alloway et al., 2005; Carretti et al., 2009; Daneman & Carpenter, 1980, 2006). Thus, in Experiment 4, we developed a school-based intervention and assessed the effects of executive control training (relative to speed training) with a particular focus on high-order processes of reading comprehension (inference making and information updating).

Together with other more theoretical objectives, an additional aim of this work was to control for several methodological factors that are subjects of frequent discussion across the training literature (Melby-Lervåg et al., 2016; Shipstead et al., 2012; Simons et al., 2016). The first factor we wanted to address has to do with the nature of the activities performed by the control groups as appropriate conditions for group comparison. Thus, a clear strength of our studies is that they included active control groups that engaged in tasks that essentially required processing speed, which kept participants at a similar level of motivation and engagement across groups (for related approaches, see Goldin et al., 2014; Lawlor-Savage & Goghari, 2016). The use of active control groups in training studies is not a common practice, especially with older adults (Karbach & Verhaeghen, 2014; Kelly et al., 2014). By contrast, studies using only passive control groups only allow for the control of test-retest effects, while the presence of an active control group controls for motivation and expectancies that may drive training improvements (Boot, Champion, et al., 2013; Dougherty et al., 2016; Mohr et al., 2009). Thus, the systematic use of an active control condition across the studies has provided the opportunity to more clearly disentangle the specific effects of the experimental training conditions. The second factor is the nature of the training procedure. There has been the question of whether the use of a single training task leads to broader effects of generalization. In our studies we took a process-based approach and used different training tasks for the target processes in order to increase the probability of generalization. Finally, we addressed a third factor, individual differences. As training does not yield equal benefits to all individuals, the "one-size-fits-all" hypothesis has no place in this particular field of research. Thus, the consideration of individual differences becomes paramount in supporting the positive benefits of training, and it has been taken into account throughout the studies conducted in this thesis.

Taken together, the experiments reported here aimed to address two main questions: i) *can executive control training lead to enhanced functioning of related cognitive domains (WM, IC, speed processing, and adjustment between modes of control) and dissimilar domains (abstract reasoning/fluid intelligence, episodic memory, and reading comprehension)?* ii) *If any, are these transfer effects modulated by individual differences in relation to age, training performance, baseline capacities, and motivation?* These two questions cannot be answered using a simple "yes" or "no," given that they are highly complex and entail the interaction of many factors. Thus, in the next sections, we will discuss and summarize the findings obtained in the present studies by addressing the previous questions. First, we will discuss the transfer effects across the different cognitive domains and will compare them across studies according to age. This will be done by considering the theoretical models and the logic behind transfer effects in order to explain the success or failure in finding them. Thereafter, we will address the role of individual differences in training improvement, baseline capacities, and motivation. Finally, we will conclude with some theoretical and practical implications derived from the current set of experiments. We will then highlight the limitations of our studies as well as the future lines of research in the promising field of cognitive enhancement.

Transfer Effects after Executive Control Training

Evaluating transfer effects after cognitive training might provide insights into the malleability of the underlying hypothesized function. If training in one type of task also improves performance in untrained measures of the same ability, this would be a sign that the underlying ability has been enhanced (Lövdén et al., 2010). Our training programs led to transfer effects in different cognitive domains, although individual differences in age, baseline capacities, training improvement, and motivation seemed to influence them. In the following paragraphs, we will detail the transfer effects across the different cognitive domains evaluated in our studies, providing comparisons, when possible, of the performance between the different age groups.

Inhibitory control and conflict resolution

Inhibition was analyzed on the basis of performance on the Stroop (only in young adults) and Stop-Signal (young and older adults) tasks. For the young adults, we only found transfer effects to the Stroop task after IC training (not for any of the remaining conditions). As for the Stop-Signal task, the IC training group was the only one with young adults who specifically demonstrated benefits from response inhibition (SSRT). In the study with the older adults, only the executive control group improved its inhibition index after the training. This suggests that adaptive training, either only with conflict resolution tasks or in combination with WM tasks, may improve performance in other tasks that are thought to tap into conflict resolution mechanisms (for related results, see Berkman et al., 2014; Dovis et al., 2015; Enge et al., 2014; Spierer et al., 2013).

Working Memory

WM was assessed by means of the *n*-back task (young adults), the Operation-Span (O-Span) task with the combined index of equations accuracy × words recalled (in young and older adults) and intrusions (young adults), and finally, with the dot counting span task (in children).

Regarding young adults, specific transfer effects to the n-back task were observed for WM training, but not for IC training or for active or passive controls. Because this task was similar to the trained one, the direct transfer effect was training specific. An additional specific effect regarding the young adults undergoing the WM raining was found in the O-Span task, with a reduction in the number of intrusions. This is consistent with previous studies that have reported that high WMC relates to more efficient intrusion suppression in span (Borella et al., 2008; Rosen & Engle, 1998; Turley-Ames & Whitfield, 2003). Furthermore, in relation to the dual task index of the non-trained WM task (O-Span: equations accuracy × words recalled), we observed a broader effect of the training. For the young adults, both training groups (WM and IC) improved their performance relative to the controls. More relevant, this effect was also observed in the study with older adults but only in the group that underwent WM and IC training (related findings of improved complex span scores were reported after simple, complex span, and visual search training (Harrison et al., 2013), rehearsal strategy training (Turley-Ames & Whitfield, 2003), or task-switching training (Karbach & Kray, 2009)). These results suggest that dual tasking may require both WMC and IC mechanisms (Chein et al., 2011; Smith et al., 2001; Towse et al., 2000; Unsworth, 2010) and are suggestive of how much trained and transfer processes may overlap in their underlying neurocognitive networks. Kane and Engle (2002) have proposed that the dorsolateral prefrontal cortex could play a role in WMC in contexts providing potential interference (and requiring attentional control). Conway et al. (2003) and Gray et al. (2003) agree that in WM span tasks, regions in the prefrontal cortex are activated when an executive control mechanism is recruited to reduce interference during the maintenance and manipulation of information.

Despite these positive effects, we observed two puzzling results in relation to transfer to WM. First, we found a training effect in the active (speed processing) control group in the O-Span task, which did not differ from that observed for the WM training group. Although the speed training did not increase the cognitive load over the training levels, we used activities that involved increasing difficulty by augmenting the speed of processing. Thus, as predicted, it is possible that the positive effect for this control group stemmed from the overarching time-limited nature of the tasks. Increased processing speed could have led to more efficient processing and maintenance in WM, which would have resulted in better performance in the O-Span task. Similarly, faster speed processing has been proposed to reduce the possibility of forgetting items, and less time for rehearsing or refreshing processes (Hudjetz & Oberauer, 2007; Towse et al., 2000; Unsworth, 2010). Second, and in contrast to previous studies of WM training in children (Carretti et al., 2017; Chein & Morrison, 2010; Dahlin, 2010; Karbach et al., 2014; Loosli et al., 2012), our study failed to observe near transfer to our measure of WMC. This lack of effect could be partly explained by the features of the task itself. Despite the increase in performance observed in the WM training activities, the use of a single measure to assess transfer, which differed in several respects from those trained, makes it difficult to pinpoint the reasons why we did not observe transfer to WM. WM involves maintenance, as well as executive processing of differing nature, and it is difficult to assess exactly what aspect of WM has been improved by training. Thus, future studies should consider the recommendation of using more than one outcome measure to analyze transfer effects (Colom et al., 2013; Unsworth et al., 2009)

Proactive/reactive adjustment

The AX-CPT was used to explore whether training effects might change the control mode used by the participants. This task has been widely used to explore the dynamic adjustment of cognitive control strategies, and it has been shown to be very sensitive to individual differences in cognitive control (Braver, 2012; Braver et al., 2009; Burgess et al., 2011). Proactive control requires goal maintenance and is related to paying attention to contextual cues in order to effectively solve interference while keeping the monitored cues in mind (Rush, 2006). In this version of the task, the use of a proactive control strategy was encouraged since the context was highly predictive (the A cue precedes the X target in 70% of the trials); thus, a control mode that involves sustained maintenance of task-relevant information would lead to a high success rate, albeit leading to errors in trials where the cue was A but the probe was not X (AY trials; 10% of the trials). As a result, this experimental task is very informative and, from the combination of the performance in different conditions, could allow us to disentangle the effects of executive control training on the adjustment of the modes of control. To do so, we used the Behavioral Shift Index (Braver et al., 2009; Chiew & Braver, 2014), which is based on the relative performance on the AY and BX trials (AY-BX/AY+BX errors and reaction times combined). Thus, enhanced proactive control is expected to increase AY errors and reduce BX errors, with the BSI tending to larger values since the cue in BX trials does not signal a "yes" response. As this is usually the most efficient strategy, young adults exhibit behavioral performance and brain activity (sustained lateral PFC activation) consistent with a predominant proactive control strategy (Braver, 2012; Morales et al., 2013). In contrast, older adults tend to prefer the use of a more reactive mode of control since a proactive strategy is more resource consuming in terms of cognitive demands (Paxton et al., 2006, 2008). Although they were not directly compared in our studies, we observed that at the baseline level, older adults showed a numerically smaller BSI compared to young adults, confirming a greater reliance on reactive control with aging. The finding that older adults rely less on the proactive control mode is not incompatible with the idea of an inhibitory deficit in older adults (Hasher & Zacks, 1988). Because reactive control is a less efficient and more vulnerable form of control, through its reliance on the late correction of interference effects, the increased utilization of reactive versus proactive control might be a behavioral reflection of impairment in inhibitory and interference control mechanisms. Going a step further, the results from our experiments regarding the BSI indicated a differential pattern in relation to age after training. For young adults, higher reliance on proactive control was observed after either WM or IC training (relative to the control groups). For older adults, however, none of the groups modified their BSI after the training. Previous studies have reported the malleability of cognitive control mechanisms engaged in the AX-CPT due to experience-based conditions such as bilingualism (Morales et al., 2013; Morales et al., 2015) or different kinds of training interventions (older adults (Paxton et al., 2006, 2008) and people with schizophrenia (Braver et al., 2009; Edwards et al., 2010) were more prone to engage proactive control modes after task-strategy training)). Previous studies have also reported proactive shifts in PFC regions after strategy (Braver et al., 2009) and IC training (Berkman et al., 2014), further supporting the assumption that the lateral prefrontal cortex might serve to anticipate upcoming control demands across a range of executive control domains. Our results replicate and extend these findings by showing behavioral shifts toward proactive control after both IC and WM training, further suggesting some common executive resources in IC and WM processes. However, no effect was observed for older adults when both training procedures were combined for a group of participants. This would seem to suggest that aging brings greater impairment to cognitive flexibility, which is not generalizable to other cognitive domains, since we found training-related gains in other functions. In particular, context processing and task-goal maintenance significantly improved in the older adults from the executive control training condition. Response times for the A cues were significantly reduced. Moreover, at the neural level, increased activity in the PFC was observed in the comparison between the B and A cues after the training.

Speed of processing

Processing speed has been identified as one of the factors leading to cognitive deficits in the elderly (Salthouse, 1996, 2007). Therefore, although our speed training program was designed to provide a suitable control for the executive control training program, it was also of interest to evaluate its effects, especially in tasks related to processing speed. In addition, it was interesting to evaluate whether processing speed was also affected by executive control training. For this reason, this domain was specifically tested in the study with older adults (Experiment 2A). The measure of symbol comparison served as a control index to analyze speed training transfer. While we expected both groups to improve in this measure with training, surprisingly, only the executive control group demonstrated greater efficiency in processing symbols in the post-test. This is important since it suggests that general processing speed is not related to overall response speed and that it also involves more efficient performance of the cognitive processes involved in the tasks.

Abstract reasoning/fluid intelligence

Fluid intelligence was measured using Raven's Advanced Progressive Matrices (in young and older adults) and the Cattell Fair Culture tests (for older adults). Regarding the young adults, our results revealed some degree of specificity. Specifically, we observed a benefit for the IC training group but not for the WM training group. In terms of performance on both tasks as a measure of fluid intelligence, we observed only a reliable improvement for the older adults who underwent executive control training adults. The question of whether cognitive training could improve fluid intelligence is a recurrent controversial area of research, with a considerable number of studies reporting contradictory (Melby-Lervåg & Hulme, 2013; Shipstead et al., 2012) or supporting (Au et al., 2014; Morrison & Chein, 2011) data. Thus, our findings regarding the IC training group of young adults and the executive control training of older adults join others in demonstrating better reasoning performance after training. Karbach and Kray (2009) reported improved performance in a composite measure of reasoning after four sessions of task-switching training in children and young and older adults compared to an active control group. Similarly, Rueda et al. (2005) found benefits in a measure of reasoning after 5 and 10 days (Rueda et al., 2012) of executive control training in pre-school children relative to control groups (for failures to show such positive effects, see Enge et al., 2014; Thorell et al., 2009).

Our (young) group undergoing WM, however, did not show benefits in abstract reasoning. Although fluid intelligence and WM share common variances (Colom, 2004; Friedman et al., 2006; Harrison et al., 2015; Oberauer et al., 2005) and executive functions have been related to reasoning operations (Dempster & Corkill, 1999; Engle & Kane, 2004; Jarosz & Wiley, 2012; Shipstead et al., 2015), it is possible that our WM training participants did not reach the level of difficulty needed to demonstrate far transfer.

Episodic memory

We analyzed transfer to episodic memory (in older adults) using the retrieval practice paradigm (Anderson et al., 1994), which is a suitable tool for assessing two different processes: namely, forgetting and practice effects. It is well known that aging brings progressive decline in a variety of processes related to episodic memory (Reuter-Lorenz & Silvester, 2005; Zacks, Hasher, & Li, 2000), and extensive behavioral and neuropsychological research has highlighted the relevant role that executive control plays in episodic memory (Anderson, 2003, 2000; Dobbins et al., 2001; Johnson et al., 1993; Román et al., 2009; Schacter et al., 1984; Shimamura et al., 1991). In Experiment 3, we observed a specific deficit in older adults compared to young adults, which resulted in a lack of forgetting effect and a reduction in theta power in the mid-frontal cortical regions. We then wondered whether executive control training could compensate this inability to unintentionally forget. None of the groups of older adults showed a reliable forgetting effect after the training, and there were no differences between the two training conditions. This indicates that the mechanisms underlying retrieval-induced forgetting were not modulated by executive control training. We hypothesized that the lack of forgetting in older adults might be driven by the inhibitory deficits usually observed in the elderly (Gazzeley et al., 2005, Lustig et al., 2007). On the contrary, we observed an enhancement in episodic memory, as revealed by an increased practice effect after the executive control training intervention. Given that only those participants who were trained in executive control showed an enhanced practice effect, it seems that the training enabled older adults to benefit from what they practiced. This is consistent with previous findings showing that older adults can benefit from memory strategy instruction (Wenger & Shing, 2016).

Thus, our results suggest that executive control training benefits those memory processes that are repeatedly called into play when retrieving information from long-term memory. However, executive control training could not significantly compensate for the previously reported impairments in interference detection in older adults, which was revealed by a lack of forgetting. Given that our transfer hypothesis lay in the idea of shared neurocognitive substrates, the fact that executive control training did not impact inhibitory memory control might be suggestive of a smaller overlap across cognitive domains than expected. Alternatively, the lack of effect on memory control in older adults could also relate to the level of improvement achieved by them, which was not sufficient to promote transfer.

Reading comprehension

We also analyzed transfer to reading comprehension (in children) at different levels of processing: at the low level, by using a combined measure of lexical, phonological, semantic, and syntactical abilities, and at a high level of text comprehension, by using the situation model revision task. Reading comprehension is a highly demanding activity that recruits different processes, and it is widely accepted that WM and other executive functions play a key role in successful comprehension (Sesma et al. 2009; Cain et al., 2004; Swanson et al., 2006). During a school-based intervention, we observed that WM training did not benefit the reading processes involving lexical, phonological, semantic, and syntactical abilities, which is consistent with previous findings that failed to show training-related gains in tests of word decoding and orthographic verification, even though training did enhance reading comprehension (Dahlin, 2010). Moreover, basic comprehension skills (general reading efficiency) did not seem to be sensitive to the effects of WM training. In contrast, higher-order processes engaged at the text level were enhanced after WM training. We observed that the children who completed this training were more efficient at updating their situation models, although their inference-making ability was not affected by the intervention.

Regarding this latter absence of effect, Pérez et al. (2014) found that individual differences in cognitive control predicted updating but not inference generation. Thus, our results suggest that WM training only enhances reading comprehension processes (i.e., updating) that largely rely on WM.

Individual Differences in Training and Transfer Effects

There is compelling evidence to suggest that cognitive training is not equally effective for all participants across all studies. Meta-analytic work has pointed out a number of potential factors that may modulate transfer effects in training studies (Au, 2014; Karbach & Vergueghen, 2014; Melby-Lervag, 2016, 2013; Schwaignofer, 2015). In particular, these studies have considered factors such as the type of cognitive training (strategy-based, process-based, multi-domain with one or more tasks), participants' age (children, younger and older adults), participants' status (healthy and normal functioning versus disabled or impaired cognitive capacities), personality factors (persistence (Nemmi, Nymberg, Helander, & Klingberg, 2016) or neuroticism and conscientiousness (Studer-Luethi, Jaeggi, Buschkuehl, & Perrig, 2012)), training dose (few versus many training sessions), training distribution (massed or spaced sessions), training leveling (adapted or fixed difficulty), randomization (randomized versus non-randomized), type of control group (treated/active versus non-treated/passive), remuneration for participation, the type of publication, the geographic location, etc. Unfortunately, however, the authors of these meta-analyses have disagreed about the appropriate methods for conducting a meta-analysis, which has resulted in mixed findings and, in some cases, contradictory conclusions about the overall efficacy of cognitive training. In this sense, the current controversy regarding the existence of far transfer effects highlights the importance of considering moderating variables when evaluating the effect of training (Könen & Karbach, 2015). Thus, attention to modulating variables might have significant implications, not only for our ability to improve our theoretical understanding of cognitive training, but also for implementing real-world individual interventions. In what follows, we will discuss the results derived from the analyses of individual differences in motivation and baseline performance across our set of training experiments. This focus on individual differences provides important insights into the development of future and more effective interventions aimed at promoting transfer.

Baseline capacities

Individual differences in cognitive functioning at baseline performance may predict training outcomes (see Jaeggi et al., 2013, for evidence in young adults and Borella et al., 2017, for older adults). Two different accounts of individual differences in training-related performance gains have been proposed: one based on compensation effects and the other on magnification effects (Karbach & Kray, 2016). Magnification implies that individuals who already perform well will benefit the most from executive control training ("the rich may get richer"), whereas compensation means that high-performing individuals will benefit less from training. In particular, we observed different compensation and magnification effects as a function of age. Our studies with children as well as with younger adults evidenced a magnification effect by which participants with higher capacities – specifically WM (children and young adults), reading comprehension (children), and fluid intelligence (younger adults) – reached higher levels of performance during executive control training. From this point of view, high-performing participants may have more efficient cognitive resources and, therefore, be in a better position to learn and implement new abilities. The positive relation between baseline cognitive performance and the training gains found here could stem from the fact that because the procedure used in our training program was highly demanding, only those with higher baseline capacities were able to reach and fulfill increased executive control demands. Thus, baseline cognitive performance should be positively associated with training-related gains, and training should result in a magnification of age and individual differences (Jaeggi et al., 2013; Katz et al., 2016). In fact, a number of earlier studies support this account, most of which are from the field of memory strategy training (for a review, see Rebok et al., 2007).

However, we observed the opposite (compensation) effect in our study with older adults. The lower the scores of the older adults in WMC and fluid intelligence on the pre-test, the greater their improvement during training. This effect is consistent with previous reports in the training literature on aging (Carretti et al., 2017; Karbach & Kray, 2016; Karbach & Unger 2014; Willis & Caske, 2013; Zinke et al., 2014). In the present study, the effect was similar for both conditions, since in the case of the active control, older adults with lower processing speed were the ones who gained the most during the training process.

Studies have also revealed a close relationship between training improvement and the magnitude of transfer, with many showing that the amount of improvement in training tasks does contribute to the amount of transfer gains in certain executive control and verbal WM tasks (Chein & Morrison, 2011; Jaeggi et al., 2011; Schmiedek et al., 2010). However, it is worth keeping in mind that the source of individual differences at the baseline may differ across studies. In some studies, individuals with lower baselines may have less experience or even be younger or older (Katz et al., 2016). It is also possible that different training paradigms may result in different patterns of performance across individuals with high and low baseline capacities. Finally, recent work has applied latent variable approaches to look at individual differences in performance changes and have provided evidence of the variability of the magnification and compensation effects after different procedures of executive control training (Könen & Karbach, 2015).

Motivation

Participants' motivation, either to complete the intervention or to improve their cognitive capacity, is a relevant factor that impacts training and transfer and, hence, is worthy of consideration. Across the studies, we assessed motivation and engagement during training by means of different self-report questionnaires, and a consistent finding was that motivation plays a role in improving performance, albeit only for executive control training.

In the case of the younger adults, the motivation questionnaire revealed similar levels of implication, perceived difficulty and perceived challenges, and expectations during training for the three experimental training groups, which indicates that transfer differences among the groups could not be due to differences in motivation or perceived difficulty. Interestingly, while motivation could not easily account for the differences between the training and control groups, it predicted training improvement in the experimental groups; thus, highly motivated participants – those who were more involved and perceived the training as less difficult – showed greater improvement across the training sessions than less-motivated participants. As for the older adults, we observed that motivation was only a significant modulator of training improvement in the executive control training condition and that those who perceived themselves as more competent and reported greater interest and enjoyment reached higher levels of performance on the WM activities during the training. Finally, we also observed that the children's engagement during training induced greater gains, but only for the WM training group. The fact that training engagement was a relevant predictor of improvement only for this training group suggests that when training involves easy low-demanding activities, the level of engagement does not affect performance and that it is only when training involves challenging activities, requiring high levels of engagement, that gains become larger (Katz et al., 2016; Maraver et al., 2016). This is consistent with the premise that specific, challenging (but achievable) goals tend to increase motivation and effort and thus improve performance (Locke & Latham, 2002).

Taken together, our results support the necessity of considering motivational factors when exploring the effects of training across different age populations. Apart from motivation, future studies should consider including additional self-reports regarding beliefs about the fixed or malleable nature of cognition (Jaeggi et al., 2013), expectancy, and perceived improvement (Boot et al., 2011).

The importance of considering individual differences is obvious from an applied point of view, especially when it comes to adapting training interventions to populations with special needs, such as children with learning difficulties or older adults. The apparent one-size-fits-all regarding training suggests that individual training paradigms need to be developed. Thus, we should not only ask whether executive control training works, on average, but also, for whom it works and in which contexts and situations.

Conclusions and Future Research Questions

What cognitive training tells us about brain plasticity

Cognitive training provides a scenario of an enriched environment (Hertzog et al., 2008; Karbach & Verbruggen, 2014), whereby participants may attempt to take their cognitive capacities to their limit in order to enhance them. Our results suggest that what is trained is not a specific process, but one or more executive components that can lead to generalization to other related cognitive domains because trained and non-trained functions share common capacities and brain networks (Miyake et al., 2000, 2012; Niedman, 2012). The general idea is that if executive control processes (WM, IC, and cognitive flexibility) can be enhanced, even just marginally, by training, other cognitive abilities that are strongly related to them (like reasoning, episodic memory, or reading comprehension) could also be enhanced. The fact that executive control training transfer to other components of executive functions, while these effects are smaller than the gains in the training tasks, is in line with the idea that executive control and executive functions are a set of separable but highly correlated control functions (Dahlin et al., 2010; Loosli et al., 2012; Maraver et al., 2016).

However, the question of whether valid far transfer effects to different cognitive functions exist is highly controversial. To date, this evolving research field has established a longstanding and heating debate, with empirical disagreements at all levels of evidence, including individual studies, systematic reviews, and meta-analyses (Karbach & Verhaeghen, 2014; Melby-Lervåg & Hulme, 2013; Morrison & Chein, 2011; Simons et al., 2016). The generalization of training effects to laboratory tasks seems to be reasonably well established – and our data clearly support this – although the durability of the improvement is open to question. From a more applied point of view, even small improvements in cognitive performance could be extremely relevant for individuals with cognitive deficits. Moreover, these small effects could even be significantly increased by paying attention to individual differences, which is why we need a more precise understanding of which features of training moderate the effectiveness of the intervention and how this effectiveness can be maximized (Oberauer et al., 2005). This should be a central determinant of the value of executive control interventions, since training outcomes need to generalize to other cognitive abilities to optimally support participants in their daily lives. As a result, the study of cognitive enhancement constitutes a research area that is certainly worthy of current efforts and future investigations (Colzato & Hommel, 2016).

Limitations

Despite the fact that our results are promising, it must be noted that the present research is not without limitations. First, the low statistical power due to small sample sizes and high variability among the groups in our studies of older adults and children presents a weakness. In a recent meta-analysis, Melby-Lervåg et al. (2016) established that training studies with large effect sizes normally included small sample sizes (less than 20 participants per training condition) and untreated (passive) control groups, which produce biases toward significant – but low-powered – results (see also Enge et al., 2014). In all of our studies, our samples exceeded 20 participants per condition, and we included active control groups and even a passive control group in the case of the study with younger adults. Second, our training interventions were short in comparison with the training procedures of other studies. However, studies with shorter interventions than ours have also reported positive training effects (Borella et al., 2010, 2014, 2017). Thus, the magnitude of the transfer effects when training is extended over longer periods of time is yet to be explored. Third, the absence of follow-up assessments removes the possibility of knowing precisely how long these putative training effects may last. Future studies should address this issue because the value of training interventions essentially relies on the durability of training-induced results. Fourth, to ensure that training and transfer effects reflect changes in the underlying cognitive abilities and not just particular task-specific skills, it might be necessary to demonstrate transfer at the level of abilities rather than at that of single tasks (Noack et al., 2009). Despite the promising evidence of our transfer effects in individual tasks, it is important to consider that not all studies have minimized task-specific overlaps between the training and the near transfer tasks (Shipstead et al., 2012). Ideally, transfer should be evaluated on the latent ability level. Evidence of near transfer effects on latent variables would be stronger in demonstrating training-induced increases in executive control functions and, thus, would be an optimal foundation for the investigation of far transfer effects. Thus, future research using large sample sizes and latent variable analyses would be of benefit in evaluating training-derived changes by increasing measurement validity. Finally, our studies did not consider the possibility of generalization to everyday activities. One of the most desired applications of training is its potential transfer to everyday life. The majority of training studies have focused primarily on laboratory-based measures when examining cognitive abilities, especially in older adults. Generalization can occur, but more research is still necessary to build a bridge between the laboratory and the real world. Some authors have proposed that a possible lab-to-life route could be to use training interventions with video games or serious game scenarios, such as those used in our interventions. The idea is to make participants work with tasks that match everyday challenges (Binder et al., 2015) and engage in novel and cognitively demanding activities (Spencer-Smith & Klingberg, 2015).

Reproducibility is an essential feature of psychological research, and specifically in the subfield of cognitive training, replication and follow-up studies are less common than expected. Furthermore, it is evident that cognitive training interventions often lack ecological validity. Thus, future research should make an attempt to join forces between experts in training and those in other fields (i.e., development) in order to design comprehensive, reliable, and valid test batteries for assessing training-related improvements outside the laboratory. This would help shed light on the effects of cognitive training, enhancement in overall functioning, as well as designing and making better use of training interventions and their transfer to all the dimensions of participants' lives.

Other attempts at enhancing executive control

The recent growth in cognitive training research parallels that of the industry of brain training devices and software. Programs are often built upon ideas from research, and in some cases, they include practice with similar tasks in a more "game-like" setting. Since Klingberg's program became commercially available, a wide range of variants emerged to explore other possible training regimes, often with apparent success. However, such training regimes tend to be poorly supported by scientific evidence and lack experimental control and adequate research trials. Consequently, this calls into question whether such commercial products really achieve anything of practical value. However, because there is a general social interest in enhancing cognitive abilities, adverts such as "become smarter" or "improve your memory" often underwrite commercial products that lack strict empirical elucidation as to whether advertised cognitive training effects are indeed effective. Studies have failed to report transfer using, for example, Brain Age and Mario Kart (Boot et al., 2013) and commercial brain training programs, as compared to with a reasoning and problem-solving control condition on a large-scale study that tested 11,000 (young/young-old) participants (Owen et al., 2010). Nevertheless, there are also published reports of transfer using commercial training software such as Brain Age with Tetris (Nouchi et al., 2012), the Lumosity training program (Ballesteros et al., 2014; Mayas, Parmentier, Andrés, & Ballesteros, 2014; Toril, Reales, Mayas, & Ballesteros, 2016), or even Nintendo Brain Training (McDougall & House, 2012) and video games (Colzato, van den Wildenberg, Zmigrod, & Hommel, 2013). Despite the appeal of these products in terms of transfer effects, such findings should be interpreted with caution, since the studies involve considerable variability in terms of essential methodological and experimental issues.

Despite this commercial interest, cognitive training – supported by systematic experimental designs and mechanistic theoretical models – may provide a highly enriched environment that challenges participants' cognitive abilities (Colzato & Hommel, 2016). It has long been known that living in environments that are rich in terms of cognitive challenges can affect an organism's cognitive ability. An early example of this was the study by Hebb (1947), which showed that old rats that had been raised in enriched environments were superior to their lab counterparts in cognitive performance, as measured by maze navigation. The literature is replete with other examples of environments that are rich and varied in terms of cognitive demands that have been shown to impact human cognition. For example, London taxi drivers have a larger posterior hippocampus than non-taxi drivers due to extensive training in road navigation (Maguire et al., 2000). Such changes are usually called enrichment effects since they are the result of "enriched" environments. Multilingual education (Bialystok & Martin, 2004; Carlson & Meltzoff, 2008; Morales, Calvo, et al., 2013), musical training (Benz, Sellaro, Hommel, & Colzato, 2016; Bergman-Nutley et al., 2014;

George & Coch, 2011), or mindfulness practice (Chambers, Lo, & Allen, 2008; Colzato, Szapora, Lippelt, & Hommel, 2017; Zeidan, Johnson, Diamond, David, & Goolkasian, 2010) also represent natural conditions of expertise and enriched environments that frequently lead to enhanced cognition.

Moreover, and in addition to the behavioral attempts at enhancing executive control, non-invasive brain stimulation techniques – in particular, transcranial direct current stimulation (tDCS), which modulates cortical excitability – provide causal links between brain areas and task performance. The use of this technique (Gill, Shah-Basak, & Hamilton, 2014; Gómez-Ariza & Morales, 2017; Miniussi et al., 2008) and its combination with cognitive training interventions (Au et al., 2016; Jones, Peterson, Blacker, & Berryhill, 2017; Katz et al., 2016) have demonstrated that executive control can be modulated and that even the generalization effects of training may be long-lasting.

To sum up and look forward

The current work supports the idea that executive functioning may be enhanced and challenges the long-standing assumption that cognitive abilities remain fixed over time. Training cognition is not a new concept (Boot & Kramer, 2014; Jolles & Crone, 2012; Schubert et al., 2014), but the idea that training and experience can generalize to tasks and domains beyond those trained remains controversial. Especially when it comes to far transfer, the existing evidence is mixed and has recently inspired heated debates in the field. Many inconsistent findings can be explained by large differences in the type and intensity of the training as well as in the research design and analytical methods applied (Anguera et al., 2013; Au et al., 2014; Karbach & Kray, 2009; Karbach & Unger, 2014; Kray & Fehér, 2014; Kray & Ferdinand, 2013; Strobach et al., 2014; Karbach & Verhaeghen, 2014). Skepticism is necessary and it is actually the way of good science. In this sense, our results, while modest at the task level rather than at the construct level, are promising and support substantial plasticity of cognitive control mechanisms by means of training across the lifespan. Interestingly, the results also suggest that there is some specificity in the consequences of the trained processes so that transfer occurs only when the specific trained process is tapped by the transfer task and domain. Taking previous and the present findings into account, transfer seems to occur more consistently if: i) the training is process-based and engage higher-order control processes such as executive control rather than task-specific strategies; ii) the training and transfer tasks recruit overlapping neurocognitive substrates, iii) the training is adaptive or variable, thus fostering greater generalization (by including changing tasks and processes); and iv) the training pushes cognitive functions to their limits by imposing extraordinary executive control demands (i.e., high WM load, high levels of interference, ambiguous stimuli, or changing task modalities). Evidence of transfer effects would significantly impact our theoretical understanding of executive control and transfer constructs in terms of plasticity. Furthermore, it could also positively impact future intervention programs, where even small gains could actually make a relevant difference to everyday life. The future of cognitive training is essentially dependent on methodological, theoretical, and societal development, with discussion between researchers being the active agent of such development (Colzato & Hommel, 2016). Thus, although training studies are considerably resource demanding for researchers, participants, and funders, larger samples will need to be included in future studies in order to substantiate that executive control training can give rise to broad and consistent transfer effects.

Our results contribute to the rapidly growing corpus of cognitive neuroscience research on the topic by providing additional evidence of the efficacy of executive control training in different age groups. This, undoubtedly, led us to conclude that executive control, as a domain-general system, is to some extent plastic. However, as stated by Diamond (2013), "since no two human brains are exactly alike, no one enriched environment will completely satisfy all learners for an extended period." The wide range of enriched environments for human beings is endless. For some, interacting physically with objects is gratifying; for others, working with creative ideas is most enjoyable, and for others still, reaching high levels of performance in cognitive training procedures is exciting and rewarding. Yet, despite the form of enrichment, it is the challenge to the brain function that is important. Data indicates that passive observation is not enough; one must interact with the environment: "one way to be certain of continued enrichment is to stimulate and maintain curiosity throughout a lifetime." (Diamond, 2013).

Capítulo IX

Resumen y Conclusiones

El entrenamiento de las funciones ejecutivas, como un medio para mejorar las capacidades cognitivas, ha recibido mucha atención en los últimos años. En este sentido, los estudios incluidos en esta tesis tienen como objetivo investigar hasta qué punto el entrenamiento en funciones ejecutivas se puede generalizar no solo a dominios cognitivos similares a los que se han entrenado, sino también a dominios no entrenados. Por lo tanto, nos centramos en investigar el rendimiento durante un entrenamiento basado en procesos y dirigido a mejorar las funciones ejecutivas, así como sus efectos de transferencia. Con este objetivo como referencia, nuestro programa de entrenamiento se ha basado en el modelo teórico de "Unidad y Diversidad" de las funciones ejecutivas propuesto por Miyake y cols. (2000). El principal rasgo de este modelo es que el sistema de funciones ejecutivas se puede descomponer en procesos que se solapan (unidad) y a su misma vez difieren (diversidad). De esta manera, nuestro programa incluye tareas de entrenamiento diseñadas para implicar inhibición, flexibilidad, y actualización, con el objetivo de desarrollar ampliamente el sistema de control ejecutivo. Esperábamos efectos de transferencia basados en la hipótesis de que los procesos entrenados y no entrenados comparten recursos cognitivos y bases neurales (Miyake & Friedman, 2012; Miyake y cols., 2000; Niendam y cols., 2012). Los resultados de este conjunto de experimentos apoyan la hipótesis de unidad y diversidad de las funciones ejecutivas. Aunque no se ha comparado directamente entre estudios, la inclusión de muestras de participantes de adultos jóvenes, mayores y niños nos permite explorar cómo de modificables son las funciones ejecutivas en función de la edad. Por lo tanto, los resultados de estas series experimentales proporcionan nuevos datos para el estudio del entrenamiento cognitivo como un medio para mejorar el control ejecutivo, considerando la plasticidad neurocognitiva a lo largo de distintas etapas de la vida.

A través de la presente serie de experimentos desafiamos la premisa de que los procesos cognitivos permanecen fijos y estáticos a lo largo del tiempo, y establecimos objetivos específicos en cada uno de los estudios. En el Experimento 1, analizamos la especificidad del entrenamiento del control ejecutivo, comparando directamente un programa de entrenamiento centrado en la memoria de trabajo, con otro basado en el control inhibitorio en una población de adultos jóvenes. Como rasgo destacable, incluimos un grupo de entrenamiento en velocidad de procesamiento que actuó como grupo control activo, y también un grupo control pasivo. Nuestros resultados demuestran los beneficios del entrenamiento en inhibición y memoria de trabajo en tareas experimentales de dominios cognitivos relacionados, tales como la memoria de trabajo, la inhibición o el ajuste entre mecanismos de control proactivo y reactivo (efectos de transferencia cercana). Además, demuestran que el entrenamiento del control inhibitorio también puede generalizarse a dominios no relacionados como el razonamiento abstracto/inteligencia fluida (transferencia lejana). En el Experimento 2A, investigamos los efectos de entrenamiento y transferencia de un programa de intervención en control ejecutivo en personas mayores de 60 años con envejecimiento normal. Teniendo en cuenta que hay numerosos datos que demuestran que el envejecimiento conlleva un declive progresivo de funciones ejecutivas, comparamos los posibles efectos del entrenamiento en control ejecutivo (combinando actividades de memoria de trabajo y control inhibitorio) con un grupo de entrenamiento en velocidad como condición control. De la misma manera que en el estudio con adultos jóvenes, observamos transferencia del entrenamiento del control ejecutivo a medidas de memoria de trabajo, control inhibitorio, velocidad de procesamiento y razonamiento. En cuanto al ajuste entre procesos de control proactivo y reactivo, observamos un beneficio del entrenamiento tanto a nivel comportamental como neural sobre el mantenimiento de objetivos y el procesamiento del contexto, procesos cognitivos en los que los mayores suelen mostrar dificultades. Yendo un paso más allá en el estudio de los efectos de transferencia lejana, y teniendo en cuenta los déficits de memoria episódica que frecuentemente se observan en el envejecimiento, realizamos el Experimento 3 como una primera aproximación a las diferencias entre jóvenes y mayores en el recuerdo episódico. En este estudio, nos interesamos por las bases neurales de la memoria episódica utilizando el paradigma de práctica en la recuperación, y observamos cómo los mayores muestran una menor actividad en la banda de frecuencias theta (~6-8 Hz) en comparación con los jóvenes. Este resultado nos sugiere una dificultad de los mayores para detectar la interferencia entre la información que compite al intentar recuperar información episódica. Ya que los fallos de memoria episódica ocurren con frecuencia en las poblaciones de mayores, también hemos querido analizar la posible transferencia del entrenamiento del control ejecutivo a un dominio no entrenado, pero muy estrechamente relacionado, como es la memoria episódica. Con este objetivo, comparamos el rendimiento en la tarea de práctica en la recuperación (similar al Experimento 3) entre mayores que realizaron el entrenamiento en control ejecutivo y los que realizaron el entrenamiento en velocidad (también como grupo control activo). En este estudio, observamos que los mayores entrenados en control ejecutivo se beneficiaron de la práctica y fueron capaces de mejorar el recuerdo de la información que recuperan sistemáticamente durante la fase de práctica, en comparación con el grupo que entrenó velocidad. A nivel neural, esta mejora en el recuerdo se acompaña de una mayor actividad en las bandas de frecuencias alfa/beta (~8-20 Hz). Finalmente, en la última serie experimental, analizamos los efectos de transferencia lejana del entrenamiento de la memoria de trabajo en la comprensión lectora de niños. Tanto la memoria de trabajo como los procesos de control ejecutivo están muy implicados en la comprensión lectora (Alloway y cols., 2005; Carretti y cols., 2009; Daneman & Carpenter, 1980, 2006). Por lo tanto, en el Experimento 4 desarrollamos un programa de entrenamiento dentro del contexto escolar en el que comparamos los efectos del entrenamiento en control ejecutivo con el entrenamiento en velocidad (como control activo), y observamos su transferencia a procesos de comprensión lectora de alto nivel como la actualización de la información durante la comprensión de textos.

Junto con los objetivos teóricos, una meta adicional de este trabajo ha sido controlar factores metodológicos que frecuentemente son objeto de discusión en los estudios de entrenamiento de la literatura actual (Melby-Lervåg y cols., 2016; Shipstead y cols., 2012; Simons y cols., 2016). En primer lugar, el tipo y naturaleza de los grupos controles determina su efectividad como condición de comparación. En este sentido, un aspecto destacable de nuestros estudios es la inclusión de grupos controles activos que trabajaron con tareas que únicamente requerían velocidad de procesamiento, lo que nos permitía mantener un nivel de motivación similar entre los grupos (ver Goldin y cols., 2014; Lawlor-Savage & Goghari, 2016, para aproximaciones similares). Los estudios que solo utilizan controles pasivos únicamente permiten controlar los efectos de test-retest, mientras que el uso de controles activos permite controlar la motivación y las expectativas de los participantes que puedan condicionar las ganancias durante el entrenamiento. Por lo tanto, en nuestro caso, el empleo sistemático de una condición de control activo en los distintos estudios nos permite disociar los efectos específicos de las distintas condiciones experimentales de entrenamiento. En segundo lugar, consideramos la naturaleza de los programas de entrenamiento. En la literatura también se cuestiona si el uso de una única tarea de entrenamiento conlleva efectos de generalización más amplios y de mayor magnitud. En nuestros estudios, planteamos un enfoque basado en procesos y utilizamos distintas tareas de entrenamiento para aumentar la probabilidad de generalización. Por último, consideramos un tercer factor de gran relevancia: las diferencias individuales. Ya que el entrenamiento cognitivo no produce los mismos beneficios en todos los individuos, la hipótesis de la "talla única" no tiene cabida en este campo de investigación en particular. Por lo tanto, tener en cuenta las diferencias individuales en cuanto a motivación o capacidades de línea de base es esencial para apoyar los efectos positivos del entrenamiento, y se han tenido en cuenta a lo largo de todos los estudios desarrollados en esta tesis.

El entrenamiento cognitivo pretende mejorar el nivel inicial de los individuos entrenados (Boot & Kramer, 2014; Jolles & Crone, 2012; Schubert y cols., 2014), pero los efectos de transferencia a tareas y dominios cognitivos más allá de los entrenados constituyen un tema de investigación controvertido. Especialmente en los efectos de transferencia lejana, los resultados son variables, inconsistentes y diversos, desencadenando intensos debates en el área con resultados tanto a favor como en contra (Anguera y cols., 2013; Au y cols., 2014; Karbach & Kray, 2009; Karbach & Unger, 2014; Kray & Fehér, 2014; Kray & Ferdinand, 2013; Strobach y cols., 2014; Karbach & Verhaeghen, 2014). El escepticismo es necesario y además marca la ciencia bien hecha. A pesar de que muchos actualmente consideran la investigación sobre entrenamiento como un campo "científicamente infértil", estos y otros muchos resultados siguen sugiriendo que estudiar cómo se pueden mejorar las funciones cognitivas aún merece la pena. En este sentido, nuestros resultados, aunque modestos y a nivel de tarea, hacen una contribución relevante en el campo de la neurociencia cognitiva, y apoyan la plasticidad del control ejecutivo como resultado del entrenamiento cognitivo en distintas etapas de la vida.

References

Aguirre, C., Gómez-Ariza, C. J., Bajo, M. T., Andrés, P., & Mazzoni, G. (2014). Selective voluntary forgetting in young and older adults. *Psychology and Aging*, *29*(1), 128–39. doi:10.1037/a0035598

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, *106*(1), 20–29. doi:10.1016/j.jecp.2009.11.003

Alloway, T. P., Bibile, V., & Lau, G. (2013). Computerized working memory training: Can it lead to gains in cognitive skills in students? *Computers in Human Behavior*, *29*(3), 632–638. doi:10.1016/j.chb.2012.10.023

Alloway, T. P., Gathercole, S. E., Adams, A.-M., Willis, C., Eaglen, R., & Lamont, E. (2005). Working memory and phonological awareness as predictors of progress towards early learning goals at school entry. *British Journal of Developmental Psychology*, *23*(3), 417–426. doi:10.1348/026151005X26804

Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2009). The cognitive and behavioral characteristics of children with low working memory. *Child Development*, *80*, 606–621. doi:10.1111/j.1467-8624.2009.01282.x

Alonso-Tapia, J., & de la Red Fadrique, I. (2007). Evaluar "para" el aprendizaje, aprender para estar motivado: el orden de los factores sí afecta al producto. *Revista Española de Orientación Y Psicopedagogía.*, *18*, 241–253.

Altmann, G. T. M., & Kamide, Y. (1999). Incremental interpretation at verbs: Restricting the domain of subsequent reference. *Cognition*, *73*(3), 247–264. doi:10.1016/S0010-0277(99)00059-1

Anderson, M. C. (2003). *Rethinking interference theory: Executive control and the mechanisms of forgetting. Journal of Memory and Language* (Vol. 49). doi:10.1016/j.jml.2003.08.006

Anderson, M. C., Bjork, E., & Bjork, R. (2000). Retrieval-induced forgetting: Evidence for a recall-specific mechanism. *Psychonomic Bulletin & Review*, *7*(3), 522–530. doi:10.3758/BF03214366

Anderson, M. C., Bjork, R. a, & Bjork, E. L. (1994). Remembering Can Cause Forgetting: Retrieval Dynamics in Long-Term Memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(5), 1063–1087. doi:10.1037/0278-7393.20.5.1063

Anderson, M. C., Reinholz, J., Kuhl, B. a., & Mayr, U. (2011). Intentional suppression of unwanted memories grows more difficult as we age. *Psychology and Aging*, *26*(2), 397–405. doi:10.1037/a0022505

Anguera, J. a, Boccanfuso, J., Rintoul, J. L., Al-Hashimi, O., Faraji, F., Janowich, J., … Gazzaley, a. (2013). Video game training enhances cognitive control in older adults. *Nature*, *501*(7465), 97–101. doi:10.1038/nature12486

Arrington, C. N., Kulesz, P. a, Francis, D. J., Fletcher, J. M., & Barnes, M. a. (2014). The contribution of attentional control and working memory to reading comprehension and decoding. *Scientific Studies of Reading*, *18*(5), 325–346. doi:10.1080/10888438.2014.902461

Aslan, A., & Bäuml, K.-H. T. (2012). Retrieval-induced forgetting in old and very old age. *Psychology and Aging*, *27*(4), 1027–1032. doi:10.1037/a0028379

Au, J., Katz, B., Buschkuehl, M., Bunarjo, K., Senger, T., Zabel, C., … Jonides, J. (2016). Enhancing Working Memory Training with Transcranial Direct Current Stimulation. *Journal of Cognitive Neuroscience*, *28*(9), 1419–1432.

Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Jaeggi, S. M. (2014). Improving fluid intelligence with training on working memory: a meta-analysis. *Psychonomic Bulletin & Review*, *105*(19), 6829–6833. doi:10.3758/s13423-014-0699-x

Axmacher, N., Mormann, F., Fernández, G., Elger, C. E., & Fell, J. (2006). Memory formation by neuronal synchronization. *Brain Research Reviews*, *52*(1), 170–182. doi:10.1016/j.brainresrev.2006.01.007

Bäckman, L. (1989). Varieties of memory compensation by older adults. In Poon, L.W., D. C. Rubin, & B. A. Wilson (Eds.), *Everyday Cognition in Adulthood and Late Life* (pp. 509–544). New York, NY: Cambridge University Press.

Bäckman, L., & Nyberg, L. (2013). Dopamine and training-related working-memory improvement. *Neuroscience and Biobehavioral Reviews*, *37*(9), 2209–2219. doi:10.1016/j.neubiorev.2013.01.014

Baddeley, A. (1996). Exploring the Central E xecutive. *The Quarterly Journal of Experimental Psychology*, *49A*(1), 5–28. doi:10.1080/713755608

Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature Reviews Neuroscience*, *4*(10), 829–839. doi:10.1038/nrn1201

Baddeley, A. (2012). Working Memory: Theories, Models, and Controversies. *Annual Review of Psychology*, *63*(1), 1–29. doi:10.1146/annurev-psych-120710-100422

Baddeley, A. D., & Hitch, G. J. (1974). Working Memory. *Psychology of Learning and Motivation*, *8*, 47–89. doi:10.1016/S0079-7421(08)60452-1

Baddeley, A. D., & Hitch, G. J. (2000). Development of Working Memory: Should the Pascual-Leone and the Baddeley and Hitch Models Be Merged? *Journal of Experimental Child Psychology*, *77*(2), 128–137. doi:10.1006/jecp.2000.2592

Baddeley, A., Eysenck, M. W., & Anderson, M. C. (2015). *Memory*. Psychology Press. doi:10.1017/CBO9781107415324.004

Bajo, M. T., Gómez-Ariza, C. J., Fernandez, A., & Marful, A. (2006). Retrieval-induced forgetting in perceptually driven memory tests. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*(5), 1185–1194. doi:10.1037/0278-7393.32.5.1185

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., … Willis, S. L. (2002). Effects of Cognitive Training Interventions With Older Adults. *Library*, *288*(18), 2271–2281. doi:10.1001/jama.288.18.2271

Ball, K., Edwards, J. D., Ross, L. a., & McGwin, G. (2010). Cognitive training decreases motor vehicle collision involvement of older drivers. *Journal of the American Geriatrics Society*, *58*(11), 2107–2113. doi:10.1111/j.1532-5415.2010.03138.x

Ballesteros, S., Prieto, A., Mayas, J., Toril, P., Pita, C., Ponce de León, L., … Waterworth, J. (2014). Brain training with non-action video games enhances aspects of cognition in older adults: a randomized controlled trial. *Frontiers in Aging Neuroscience*, *6*(October), 277. doi:10.3389/fnagi.2014.00277

Banducci, S. E., Daugherty, A. M., Biggan, J. R., Cooke, G. E., Voss, M., Noice, T., … Kramer, A. F. (2017). Active Experiencing Training Improves Episodic Memory Recall in Older Adults, *9*(May), 1–11. doi:10.3389/fnagi.2017.00133

Banich, M. T. (2009). Executive Functions: The Search for an Integrated Account. *Current Directions in Psychological Science*, *18*(2), 89–94. doi:10.1111/j.1467-8721.2009.01615.x

Baniqued, P. L., Allen, C. M., Kranz, M. B., Johnson, K., Sipolins, A., Dickens, C., … Kramer, A. F. (2015). Working memory, reasoning, and task switching training: Transfer effects, limitations, and great expectations? *PLoS ONE*, *10*(11), 1–29. doi:10.1371/journal.pone.0142169

Baniqued, P. L., Kranz, M. B., Voss, M. W., Lee, H., Cosman, J. D., Severson, J., & Kramer, A. F. (2014). Cognitive training with casual video games: points to consider. *Frontiers in Psychology*, *4*(January), 1010. doi:10.3389/fpsyg.2013.01010

Barch, D. M., Braver, T. S., Akbudak, E., Conturo, T., Ollinger, J., & Snyder, a. (2001). Anterior cingulate cortex and response conflict: effects of response modality and processing domain. *Cerebral Cortex (New York, N.Y. : 1991)*, *11*(9), 837–848. doi:10.1093/cercor/11.9.837

Barkley, R. a. (2001). The Executive Functions and Self-Regulation: An Evolutionary Neuropsychological Perspective. *Neuropsychology Review*, *11*(1), 1–29. doi:10.1023/A:1009085417776

Barnes, D., Yaffe, K., & Belfor, N. (2009). Computer-based cognitive training for mild cognitive impairment: results from a pilot randomized, controlled trial. *Alzheimer Disease …*, *23*(3), 205–210. doi:10.1097/WAD.0b013e31819c6137.Computer-Based

Beauchamp, K. G., Kahn, L. E., & Berkman, E. T. (2016). Does inhibitory control training transfer?: Behavioral and neural effects on an untrained emotion regulation task. *Social Cognitive and Affective Neuroscience*, (May), 1–28. doi:10.1093/scan/nsw061

Bedard, A., Nichols, S., Jose, A., Schachar, R., Logan, G. D., & Tannock, R. (2002). The Development of Selective Inhibitory Control Across the Life Span. *Developmental Neuropsychology*, *21*(1), 93–111. doi:10.1207/S15326942DN2101

Benikos, N., Johnstone, S. J., & Roodenrys, S. J. (2013). Short-term training in the Go/Nogo task: Behavioural and neural changes depend on task demands. *International Journal of Psychophysiology*, *87*(3), 301–312. doi:10.1016/j.ijpsycho.2012.12.001

Benz, S., Sellaro, R., Hommel, B., & Colzato, L. S. (2016). Music makes the world go round: The impact of musical training on non-musical cognitive functions-a review. *Frontiers in Psychology*, *6*(JAN), 1–5. doi:10.3389/fpsyg.2015.02023

Bergman-Nutley, S., Darki, F., & Klingberg, T. (2014). Music practice is associated with development of working memory during childhood and adolescence. *Frontiers in Human Neuroscience*, *7*(January), 1–9. doi:10.3389/fnhum.2013.00926

Bergman-Nutley, S., & Klingberg, T. (2014). Effect of working memory training on working memory, arithmetic and following instructions. *Psychological Research*, *78*(6), 869–77. doi:10.1007/s00426-014-0614-0

Berkman, E. T., Kahn, L. E., & Merchant, J. S. (2014). Training-induced changes in inhibitory control network activity. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *34*(1), 149–57. doi:10.1523/JNEUROSCI.3564-13.2014

Berlucchi, G., & Buchtel, H. a. (2009). Neuronal plasticity: Historical roots and evolution of meaning. *Experimental Brain Research*, *192*(3), 307–319. doi:10.1007/s00221-008-1611-6

Berry, A. S., Zanto, T. P., Clapp, W. C., Hardy, J. L., Delahunt, P. B., Mahncke, H. W., & Gazzaley, A. (2010). The influence of perceptual training on working memory in older adults. *PLoS ONE*, *5*(7). doi:10.1371/journal.pone.0011537

Berryhill, M. E., & Hughes, H. C. (2009). On the minimization of task switch costs following long-term training. *Attention, Perception & Psychophysics*, *71*(3), 503–514. doi:10.3758/APP

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training Effects on Dual-Task Performance : Are There Age-Related Differences in Plasticity of Attentional Control ?, *20*(4), 695–709. doi:10.1037/0882-7974.20.4.695

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2006). Testing the limits of cognitive plasticity in older adults: Application to attentional control. *Acta Psychologica*, *123*(3), 261–278. doi:10.1016/j.actpsy.2006.01.005

Bialystok, E., & Martin, M. M. (2004). Attention and inhibition in bilingual children: evidence from the dimentional change card sort task. *Developmental Science*, *7*(3), 325–339. doi:10.1111/j.1467-7687.2004.00351.x

Binder, J. C., Martin, M., Zöllig, J., Röcke, C., Mérillat, S., Eschen, A., … Shing, Y. L. (2016). Multi-domain training enhances attentional control. *Psychology and Aging*, *31*(4), 390–408. doi:10.1037/pag0000081

Biss, R. K., Campbell, K. L., & Hasher, L. (2013). Interference from previous distraction disrupts older adults' memory. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, *68*(4), 558–561. doi:10.1093/geronb/gbs074

Blair, C., & Razza, R. P. (2007). Relating Effortful Control , Executive Function , and False Belief Understanding to Emerging Math and Literacy Ability in Kindergarten Author (s): Clancy Blair and Rachel Peters Razza Published by : Wiley on behalf of the Society for Research in Child D, *78*(2), 647–663.

Bogg, T., & Lasecki, L. (2015). Reliable gains? Evidence for substantially underpowered designs in studies of working memory training transfer to fluid intelligence. *Frontiers in Psychology*, *5*(January), 1–8. doi:10.3389/fpsyg.2014.01589

Bojko, A., Kramer, A. F., & Peterson, M. S. (2004). Age equivalence in switch costs for prosaccade and antisaccade tasks. *Psychology and Aging*, *19*(1), 226–234. doi:10.1037/0882-7974.19.1.226

Boot, W. R., Blakely, D. P., & Simons, D. J. (2011). Do action video games improve perception and cognition? *Frontiers in Psychology*, *2*(SEP), 1–6. doi:10.3389/fpsyg.2011.00226

Boot, W. R., Champion, M., Blakely, D. P., Wright, T., Souders, D. J., & Charness, N. (2013). Video Games as a Means to Reduce Age-Related Cognitive Decline: Attitudes, Compliance, and Effectiveness. *Frontiers in Psychology*, *4*(February), 1–9. doi:10.3389/fpsyg.2013.00031

Boot, W. R., & Kramer, A. F. (2014). The Brain-Games Conundrum: Does Cognitive Training Really Sharpen the Mind? *Cerebrum: The Dana Forum on Brain Science*, *2014*(November), 15. doi:PMC4445580

Boot, W. R., Simons, D. J., Stothart, C., & Stutts, C. (2013). The Pervasive Problem With Placebos in Psychology: Why Active Control Groups Are Not Sufficient to Rule Out Placebo Effects. *Perspectives on Psychological Science*, *8*(4), 445–454. doi:10.1177/1745691613491271

Borella, E., Carbone, E., Pastore, M., De Beni, R., & Carretti, B. (2017). Working Memory Training for Healthy Older Adults: The Role of Individual Characteristics in Explaining Short- and Long-Term Gains. *Frontiers in Human Neuroscience*, *11*(March). doi:10.3389/fnhum.2017.00099

Borella, E., Carretti, B., Cantarella, A., Riboldi, F., Zavagnin, M., & De Beni, R. (2014). Benefits of training visuospatial working memory in young-old and old-old. *Developmental Psychology*, *50*(3), 714–27. doi:10.1037/a0034293

Borella, E., Carretti, B., & De Beni, R. (2008). Working memory and inhibition across the adult life-span. *Acta Psychologica*, *128*(1), 33–44. doi:10.1016/j.actpsy.2007.09.008

Borella, E., Carretti, B., Riboldi, F., & De Beni, R. (2010). Working memory training in older adults: evidence of transfer and maintenance effects. *Psychology and Aging*, *25*(4), 767–78. doi:10.1037/a0020683

Borella, E., Ghisletta, P., & Ribeaupierre, A. De. (2011). Age differences in text processing: The role of working memory, inhibition, and processing speed. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, *66*(3), 311–320. doi:10.1093/geronb/gbr002.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences*, *8*(12), 539–546. doi:10.1016/j.tics.2004.10.003

Bowers, P. N., Kirby, J. R., & Deacon, S. H. (2010). The Effects of Morphological Instruction on Literacy Skills: A Systematic Review of the Literature. *Review of Educational Research*, *80*(2), 144–179. doi:10.3102/0034654309359353

Braver, T. S. (2012). The variable nature of cognitive control: A dual-mechanisms framework. *Trends in Cognitive Sciences*, *16*(2), 106–113. doi:10.1016/j.tics.2011.12.010.The

Braver, T. S., & Cohen, J. D. (2001). Working memory, cognitive control, and prefrontal cortex: Computational and empirical studies. *Cognitive Processing*, *2*, 25–55.

Braver, T. S., Paxton, J. L., Locke, H. S., & Barch, D. M. (2009). Flexible neural mechanisms of cognitive control within human prefrontal cortex. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(18), 7351–6. doi:10.1073/pnas.0808187106

Braver, T. S., Satpute, A. B., Rush, B. K., Racine, C. a., & Barch, D. M. (2005). Context Processing and Context Maintenance in Healthy Aging and Early Stage Dementia of the Alzheimer's Type. *Psychology and Aging*, *20*(1), 33–46. doi:10.1037/0882-7974.20.1.33

Brehmer, Y., Kalpouzos, G., Wenger, E., & Lövdén, M. (2014). Plasticity of brain and cognition in older adults. *Psychological Research*, *78*(6), 790–802. doi:10.1007/s00426-014-0587-z

Brehmer, Y., Li, S.-C., Müller, V., von Oertzen, T., & Lindenberger, U. (2007). Memory plasticity across the life span: Uncovering children's latent potential. *Developmental Psychology*, *43*(2), 465–478. doi:10.1037/0012-1649.43.2.465

Brehmer, Y., Rieckmann, A., Bellander, M., Westerberg, H., Fischer, H., & B??ckman, L. (2011). Neural correlates of training-related working-memory gains in old age. *NeuroImage*, *58*(4), 1110–1120. doi:10.1016/j.neuroimage.2011.06.079

Brehmer, Y., Shing, Y. L., Heekeren, H. R., Lindenberger, U., & Bäckman, L. (2016). Training-induced changes in subsequent-memory effects: No major differences among children, younger adults, and older adults. *NeuroImage*, *131*, 214–225. doi:10.1016/j.neuroimage.2015.11.074

Brehmer, Y., Westerberg, H., & Bäckman, L. (2012). Working-memory training in younger and older adults: training gains, transfer, and maintenance. *Frontiers in Human Neuroscience*, *6*(March), 1–7. doi:10.3389/fnhum.2012.00063

Buckner, R. L. (2004). Memory and executive function in aging and ad: Multiple factors that cause decline and reserve factors that compensate. *Neuron*, *44*(1), 195–208. doi:10.1016/j.neuron.2004.09.006

Bühner, M., König, C. J., Pick, M., & Krumm, S. (2006). Working Memory Dimensions as Differential Predictors of the Speed and Error Aspect of Multitasking Performance. *Human Performance*, *19*(3), 253–275. doi:10.1207/s15327043hup1903_4

Bull, R., & Scerif, G. (2001). Executive functionin as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*, *19*(3), 273–293. doi:10.1207/S15326942DN1903

Burgess, A., & Gruzelier, J. (2000). Short duration power changes in the EEG during recognition memory for words and faces. *Psychophysiology*, *37*(5), 596–606. doi:10.1111/1469-8986.3750596

Burgess, G. C., & Braver, T. S. (2010). Neural mechanisms of interference control in working memory: Effects of interference expectancy and fluid intelligence. *PLoS ONE*, *5*(9), 1–11. doi:10.1371/journal.pone.0012861

Burgess, G. C., Gray, J. R., Conway, A. R., & Braver, T. S. (2011). Neural mechanisms of interference control underlie the relationships between Fluid intelligence and working memory span. *Journal of Experimental Psychology. General*, *140*(4), 674–92. doi:10.1037/a0024695.Neural

Burke, D., & Light, L. (1981). Memory and aging: The role of retrieval processes. *Psychological Bulletin*, *90*(3), 513–546.

Burke, J. F., Long, N. M., Zaghloul, K. a., Sharan, A. D., Sperling, M. R., & Kahana, M. J. (2014). Human intracranial high-frequency activity maps episodic memory formation in space and time. *NeuroImage*, *85*, 834–843. doi:10.1016/j.neuroimage.2013.06.067

Bürki, C. N., Ludwig, C., Chicherio, C., & de Ribaupierre, A. (2014). Individual differences in cognitive plasticity: an investigation of training curves in younger and older adults. *Psychological Research*, *78*(6), 821–835. doi:10.1007/s00426-014-0559-3

Buschkuehl, M., Jaeggi, S. M., Hutchison, S., Perrig-Chiello, P., Däpp, C., Müller, M., … Perrig, W. J. (2008). Impact of working memory training on memory performance in old-old adults. *Psychology and Aging*, *23*(4), 743–753. doi:10.1037/a0014342

Buschkuehl, M., Jaeggi, S. M., & Jonides, J. (2012). Neuronal effects following working memory training. *Developmental Cognitive Neuroscience*, *2*(SUPPL. 1), S167–S179. doi:10.1016/j.dcn.2011.10.001

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends.Cogn Sci.*, *4*(6), 215–222. doi:10.1016/S1364-6613(00)01483-2

Butler, K. M., & Zacks, R. T. (2006). Age deficits in the control of prepotent responses: evidence for an inhibitory decline. *Psychology and Aging*, *21*(3), 638–643. doi:10.1037/0882-7974.21.3.638

Cabeza, R., Anderson, N. D., Locantore, J. K., & McIntosh, A. R. (2002). Aging Gracefully: Compensatory Brain Activity in High-Performing Older Adults. *NeuroImage*, *17*(3), 1394–1402. doi:10.1006/nimg.2002.1280

Cabeza, R., Ciaramelli, E., Olson, I., & Moscovitch, M. (2009). Parietal Cortex and Episodic Memory: An Attentional Account. *Nature Reviews …*, *9*(8), 613–625. doi:10.1038/nrn2459.Parietal

Cabeza, R., Daselaar, S., Dolcos, F., Prince, S., Budde, M., & Nyberg, L. (2004). Task-independent and Task-specific Age Effects on Brain Activity during Working Memory, Visual Attention and Episodic Retrieval. *Cerebral Cortex*, *14*(4), 364–375. doi:10.1093/cercor/bhg133

Cabeza, R., Grady, C. L., Nyberg, L., McIntosh, a R., Tulving, E., Kapur, S., … Craik, F. I. (1997). Age-related differences in neural activity during memory encoding and retrieval: A positron emission tomography study. *Journal of Neuroscience*, *17*(1), 391–400. doi:0270-6474/96/170391-10$05.00/0

Cahana-Amitay, D., & Albert, M. L. (2014). Brain and Language : Evidence for Neural Multifunctionality. *Behavioural Neurology*, *2014*(1). doi:10.1155/2014/260381

Cahn-Weiner, D. a, Boyle, P. a, & Malloy, P. F. (2002). Tests of executive function predict instrumental activities of daily living in community-dwelling older individuals. *Applied Neuropschology*, *9*(3), 187–191. doi:10.1207/S15324826AN0903

Cain, K., Cain, K., Oakhill, J., & Bryant, P. (2004). Children ' s Reading Comprehension Ability : Concurrent Prediction by Working Memory , Verbal Ability , and Component Skills Children ' s Reading Comprehension Ability : Concurrent Prediction by Working Memory , Verbal Ability , and Component Skills, (MARCH 2004). doi:10.1037/0022-0663.96.1.31

Cain, K. E., & Oakhill, J. V. (1999). Inference making ability and its relation to comprehension failure in young children. *Reading and Writing*, *11*(5/6), 489–503. doi:10.1023/A:1008084120205

Carlson, S. M., & Meltzoff, A. N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science*, *11*(2), 282–298. doi:10.1111/j.1467-7687.2008.00675.x

Carretti, B., Borella, E., Cornoldi, C., & De Beni, R. (2009). Role of working memory in explaining the performance of individuals with specific reading comprehension difficulties: A meta-analysis. *Learning and Individual Differences*, *19*(2), 246–251. doi:10.1016/j.lindif.2008.10.002

Carretti, B., Borella, E., Elosúa, M. R., Gómez-Veiga, I., & García-Madruga, J. A. (2017). Improvements in Reading Comprehension Performance After a Training Program Focusing on Executive Processes of Working Memory. *Journal of Cognitive Enhancement*. doi:10.1007/s41465-017-0012-9

Carretti, B., Borella, E., Zavagnin, M., & De Beni, R. (2013). Gains in language comprehension relating to working memory training in healthy older adults. *International Journal of Geriatric Psychiatry*, *28*(5), 539–546. doi:10.1002/gps.3859

Carretti, B., Caldarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training programmes focusing on metacognition and working memory. *British Journal of Educational Psychology*, *84*(2), 194–210. doi:10.1111/bjep.12022

Carter, C. S. (1998). Anterior Cingulate Cortex, Error Detection, and the Online Monitoring of Performance. *Science*, *280*(5364), 747–749. doi:10.1126/science.280.5364.747

Case, R., Kurland, D. M., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology*, *33*(3), 386–404.

Cattell, R. B., & Cattell, A. K. S. (1963). *Cattell test of "g": Culture Fair*. Champaign, III.: Institute for Personality and Ability Testing.

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin*, *98*(1), 67–83. doi:10.1037/0033-2909.98.1.67

Chambers, R., Lo, B. C. Y., & Allen, N. B. (2008). The impact of intensive mindfulness training on attentional control, cognitive style, and affect. *Cognitive Therapy and Research*, *32*(3), 303–322. doi:10.1007/s10608-007-9119-0

Chapman, S. B., Aslan, S., Spence, J. S., Keebler, M. W., DeFina, L. F., Didehbani, N., … D'Esposito, M. (2016). Distinct Brain and Behavioral Benefits from Cognitive vs. Physical Training: A Randomized Trial in Aging Adults. *Frontiers in Human Neuroscience*, *10*(July), 1–15. doi:10.3389/fnhum.2016.00338

Chase, W. G., & Ericsson, K. A. (1982). Skill and working memory. *Psychology of Learning and Motivation - Advances in Research and Theory*, *16*(C), 1–58. doi:10.1016/S0079-7421(08)60546-0

Chein, J. M., Moore, A. B., & Conway, A. R. a. (2011). Domain-general mechanisms of complex working memory span. *NeuroImage*, *54*(1), 550–559. doi:10.1016/j.neuroimage.2010.07.067

Chein, J. M., & Morrison, A. B. (2010). Expanding the mind's workspace: training and transfer effects with a complex working memory span task. *Psychonomic Bulletin & Review*, *17*(2), 193–199. doi:10.3758/PBR.17.2.193

Chiappe, P., Hasher, L., & Siegel, L. S. (2000). Working memory, inhibitory control, and reading disability. *Memory & Cognition*, *28*(1), 8–17. doi:10.3758/BF03211570

Chiew, K. S., & Braver, T. S. (2014). Dissociable influences of reward motivation and positive emotion on cognitive control. *Cognitive, Affective & Behavioral Neuroscience*, *14*(2), 509–29. doi:10.3758/s13415-014-0280-0

Chiew, K. S., & Braver, T. S. (2017). Context processing and control in the human brain: from gating models to dual mechanisms. *The Wiley Handbook of Cognitive Control*, 143–166.

Chooi, W.-T., & Thompson, L. a. (2012). Working memory training does not improve intelligence in healthy young adults. *Intelligence*, *40*(6), 531–542. doi:10.1016/j.intell.2012.07.004

Clark, C. M., Lawlor-savage, L., & Goghari, V. M. (2017). Working memory training in healthy young adults : Support for the null from a randomized comparison to active and passive control groups, 1–25. doi:10.6084/m9.figshare.4551517

Cohen, M. X. (2014). A neural microcircuit for cognitive conflict detection and signaling. *Trends in Neurosciences*, *37*(9), 480–490. doi:10.1016/j.tins.2014.06.004

Colcombe, S. J., Kramer, A. F., Erickson, K. I., & Scalf, P. (2005). The Implications of Cortical Recruitment and Brain Morphology for Individual Differences in Inhibitory Function in Aging Humans. *Psychology and Aging*, *20*(3), 363–375. doi:10.1037/0882-7974.20.3.363

Colom, R., Román, F. J., Abad, F. J., Shih, P. C., Privado, J., Froufe, M., … Jaeggi, S. M. (2013). Adaptive n-back training does not improve fluid intelligence at the construct level: Gains on individual tests suggest that training may enhance visuospatial processing. *Intelligence*, *41*(5), 712–727. doi:10.1016/j.intell.2013.09.002

Colzato, L. S., & Hommel, B. (2016). The Future of Cognitive Training. In *Cognitive Training: An Overview of Features and Applications* (pp. 201–212). doi:10.1007/978-3-319-42662-4

Colzato, L. S., Slagter, H. a., de Rover, M., & Hommel, B. (2011). Dopamine and the Management of Attentional Resources: Genetic Markers of Striatal D2 Dopamine Predict Individual Differences in the Attentional Blink. *Journal of Cognitive Neuroscience*, *23*(11), 3576–3585. doi:10.1162/jocn_a_00049

Colzato, L. S., Szapora, A., Lippelt, D., & Hommel, B. (2017). Prior Meditation Practice Modulates Performance and Strategy Use in Convergent- and Divergent-Thinking Problems. *Mindfulness*, *8*(1), 10–16. doi:10.1007/s12671-014-0352-9

Colzato, L. S., van den Wildenberg, W. P. M., Zmigrod, S., & Hommel, B. (2013). Action video gaming and cognitive control: Playing first person shooter games is associated with improvement in working memory but not action inhibition. *Psychological Research*, *77*(2), 234–239. doi:10.1007/s00426-012-0415-2

Conway, A. R. a., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. . (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, *30*(2), 163–183. doi:10.1016/S0160-2896(01)00096-4

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user ' s guide. *Psychonomic Bulletin & Review*, *12*(5), 769–786.

Conway, A. R. a., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences*, *7*(12), 547–552. doi:10.1016/j.tics.2003.10.005

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information-processing system. *Psychological Bulletin*, *104*(2), 163–191. doi:10.1037/0033-2909.104.2.163

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, *24*(1), S0140525X01003922. doi:10.1017/S0140525X01003922

Cowan, N. (2010). The Magical Mystery Four. *Current Directions in Psychological Science*, *19*(1), 51–57. doi:10.1177/0963721409359277

Cowan, N., Elliott, E. M., Saults, S. J., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. a. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology*, *51*(1), 42–100. doi:10.1016/j.cogpsych.2004.12.001

Craik, F. I. (1994). Memory Changes in Normal Aging. *Current Directions in Psychological Science*, *3*(5), 155–158.

Craik, F., & Jennings, J. M. (1992). Human Memory. In F. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 51–110). Hillsdale, NJ: Erlbaum.

Cuetos, F., Rodríguez, B., Ruano, E., & Arribas, D. (2007). PROLEC-R. Batería de evaluación de los procesos lectores, revisada. *Madrid: TEA*.

Cutler, S. J., & Grams, a E. (1988). Correlates of self-reported everyday memory problems. *Journal of Gerontology*, *43*(3), S82–S90. doi:10.1093/geronj/43.3.S82

Cutting, L., & Scarborough, H. (2006). Prediction of Reading Comprehension: Relative Contributions of Word Recognition, Language Proficiency, and Other Cognitive Skills Can Depend on How Comprehension Is Measured. *Scientific Studies of Reading*, *10*(3), 277–299. doi:10.1207/s1532799xssr0104

Czernochowski, D. (2015). ERPs dissociate proactive and reactive control: Evidence from a task-switching paradigm with informative and uninformative cues. *Cognitive, Affective, & Behavioral Neuroscience*, *15*(1), 117–131. doi:10.3758/s13415-014-0302-y

Dahlin, E., Nyberg, L., Ba, L., & Neely, A. S. (2008). Plasticity of Executive Functioning in Young and Older Adults : Immediate Training Gains , Transfer , and Long-Term Maintenance, *23*(4), 720–730. doi:10.1037/a0014296

Dahlin, K. (2013). Working Memory Training and the Effect on Mathematical Achievement in Children with Attention Deficits and Special Needs. *Journal of Education and Learning*, *2*(1), 118–133. doi:10.5539/jel.v2n1p118

Dahlin, K. I. E. (2010). Effects of working memory training on reading in children with special needs. *Reading and Writing*, *24*(4), 479–491. doi:10.1007/s11145-010-9238-y

Daigneault, S., & Braun, C. (1993). Working memory and the self-ordered pointing task: Further evidence of early prefrontal decline in normal aging. *Journal of Clinical and Experimental Neuropsychology*, *15*(6), 881–895. doi:10.1080/01688639308402605

Daneman, M., & Carpenter, P. A. (1980). Individual Differences in Working Memory and Reading. *Journal of Verbal Learning and Verbal Behavior*, *19*(4), 450–466.

Daneman, M., & Green, I. (1986). Individual Differences in Comprehending in Context and Producing Words. *Journal of Memory and Language*, *25*, 1–18. doi:10.1016/0749-596X(86)90018-5

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin & Review*, *3*(4), 422–433. doi:10.3758/BF03214546

Danielsson, H., Henry, L., Rönnberg, J., & Nilsson, L.-G. (2010). Executive functions in individuals with intellectual disability. *Research in Developmental Disabilities*, *31*, 1299–1304. doi:10.1016/j.ridd.2010.07.012

Davidson, D. J., Zacks, R. T., & Williams, C. C. (2003). Stroop Interference, Practice, and Aging. *Aging, Neuropsychology, and Cognition (Neuropsychology, Development and Cognition: Section B)*, *10*(2), 85–98. doi:10.1076/anec.10.2.85.14463

De Jong, P. F. (1998). Working Memory Deficits of Reading Disabled Children. *Journal of Experimental Child Psychology*, *70*(2), 75–96. doi:10.1006/jecp.1998.2451

De Jonge, P. F., & de Jong. (1996). Assessment of Attention: Further Validation of the Star Counting Test. *European Journal of Psychological Assessment*, *11*(2), 89–97. doi:10.1027/1015-5759.11.2.89

Deak, G. O. (2003). The development of cognitive flexibilty and language abilities. *Advances in Child Development and Behavior*, *31*, 271–327. doi:http://dx.doi.org/10.1016/S0065-2407(03)31007-9

Deci, E. L., Eghrari, H., Patrick, B. C., & Leone, D. R. (1994). Facilitating Internalization: The Self Determination Theory Perspective. *Journal of Personality*. doi:10.1111/j.1467-6494.1994.tb00797.x

Delaney, P. F., Nghiem, K. N., & Waldum, E. R. (2009). The selective directed forgetting effect: Can people forget only part of a text? *Quarterly Journal of Experimental Psychology*, *62*(8), 1542–1550. doi:10.1080/17470210902770049

Della-Maggiore, V., Sekuler, A. B., Grady, C. L., Bennett, P. J., Sekuler, R., & McIntosh, A. R. (2000). Corticolimbic Interactions Associated with Performance on a Short-Term Memory Task Are Modified by Age. *J. Neurosci.*, *20*(22), 8410–8416. doi:20/22/8410 [pii]

Demarin, V., Morovic, S., & Bene, R. (2014). Neuroplasticity. *Periodicum Biologorum*, *116*(2), 209–211.

Dempster, F. N., & Corkill, A. J. (1999). Interference and inhibition in cognition and behavior: Unifying themes for educational psychology. *Educational Psychology Review*, *11*(1), 1–88. doi:Doi 10.1023/A:1021992632168

Dempster, F. N., & Vegas, L. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, *12*(1), 45–75. doi:10.1016/0273-2297(92)90003-K

Diamond, A. (2013). Executive functions. *The Annual Review of Psychology*, *64*, 135–168. doi:10.1146/annurev-psych-113011-143750

Diamond, M. C. (1996). The Brain … Use it or Lose It. *Mindshift Connection. Reprinted in "New Horizons for Learning" Series, Johns Hopkins School of Education.*, *1*(1).

Díez, E., Fernández, A., & Alonso, M. A. (2006). NIPE: Normas e índices de interés en Psicología Experimental. *Accesible at Http://campus.usal.es/~gimc/nipe/*, 2006.

Dixon, R. a., & Hultsch, D. F. (1983). Structure and development of metamemory in adulthood. *Journal of Gerontology*, *38*(6), 682–688. doi:10.1093/geronj/38.6.682

Dobbins, I. G., Foley, H., Schacter, D. L., & Wagner, A. D. (2002). Executive Control during Episodic Retrieval. *Neuron*, *35*(5), 989–996. doi:10.1016/S0896-6273(02)00858-9

Dobbins, I. G., & Han, S. (2006). Cue- versus probe-dependent prefrontal cortex activity during contextual remembering. *Journal of Cognitive Neuroscience*, *18*(9), 1439–52. doi:10.1162/jocn.2006.18.9.1439

Dotson, V. M., Sozda, C. N., Marsiske, M., & Perlstein, W. M. (2013). Within-session practice eliminates age differences in cognitive control. *Aging, Neuropsychology, and Cognition*, *20*(5), 522–531. doi:10.1080/13825585.2012.736469

Dougherty, M. R., Hamovitz, T., & Tidwell, J. W. (2016). Reevaluating the effectiveness of n-back training on transfer through the Bayesian lens: Support for the null. *Psychonomic Bulletin & Review*, *23*, 306–316. doi:10.3758/s13423-015-0865-9

Dovis, S., Van Der Oord, S., Wiers, R. W., & Prins, P. J. M. (2015). Improving executive functioning in children with ADHD: Training multiple executive functions within the context of a computer game. A randomized double-blind placebo controlled trial. *PLoS ONE*, *10*(4), 1–30. doi:10.1371/journal.pone.0121651

Dowsett, S. M., & Livesey, D. J. (2000). The development of inhibitory control in preschool children: Effects of “executive skills” training. *Developmental Psychobiology*, *36*(2), 161–174. doi:10.1002/(SICI)1098-2302(200003)36:2<161::AID-DEV7>3.0.CO;2-0

Duchek, J. M., Balota, D. A., Thessing, V. C., Duchek, J. M., Balota, D. A., & Thessing, V. C. (1998). Inhibition of Visual and Conceptual Information During Reading in Healthy Aging and Alzheimer ’ s Disease . *Aging, Neuropsychology, and Cognition*, *5*(3), 169–181.

Dudukovic, N. M., & Kuhl, B. a. (2017). Cognitive Control in Memory Encoding and Retrieval. *The Wiley Handbook of Cognitive Control*, 355–375.

Duncan, J., & Miller, E. K. (2002). Cognitive focusing through adaptive neural coding in the primate prefrontal cortex. In D. T. Stuss & R. Knight (Eds.), *Principles of frontal lobe function* (Vol. 6, pp. 278–291). New York, NY: Oxford University Press. doi:10.1093/acprof

Dunning, D. L., Holmes, J., & Gathercole, S. E. (2013). Does working memory training lead to generalized improvements in children with low working memory? A randomized controlled trial. *Developmental Science*, *16*(6), 915–925. doi:10.1111/desc.12068

Düzel, E., Penny, W. D., & Burgess, N. (2010). Brain oscillations and memory. *Current Opinion in Neurobiology*, *20*(2), 245–257. doi:10.1016/j.conb.2010.01.004

Edwards, B. G., Barch, D. M., & Braver, T. S. (2009). Improving prefrontal cortex function in schizophrenia through focused training of cognitive control. *Frontiers in Neuroscience*, *4*(April), 1–26. doi:10.3389/fnhum.2010.00032

Enge, S., Behnke, A., Fleischhauer, M., Küttler, L., Kliegel, M., & Strobel, A. (2014). No evidence for true training and transfer effects after inhibitory control training in young healthy adults. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *40*(4), 987–1001. doi:10.1037/a0036165

Engle, R. W. (1996). Working memory and retrieval: An inhibition-resource approach. In J. T. E. Richardson, R. W. Engle, L. Hasher, R. Logie, E. R. Stoltzfus, & R. T. Zacks (Eds.), *Working Memory and Human Cognition*. Oxford University Press.

Engle, R. W., & Kane, M. J. (2004). Executive Attention, Working Memory Capacity, and a Two-Factor Theory of Cognitive Control. *The Psychology of Learning and Motivation: Advances in Research and Theory*, 145–199. doi:10.1016/S0079-7421(03)44005-X

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control.*, (May 2016), 102–134. doi:10.1037/a0021324

Erickson, K. I., Colcombe, S. J., Wadhwa, R., Bherer, L., Peterson, M. S., Scalf, P. E., … Kramer, A. F. (2007). Training-induced plasticity in older adults: Effects of training on hemispheric asymmetry. *Neurobiology of Aging*, *28*(2), 272–283. doi:10.1016/j.neurobiolaging.2005.12.012

Fernandez-Duque, D., Baird, J. a, & Posner, M. I. (2000). Executive attention and metacognitive regulation. *Consciousness and Cognition*, *9*(2 Pt 1), 288–307. doi:10.1006/ccog.2000.0447

Ferreira, C. S., Marful, A., Staudigl, T., Bajo, T., & Hanslmayr, S. (2014). Medial Prefrontal ThetaOscillations Track the Time Course of Interference during Selective Memory Retrieval. *Journal of Cognitive Neuroscience*, *26*(4), 777–791. doi:10.1162/jocn

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). “Mini-mental state”. A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*(3), 189–198. doi:10.1016/0022-3956(75)90026-6

Foy, J. G., & Mann, V. A. (2014). Adaptive Cognitive Training Enhances Executive Control and Visuospatial and Verbal Working Memory in Beginning Readers. *International Education Research*, *2*(2), 19–43. doi:10.12735/ier.v2i2p19

Friedman, M. C., & Castel, A. D. (2013). Memory, priority encoding, and overcoming high-value proactive interference in younger and older adults. *Aging, Neuropsychology, and Cognition. Section B: Aging, Neuropsychology and Cognition.*, *20*(6), 660–683. doi:10.1080/13825585.2012.762083

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variable analysis. *Journal of Experimental Psychology. General*, *133*(1), 101–35. doi:10.1037/0096-3445.133.1.101

Friedman, Naomi, P., Friedman, Naomi, P., Miyake, A., Miyake, A., Corley, R. P., Corley, R. P., … Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science*, *17*(2), 172–9. doi:10.1111/j.1467-9280.2006.01681.x

Gaál, A., & Czigler, I. (2017). Task-Switching Training and Transfer : Age-Related Effects on Late ERP Components. *Journal of Psychophysiology*, 3. doi:https://doi.org/10.1027/0269-8803/a000189

Gajewski, P. D., & Falkenstein, M. (2012). Training-Induced Improvement of Response Selection and Error Detection in Aging Assessed by Task Switching: Effects of Cognitive, Physical, and Relaxation Training. *Frontiers in Human Neuroscience*, *6*(May), 1–18. doi:10.3389/fnhum.2012.00130

Garavan, H., Hester, R., Murphy, K., Fassbender, C., & Kelly, C. (2006). Individual differences in the functional neuroanatomy of inhibitory control. *Brain Research*, *1105*(1), 130–142. doi:10.1016/j.brainres.2006.03.029

García-Madruga, J. a., Gómez-Veiga, I., & Vila, J. Ó. (2016). Executive Functions and the Improvement of Thinking Abilities: The Intervention in Reading Comprehension. *Frontiers in Psychology*, *7*(February), 1–15. doi:10.3389/fpsyg.2016.00058

Gathercole, S. E. (1999). Cognitive approaches to the development of short-term memory. *Trends in Cognitive Sciences*, *3*(11), 410–419. doi:10.1016/S1364-6613(99)01388-1

Gathercole, S. E., Alloway, T. P., Willis, C. S., & Adams, A.-M. (2006). Working memory in children with reading disabilities. *Journal of Experimental Child Psychology*, *93*(3), 265–81. doi:10.1016/j.jecp.2005.08.003

Gathercole, S. E., Dunning, D. L., & Holmes, J. (2012). Cogmed training: Let’s be realistic about intervention research. *Journal of Applied Research in Memory and Cognition*, *1*(3), 201–203. doi:10.1016/j.jarmac.2012.07.007

Gathercole, S., & Pickering, S. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology*, *40*(2), 177–190. doi:10.1037/0012-1649.40.2.177

Gazzaley, A., Cooney, J. W., Rissman, J., & D’Esposito, M. (2005). Top-down suppression deficit underlies working memory impairment in normal aging. *Nature Neuroscience*, *8*(10), 1298–1300. doi:10.1038/nn1543

George, E. M., & Coch, D. (2011). Music training and working memory: An ERP study. *Neuropsychologia*, *49*(5), 1083–1094. doi:10.1016/j.neuropsychologia.2011.02.001

Gernsbacher, M. a, & Faust, M. E. (1991). The mechanism of suppression: a component of general comprehension skill. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *17*(2), 245–262. doi:10.1037/0278-7393.17.2.245

Geva, E., & Yaghoub Zadeh, Z. (2006). Reading Efficiency in Native English-Speaking and English-as-a-Second-Language Children: The Role of Oral Proficiency and Underlying Cognitive-Linguistic Processes. *Scientific Studies of Reading*, *10*(1), 31–57. doi:10.1207/s1532799xssr1001_3

Gill, J., Shah-Basak, P. P., & Hamilton, R. (2014). It's the Thought That Counts: Examining the Task-dependent Effects of Transcranial Direct Current Stimulation on Executive Function. *Brain Stimulation*, *8*(2), 253–259. doi:10.1016/j.brs.2014.10.018

Glabus, M. F., Horwitz, B., Holt, J. L., Kohn, P. D., Gerton, B. K., Callicott, J. H., … Berman, K. F. (2003). Interindividual Differences in Functional Interactions among Prefrontal, Parietal and Parahippocampal Regions during Working Memory. *Cerebral Cortex*, *13*(12), 1352–1361. doi:10.1093/cercor/bhg082

Goldin, A. P., Hermida, M. J., Shalom, D. E., Elias Costa, M., Lopez-Rosenfeld, M., Segretin, M. S., … Sigman, M. (2014). Far transfer to language and math of a short software-based gaming intervention. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(17), 6443–8. doi:10.1073/pnas.1320217111

Gómez-Ariza, C. J., Martín, M. C., & Morales, J. (2017). Tempering Proactive Cognitive Control by Transcranial Direct Current Stimulation of the Right (but Not the Left) Lateral ... Tempering Proactive Cognitive Control by Transcranial Direct Current Stimulation of the Right (but Not the Left) Lateral Prefr. *Frontiers in Neuroscience*, (May). doi:10.3389/fnins.2017.00282

Gómez-Ariza, C. J., Prete, F., Prieto, L., Valle, T., Bajo, M. T., & Fernandez, A. (2017). Memory Inhibition as a Critical Factor Preventing Creative Problem Solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *43*(6), 986–996. doi:10.1037/xlm0000348

Gordon, B. a., Rykhlevskaia, E. I., Brumback, C. R., Lee, Y., Elavsky, S., Konopack, J. F., … Fabiani, M. (2008). Neuroanatomical correlates of aging, cardiopulmonary fitness level, and education. *Psychophysiology*, *45*(5), 825–838. doi:10.1111/j.1469-8986.2008.00676.x

Goulandris, N. (2003). Dyslexia in Different Languages: Cross Linguistic Comparisons. *Dyslexia*, 220.

Grady, C. (2012). The cognitive neuroscience of ageing. *Nature Reviews Neuroscience*, *13*(7), 491–505. doi:10.1038/nrn3256

Grady, C. L., & Craik, F. I. (2000). Changes in memory processing with age. *Current Opinion in Neurobiology*, *10*(2), 224–231. doi:10.1016/S0959-4388(00)00073-8

Gray, J. R., Chabris, C. F., & Braver, T. S. (2003). Neural mechanisms of general fluid intelligence. *Nature Neuroscience*, *6*(3), 316–322. doi:10.1038/nn1014

Gross, A. L., Parisi, J. M., Spira, A. P., Kueider, A. M., Ko, J. Y., Saczynski, J. S., … Rebok, G. W. (2012). Memory training interventions for older adults: A meta-analysis. *Aging & Mental Health*, *16*(6), 722–734. doi:10.1080/13607863.2012.667783

Hambrick, D. Z., & Oswald, F. L. (2007). Predictors of Multitasking Performance in a Synthetic Work Paradigm. *Applied Cognitive Psychology*, *21*(December 2006), 1057–1075. doi:10.1002/acp

Hansen, L. B., Morales, J., Macizo, P., Duñabeitia, J. A., Saldaña, D., Carreiras, M., … Bajo, M. T. (2016). Reading comprehension and Immersion schooling: Evidence from component skills. *Developmental Science*. doi:10.1111/desc.12454

Hanslmayr, S., Pastötter, B., Bäuml, K.-H., Gruber, S., Wimber, M., & Klimesch, W. (2008). The Electrophysiological Dynamics of Interference during the Stroop Task. *Journal of Cognitive Neuroscience*, *20*(2), 215–225. doi:10.1162/jocn.2008.20020

Hanslmayr, S., Staresina, B. P., & Bowman, H. (2016). Oscillations and Episodic Memory: Addressing the Synchronization/Desynchronization Conundrum. *Trends in Neurosciences*, *39*(1), 16–25. doi:10.1016/j.tins.2015.11.004

Hanslmayr, S., Staudigl, T., Aslan, A., & Bäuml, K.-H. (2010). Theta oscillations predict the detrimental effects of memory retrieval. *Cognitive, Affective, & Behavioral Neuroscience*, *10*(3), 329–338. doi:10.3758/CABN.10.3.329

Hanslmayr, S., Staudigl, T., & Fellner, M.-C. (2012). Oscillatory power decreases and long-term memory: the information via desynchronization hypothesis. *Frontiers in Human Neuroscience*, *6*(April), 1–12. doi:10.3389/fnhum.2012.00074

Hanslmayr, S., Volberg, G., Wimber, M., Raabe, M., Greenlee, M. W., & Bauml, K.-H. T. (2011). The Relationship between Brain Oscillations and BOLD Signal during Memory Formation: A Combined EEG-fMRI Study. *Journal of Neuroscience*, *31*(44), 15674–15680. doi:10.1523/JNEUROSCI.3140-11.2011

Hardy, J. L., Nelson, R. a., Thomason, M. E., Sternberg, D. a., Katovich, K., Farzin, F., & Scanlon, M. (2015). Enhancing cognitive abilities with comprehensive training: A large, online, randomized, active-controlled trial. *PLoS ONE*, *10*(9), 1–17. doi:10.1371/journal.pone.0134467

Harrison, T. L., Shipstead, Z., & Engle, R. W. (2015). Why is working memory capacity related to matrix reasoning tasks? *Memory & Cognition*, *43*(3), 389–396. doi:10.3758/s13421-014-0473-3

Harrison, T. L., Shipstead, Z., Hicks, K. L., Hambrick, D. Z., Redick, T. S., & Engle, R. W. (2013). Working Memory Training May Increase Working Memory Capacity but Not Fluid Intelligence. *Psychological Science*, *24*(12), 2409–2419. doi:10.1177/0956797613492984

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *17*(1), 163–169. doi:10.1037/0278-7393.17.1.163

Hasher, L., & Zacks, R. T. (1988). Working Memory, Comprehension, and Aging: A Review and a New View. *Psychology of Learning and Motivation - Advances in Research and Theory*, *22*(C), 193–225. doi:10.1016/S0079-7421(08)60041-9

Hebb, D. O. (1947). The effects of early experience on problem solving at maturity. *American Psychologist*, *2*, 306–307.

Henry, L., Messer, D., & Nash, G. (2014). Testing for Near and Far Transfer Effects with a Short, Face-to-Face Adaptive Working Memory Training Intervention in Typical Children. *Infant and Child Development*, *23*, 84–103. doi:10.1002/icd

Hertzog, C., Kramer, a. F., Wilson, R. S., & Lindenberger, U. (2009). Enrichment Effects on Adult Cognitive Development. *Psychological Science*, *9*(1), 1–65. doi:10.1111/j.1539-6053.2009.01034.x

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences*, *16*(3), 174–180. doi:10.1016/j.tics.2012.01.006

Holmes, J., Butterfield, S., Cormack, F., Loenhoud, A. Van, Ruggero, L., Kashikar, L., & Gathercole, S. (2015). Improving working memory in children with low language abilities. *Frontiers in Psychology*, *6*(April), 1–9. doi:10.3389/fpsyg.2015.00519

Holtzer, R., Stern, Y., & Rakitin, B. C. (2004). Age-related differences in executive control of working memory. *Memory & Cognition*, *32*(8), 1333–45. doi:10.3758/BF03206324

Horiba, Y. (1996). Comprehension processes in L2 reading: Language competence, textual coherence, and inferences. *Studies in Second Language Acquisition*, *18*(04), 433. doi:10.1017/S0272263100015370

Horiba, Y. (2015). Reading and learning from L2 text : Effects of reading goal , topic familiarity , and language proficiency. *Reading in a Foreign Language*, *27*(1), 22–46.

Horn, J., Donaldson, G., & Engstrom, R. (1981). Apprehension, Memory, and Fluid Intelligence Decline in Adulthood. *Research on Aging*, *3*(1), 33–84.

Hsu, N. S., Novick, J. M., & Jaeggi, S. M. (2014). The development and malleability of executive control abilities. *Frontiers in Behavioral Neuroscience*, *8*(June), 221. doi:10.3389/fnbeh.2014.00221

Hudjetz, A., & Oberauer, K. (2007). The effects of processing time and processing rate on forgetting in working memory. *Memory and Cognition*, *35*(7), 1675. doi:10.3758/BF03193501

Hussey, E. K., & Novick, J. M. (2012). The benefits of executive control training and the implications for language processing. *Frontiers in Psychology*, *3*(MAY), 1–14. doi:10.3389/fpsyg.2012.00158

Izura, C., Cuetos, F., & Brysbaert, M. (2013). Lextale-Esp: A Test to Rapidly and Efficiently Assess the Spanish Vocabulary Size. *Psicologica: International Journal of Methodology and Experimental Psychology*, *35*(1), 49–66.

Jacques, S., & Zelazo, P. D. (2005). Language and the Development of Cognitive Flexibility: Implications for Theory of Mind. In J. Astington & J. Baird (Eds.), *Why Language Matters for Theory of Mind* (pp. 144–162). New York, NY: Oxford University Press. doi:10.1093/acprof

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *PNAS*, *105*(19), 6829–6833.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Shah, P. (2011). Short- and long-term benefits of cognitive training. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(25), 10081–6. doi:10.1073/pnas.1103228108

Jaeggi, S. M., Buschkuehl, M., Shah, P., & Jonides, J. (2013). The role of individual differences in cognitive training and transfer. *Memory & Cognition*, *42*(3), 464–80. doi:10.3758/s13421-013-0364-z

Jaeggi, S. M., Studer-Luethi, B., Buschkuehl, M., Su, Y. F., Jonides, J., & Perrig, W. J. (2010). The relationship between n-back performance and matrix reasoning - implications for training and transfer. *Intelligence*, *38*(6), 625–635. doi:10.1016/j.intell.2010.09.001

James, W. (1890). *The principles of psychology (Vol. 1).* (Vol. 1). Holt, New York.

Jarosz, A. F., & Wiley, J. (2012). Why does working memory capacity predict RAPM performance? A possible role of distraction. *Intelligence*, *40*(5), 427–438. doi:10.1016/j.intell.2012.06.001

Jaušovec, N., & Jaušovec, K. (2012). Working memory training: Improving intelligence - Changing brain activity. *Brain and Cognition*, *79*(2), 96–106. doi:10.1016/j.bandc.2012.02.007

Jennings, J. M., & Jacoby, L. L. (2003). Improving memory in older adults: Training recollection. *Neuropsychological Rehabilitation*, *13*(4), 417–440. doi:10.1080/09602010244000390

Jolles, D. D., & Crone, E. a. (2012). Training the developing brain: a neurocognitive perspective. *Frontiers in Human Neuroscience*, *6*(April), 76. doi:10.3389/fnhum.2012.00076

Jones, K. T., Peterson, D. J., Blacker, K. J., & Berryhill, M. E. (2017). Frontoparietal neurostimulation modulates working memory training benefits and oscillatory synchronization. *Brain Research*, *1667*, 28–40. doi:10.1016/j.brainres.2017.05.005

Jongkees, B. J., Hommel, B., & Colzato, L. S. (2014). People are different: Tyrosine's modulating effect on cognitive control in healthy humans may depend on individual differences related to dopamine function. *Frontiers in Psychology*, *5*(OCT), 10–13. doi:10.3389/fpsyg.2014.01101

Jonker, T. R., Seli, P., & MacLeod, C. M. (2015). Retrieval-Induced Forgetting and Context. *Current Directions in Psychological Science*, *24*(4), 273–278. doi:10.1177/0963721415573203

Jurado, M. B., & Rosselli, M. (2007). The elusive nature of executive functions: A review of our current understanding. *Neuropsychology Review*, *17*(3), 213–233. doi:10.1007/s11065-007-9040-z

Kahneman, D. (1975). *Attention and Effort. The American Journal of Psychology* (Vol. 88). doi:10.2307/1421603

Kane, M. J., Bleckley, M. K., Conway, A. R. a., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General*, *130*(2), 169–183. doi:10.1037//0096-3445.130.2.169

Kane, M. J., Conway, A. R. A., Hambrick, D. Z., & Engle, R. W. (2007). Variation in WM capacity as Variation in Executive Attention and Control. In *Variation in Working Memory 1* (pp. 21–48).

Kane, M. J., & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(2), 336–358. doi:10.1037/0278-7393.26.2.336

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review*, *9*(4), 637–671. doi:10.3758/BF03196323

Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science*, *12*(6), 978–990. doi:10.1111/j.1467-7687.2009.00846.x

Karbach, J., Strobach, T., & Schubert, T. (2014). Adaptive working-memory training benefits reading, but not mathematics in middle childhood. *Child Neuropsychology*, *21*(3), 285–301. doi:10.1080/09297049.2014.899336

Karbach, J., & Unger, K. (2014). Executive control training from middle childhood to adolescence. *Frontiers in Psychology*, *5*(MAY), 1–14. doi:10.3389/fpsyg.2014.00390

Karbach, J., & Verhaeghen, P. (2014). Making Working Memory Work: A Meta-Analysis of Executive-Control and Working Memory Training in Older Adults. *Psychological Science*, *25*, 2027–2037. doi:10.1177/0956797614548725

Katz, B., Au, J., Buschkuehl, M., Abagis, T., Zabel, C., Jaeggi, S. M., & Jonides, J. (2016). Individual Differences and Long-term Consequences of tDCS-augmented Cognitive Training. *Journal of Cognitive Neuroscience*, *29*(9), 1498–1508. doi:10.1162/jocn

Katz, B., Jaeggi, S., Buschkuehl, M., Stegman, A., & Shah, P. (2014). Differential effect of motivational features on training improvements in school-based cognitive training. *Frontiers in Human Neuroscience*, *8*(April), 242. doi:10.3389/fnhum.2014.00242

Katz, B., Jones, M. R., Shah, P., Buschkuehl, M., & Jaeggi, S. M. (2016). Individual Differences and Motivational Effects. In T. Strobach & J. Karbach (Eds.), *Cognitive Training: An Overview of Features and Applications* (pp. 157–166). Springer International Publishing. doi:http://doi.org/10.1007/978-3-319-42662-4_15

Kelly, C., Foxe, J. J., & Garavan, H. (2006). Patterns of Normal Human Brain Plasticity After Practice and Their Implications for Neurorehabilitation. *Archives of Physical Medicine and Rehabilitation*, *87*(12 SUPPL.), 20–29. doi:10.1016/j.apmr.2006.08.333

Kelly, M. E., Loughrey, D., Lawlor, B. a., Robertson, I. H., Walsh, C., & Brennan, S. (2014). The impact of cognitive training and mental stimulation on cognitive and everyday functioning of healthy older adults: A systematic review and meta-analysis. *Ageing Research Reviews*, *15*(1), 28–43. doi:10.1016/j.arr.2014.02.004

Khader, P. H., & Rösler, F. (2011). EEG power changes reflect distinct mechanisms during long-term memory retrieval. *Psychophysiology*, *48*(3), 362–369. doi:10.1111/j.1469-8986.2010.01063.x

Khanna, M. M., & Boland, J. E. (2010). Children's use of language context in lexical ambiguity resolution. *Quarterly Journal of Experimental Psychology*, *63*(1), 160–193. doi:10.1080/17470210902866664

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching—A review. *Psychological Bulletin*, *136*(5), 849–874. doi:10.1037/a0019842

Kirchhoff, B. a., Anderson, B. a., Smith, S. E., Barch, D. M., & Jacoby, L. L. (2012). Cognitive training-related changes in hippocampal activity associated with recollection in older adults. *NeuroImage*, *62*(3), 1956–1964. doi:10.1016/j.neuroimage.2012.06.017

Kliegl, R., Smith, J., & Baltes, P. B. (1990). On the locus and process of magnification of age differences during mnemonic training. *Developmental Psychology*, *26*(6), 894–904. doi:10.1037/0012-1649.26.6.894

Kliegl, R., Smith, J., Heckhausen, J., & Baltes, P. B. (1987). Mnemonic Training for the Acquisition of Skilled Digit Memory. *Cognition and Instruction*, *4*(4), 203–223. doi:10.1207/s1532690xci0404_1

Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences*, *14*(7), 317–324. doi:10.1016/j.tics.2010.05.002

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., … Westerberg, H. (2005). Computerized training of working memory in children with ADHD--a randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry*, *44*(2), 177–86. doi:10.1097/00004583-200502000-00010

Kondo, Y., Suzuki, M., Mugikura, S., Abe, N., Takahashi, S., Iijima, T., & Fujii, T. (2005). Changes in brain activation associated with use of a memory strategy: A functional MRI study. *NeuroImage*, *24*(4), 1154–1163. doi:10.1016/j.neuroimage.2004.10.033

Könen, T., & Karbach, J. (2015). The benefits of looking at intraindividual dynamics in cognitive training data. *Frontiers in Psychology*, *6*(May), 4–7. doi:10.3389/fpsyg.2015.00615

Kramer, A. F., Erickson, K. I., & Colcombe, S. J. (2006). Neural Changes Associated with Training Exercise, cognition, and the aging brain. *J Appl Physiol*, *101*, 1237–1242. doi:10.1152/japplphysiol.000500.2006.

Kramer, A. F., Humphrey, D. G., Larish, J. F., & Logan, G. D. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging*, *9*(4), 491–512. doi:10.1037/0882-7974.9.4.491

Kray, J., Karbach, J., Haenig, S., & Freitag, C. (2012). Can Task-Switching Training Enhance Executive Control Functioning in Children with Attention Deficit/-Hyperactivity Disorder? *Frontiers in Human Neuroscience*, *5*(January), 1–9. doi:10.3389/fnhum.2011.00180

Kueider, A. M., Parisi, J. M., Gross, A. L., & Rebok, G. W. (2012). Computerized cognitive training with older adults: A systematic review. *PLoS ONE*, *7*(7). doi:10.1371/journal.pone.0040588

Kuhl, B. a, Dudukovic, N. M., Kahn, I., & Wagner, A. D. (2007). Decreased demands on cognitive control reveal the neural processing benefits of forgetting. *Nature Neuroscience*, *10*(7), 908–914. doi:10.1038/nn1918

Kyllonen, P. C., & L. Stephens, D. (1990). Cognitive abilities as determinants of success in acquiring logic skill. *Learning and Individual Differences*, *2*(2), 129–160. doi:10.1016/1041-6080(90)90020-H

Lampit, A., Hallock, H., Suo, C., Naismith, S. L., & Valenzuela, M. (2015). Cognitive training-induced short-term functional and long-term structural plastic change is related to gains in global cognition in healthy older adults: A pilot study. *Frontiers in Aging Neuroscience*, *7*(MAR), 1–13. doi:10.3389/fnagi.2015.00014

Lampit, A., Hallock, H., & Valenzuela, M. (2014). Computerized Cognitive Training in Cognitively Healthy Older Adults: A Systematic Review and Meta-Analysis of Effect Modifiers. *PLoS Medicine*, *11*(11), e1001756. doi:10.1371/journal.pmed.1001756

LaRue, A. (1992). *Aging and Neuropsychological Assessment.* (S. S. & B. Media., Ed.).

Lawlor-Savage, L., & Goghari, V. M. (2016). Dual N-back working memory training in healthy adults: A randomized comparison to processing speed training. *PLoS ONE*, *11*(4), 1–17. doi:10.1371/journal.pone.0151817

Lee, Y., Lu, M., & Ko, H. (2007). Effects of skill training on working memory capacity. *Learning and Instruction*, *17*(3), 336–344. doi:10.1016/j.learninstruc.2007.02.010

Lesh, T. a., Westphal, A. J., Niendam, T. a., Yoon, J. H., Minzenberg, M. J., Ragland, J. D., … Carter, C. S. (2013). Proactive and reactive cognitive control and dorsolateral prefrontal cortex dysfunction in first episode schizophrenia. *NeuroImage: Clinical*, *2*(1), 590–599. doi:10.1016/j.nicl.2013.04.010

Levy, B. J., & Anderson, M. C. (2002). Inhibitory processes and the control of memory retrieval. *Trends in Cognitive Sciences*, *6*(7), 299–305. doi:10.1016/S1364-6613(02)01923-X

Li, B., Zhu, X., Hou, J., Chen, T., Wang, P., & Li, J. (2016). Combined cognitive training vs. memory strategy training in healthy older adults. *Frontiers in Psychology*, *7*(JUN), 1–11. doi:10.3389/fpsyg.2016.00834

Li, S.-C., Schmiedek, F., Huxhold, O., Röcke, C., Smith, J., & Lindenberger, U. (2008). Working memory plasticity in old age: practice gain, transfer, and maintenance. *Psychology and Aging*, *23*(4), 731–42. doi:10.1037/a0014343

Light, L. L. (1991). Memory and aging: four hypotheses in search of data. *Annual Review of Psychology*, *42*, 333–376. doi:10.1146/annurev.ps.42.020191.002001

Light, L. L. (1996). Memory and Aging. *Memory*, (November), 443–490.

Liotti, M., Woldorff, M. G., Perez, R., & Mayberg, H. S. (2000). An ERP study of the temporal course of the Stroop color-word interference effect. *Neuropsychologia*, *38*(5), 701–711. doi:10.1016/S0028-3932(99)00106-2

Liu, Q., Zhu, X., Ziegler, A., & Shi, J. (2015). The effects of inhibitory control training for preschoolers on reasoning ability and neural activity. *Scientific Reports*, *5*(August), 14200. doi:10.1038/srep14200

Locke, E. a., & Latham, G. P. (2002). Building a practically useful theory of goal setting and task motivation. *American Psychologist*, *57*(9), 705–717. doi:10.1037/0003-066X.57.9.705

Logan, J. M., Sanders, A. L., Snyder, A. Z., Morris, J. C., & Buckner, R. L. (2002). Under-recruitment and nonselective recruitment: Dissociable neural mechanisms associated with aging. *Neuron*, *33*(5), 827–840. doi:10.1016/S0896-6273(02)00612-8

Long, N. M., Burke, J. F., & Kahana, M. J. (2014). Subsequent memory effect in intracranial and scalp EEG. *NeuroImage*, *84*, 488–494. doi:10.1016/j.neuroimage.2013.08.052

Loosli, S. V, Buschkuehl, M., Perrig, W. J., & Jaeggi, S. M. (2012a). Working memory training improves reading processes in typically developing children. *Child Neuropsychology : A Journal on Normal and Abnormal Development in Childhood and Adolescence*, *18*(1), 62–78. doi:10.1080/09297049.2011.575772

Loosli, S. V, Buschkuehl, M., Perrig, W. J., & Jaeggi, S. M. (2012b). Working memory training improves reading processes in typically developing children. *Child Neuropsychology : A Journal on Normal and Abnormal Development in Childhood and Adolescence*, *18*(1), 62–78. doi:10.1080/09297049.2011.575772

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: an open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience*, *8*(April), 1–14. doi:10.3389/fnhum.2014.00213

Lopez-Calderón, J., & Luck, S. J. (2014). ERPLAB : an open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience*, *8*(April), 1–14. doi:10.3389/fnhum.2014.00213

Lövdén, M., Bäckman, L., Lindenberger, U., Schaefer, S., & Schmiedek, F. (2010). A theoretical framework for the study of adult cognitive plasticity. *Psychological Bulletin*, *136*(4), 659–676. doi:10.1037/a0020080

Lövdén, M., Wenger, E., Mårtensson, J., Lindenberger, U., & Bäckman, L. (2013). Structural brain plasticity in adult learning and development. *Neuroscience and Biobehavioral Reviews*, *37*(9), 2296–2310. doi:10.1016/j.neubiorev.2013.02.014

Lustig, C., Hasher, L., & Zacks, R. T. (2007). Inhibitory deficit theory: Recent developments in a "new view." *Inhibition in Cognition*, (571), 145–162. doi:http://dx.doi.org/10.1037/11587-008

Lustig, C., Shah, P., Seidler, R., & Reuter-Lorenz, P. (2009). Aging, Training, and the Brain: a Review and Future Directions. *Neuropsychology Review*, *19*, 504–522. doi:10.1007/s11065-009-9119-9

MacDonald III, a W., & Carter, C. S. (2003). Event-related fMRI study of context processing in dorsolateral prefrontal cortex of patients with schizophrenia. *Journal of Abnormal Psychology*, *112*(4), 689–697.

Macleod, C. M. (1991). Half a century of research on the Stroop effect: An integrative Review. *Psychological Bulletin*, *109*(2), 163–203. doi:Doi 10.1037//0033-2909.109.2.163

Madden, D. J. (2007). Aging and Visual Attention. *Current Directions in Psychological Science*, *16*(2), 70–74.

Maguire, E. a., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S. J., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences*, *97*(8), 4398–4403. doi:10.1073/pnas.070039597

Maguire, E. a., Valentine, E. R., Wilding, J. M., & Kapur, N. (2002). Routes to remembering: the brains behind superior memory. *Nature Neuroscience*, *6*(1), 90–95. doi:10.1038/nn988

Mahncke, H. W., Connor, B. B., Appelman, J., Ahsanuddin, O. N., Hardy, J. L., Wood, R. a, … Merzenich, M. M. (2006). Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(33), 12523–8. doi:10.1073/pnas.0605194103

Manuel, A. L., Bernasconi, F., & Spierer, L. (2013). Plastic modifications within inhibitory control networks induced by practicing a stop-signal task: An electrical neuroimaging study. *Cortex*, *49*(4), 1141–1147. doi:10.1016/j.cortex.2012.12.009

Maraver, M. J., Bajo, M. T., & Gomez-Ariza, C. J. (2016). Training on Working Memory and Inhibitory Control in Young Adults. *Frontiers in Human Neuroscience*, *10*(November), Article 588. doi:10.3389/fnhum.2016.00588

Marful, A., Amado, J. C. G., Ferreira, C. S., & Bajo, M. T. (2015). Face naming and retrieval inhibition in old and very old age. *Experimental Aging Research*, *41*(1), 39–56. doi:10.1080/0361073X.2015.978205

Marful, A., Díez, E., & Fernández, A. (2015). Normative data for the 56 categories of Battig and Montague (1969) in Spanish. *Behavior Research Methods*, *47*(3), 902–910. doi:10.3758/s13428-014-0513-8

Martin, M., Clare, L., Altgassen, A. M., Cameron, M. H., & Zehnder, F. (2011). Cognition-based interventions for healthy older people and people with mild cognitive impairment. *Cochrane Database of Systematic Reviews*, (1), CD006220. doi:10.1002/14651858.CD006220.pub2

Martínez, K., Burgaleta, M., Román, F. J., Escorial, S., Shih, P. C., Quiroga, M. Á., & Colom, R. (2011). Can fluid intelligence be reduced to “simple” short-term storage? *Intelligence*, *39*(6), 473–480. doi:10.1016/j.intell.2011.09.001

Martinez, K., & Colom, R. (2009). Working memory capacity and processing efficiency predict fluid but not crystallized and spatial intelligence: Evidence supporting the neural noise hypothesis. *Personality and Individual Differences*, *46*(3), 281–286. doi:10.1016/j.paid.2008.10.012

Mather, M., & Carstensen, L. L. (2005). Aging and motivated cognition: the positivity effect in attention and memory. *Trends in Cognitive Sciences*, *9*(10), 496–502. doi:10.1016/j.tics.2005.08.005

Mather, N., & Schrank, F. A. (2001). Use of the WJ III Discrepancy Procedures for Learning Disabilities Identification and Diagnosis. In *Woodcock-Johnson III Assessment Service Bulletin No. 3* (Itasca, IL.).

Mattay, V. S., Fera, F., Tessitore, A., Hariri, A. R., Berman, K. F., Das, S., … Weinberger, D. R. (2006). Neurophysiological correlates of age-related changes in working memory capacity. *Neuroscience Letters*, *392*(1-2), 32–37. doi:10.1016/j.neulet.2005.09.025

May, C. P., Hasher, L., & Kane, M. J. (1999). The role of interference in memory span. *Memory & Cognition*, *27*(5), 759–767. doi:10.3758/BF03198529

Mayas, J., Parmentier, F. B. R., Andrés, P., & Ballesteros, S. (2014). Plasticity of attentional functions in older adults after non-action video game training: a randomized controlled trial. *PloS One*, *9*(3), e92269. doi:10.1371/journal.pone.0092269

Mayringer, H., & Wimmer, H. (2000). Pseudoname Learning by German-Speaking Children with Dyslexia: Evidence for a Phonological Learning Deficit. *Journal of Experimental Child Psychology*, *75*(2), 116–133. doi:10.1006/jecp.1999.2525

McDougall, S., & House, B. (2012). Brain training in older adults: Evidence of transfer to memory span performance and pseudo-Matthew effects. *Aging, Neuropsychology, and Cognition*, *19*(1-2), 195–221. doi:10.1080/13825585.2011.640656

McLean, J. F., & Hitch, G. J. (1999). Working memory impairments in children with specific arithmetic learning difficulties. *Journal of Experimental Child Psychology*, *74*(3), 240–60. doi:10.1006/jecp.1999.2516

McVay, J. C., & Kane, M. J. (2012). Why does working memory capacity predict variation in reading comprehension? On the influence of mind wandering and executive attention. *Journal of Experimental Psychology: General*, *141*(2), 302–320. doi:10.1037/a0025250

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology*, *49*(2), 270–291.

Melby-Lervåg, M., Redick, T., & Hulme, C. (2016). Working Memory Training Does Not Improve Performance on Measures of Intelligence or Other Measures of "Far Transfer": Evidence from a Meta-Analytic Review. *Perspectives on Psychological Science*, *11*(4), 512–534. doi:10.3837/tiis.0000.00.000

Mensink, G., & Raaijmakers, J. G. (1988). A model for interference and forgetting. *Psychological Review*, *95*(4), 434–455. doi:10.1037/0033-295X.95.4.434

Milham, M. P., Erickson, K. I., Banich, M. T., Kramer, A. F., Webb, A., Wszalek, T., & Cohen, N. J. (2002). Attentional Control in the Aging Brain: Insights from an fMRI Study of the Stroop Task. *Brain and Cognition*, *49*(3), 277–296. doi:10.1006/brcg.2001.1501

Miniussi, C., Cappa, S. F., Cohen, L. G., Floel, A., Fregni, F., Nitsche, M. a., … Walsh, V. (2008). Efficacy of repetitive transcranial magnetic stimulation/transcranial direct current stimulation in cognitive neurorehabilitation. *Brain Stimulation*, *1*(4), 326–336. doi:10.1016/j.brs.2008.07.002

Miyake, A., & Friedman, N. P. (2012). The Nature and Organisation of Individual Differences in Executive Functions : Four General Conclusions. *Current Directions in Psychological Science*, *21*(1), 8–14. doi:10.1177/0963721411429458.The

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, a H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. doi:10.1006/cogp.1999.0734

Mohr, D. C., Spring, B., Freedland, K. E., Beckner, V., Arean, P., Hollon, S. D., … Kaplan, R. (2009). The selection and design of control conditions for randomized controlled trials of psychological interventions. *Psychotherapy and Psychosomatics*, *78*(5), 275–284. doi:10.1159/000228248

Montejo, P., Montenegro, M., Fernández, M. a., & Maestú, F. (2012). Memory complaints in the elderly: Quality of life and daily living activities. A population based study. *Archives of Gerontology and Geriatrics*, *54*(2), 298–304. doi:10.1016/j.archger.2011.05.021

Montgomery, J. W., Magimairaj, B. M., & O'Malley, M. H. (2008). Role of working memory in typically developing children's complex sentence comprehension. *Journal of Psycholinguistic Research*, *37*(5), 331–354. doi:10.1007/s10936-008-9077-z

Morales, J., Calvo, A., & Bialystok, E. (2013). Working memory development in monolingual and bilingual children. *Journal of Experimental Child Psychology*, *114*(2), 187–202. doi:10.1016/j.jecp.2012.09.002

Morales, J., Gómez-Ariza, C. J., & Bajo, M. T. (2013). Dual mechanisms of cognitive control in bilinguals and monolinguals. *Journal of Cognitive Psychology*, *25*(5), 531–546. doi:10.1080/20445911.2013.807812

Morales, J., Yudes, C., Gómez-Ariza, C. J., & Bajo, M. T. (2015). Bilingualism modulates dual mechanisms of cognitive control: Evidence from ERPs. *Neuropsychologia*, *66*, 157–169. doi:10.1016/j.neuropsychologia.2014.11.014

Morris, N., & Jones, D. M. (1990). Memory updating in working memory: The role of the central executive. *British Journal of Psychology*, *81*(2), 111–121. doi:10.1111/j.2044-8295.1990.tb02349.x

Morrison, A. B., & Chein, J. M. (2011). Does working memory training work? The promise and challenges of enhancing cognition by training working memory. *Psychonomic Bulletin & Review*, *18*(1), 46–60. doi:10.3758/s13423-010-0034-0

Muller, U., Jacques, S., Brocki, K., Zelazo, P. D., Jacques, S., Brocki, K., & Zelazo, P. D. (2009). The Executive Functions of Language in Preschool Children. In A. Winsler, C. Fernyhough, & I. Montero (Eds.), *Private Speech, Executive Functioning, and the Development of Verbal Self Regulation* (pp. 53–68). New York, NY: Cambridge University Press. doi:http://dx.doi.org/10.1017/CBO9780511581533.005

Murray, B. D., Anderson, M. C., & Kensinger, E. a. (2015). Older Adults Can Suppress Unwanted Memories When Given an Appropriate Strategy. *Psychology and Aging*, *30*(1), 9–25. doi:10.1037/a0038611

Myerson, J., Hale, S., Wagstaff, D., Poon, L. W., & Smith, G. a. (1990). The information-loss model: a mathematical theory of age-related cognitive slowing. *Psychological Review*, *97*(4), 475–487. doi:10.1037/0033-295X.97.4.475

Nation, K., Adams, J. W., Bowyer-Crane, C. a, & Snowling, M. J. (1999). Working memory deficits in poor comprehenders reflect underlying language impairments. *Journal of Experimental Child Psychology*, *73*(2), 139–58. doi:10.1006/jecp.1999.2498

Nelson, J. K., Reuter-Lorenz, P. a., Persson, J., Sylvester, C. Y. C., & Jonides, J. (2009). Mapping interference resolution across task domains: A shared control process in left inferior frontal gyrus. *Brain Research*, *1256*, 92–100. doi:10.1016/j.brainres.2008.12.001

Nemmi, F., Nymberg, C., Helander, E., & Klingberg, T. (2016). Grit Is Associated with Structure of Nucleus Accumbens and Gains in Cognitive Training. *Journal of Cognitive Neuroscience*, 1–12. doi:10.1162/jocn

Nessler, D., Friedman, D., Johnson, R., & Bersick, M. (2007). ERPs suggest that age affects cognitive control but not response conflict detection. *Neurobiology of Aging*, *28*(11), 1769–1782. doi:10.1016/j.neurobiolaging.2006.07.011

Newman, A. J., Tremblay, A., Nichols, E. S., Neville, H. J., & Ullman, M. T. (2012). The Influence of Language Proficiency on Lexical Semantic Processing in Native and Late Learners of English. *Journal of Cognitive Neuroscience*, *24*(5), 1205–1223. doi:10.1162/jocn_a_00143

Nielson, K. a, Langenecker, S. a, & Garavan, H. (2002). Differences in the functional neuroanatomy of inhibitory control across the adult life span. *Psychology and Aging*, *17*(1), 56–71. doi:10.1037//0882-7974.17.1.56

Niendam, T. a., Laird, A. R., Ray, K. L., Dean, Y. M., Glahn, D. C., & Carter, C. S. (2012). Meta-analytic evidence for a superordinate cognitive control network subserving diverse executive functions. *Cognitive, Affective, & Behavioral Neuroscience*, *12*(2), 241–268. doi:10.3758/s13415-011-0083-5

Noack, H., Lövdén, M., Schmiedek, F., & Lindenberger, U. (2009). Cognitive plasticity in adulthood and old age: Gauging the generality of cognitive intervention effects. *Restorative Neurology and Neuroscience*, *27*(5), 435–453. doi:10.3233/RNN-2009-0496

Noack, H., Lövdén, M., Schmiedek, F., & Lindenberger, U. (2013). Age-Related Differences in Temporal and Spatial Dimensions of Episodic Memory Performance Before and After Hundred Days of Practice. *Psychology and Aging*, (c), No Pagination Specified. doi:10.1037/a0031489

Noh, E., Herzmann, G., Curran, T., & De Sa, V. R. (2014). Using single-trial EEG to predict and analyze subsequent memory. *NeuroImage*, *84*, 712–723. doi:10.1016/j.neuroimage.2013.09.028

Norman, D. A., & Shallice, T. (1986). Attention to Action. In D. R.J., S. G.E., & S. D. (Eds.), *Consciousness and Self-Regulation* (Vol. 4). Boston, MA: Springer.

Nouchi, R., Taki, Y., Takeuchi, H., Hashizume, H., Akitsuki, Y., Shigemune, Y., … Kawashima, R. (2012). Brain training game improves executive functions and processing speed in the elderly: A randomized controlled trial. *PLoS ONE*, *7*(1). doi:10.1371/journal.pone.0029676

Nyberg, L., Lövdén, M., Riklund, K., Lindenberger, U., & Bäckman, L. (2012). Memory aging and brain maintenance. *Trends in Cognitive Sciences*, *16*(5), 292–305. doi:10.1016/j.tics.2012.04.005

Nyberg, L., Nilsson, L. G., Olofsson, U., & Bäckman, L. (1997). Effects of division of attention during encoding and retrieval on age differences in episodic memory. *Experimental Aging Research*, *23*(2), 137–143. doi:10.1080/03610739708254029

Nyberg, L., Sandblom, J., Jones, S., Neely, a. S., Petersson, K. M., Ingvar, M., & Backman, L. (2003). Neural correlates of training-related memory improvement in adulthood and aging. *Proceedings of the National Academy of Sciences*, *100*(23), 13728–13733. doi:10.1073/pnas.1735487100

Nyhus, E., & Barceló, F. (2009). The Wisconsin Card Sorting Test and the cognitive assessment of prefrontal executive functions: A critical update. *Brain and Cognition*, *71*(3), 437–451. doi:10.1016/j.bandc.2009.03.005

Nyhus, E., & Curran, T. (2010). Functional role of gamma and theta oscillations in episodic memory. *Neuroscience and Biobehavioral Reviews*, *34*(7), 1023–1035. doi:10.1016/j.neubiorev.2009.12.014

O'Brien, J. L., Edwards, J. D., Maxfield, N. D., Peronto, C. L., Williams, V. a., & Lister, J. J. (2013). Cognitive training and selective attention in the aging brain: An electrophysiological study. *Clinical Neurophysiology*, *124*(11), 2198–2208. doi:10.1016/j.clinph.2013.05.012

O'Reilly, R. C., & Frank, M. J. (2006). Making Working Memory Work: A Computational Model of Learning in the Prefrontal Cortex and Basal Ganglia. *Neural Computation*, *18*(2), 283–328.

Oakhill, J. V., Cain, K., & Bryant, P. E. (2003). The dissociation of word reading and text comprehension: Evidence from component skills. *Language and Cognitive Processes*, *18*(4), 443–468. doi:10.1080/01690960344000008

Oberauer, K. (2009). Design for a Working Memory. In *The Psychology of Learning and Motivation* (1st ed., Vol. 51, pp. 45–100). Elsevier Inc. doi:10.1016/S0079-7421(09)51002-X

Olesen, P. J., Westerberg, H., & Klingberg, T. (2004). Increased prefrontal and parietal activity after training of working memory. *Nature Neuroscience*, *7*(1), 75–9. doi:10.1038/nn1165

Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J. M. (2011). FieldTrip: Open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Computational Intelligence and Neuroscience*, *2011*. doi:10.1155/2011/156869

Ortega, A., Gómez-Ariza, C. J., Román, P., & Bajo, M. T. (2012). Memory inhibition, aging, and the executive deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(1), 178–186. doi:10.1037/a0024510

Owen, A. M., Hampshire, A., Grahn, J. a, Stenton, R., Dajani, S., Burns, A. S., … Ballard, C. G. (2010). Putting brain training to the test. *Nature*, *465*(7299), 775–8. doi:10.1038/nature09042

Palladino, P., & Cornoldi, C. (2001). Working memory and updating processes in reading comprehension. *Memory & Cognition*, *29*(2), 344–354.

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging*, *17*(2), 299–320. doi:10.1037/0882-7974.17.2.299

Park, D. C., Polk, T. a., Park, R., Minear, M., Savage, A., & Smith, M. R. (2004). Aging reduces neural specialization in ventral visual cortex. *Proceedings of the National Academy of Sciences*, *101*(35), 13091–13095. doi:10.1073/pnas.0405148101

Park, D. C., & Reuter-Lorenz, P. (2009). The Adaptive Brain: Aging and Neurocognitive Scaffolding. *Annual Review of Psychology*, *60*(1), 173–196. doi:10.1146/annurev.psych.59.103006.093656

Parkinson, S. R., & Dannenbaum, S. E. (1985). Adult Age Differences in Short-Term Forgetting. *Acta Psychologica*, *60*, 83–101.

Paxton, J. L., Barch, D. M., Racine, C. A., & Braver, T. S. (2008). Cognitive Control, Goal Maintenance, and Prefrontal Function in Healthy Aging. *Cerebral Cortex*, *18*(5), 1010–1028. doi:10.1093/cercor/bhm135.Cognitive

Paxton, J. L., Barch, D. M., Storandt, M., & Braver, T. S. (2006). Effects of Environmental Support and Strategy Training on Older Adults: Use of Context. *Psychology and Aging*, *21*(3), 499–509. doi:10.1017/CBO9781107415324.004

Peirce, J. W. (2007). PsychoPy-Psychophysics software in Python. *Journal of Neuroscience Methods*, *162*(1-2), 8–13. doi:10.1016/j.jneumeth.2006.11.017

Peng, H., Wen, J., Wang, D., & Gao, Y. (2012). The Impact of Processing Speed Training on Working Memory in Old Adults. *Journal of Adult Development*, *19*(3), 150–157. doi:10.1007/s10804-012-9142-6

Pérez, A., Cain, K., Castellanos, M. C., & Bajo, T. (2015). Inferential revision in narrative texts: An ERP study. *Memory & Cognition*, *43*(8), 1105–1135. doi:10.3758/s13421-015-0528-0

Pérez, A. I., Paolieri, D., Macizo, P., & Bajo, T. (2014). The role of working memory in inferential sentence comprehension. *Cognitive Processing*, *15*(3), 405–413. doi:10.1007/s10339-014-0611-7

Pérez, A., Joseph, H. S. S. L., Bajo, T., & Nation, K. (2016). Evaluation and revision of inferential comprehension in narrative texts: an eye movement study. *Language, Cognition and Neuroscience*, *31*(4), 549–566. doi:10.1080/23273798.2015.1115883

Persson, J., & Reuter-Lorenz, P. a. (2008). Gaining control: training executive function and far transfer of the ability to resolve interference. *Psychological Science*, *19*(9), 881–8. doi:10.1111/j.1467-9280.2008.02172.x

Persson, J., Sylvester, C. Y. C., Nelson, J. K., Welsh, K. M., Jonides, J., & Reuter-Lorenz, P. a. (2004). Selection requirements during verb generation: Differential recruitment in older and younger adults. *NeuroImage*, *23*(4), 1382–1390. doi:10.1016/j.neuroimage.2004.08.004

Pharo, H., Sim, C., Graham, M., Gross, J., & Hayne, H. (2011). Risky business: Executive function, personality, and reckless behavior during adolescence and emerging adulthood. *Behavioral Neuroscience*, *125*(6), 970–978. doi:10.1037/a0025768

Posner, M. I., Rothbart, M. K., Sheese, B. E., & Tang, Y. (2007). The anterior cingulate gyrus and the mechanism of self-regulation. *Cognitive, Affective, & Behavioral Neuroscience*, *7*(4), 391–395. doi:10.3758/CABN.7.4.391

Prakash, R. S., Erickson, K. I., Colcombe, S. J., Kim, J. S., Voss, M. W., & Kramer, A. F. (2009). Age-related differences in the involvement of the prefrontal cortex in attentional control. *Brain and Cognition*, *71*(3), 328–335. doi:10.1016/j.bandc.2009.07.005

Ramón y Cajal, S. (1911). Histologie du systeme nerveux de l ' homme & des vertebres. *Consejo Superior de Investigaciones Cientificas, Instituto Ramon Y Cajal.*, 1955.

Rapp, D. N., & Kendeou, P. (2007). Revising what readers know: updating text representations during narrative comprehension. *Memory & Cognition*, *35*(8), 2019–2032. doi:10.3758/BF03192934

Rapport, M. D., Scanlan, S. W., & Denney, C. B. (1999). Attention-deficit/hyperactivity disorder and scholastic achievement: a model of dual developmental pathways. *Journal of Child Psychology and Psychiatry*, *40*(08), 1169–1183. doi:10.1111/1469-7610.00534

Raven, J. C. (1990). *Advanced Progressive Matrices: Sets I, II.* Oxford: Oxford University Press.

Raz, N., Ghisletta, P., Rodrigue, K. M., Kennedy, K. M., & Lindenberger, U. (2010). Trajectories of brain aging in middle-aged and older adults: Regional and individual differences. *NeuroImage*, *51*(2), 501–511. doi:10.1016/j.neuroimage.2010.03.020

Rebai, M., Bernard, C., & Lannou, J. (1997). The Stroop's test evokes a negative brain potential, the N400. *The International Journal of Neuroscience*, *91*(1-2), 85–94. doi:10.3109/00207459708986367

Rebok, G. W., Carlson, M. C., & Langbaum, J. B. S. (2007). Training and maintaining memory abilities in healthy older adults: Traditional and novel approaches. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, *62*(SPEC. ISSUE 1), 53–61. doi:10.1093/geronb/62.special_issue_1.53

Redick, T. S., Shipstead, Z., Harrison, T. L., Hicks, K. L., Fried, D. E., Hambrick, D. Z., … Engle, R. W. (2013). No Evidence of Intelligence Improvement After Working Memory Training: A Randomized, Placebo-Controlled Study. *Journal of Experimental Psychology: General*, *142*(2), 359–379. doi:10.1037/a0029082

Reiter, a, Tucha, O., & Lange, K. (2005). Executive functions in children with dyslexia. *Dyslexia*, *11*(2), 116–131. doi:10.1002/dys.289

Reuter-Lorenz, P. a., & Cappell, K. a. (2008). Neurocognitive aging and the compensation hypothesis. *Current Directions in Psychological Science*, *17*(3), 177–182. doi:10.1111/j.1467-8721.2008.00570.x

Reuter-Lorenz, P. a., & Lustig, C. (2005). Brain aging: Reorganizing discoveries about the aging mind. *Current Opinion in Neurobiology*, *15*(2), 245–251. doi:10.1016/j.conb.2005.03.016

Richmond, L. L., Morrison, A. B., Chein, J. M., & Olson, I. R. (2011). Working memory training and transfer in older adults. *Psychology and Aging*, *26*(4), 813–822. doi:10.1037/a0023631

Richmond, L., Redick, T. S., & Braver, T. S. (2015). Remembering to prepare: The benefits (and costs) of high working memory capacity. *JOURNAL OF EXPERIMENTAL LEARNING MEMORY AND COGNITION*, *41*(6), 1764–1777. doi:10.1016/j.bbamem.2015.02.010.Cationic

Roberts, A. C. (1998). *THE PREFRONTAL CORTEX—EXECUTIVE AND COGNITIVE FUNCTIONS*. (A. C. Roberts, T. W. Robbins, & L. Weiskrantz, Eds.). NY, US: Oxford University Press. doi:10.1177/016344399021006018

Román, P., Soriano, M. F., Gómez-Ariza, C. J., & Bajo, M. T. (2009). Retrieval-induced forgetting and executive control. *Psychological Science*, *20*(9), 1053–1058. doi:10.1111/j.1467-9280.2009.02415.x

Rosen, A., Sugiura, L., Kramer, J., Whitfield-Gabrieli, S., & Gabrieli, J. (2011). Cognitive training changes hippocampal function in mild cognitive impairment: a pilot study. *Journal of Alzheimers Disease*, *26*(Suppl. 3), 349–57. doi:10.3233/JAD-2011-0009.Cognitive

Rosen, V. M., & Engle, R. W. (1998). Working memory capacity and suppression. *Journal of Memory and Language*, *39*, 418–436. doi:10.1006/jmla.1998.2590

Rueda, M. R., Checa, P., & Combita, L. M. (2012). Enhanced efficiency of the executive attention network after training in preschool children: Immediate changes and effects after two months. *Developmental Cognitive Neuroscience*, *2*(SUPPL. 1), S192–S204. doi:10.1016/j.dcn.2011.09.004

Rueda, M. R., Checa, P., & Cómbita, L. M. (2012). Enhanced efficiency of the executive attention network after training in preschool children: immediate changes and effects after two months. *Developmental Cognitive Neuroscience*, *2 Suppl 1*, S192–204. doi:10.1016/j.dcn.2011.09.004

Rueda, M. R., Rothbart, M. K., Mccandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). Training , maturation , and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences of the United States of America*, 2–7.

Rush, B. K., Barch, D. M., & Braver, T. S. (2006). Accounting for cognitive aging: context processing, inhibition or processing speed? *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn*, *13*(3-4), 588–610. doi:10.1080/13825580600680703

Ryan, E. B. (1992). Beliefs about memory changes across the adult life span. *Journal of Gerontology*, *47*(1), P41–P46.

Ryan, R. M., Connell, J. P., & Plant, R. W. (1990). Emotions in nondirected text learning. *Learning and Individual Differences*, *2*(1), 1–17. doi:10.1016/1041-6080(90)90014-8

Ryan, R. M., Koestner, R., & Deci, E. L. (1991). Ego-involved persistence: When free-choice behavior is not intrinsically motivated. *Motivation and Emotion*, *15*(3), 185–205. doi:10.1007/BF00995170

Rypma, B., & D'Esposito, M. (2000). Isolating the neural mechanisms of age-related changes in human working memory. *Nature Neuroscience*, *3*(5), 509–515. doi:10.1038/74889

Sahakyan, L., Delaney, P. F., & Goodmon, L. B. (2008). Oh, honey, I already forgot that: Strategic control of directed forgetting in older and younger adults. *Psychology and Aging*, *23*(3), 621–633. doi:10.1037/a0012766

Salthouse, T. A. (1991). Mediation of Adult Age Differences in Cognition By Reductions in Working Memory and Speed of Processing. *Psychological Science*, *2*(3), 179–183. doi:10.1111/j.1467-9280.1991.tb00127.x

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, *103*(3), 403–428. doi:10.1037/0033-295X.103.3.403

Salthouse, T. A. (2007). Implications of within-person variability in cognitive and neuropsychological functioning for the interpretation of change. *Neuropsychology*, *21*(4), 401–411. doi:10.1037/0894-4105.21.4.401

Salthouse, T. A., & Mitchell, D. R. D. (1990). Effects of Age and Naturally Occurring Experience on Spatial Visualization Performance. *Developmental Psychology*, *26*(5), 845–854. doi:10.1037/0012-1649.26.5.845

Schmidt, R. A., & Bjork, R. A. (1992). New Conceptualizations of Practice: Common Principles in Three Paradigms Suggest New Concepts for Training. *Psychological Science*, *3*(4), 207–217. doi:10.1111/j.1467-9280.1992.tb00029.x

Schmiedek, F., Lövdén, M., & Lindenberger, U. (2010). Hundred days of cognitive training enhance broad cognitive abilities in adulthood: Findings from the COGITO study. *Frontiers in Aging Neuroscience*, *2*(JUL), 1–10. doi:10.3389/fnagi.2010.00027

Schubert, T., Strobach, T., & Karbach, J. (2014). New directions in cognitive training: on methods, transfer, and application. *Psychological Research*, *78*(6), 749–755. doi:10.1007/s00426-014-0619-8

Schwaighofer, M., Fischer, F., & Bühner, M. (2015). Does working memory training transfer? A meta-analysis including training conditions as moderators. *Educational Psychologist*, *50*(2), 138–166. doi:10.1080/00461520.2015.1036274

Schweizer, S., Hampshire, A., & Dalgleish, T. (2011). Extending brain-training to the affective domain: Increasing cognitive and affective executive control through emotional working memory training. *PLoS ONE*, *6*(9). doi:10.1371/journal.pone.0024372

Sego, S. A., Golding, J. M., & Gottlob, L. R. (2006). Directed forgetting in older adults using the item and list methods. *Aging, Neuropsychology, and Cognition. Section B: Aging, Neuropsychology and Cognition.*, *13*(1), 95–114. doi:10.1080/138255890968682

Seigneuric, A., & Ehrlich, M.-F. (2005). Contribution of working memory capacity to children's reading comprehension: a longitudinal investigation. *Reading and Writing: An Interdisciplinary Journal*, *18*(7-9), 617–656. doi:10.1007/s11145-005-2038-0

Seigneuric, A., Ehrlich, M.-F., Oakhill, J. V, & Yuill, N. M. (2000). Working memory resources and children's reading comprehension. *Reading and Writing*, *13*(1988), 81–103. doi:10.1023/A:1008088230941

Sesma, H. W., Mahone, E. M., Levine, T., Eason, S. H., & Cutting, L. E. (2009). The Contribution of Executive Skills to Reading Comprehension. *Child Neuropsychology*, *15*(3), 232–246. doi:10.1080/09297040802220029

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, *84*(2), 127–190.

Shimamura, A. P., & Squire, L. R. (1991). The relationship between fact and source memory: Findings from amnesiac patients and normal subjects. *Psychobiology*, *19*(1), 1–10.

Shin, E., Lee, H., Yoo, S.-A., & Chong, S. C. (2015). Training Improves the Capacity of Visual Working Memory When It Is Adaptive, Individualized, and Targeted. *PloS One*, *10*(4), e0121702. doi:10.1371/journal.pone.0121702

Shing, Y. L., Werkle-Bergner, M., Brehmer, Y., Müller, V., Li, S. C., & Lindenberger, U. (2010). Episodic memory across the lifespan: The contributions of associative and strategic components. *Neuroscience and Biobehavioral Reviews*, *34*(7), 1080–1091. doi:10.1016/j.neubiorev.2009.11.002

Shipstead, Z., Harrison, T. L., & Engle, R. W. (2015). Working memory capacity and the scope and control of attention. *Attention, Perception & Psychophysics*, *77*(6), 1863–80. doi:10.3758/s13414-015-0899-0

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective? *Psychological Bulletin*, *138*(4), 628–54. doi:10.1037/a0027473

Shute, V. J. (1995). Who is Likely to Acquire Programming Skills? *Journal of Educational Computing Research*, *7*(1), 1–24. doi:10.2190/VQJD-T1YD-5WVB-RYPJ

Simons, D. J., Boot, W. R., Charness, N., Gathercole, S. E., Chabris, C. F., Hambrick, D. Z., & Stine-Morrow, E. a. L. (2016). Do "Brain-Training" Programs Work? *Psychological Science in the Public Interest*, *17*(3), 103–186. doi:10.1177/1529100616661983

Singer, T., Lindenberger, U., & Baltes, P. B. (2003). Plasticity of memory for new learning in very old age: A story of major loss? *Psychology and Aging*, *18*(2), 306–317. doi:10.1037/0882-7974.18.2.306

Smith, E. E., Geva, a, Jonides, J., Miller, a, Reuter-Lorenz, P., & Koeppe, R. a. (2001). The neural basis of task-switching in working memory: effects of performance and aging. *Proceedings of the National Academy of Sciences of the United States of America*, *98*(4), 2095–2100. doi:10.1073/pnas.98.4.2095

Smith, E. E., & Jonides, J. (1997). Working memory: a view from neuroimaging. *Cognitive Psychology*, *33*(1), 5–42. doi:10.1006/cogp.1997.0658

Söderqvist, S., Nutley, S. B., Ottersen, J., Grill, K. M., & Klingberg, T. (2012). Computerized training of non-verbal reasoning and working memory in children with intellectual disability. *Frontiers in Human Neuroscience*, *6*(October), 271. doi:10.3389/fnhum.2012.00271

Solesio-Jofre, E., Lorenzo-L??pez, L., Guti??rrez, R., L??pez-Frutos, J. M., Ruiz-Vargas, J. M., & Maest??, F. (2012). Age-related effects in working memory recognition modulated by retroactive interference. *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*, *67 A*(6), 565–572. doi:10.1093/gerona/glr199

Souchay, C., Isingrini, M., & Espagnet, L. (2000). Aging, episodic memory feeling-of-knowing, and frontal functioning. *Neuropsychology*, *14*(2), 299–309. doi:10.1037/0894-4105.14.2.299

Spencer-Smith, M., & Klingberg, T. (2015). Benefits of a working memory training program for inattention in daily life: A systematic review and meta-analysis. *PLoS ONE*, *10*(3), 1–18. doi:10.1371/journal.pone.0119522

Spierer, L., Chavan, C. F., & Manuel, A. L. (2013). Training-induced behavioral and brain plasticity in inhibitory control. *Frontiers in Human Neuroscience*, *7*(August), 427. doi:10.3389/fnhum.2013.00427

Sprenger, A. M., Atkins, S. M., Bolger, D. J., Harbison, J. I., Novick, J. M., Chrabaszcz, J. S., … Dougherty, M. R. (2013). Training working memory: Limits of transfer. *Intelligence*, *41*(5), 638–663. doi:10.1016/j.intell.2013.07.013

St. Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology (2006)*, *59*(4), 745–759. doi:10.1080/17470210500162854

Staudigl, T., Hanslmayr, S., & Bauml, K.-H. T. (2010). Theta Oscillations Reflect the Dynamics of Interference in Episodic Memory Retrieval. *Journal of Neuroscience*, *30*(34), 11356–11362. doi:10.1523/JNEUROSCI.0637-10.2010

Steinhauser, M., & Hu, R. (2009). Distinguishing Response Conflict and Task Conflict in the Stroop Task : Evidence From Ex-Gaussian Distribution Analysis, *35*(5), 1398–1412. doi:10.1037/a0016467

Stephenson, C. L., & Halpern, D. F. (2013). Improved matrix reasoning is limited to training on tasks with a visuospatial component. *Intelligence*, *41*(5), 341–357. doi:10.1016/j.intell.2013.05.006

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society*, *8*(03), 448–460. doi:10.1017/S1355617702813248

Stine, E. A. L. (1995). Aging and the Distribution of Resources in Working Memory. *Elsevier Science B.V.*, (603), 171–186.

Stine-Morrow, E. a. L., Parisi, J. M., Morrow, D. G., & Park, D. C. (2008). The effects of an engaged lifestyle on cognitive vitality: A field experiment. *Psychology and Aging*, *23*(4), 778–786. doi:10.1037/a0014341

Stokes, M. G., Buschman, T. J., & Miller, E. K. (2017). Dynamic Coding for Flexible Cognitive Control. In *The Wiley Handbook of Cognitive Control* (pp. 221–241).

Storm, B. C., & Levy, B. J. (2012). A progress report on the inhibitory account of retrieval-induced forgetting. *Memory & Cognition*, *40*(6), 827–843. doi:10.3758/s13421-012-0211-7

Strobach, T., & Karbach, J. (2016). *Cognitive training: An Overview of Features and Applications*. *Alzheimer's and Dementia* (Vol. 7). Springer. doi:10.1016/j.jalz.2011.05.209

Strobach, T., Liepelt, R., Schubert, T., & Kiesel, A. (2012). Task switching: Effects of practice on switch and mixing costs. *Psychological Research*, *76*(1), 74–83. doi:10.1007/s00426-011-0323-x

Strobach, T., Salminen, T., Karbach, J., & Schubert, T. (2014). Practice-related optimization and transfer of executive functions: a general review and a specific realization of their mechanisms in dual tasks. *Psychological Research*, *78*(6), 836–851. doi:10.1007/s00426-014-0563-7

Studer-Luethi, B., Jaeggi, S. M., Buschkuehl, M., & Perrig, W. J. (2012). Influence of neuroticism and conscientiousness on working memory training outcome. *Personality and Individual Differences*, *53*(1), 44–49. doi:10.1016/j.paid.2012.02.012

Swanson, H. L., & Berninger, V. (1995). The role of working memory in skilled and less skilled readers' comprehension. *Intelligence*, *21*(1), 83–108. doi:10.1016/0160-2896(95)90040-3

Szczepanski, S. M., & Knight, R. T. (2014). Insights into Human Behavior from Lesions to the Prefrontal Cortex. *Neuron*, *83*(5), 1002–1018. doi:10.1016/j.neuron.2014.08.011

Takeuchi, H., & Kawashima, R. (2012). Effects of processing speed training on cognitive functions and neural systems. *Reviews in the Neurosciences*, *23*(3), 289–301. doi:10.1515/revneuro-2012-0035

Tanenhaus, M. K., & Hare, M. (2007). Phonological typicality and sentence processing. *Trends in Cognitive Sciences*, *11*(3), 93–95. doi:10.1016/j.tics.2006.11.010

Tardif, S., & Simard, M. (2011). Cognitive stimulation programs in healthy elderly: a review. *International Journal of Alzheimer's Disease*, *2011*, 378934. doi:10.4061/2011/378934

Taya, F., Sun, Y., Babiloni, F., Thakor, N., & Bezerianos, A. (2015). Brain enhancement through cognitive training: a new insight from brain connectome. *Frontiers in Systems Neuroscience*, *9*(April), 1–19. doi:10.3389/fnsys.2015.00044

Tays, W. J., Dywan, J., Mathewson, K. J., & Segalowitz, S. J. (2008). Age differences in target detection and interference resolution in working memory: An event-related potential study. *Journal of Cognitive Neuroscience*, *20*(12), 2250–2262. doi:http://dx.doi.org/10.1162/jocn.2008.20158

Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science*, *12*(1), 106–13. doi:10.1111/j.1467-7687.2008.00745.x

Titz, C., & Karbach, J. (2014). Working memory and executive functions: effects of training on academic achievement. *Psychological Research*, *78*(6), 852–868. doi:10.1007/s00426-013-0537-1

Tokowicz, N., Michael, E. B., & Kroll, J. F. (2004). The roles of study-abroad experience and working-memory capacity in the types of errors made during translation\n \n . *Bilingualism: Language and Cognition*, *7*(2004), 255–272. doi:10.1017/S1366728904001634

Toril, P., Reales, J. M., Mayas, J., & Ballesteros, S. (2016). Video Game Training Enhances Visuospatial Working Memory and Episodic Memory in Older Adults. *Frontiers in Human Neuroscience*, *10*(May), 1–14. doi:10.3389/fnhum.2016.00206

Towse, J. N., Hitch, G. J., & Hutton, U. (2000). On the interpretation of working memory span in adults. *Memory & Cognition*, *28*(3), 341–348. doi:10.3758/BF03198549

Turley-Ames, K. J., & Whitfield, M. M. (2003). Strategy training and working memory task performance. *Journal of Memory and Language*, *49*(4), 446–468. doi:10.1016/S0749-596X(03)00095-0

Turner, G. R., & Spreng, R. N. (2012). Executive functions and neurocognitive aging: Dissociable patterns of brain activity. *Neurobiology of Aging*, *33*(4), 826.e1–826.e13. doi:10.1016/j.neurobiolaging.2011.06.005

Turner, M. L., & Engle, R. W. (1989). Is Working Memory Capacity Task Dependent?, *28*(2), 127–154. doi:10.1016/0749-596X(89)90040-5

Umanath, S., & Marsh, E. J. (2014). Understanding How Prior Knowledge Influences Memory in Older Adults. *Perspectives on Psychological Science*, *9*(4), 408–426. doi:10.1177/1745691614535933

Unsworth, N. (2010). Interference control, working memory capacity, and cognitive abilities: A latent variable analysis. *Intelligence*, *38*(2), 255–267. doi:10.1016/j.intell.2009.12.003

Unsworth, N., Redick, T. S., Heitz, R. P., Broadway, J. M., & Engle, R. W. (2009). Complex working memory span tasks and higher-order cognition: a latent-variable analysis of the relationship between processing and storage. *Memory*, *17*(6), 635–54. doi:10.1080/09658210902998047

Van Dijk, T. a, & Kintsch, W. (1983). *Strategies of Discourse Comprehension. New York: Academic Press*. New York: Academic Press. doi:10.2307/415483

Verbruggen, F., & Logan, G. (2008). Response inhibition in the stop-signal pardigm. *Trends in Cognitive Sciences*, *12*(11), 418–424. doi:10.1016/j.tics.2008.07.005.Response

Verbruggen, F., Logan, G. D., & Stevens, M. a. (2008). STOP-IT: Windows executable software for the stop-signal paradigm. *Behavior Research Methods*, *40*(2), 479–483. doi:10.3758/BRM.40.2.479

Verhaeghen, P., Marcoen, A., & Goossens, L. (1992). Improving memory performance in the aged through mnemonic training: A meta-analytic study. *Psychology and Aging*, *7*(2), 242–251. doi:10.1037/0882-7974.7.2.242

Von Bastian, C. C., & Oberauer, K. (2013). Distinct transfer effects of training different facets of working memory capacity. *Journal of Memory and Language*, *69*(1), 36–58. doi:10.1016/j.jml.2013.02.002

Wadley, V. G., Benz, R. L., Ball, K. K., Roenker, D. L., Edwards, J. D., & Vance, D. E. (2006). Development and Evaluation of Home-Based Speed-of-Processing Training for Older Adults. *Archives of Physical Medicine and Rehabilitation*, *87*(6), 757–763. doi:10.1016/j.apmr.2006.02.027

Wagner, a D., Maril, A., Bjork, R. a, & Schacter, D. L. (2001). Prefrontal contributions to executive control: fMRI evidence for functional distinctions within lateral Prefrontal cortex. *Neuroimage*, *14*(6), 1337–1347. doi:10.1006/nimg.2001.0936

Wagner, A. D., Shannon, B. J., Kahn, I., & Buckner, R. L. (2005). Parietal lobe contributions to episodic memory retrieval. *Trends in Cognitive Sciences*, *9*(9), 445–453. doi:10.1016/j.tics.2005.07.001

Waldhauser, G. T., Johansson, M., & Hanslmayr, S. (2012). Alpha/Beta Oscillations Indicate Inhibition of Interfering Visual Memories. *Journal of Neuroscience*, *32*(6), 1953–1961. doi:10.1523/JNEUROSCI.4201-11.2012

Wang, Y., Fu, S., Greenwood, P., Luo, Y., & Parasuraman, R. (2012). Perceptual load, voluntary attention, and aging: An event-related potential study. *International Journal of Psychophysiology*, *84*(1), 17–25. doi:10.1016/j.ijpsycho.2012.01.002

Wang, Z., Zhou, R., & Shah, P. (2014). Spaced cognitive training promotes training transfer. *Frontiers in Human Neuroscience*, *8*(April), 217. doi:10.3389/fnhum.2014.00217

Wass, S. V., Scerif, G., & Johnson, M. H. (2012). Training attentional control and working memory - Is younger, better? *Developmental Review*, *32*(4), 360–387. doi:10.1016/j.dr.2012.07.001

Weicker, J., Villringer, A., & Thöne-Otto, A. (2016). Can impaired working memory functioning be improved by training? A meta-analysis with a special focus on brain injured patients. *Neuropsychology*, *30*(2), 190–212. doi:10.1037/neu0000227

Weller, P. D., Anderson, M. C., Gómez-Ariza, C. J., & Bajo, M. T. (2013). On the status of cue independence as a criterion for memory inhibition: Evidence against the covert blocking hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *39*(4), 1232–1245. doi:10.1037/a0030335

Wenger, E., & Shing, Y. L. (2016). Episodic Memory. In T. Strobach & J. Karbach (Eds.), *Cognitive Training: An Overview of Features and Applications* (pp. 69–80). Springer, Cham.

West, R. (2004). The effects of aging on controlled attention and conflict processing in the Stroop task. *Journal of Cognitive Neuroscience*, *16*(1), 103–13. doi:10.1162/089892904322755593

West, R., & Alain, C. (2000). Effects of task context and fluctuations of attention on neural activity supporting performance of the Stroop task. *Brain Research*, *873*(1), 102–111. doi:10.1016/S0006-8993(00)02530-0

West, R., & Bailey, K. (2012). ERP correlates of dual mechanisms of control in the counting Stroop task. *Psychophysiology*, *49*(10), 1309–1318. doi:10.1111/j.1469-8986.2012.01464.x

West, R., & Schwarb, H. (2006). The influence of aging and frontal function on the neural correlates of regulative and evaluative aspects of cognitive control. *Neuropsychology*, *20*(4), 468–481. doi:10.1037/0894-4105.20.4.468

West, R., Alain, C. (1999). Event-related neural activity associated with the Stroop task. *Cognitive Brain Research*, *8*(2), 157–164.

Whalley, L. J., Deary, I. J., Appleton, C. L., & Starr, J. M. (2004). Cognitive reserve and the neurobiology of cognitive aging. *Ageing Research Reviews*, *3*(4), 369–382. doi:10.1016/j.arr.2004.05.001

Wiecki, T. V., & Frank, M. J. (2013). A computational model of inhibitory control in frontal cortex and basal ganglia. *Psychol Rev*, *120*(2), 329–355. doi:10.1037/a0031542

Wiesel, T. N., & Hubel, D. H. (1965). Comparison of the effects of unilateral and bilateral eye closure on cortical unit responses in kittens. *Journal of Neurophysiology*, *28*(6), 1029–1040.

Wild-Wall, N., Falkenstein, M., & Gajewski, P. D. (2012). Neural correlates of changes in a visual search task due to cognitive training in seniors. *Neural Plasticity*, (529057). doi:10.1155/2012/529057

Wilhelm, O., Hildebrandt, A., & Oberauer, K. (2013). What is working memory capacity, and how can we measure it? *Frontiers in Psychology*, *4*(JUL), 1–22. doi:10.3389/fpsyg.2013.00433

Wilkinson, A. J., & Yang, L. (2016). Long-Term Maintenance of Inhibition Training Effects in Older Adults : 1- and 3-Year Follow-Up, *71*(4), 622–629. doi:10.1037/a0025926

Wilkinson, G. S., & Robertson, G. S. (2006). *Wide Range Test 4* (Vol. 4).

Willis, S. L., & Caskie, G. I. L. (2013). Reasoning Training in the ACTIVE Study. *Journal of Aging and Health*, *25*(8_suppl), 43S–64S. doi:10.1177/0898264313503987

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., … Wright, E. (2006). Long-term Effects of Cognitive Training on Everyday Functional Outcomes in Older Adults. *JAMA*, *296*(23), 2805–2814.

Wimber, M., Alink, A., Charest, I., Kriegeskorte, N., & Anderson, M. C. (2015). Retrieval induces adaptive forgetting of competing memories via cortical pattern suppression. *Nature Neuroscience*, *18*(4), 582–589. doi:10.1038/nn.3973

Wimber, M., Bäuml, K.-H., Bergström, Z., Markopoulos, G., Heinze, H.-J., & Richardson-Klavehn, A. (2008). Neural markers of inhibition in human memory retrieval. *The Journal of Neuroscience*, *28*(50), 13419–13427. doi:10.1523/JNEUROSCI.1916-08.2008

Wimber, M., Rutschmann, R. M., Greenlee, M. W., & Bäuml, K.-H. (2009). Retrieval from Episodic Memory: Neural Mechanisms of Interference Resolution. *Journal of Cognitive Neuroscience*, *21*(3), 538–549. doi:10.1162/jocn.2009.21043

Wimber, M., Schott, B. H., Wendler, F., Seidenbecher, C. I., Behnisch, G., Macharadze, T., … Richardson-Klavehn, a. (2011). Prefrontal dopamine and the dynamic control of human long-term memory. *Translational Psychiatry*, *1*(7), e15. doi:10.1038/tp.2011.15

Woodard, K., Pozzan, L., & Trueswell, J. C. (2016). Taking your own path: Individual differences in executive function and language processing skills in child learners. *Journal of Experimental Child Psychology*, *141*(October), 187–209. doi:10.1016/j.jecp.2015.08.005

Woodworth, R. S., & Thorndike, E. L. (1901). The influence of improvement in one mental function upon the efficiency of other functions. (I). *Psychological Review*, *8*(3), 247–261. doi:10.1037/h0074898

World Health Organisation. (2013). Declaration of Helsinki World Medical Association Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects. *The Journal of the American Medical Association*, *310*(20), 2191–2194. doi:10.1001/jama.2013.281053

Xiang, L., Zhang, B., Wang, B., Jiang, J., & Zhang, F. (2016). The Effect of Aging on the Dynamics of Reactive and Proactive Cognitive Control of Response Interference The Effect of Aging on the Dynamics of Reactive and Proactive Cognitive Control of Response Interference, (November). doi:10.3389/fpsyg.2016.01640

Zacks, R., Hasher, L., Lynn, L., & Karen, Z. (2000). Human memory. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of Aging and Cognition* (pp. 293–357). Mahwah, NJ: Lawrence Erlbaum Associates.

Zacks, R. T., & Hasher, L. (1997). Cognitive gerontology and attentional inhibition: a reply to Burke and McDowd. *Journal of Gerontology: Psychological Sciences*, *52*(6), P274–83. doi:10.1093/geronb/52B.6.P274

Zanto, T. P., & Gazzaley, A. (2017). Cognitive Control and the Ageing Brain. In *The Wiley Handbook of Cognitive Control* (pp. 476–490).

Zeidan, F., Johnson, S. K., Diamond, B. J., David, Z., & Goolkasian, P. (2010). Mindfulness meditation improves cognition: Evidence of brief mental training. *Consciousness and Cognition*, *19*(2), 597–605. doi:10.1016/j.concog.2010.03.014

Zinke, K., Zeintl, M., Eschen, A., Herzog, C., & Kliegel, M. (2011). Potentials and limits of plasticity induced by working memory training in old-old age. *Gerontology*, *58*(1), 79–87. doi:10.1159/000324240

Zinke, K., Zeintl, M., Rose, N. S., Putzmann, J., Pydde, A., & Kliegel, M. (2014). Working memory training and transfer in older adults: Effects of age, baseline performance, and training gains. *Developmental Psychology*, *50*(1), 304–315. doi:10.1037/a0032982

Zwaan, R. A., Langston, M. C., & Graesser, A. C. (1995). The Construction of Situation Models in Narrative Comprehension: An Event-Indexing Model. *Psychological Science*, *6*(5), 292–297.

Zwaan, R., & Radvansky, G. (1998). Situation models in language comprehension and memory. *Psychological Bulletin*, *123*(2), 162–185. doi:10.1037/0033-2909.123.2.162

APPENDICES

Appendix 1: Pre-Screening Questionnaire

(Experiments 2A & 2B)

ENTRENAMIENTO COGNITIVO Y ENVEJECIMIENTO

El objetivo de este cuestionario es encontrar personas mayores de 60 años residentes en Granada que estén interesadas en participar en un estudio de entrenamiento cognitivo realizado por la Universidad de Granada en colaboración con la Universidad de Padua (Italia).

Con este estudio no pretendemos detectar ninguna enfermedad y no tiene ningún fin diagnóstico, sino que nuestro objetivo es evaluar la eficacia de un programa de entrenamiento cognitivo en atención y memoria en personas mayores sanas. Por lo tanto, necesitamos participantes mayores de 60 años cuyo envejecimiento sea normal, es decir, que no tengan afectadas sus funciones cognitivas, como la memoria, ni tengan diagnóstico o pre diagnóstico de demencia.

El estudio se compone de:

A) Dos primeras sesiones de evaluación de la atención, memoria y razonamiento. En una de las sesiones estudiaremos su actividad cerebral mientras realiza actividades cognitivas, mediante una técnica de electroencefalografía no invasiva (EEG).

B) Un programa de entrenamiento cognitivo con actividades de ordenador durante 2 semanas.

C) Dos últimas sesiones de evaluación de sus funciones cognitivas igual que al comienzo del estudio. También en una de ellas registraremos su actividad cerebral mediante EEG.

El estudio se está llevando a cabo en el Centro de Investigación Mente, Cerebro y Comportamiento (CIMCYC, Campus de la Cartuja) de la Universidad de Granada y por la participación en el mismo recibirá una compensación económica para gastos de desplazamiento.

Le pedimos que, por favor, conteste a las siguientes preguntas para que podamos saber la disponibilidad de participantes y sus preferencias de participación.

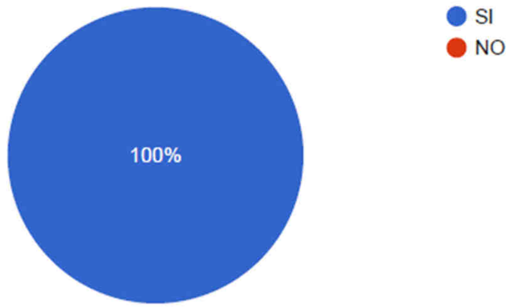
¡GRACIAS POR SU COLABORACIÓN!

Grupo de investigación Memoria y Lenguaje UGR

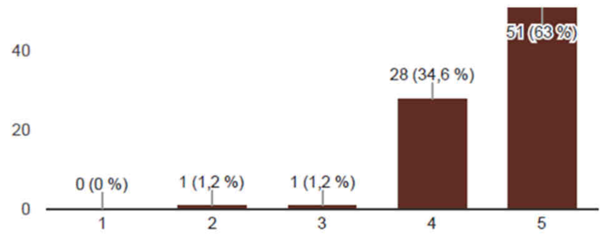
http://memory.ugr.es/

PARTICIPACIÓN EN EL ESTUDIO

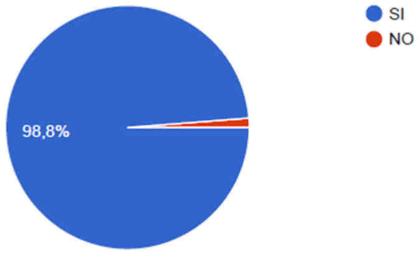
¿Está interesado en participar en un estudio sobre entrenamiento cognitivo?



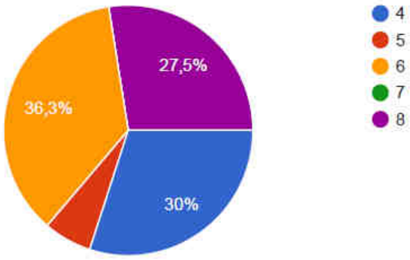
¿Hasta qué punto cree que los programas de entrenamiento cognitivo pueden ser beneficiosos para los mayores?



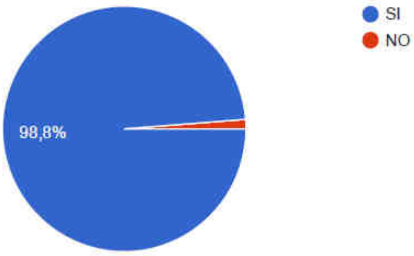
¿Estaría dispuesto a acudir al laboratorio (CIMCYC, Campus de Cartuja) a realizar el programa de entrenamiento durante 2 semanas?



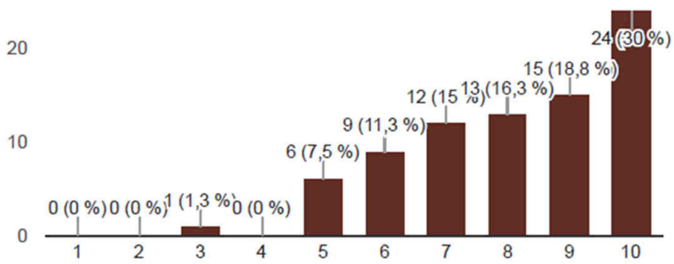
¿Cuántas veces estaría dispuesto a venir en dos semanas?



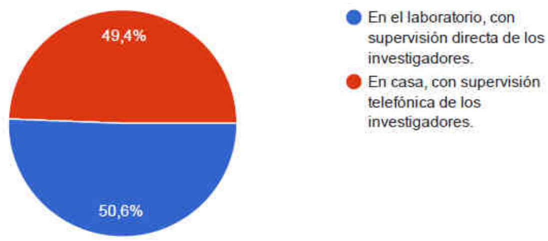
¿Tiene internet y ordenador en casa?



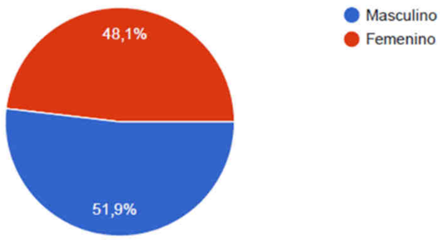
Valore en una escala de 1 a 10 el funcionamiento del internet de su casa:



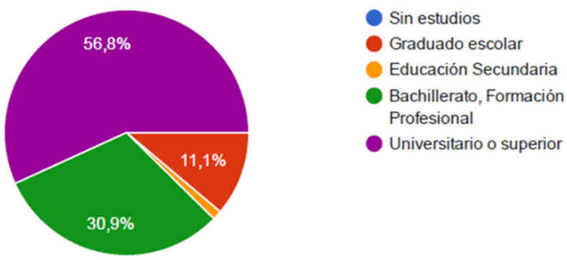
¿Dónde preferiría realizar el programa de entrenamiento cognitivo?



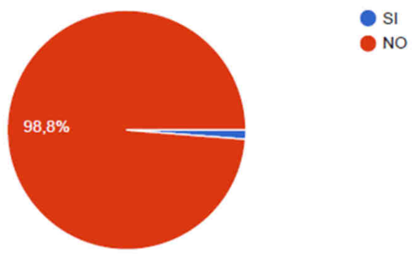
Sexo



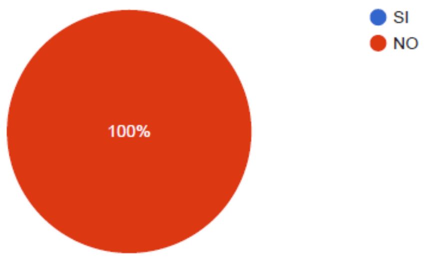
¿Cuál es su nivel de estudios?



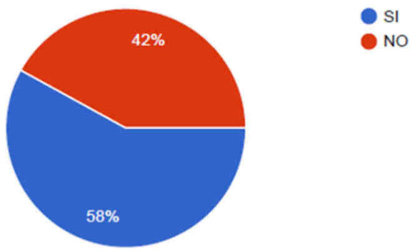
¿Tiene algún diagnóstico o pre-diagnóstico médico de alteración de sus funciones cognitivas (atención, memoria, lenguaje, razonamiento, etc.)?



El estudio requiere que la mayor parte de las tareas se realicen en un ordenador, ¿tiene alguna alteración visual que le dificulte la visión en pantallas de ordenador?



¿Ha participado alguna vez en algún estudio de investigación en Psicología?



Appendix 2: Training booklet for older adults
(Experiments 2A & 2B)

Le recordamos que es importante que complete este diario solo y en un momento del día en el que esté libre de distracciones después de haber completado cada una de las 6 sesiones de entrenamiento.

Le pedimos que responda a las siguientes preguntas con sinceridad, no hay respuestas correctas o incorrectas.

¡Muchas gracias!

PRIMERA SESIÓN DEL PROGRAMA DE ENTRENAMIENTO

Fecha: Horas de sueño:

	Actividad	Hora Inicio	Hora Fin
1	Robots		
2	Sopa		
3	Botín		
4	Acuario		

CUESTIONARIO DE MOTIVACIÓN

(Alonso-Tapia & de la Red Fadrique, 2007)

A continuación se le presentan cuatro preguntas con las que evaluaremos su motivación a lo largo del programa de entrenamiento cognitivo. Deberá valorar cada una de las frases en una escala desde 1 (Muy baja) hasta 10 (Muy alta) en función de cómo se siente en este momento:

1. Hasta ahora, mi implicación en la tarea ha sido

1	2	3	4	5	6	7	8	9	10

Muy baja Muy alta

2. Hasta ahora, el nivel de dificultad de la tarea me ha resultado

1	2	3	4	5	6	7	8	9	10

Muy baja Muy alta

3. Hasta ahora, ir superando niveles de dificultad en la tarea ha sido para mí un desafío

1	2	3	4	5	6	7	8	9	10

Muy baja Muy alta

4. Según lo hecho hasta ahora, mis expectativas de ir superando niveles de dificultad en la tarea son

1	2	3	4	5	6	7	8	9	10

Muy baja Muy alta

Ahora, deberá valorar cada una de las frases en una escala desde 1 (para nada) hasta 5 (mucho) en función de cómo se siente en este momento en relación al programa de entrenamiento cognitivo en el que participa.

5. ¿Cuánto se ha esforzado en la realización de los ejercicios?

1	2	3	4	5

Nada **Poco** **Intermedio** **Bastante** **Mucho**

6. ¿Cómo de útiles considera que son los ejercicios que ha realizado?

1	2	3	4	5

Nada **Poco** **Intermedio** **Bastante** **Mucho**

Si quiere, puede escribir aquí sus opiniones personales sobre la sesión que ha que acaba de terminar

¡ENHORABUENA!

¡Ha llegado al primer objetivo!

Appendix 3: Intrinsic Motivation Inventory (IMI)

THE POST-EXPERIMENTAL INTRINSIC MOTIVATION INVENTORY

For each of the following statements, please indicate how true it is for you, using the following scale:

1	2	3	4	5	6	7
not at all true			somewhat true			very true

Interest/Enjoyment

1. I enjoyed doing this activity very much
2. This activity was fun to do.
3. I thought this was a boring activity. (R)
4. This activity did not hold my attention at all. (R)
5. I would describe this activity as very interesting.
6. I thought this activity was quite enjoyable.
7. While I was doing this activity, I was thinking about how much I enjoyed it.

Perceived Competence

8. I think I am pretty good at this activity.
9. I think I did pretty well at this activity, compared to other students.
10. After working at this activity for a while, I felt pretty competent.
11. I am satisfied with my performance at this task.
12. I was pretty skilled at this activity.
13. This was an activity that I couldn't do very well. (R)

Effort/Importance

14. I put a lot of effort into this.
15. I didn't try very hard to do well at this activity. (R)
16. I tried very hard on this activity.
17. It was important to me to do well at this task.
18. I didn't put much energy into this. (R)

Pressure/Tension

19. I did not feel nervous at all while doing this. (R)
20. I felt very tense while doing this activity.
21. I was very relaxed in doing these. (R)
22. I was anxious while working on this task.
23. I felt pressured while doing these.

Perceived Choice

24. I believe I had some choice about doing this activity.
25. I felt like it was not my own choice to do this task. (R)
26. I didn't really have a choice about doing this task. (R)
27. I felt like I had to do this. (R)
28. I did this activity because I had no choice. (R)
29. I did this activity because I wanted to.
30. I did this activity because I had to. (R)

Value/Usefulness

31. I believe this activity could be of some value to me.
32. I think that doing this activity is useful for my memory.
33. I think that doing this activity is useful for my attention.
34. I think that doing this activity is useful for my speed.
35. I would be willing to do this again because it has some value to me.
36. I believe doing this activity could be beneficial to me.
37. I think this is an important activity.

Relatedness

38. I felt really distant to this person. (R)
39. I really doubt that this person and I would ever be friends. (R)
40. I felt like I could really trust this person.
41. I'd like a chance to interact with this person more often.
42. I'd really prefer not to interact with this person in the future. (R)
43. I don't feel like I could really trust this person. (R)
44. It is likely that this person and I could become friends if we interacted a lot.
45. I feel close to this person.

Appendix 4: Analyses on motivation after the training by IMI Subscales (Experiment 2A)

With the aim to analyze the existence of differences in the motivational dimensions assess by the IMI after completing the training, we conducted 2 × 2 ANOVAs including the seven motivational subscales as dependent variables and two between subjects factors: training condition and training setting. Table 5.4 summarizes the descriptive statistics of the six IMI subscales as a function of training setting and condition. Similar to the results of motivation during the training, in none of the seven IMI subscales we observed a reliable training condition × setting interaction (all ps > 0.05), nor main effects of training group (all ps > 0.05). As can be observed in Table 5.4, the older adults that trained in the lab had greater interest and enjoyed the training to a greater extent [$M_{lab} = 7.47$, $SD_{lab} = 1.24$; $M_{home} = 8.32$, $SD_{home} = 1.17$; $F\,(1, 36) = 4.69$; $p = 0.03$; $n^2_p = 0.11$] and tended to perceive themselves as more competent [$M_{lab} = 5.96$, $SD_{lab} = 1.43$; $M_{home} = 5.23$, $SD_{home} = 1.11$; $F\,(1, 36) = 3.89$; $p = 0.05$; $n^2_p = 0.09$].

The remaining main effects of setting did not reach significance [Effort/Importance: $F\,(1, 36) = 0.00$; $p = 0.96$; $n^2_p = 0.00$; Comfortability: $F\,(1, 36) = 1.41$; $p = 0.24$; $n^2_p = 0.03$; Perceived choice $F\,(1, 36) = 1.15$; $p = 0.29$; $n^2_p = 0.03$; Value/Usefulness $F\,(1, 36) = 3.58$; $p = 0.06$; $n^2_p = 0.09$; Relatedness: $F\,(1, 36) = 1.87$; $p = 0.17$; $n^2_p = 0.05$].

Appendix 5: Correlations at pre-test (Experiment 2A)

To investigate the relationships between the different cognitive functions tested at baseline, Pearson correlations were run on the pre-test scores for all the older adults as a whole. As shown in Table App.05, these analyses showed that WM-related measures were correlated: those participants with a higher combined score in the O-Span task showed fewer intrusions in the O-Span (r = -0.48; p < 0.01) and higher score in the Digits span (r = 0.36; p = 0.02), and Digit span score was also negatively correlated with the O-Span intrusions (r = -0.34; p = 0.03). Additionally, older adults with higher score in the O-Span index committed less false alarms in the Go/No-Go task (r = -0.33; p = 0.03) suggesting the relationship between two tasks that require facing interference.

Finally, these results confirm the strong relationship between fluid intelligence and working memory, since Cattell score correlated with the O-Span (r = 0.42; p < 0.01) and RAPM scores significantly correlated with O-Span (r = 0.55; p < 0.01), intrusions (r = -0.39; p = 0.01), digits span (r = .37; p = 0.02) and with the level obtained in the *n*-back task (r = 0.34; p =0.03).

Table App.05. Pearson correlations between outcome measures at pre-test.

	RAPM	Cattell	O-Span	Digits	Speed process.	SSRT	BSI	WM Search	N-back level	Stroop conflict
Cattell	**0.54***	-								
	0.00									
O-Span	**0.56***	**0.42***	-							
	0.00	**0.01**								
Digits	**0.37***	0.19	**0.37***	-						
	0.02	0.23	**0.02**							
Speed process.	0.02	0.17	0.25	-0.09	-					
	0.91	0.28	0.11	0.57						
SSRT	-0.11	0.02	0.17	0.02	0.28	-				
	0.48	0.92	0.29	0.91	0.07					
BSI	0.10	0.30	0.19	0.12	0.18	0.17	-			
	0.52	0.06	0.24	0.47	0.27	0.28				
WM Search setsize	0.24	0.23	0.05	-0.03	-0.25	-0.19	0.06	-		
	0.14	0.14	0.75	0.85	0.12	0.23	0.70			
N-back level	**0.34***	0.26	0.15	0.04	-0.05	-0.24	0.10	0.27	-	
	0.03	0.10	0.34	0.79	0.77	0.13	0.54	0.09		
Stroop conflict	0.05	-0.15	0.15	0.01	0.07	0.16	-0.31	-0.11	0.02	-
	0.74	0.36	0.35	0.98	0.64	0.32	0.05	0.48	0.90	