Tesis Doctoral

Modulación Reactiva y Proactiva en el Control Cognitivo y Emocional

(Reactive and Proactive Modulation in Cognitive and Emotional Control)

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Junio 2013

Editor: Editorial de la Universidad de Granada
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D.L.: GR 364-2014
ISBN: 978-84-9028-769-9

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Resumen

El estudio del control cognitivo en los últimos anos ha avanzado considerablemente, permitiendo una mayor comprensión de esta función, y resultando en una serie de modelos propuestos para explicar su funcionamiento. Algunos de estos modelos, llamados modelos unitarios, definen el control cognitivo como un mecanismo general capaz de resolver cualquier tipo de situación conflictiva (Botvinick, Braver, Barch, Carter, & Cohen 2001; Verguts & Notebaert, 2008, 2009). Por el contrario, otros modelos sugieren que el control cognitivo estaría compuesto por varios mecanismos de control (Braver, Gray, & Burgess, 2007; De Pisapia & Braver, 2006; Egner, 2008). A día de hoy el debate sigue abierto y, de hecho, constituye la motivación principal de la presente tesis doctoral.

Una forma de estudiar control cognitivo en el laboratorio es mediante el uso de tareas de interferencia. Por ejemplo, en la clásica tarea Stroop se presenta una palabra escrita en un color. Los participantes tienen que indicar el color de la palabra e ignorar su significado. En lo ensayos congruentes, el color de la tinta y el significado de la palabra coinciden (ej., rojo escrito en rojo), mientras que en los ensayos incongruentes el color y el significado de la palabra no coinciden (ej., rojo escrito en verde). En estas tareas, el solapamiento entre las dimensiones relevante (ej., color) e irrelevante (ej., significado palabra) de los estímulos que se presentan es lo que crea el conflicto, ya que ambas dimensiones llevan a la activación de respuestas incompatibles. Es decir, a la activación de la respuesta requerida en la tarea y a la activación de una respuesta (incompatible) que interfiere con la relevante. Esta interferencia se considera un índice de conflicto y se denomina efectos de congruencia (incongruentes menos congruentes). Igualmente, la reducción de los efectos de congruencia se considera el resultado de la implementación de control. En este último caso, existen dos efectos que producen una reducción del efecto de congruencia y que se estudian como un reflejo de mecanismos de control cognitivo: efectos secuenciales de congruencia (SC) y efectos de proporción de congruencia (PC). Sin embargo, no hay consenso acerca de que tipo de mecanismo de control cognitivo reflejan.

La gran mayoría de los investigadores definen los efectos SC como el beneficio de resolver conflicto en el ensayo anterior. Es decir, una vez que se resuelve conflicto, la

implementación de control sigue estando activa en el ensayo actual, lo cual hace que no se tenga que reactivar el mecanismo de control, observándose respuestas más rápidas y una mayor proporción de aciertos. Esto se lleva a cabo de ensayo a ensayo, como reacción a la presencia de conflicto.

Sin embargo, la definición de efectos PC supone más controversia. En general, los efectos PC son el resultado de manipular la proporción de ensayos congruentes e incongruentes, observándose una reducción del efecto de congruencia en contextos de alta proporción de ensayos incongruentes en comparación a contextos con alta proporción de ensayos congruentes. Para algunos autores los efectos PC son solo la suma de efectos SC (Blais, Robidoux, Risko, & Besner, 2007; Botvinick, et al., 2001). Estos autores argumentan que en contextos de alta proporción de ensayos incongruentes, las transiciones incongruente-incongruente, que es donde se producen efectos SC, son más frecuentes que en contextos de baja proporción de ensayos incongruentes (y alta de congruentes). Por lo tanto, la reducción general del efecto de congruencia no es más que la suma de todas las reducciones de los efectos de congruencia de ensayo a ensayo debida a efectos SC. Sin embargo, otros investigadores piensan que los efectos PC reflejan la adopción de un set de tarea que se crea tras experimentar cierto nivel de conflicto (ej., Cohen, Dunbar, & McClelland, 1990). Este set de tarea se concibe como una estrategia proactiva (es decir, preparatoria) y mantenida por un período de tiempo.

En un primer intento de distinguir entre estos efectos, Funes y colaboradores (Funes, Lupiáñez, & Humphreys, 2010b) realizaron un estudio en el que encontraron una disociación entre efectos SC y PC, basándose en si eran modulados por el tipo de conflicto. Los resultados encontrados mostraron que los efectos SC eran específicos al tipo de conflicto (es decir, desaparecían cuando el tipo de conflicto cambiaba entre ensayos consecutivos), mientras que los efectos PC se transferían desde el conflicto en el que se habían creado a otro tipo de conflicto, en el que la proporción de congruencia era neutral, por lo tanto, no se debían generar efectos PC. Estos resultados sugerían que ambos efectos reflejaban mecanismos de control distintos, por lo tanto, apoyaban la idea que el control cognitivo contaba como mínimo con dos mecanismos. Sin embargo, la conclusión no es tan sencilla, ya que otros estudios con efectos PC encontraron efectos específicos al tipo de contexto (Crump, Gong, & Milliken, 2008; Crump, Vaquero, & Milliken, 2008), lo cual contradice la conclusión anterior indicando que los efectos PC también pueden reflejar un mecanismo reactivo igual que los efectos SC, apoyando la idea de un modelo unitario de control cognitivo.

Esta controversia a la hora de definir efectos SC y PC refleja la discusión actual a la hora de distinguir entre control cognitivo como un mecanismo unitario reactivo (por tanto, efectos SC y PC son lo mismo), o como modelo dual de control que cuenta con un mecanismo reactivo y otro proactivo (reflejados por los efectos SC y PC respectivamente, que son efectos distintos). El único modelo propuesto que define control cognitivo como un sistema dual con un mecanismo de control reactivo y proactivo es el modelo Dual de control cognitivo descrito por Braver y colaboradores (2007). Aunque ha generado investigación, incluso a nivel neural, intentado mostrar diferencias a la hora de resolver control que apoyen una idea dual de control cognitivo, este modelo se basa en tareas de memoria de trabajo y no en tareas atencionales. La discusión de si los efectos SC y los PC reflejan mecanismos reactivos y proactivos no se basa ni apoya en un modelo atencional. Por lo tanto, en esta tesis se intenta proponer una idea de un posible modelo de control atencional, basándose en investigaciones previas y en los propios resultados.

El principal objetivo de esta tesis doctoral es el estudio del control cognitivo atencional y los mecanismos que los constituyen. Con este objetivo, hemos utilizado tres tipos de aproximaciones basadas en: 1) medidas comportamentales; 2) diferencias entre grupos, concretamente, grupos de edad; 3) medidas de neuroimagen. A continuación se describen los estudios realizados dentro de cada aproximación y los resultados principales encontrados.

1. **Aproximación comportamental**. Como se ha dicho, la pregunta de la que se parte es si el control cognitivo está constituido por un mecanismo general (ej., Botvinick et al., 2001) o uno dual (ej., Braver et al., 2007). Para resolver este objetivo llevamos a cabo tres experimentos con la intención de encontrar evidencias de disociaciones entre efectos SC y PC. En la serie experimental I, nos basamos en la idea de Funes et al. (2010b) de utilizar el tipo de conflicto como herramienta para disociar efectos SC y PC. Además, también estudiamos si los efectos PC eran realmente sostenidos, investigando si se transferían no solo a otro tipo de conflicto si no a una fase subsecuente. Para ello,

los participantes realizaron una tarea dividida en tres fases. En dos fases (pre y post entrenamiento) se presentaron de forma aleatoria dos tipos de conflicto (Simon y Stroop Espacial) y con el 50% de ensayos congruentes e incongruentes. Entre ambas fases, se realizaba una fase de entrenamiento en la que solo se presentaba Simon, manipulándose la proporción de congruencia de forma que algunos participantes llevaban a cabo un entrenamiento en alta proporción de ensayos congruentes mientras que otros lo hicieron en alta proporción de ensayos incongruentes. El objetivo era comprobar si los efectos PC se transferían de la fase de entrenamiento a la post-entrenamiento y si lo hacían a ambos tipos de conflicto. Igualmente, también se estudiaba si los efectos SC eran específicos al tipo de conflicto en la fase de post-entrenamiento. Los resultados mostraron efectos de PC en la dase de post-entrenamiento tanto en Simon como Stroop Espacial, mientras que los efectos SC eran específicos al tipo de conflicto. Por lo tanto, nuestros resultados confirmaban estudios previos (Funes et al., 2010b) y los extendían mostrando que los efectos PC se transferían de una fase a otra. De manera que, de este estudio se concluye que los efectos SC y PC reflejan mecanismos de control distintos.

Sin embargo, se podría pensar que el definir ambos efectos como formas de control distintas basándose en si la misma variable (tipo de conflicto) los modula de forma diferente no es una evidencia suficiente. De hecho, es posible que ambos reflejen el mismo mecanismo de control que reacciona de una forma u otra a la misma variable dependiendo de las circunstancias. Esto nos llevo a las series experimentales II y III en las que utilizamos una estrategia distinta para mostrar que los efectos SC y PC reflejan mecanismos distintos. Concretamente, intentamos encontrar efectos PC en ausencia de efectos SC. Como se ha dicho anteriormente, el hecho de manipular la proporción de congruencia hace que siempre exista un mayor porcentaje de transiciones incongruente-incongruente en los contextos de alta proporción de incongruentes. Sin embargo, también se ha comprobado a lo largo de la literatura, y en nuestros estudios, que los efectos SC desaparecen cuando cambia el tipo de conflicto (Akçay & Hazeltine, 2011; Egner, Delano, & Hirsch, 2007; Funes, Lupiáñez, & Humphreys, 2010a; Notebaert & Verguts, 2008; Verbruggen, et al., 2005, Experiment 2; Wendt, Kluwe, & Peters, 2006). Por lo tanto, en las series experimentales II, III y IV presentamos dos tipos de conflicto, que dan lugar a transiciones entre tipos de conflicto distintos, permitiendo estudiar el efecto de proporción de congruencia influyendo solo esas transiciones. Igualmente, en la serie experimental II manipulamos la proporción de congruencia en un tipo de conflicto para ver si se transfería al otro tipo. En esta serie experimental observamos efectos PC en ausencia de efectos SC (es decir, en los ensayos en los que el tipo de conflicto alternaba). Al contrario que en la serie experimental anterior, los efectos PC eran específicos al tipo de conflicto, es decir, solo se observaron en el tipo de conflicto en el que se había manipulado la proporción de congruencia. De este experimento podemos concluir que los efectos PC reflejan un mecanismo distinto a los efectos SC, aunque en ambos casos se vean modulados por el tipo de conflicto.

En la serie experimental III utilizamos el mismo tipo de estrategia que en la serie experimental II, con el objetivo de confirmar los resultados anteriores y extenderlos incluyendo otras manipulaciones. Estudios previos han mostrado que los efectos PC se modulan con el porcentaje de proporción de congruencia, siendo más grandes en porcentajes 80-20 que en porcentajes 60-40 (Logan & Zbofroff, 1979; Blais et al., 2010). Sin embargo, estos estudios no excluyen efectos SC, por lo tanto, esta modulación puede deberse a la presencia de efectos SC ya que, como se ha dicho, la frecuencia de transiciones incongruente-incongruente está directamente relacionada con el porcentaje de ensayos incongruentes. Por lo tanto, en nuestro estudio podemos ver si los efectos PC puros, es decir sin efectos SC, se modulan con el porcentaje de proporción de congruencia. Además, también estudiamos si el tipo de conflicto en el que se manipula la proporción de congruencia puede influir en estos efectos puros PC, manipulando la proporción de congruencia en Simon en un experimento y en Stroop Espacial en otro experimento. Varios estudios han mostrado que Simon y Stroop Espacial son tipos de conflicto distintos, con localizaciones neurales distintas (ej., Egner, 2010; Liu et al., 2006). Por lo tanto, es posible que la forma de resolverlos sea distinta, lo cual se reflejaría en diferencias a la hora de implementar control. Nuestros resultados confirmaron la presencia de efectos PC en ausencia de efectos SC. Además, observamos que los efectos puros PC eran modulados por el porcentaje de proporción de congruencia, siendo más grandes para el porcentaje 80-20 y disminuyendo gradualmente en los porcentajes 70-30 y 60/40. Un resultado interesante fue observar efectos PC específicos al tipo de conflicto cuando se manipulaba Simon y generales al tipo de conflicto cuando se manipulaba Stroop Espacial (es decir, se transferían al conflicto neural que era Simon). Como conclusión de esta serie experimental, se confirma que los efectos PC reflejan un mecanismo distinto a los efectos SC, que dicho mecanismo se modula con el porcentaje de congruencia (interpretado como nivel de conflicto) y que se comporta de forma diferencial dependiendo del tipo de conflicto.

2. **Aproximación grupos de edad**. En esta aproximación nos basamos en la idea de que diferencias entre efectos SC y PC en función del grupo de edad supondrían nuevas evidencia de que reflejan distintos mecanismos de control cognitivo Además, estudios previos han mostrado diferencias en control cognitivo en función del grupo de edad, pero sin llegar a un acuerdo de que mecanismo o proceso implicados en control cognitivo es el que falla (ej., Czernochowski, et al., 2010; Monti, et al., 2010). Por lo tanto, en la serie experimental IV, además de buscar diferencias entre los efectos SC y PC, también estudiamos si existían diferencias en función de la edad en otros procesos presentes en el control cognitivo. Concretamente, distinguimos entre: captura de la respuesta automática por la información irrelevante, que es lo que esta produciendo el conflicto; detección de conflicto; e implementación de control, dentro del cual distinguimos entre control reactivo (en mismo ensayo y a través de ensayos consecutivos) y control proactivo. Para ello utilizamos el mismo paradigma de la serie experimental dos, distinguiendo entre efectos SC y efectos puros PC. Para los análisis, nos basamos en el modelo de activación-supresión de Ridderinhof (2002), que distingue entre captura de respuesta automática y mecanismo de supresión selectiva. Según este modelo, la captura de la respuesta automática se refleja en errores rápidos, ya que la respuesta automática se activa de forma muy rápida tras la presentación de la información irrelevante. Igualmente, esta activación de la respuesta automática se reduce con el tiempo por la aplicación de un mecanismo de supresión selectiva, y esto se observa en una reducción de los efectos de congruencia en las respuestas más lentas (se necesita tiempo para aplicar este mecanismo). Según el momento de aparición del proceso, nuestros resultados mostraron: 1) captura de la respuesta automática, los adultos mayores mostraron mas errores rápidos en los incongruentes, indicando que presentaban una mayor captura de la respuesta automática; 2) detección del conflicto: los adultos mayores mostraban tiempos de reacción más lentos en os ensayos incongruentes incongruentes después de un ensayo congruente, es decir, mayor sensibilidad al conflicto cuando venían de un ensayo congruente; 3) implementación de control: en el caso del control reactivo, los adultos mayores mostraban efectos de congruencia de mayor magnitud en respuestas lentas, lo que sugería que necesitaban

más tiempo para suprimir la respuesta automática, aunque finalmente lo conseguían, mientras que no mostraban diferencias a la hora de implementar control cuando el anterior era incongruente (efectos SC) ni en control proactivo, medido en efectos PC puros. Por lo tanto, se puede concluir que los mayores eran más sensibles a la información irrelevante, pero no presentaban diferencias respeto a los adultos jóvenes a la hora de implementar control. Igualmente, se puede concluir que no existen diferencias de control entre adultos jóvenes y mayores, aunque eso no significa que exista un único mecanismo de control, sino que ninguno de los mecanismos parece deteriorarse con la edad.

3. Aproximación basada en neuroimagen. Finalmente, llevamos a cabo la serie experimental V, en la que realizamos un experimento con resonancia magnética funcional, en el que estudiamos si los efectos PC están relacionados con áreas cerebrales distintas de las descritas para los efectos SC. Además, también estudiamos si dichas áreas son distintas en función de si el conflicto a resolver es emocional o cognitivo (no emocional). Este estudio es muy novedoso ya que, por una parte, los efectos PC como reflejo de mecanismo proactivo no se han estudiado mucho en la literatura de neuroimagen (ej., Grandjean et al., 2012; Krug & Carter, 2012; Wilk et al., 2012). Igualmente, la diferencia entre control emocional y no emocional tampoco se ha investigado mucho en los mecanismos de control proactivo (ej., Krug & Carter, 2012). Con estos objetivos, un grupo de participantes realizo una versión de la tarea Stroop mientras medimos la actividad cerebral, tanto cuando el conflicto era emocional como cuando era no-emocional. Igual que en los experimentos anteriores, se manipulo la proporción de congruencia (con el fin de crear efectos PC). Los resultados indicaron actividad sostenida en áreas mediales frontales mostraban en contextos de alta proporción de ensayos incongruentes (efectos PC), que eran independientes al tipo de conflicto. Igualmente, también se observaron áreas visuales ventrales con este mismo patrón de actividad sostenida e independientemente de la naturaleza del conflicto. Estas áreas no coincidían en su mayor parte con áreas descritas con control reactivo, ya que tenían una localización más cíngulo-opercular (el control reactivo esta relacionado áreas mas dorsales de la corteza cingulada anterior y con áreas laterales de la corteza prefrontal). Además, el control reactivo se relaciona con actividad cerebral transitoria mientras que nuestros datos mostraron actividad sostenida. Por lo tanto, concluimos que los efectos PC si reflejan un mecanismo distinto al de los efectos SC y que posiblemente sea distinto porque tiene una naturaleza mas sostenida (y proactiva). Igualmente, nuestros resultados indican que la implementación de control se produce mediante la potenciación de la información relevante ya que se observó mayor actividad en contextos de control proactivo en áreas relacionadas con el procesamiento de la información relevante de la tarea.

Conclusiones

Resumiendo, los resultados de la presente tesis doctoral indican que el control atencional está formado por varios mecanismos y no por un único mecanismo general. Estos mecanismos pueden distinguirse en función de cuando se aplica control, si de forma reactiva (reflejados por efectos SC) o de forma proactiva (reflejados por efectos PC). Igualmente, parece que cada tipo de conflicto está relacionado con una forma de implementación de control, ya que una gran cantidad de estudios muestran efectos SC y PC específicos al tipo de conflicto. Entonces, ¿Cuantos mecanismos de control cognitivo existen? ¿Se definen por el tipo o por el momento de aplicarse? Como propuesta general y conclusión de esta tesis, se presenta la idea de que el control atencional es un sistema en el que el conflicto se resuelve de forma específica, por lo tanto, habría distintos mecanismos de control en función del número de conflictos presentes (principalmente dos, de respuesta y perceptivo). Sin embargo, el momento de resolver el conflicto es una variable que influiría en esta resolución, pero que es independiente al tipo de conflicto, y que a su vez se puede considerar otro mecanismo.

Index

CHAPTER 1

Introduction

Cognitive control can be defined as the function that allows us to pursuit successfully our goals, by flexibly adapting our behavior to the environment, enhancing actions towards our goals and/or preventing them towards unwanted outcomes. To do so, the coordination of several cognitive systems is necessary. Thus, memory is needed to maintain our goal, attention to select the relevant information among irrelevant one from the environment, and perception to process the information. In this thesis we will focused on the attentional part of cognitive control and the processes of selecting and inhibiting information depending on whether it is relevant or irrelevant for the task.

Attentional cognitive control is crucial for our behavior since without it none of our daily life activities would be possible. In fact, the importance of some form of control was already introduced by Norman and Shallice (1980) in their supervisory attentional system (SAS). They highlighted five situations where some form of control is needed: 1) when the situation requires planning or decision; 2) when links between the input and schema control units are not well learned; 3) when the situation requires a response that competes with a strong, habitual response; 4) when the situation requires correction or troubleshooting; 5) when the situation is difficult or dangerous. Importantly, examples of those situations are common in our daily life. For example, when one has to plan your working scheduling, or when you are learning how to drive, or when you drive in England and you have to do the roundabout in the opposite direction that the one you are used to, or when you step out of the lift in your floor but you wanted to go to your neighbor flat; or when you are biking in a very crowed traffic. Therefore, in those situations the need for a function that monitors performance and control behavior in an appropriate manner arises, since it is the only way for us to achieve our goals. *Cognitive control* selects the information related to your goal and that will produce an appropriate response, among all the information present in the environment, and inhibit the information that leads to incompatible responses that interferes with the relevant ones. Dramatically, there are situations in which cognitive control is impaired as a consequence of, for example, brain damage. People suffering frontal lobe damage typically show what is known as stimulus-driven or “utilization behavior” (Lhermitte, 1983). That is, they “use” everything that is attended by them, irrespective of whether it is part of their goal. For example, if they are looking on your desk for a pen but during the search see your glasses, they will automatically put them on.

Over the past years attentional cognitive control has been extensively studied resulting in a wealth body of theoretical and computation approaches, as well as multitude studies trying to understand its functioning, neural correlates and individual differences. Next we will explain some of those issues and will try to provide an overall idea of attentional cognitive control knowledge at present.

1. Cognitive control in the lab

To study cognitive control in the lab, interference tasks have been extensively used. Those tasks allow researchers to create conflicting situations and study how they are solved. For example, in the classical Stroop color-naming task (for a review see Macleod, 1991) participants are required to name the colour in which colour words are displayed. Response times (RTs) are reliably slower for trials where the name of the printed word is incongruent with its colour (e.g. the word RED printed in green) compared to trials where the word and colour are congruent (e.g., the word RED printed in red). This difference in performance (what is called congruency effect) provides a measure of the contribution of irrelevant word reading to performance, with greater amounts of word reading leading to larger differences in performance between congruent and incongruent trials (i.e., larger interference).

Other examples of interference tasks are: the Simon conflict task, in which participants respond to a stimulus whose irrelevant spatial location can be congruent or incongruent with the location of the corresponding response (Simon & Craft, 1972; Simon, Craft, & Webster, 1973; Simon & Small, 1969); the Spatial Stroop task (for a review, see Lu & Proctor, 1995), where the direction of an arrow that participants respond to can match or not with the location where it is displayed; or the Flanker task (Eriksen & Eriksen, 1974), where participants have to respond to a centrally presented target surrounded by compatible or incompatible distracters. According to Kornblum and colleagues (Kornblum, Hasbroucq, & Osman, 1990), when using different interference tasks it is really important to address where the conflict comes from, that is, their dimensional overlap. Tasks involve different conflict types only when they do not share the same dimensional overlap. The taxonomy presented distinguished between three conflict sources arising from an overlap between: 1) relevant or irrelevant dimension of the stimuli; 2) irrelevant dimension of the stimulus and response dimension; 3) relevant dimension of the stimulus and response dimension (Figure 1).

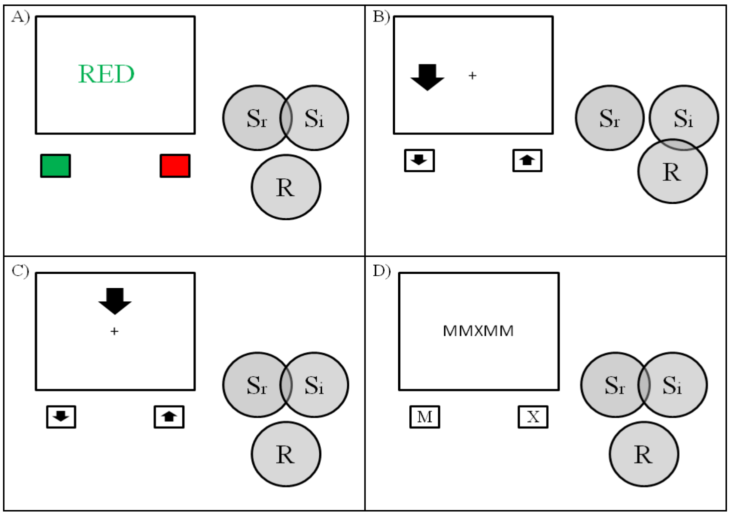

Figure 1 Examples of interference tasks and the dimensional overlaps responsible for the conflict created. A) *Color-naming Stroop* task in which there is an overlap between the relevant (ink colour) and the irrelevant (word) dimensions of the stimulus. B) *Simon* task in which the overlap is between the irrelevant dimension (location) of the stimulus and the response dimension. C) *Spatial Stroop* task, the same than the colour-naming version. D) *Flanker* task in which the irrelevant information (flankers) active the opposite response than the relevant information (target).

In all of those tasks, when the overlapped dimensions lead to incompatible relevant and irrelevant responses (incongruent trials) participants are slower and less accurate, compared to when the dimensions lead to the same response (congruent trials). The difference between incongruent and congruent trials is considered a conflict index (called congruency effects). Similarly, any reduction of congruency effects is defined as the result of control implementation and can be dynamically modulated by factors such as the level of congruency of previous trials or the overall conflict level. Specifically, in the lab two modulations of congruency effects have been systematically studied as reflexions of cognitive control: sequential congruent (SC) effects and proportion congruent (PC) effects.

Sequential congruent (SC) effects are the reduction of congruency effects when the previous trial is incongruent compared to when it is congruent (Gratton, Coles, & Donchin, 1992). Robust trial-by-trial SC effects have been reported using the Simon task (Riggio, Gherri, & Lupiáñez, 2012; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Wühr & Ansorge, 2005), the Stroop color-word task (e.g. Kerns, et al., 2004), the spatial version of the Stroop task (Freitas, Bahar, Yang, & Banai, 2007; Kunde & Wühr, 2006; Verbruggen, Liefooghe, Notebaert, & Vandierendonck, 2005) and the Eriksen flanker task (e.g. Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Gratton, et al., 1992).

On the other hand, proportion congruent (PC) effects take place as a result of manipulating the proportion of congruency within a block. Thus, in contexts where the proportion of incongruent trials is larger than the proportion of congruent trials congruency effects are reduced, compared to contexts where there is a larger proportion of congruent trials (e.g. Carter, et al., 2000; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; West & Baylis, 1998). However, other authors argue that PC effects are the results of SC effects. Since incongruent followed by incongruent transitions occur more frequently in high proportion of incongruent trials contexts, it is not surprising to find smaller congruency effects than in contexts with lower proportion of incongruent trials, where incongruent following incongruent trials are rare (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001). However, the study of whether SC and PC effects can be explained by the same mechanism is a highly discussed topic at present. As an example, previous studies in our lab, some of them which are part of the present thesis, have shown than PC effects can be dissociated from SC effects (Funes, Lupiáñez, & Humphreys, 2010b; Torres-Quesada, Funes, & Lupiáñez, 2013).

1.1. Cognitive Control level of action: specific or general?

Another important issue when studying cognitive control is whether it acts locally, that is, applied to a given conflicting situation, or it can be more general and be able to transfer to different conflicting situations. The results related to that topic are quite diverse and seems to dependent on several factors, such as whether it affects SC or PC effects, whether the manipulation includes different conflict types, different stimulus dimensions, and even individual differences.

For SC effects, the most consistent finding is that they behave specific to conflict type, thus, they are only observed when conflict type repeats across consecutive trials but not when it changes (Akçay & Hazeltine, 2011; Egner, Delano, & Hirsch, 2007;

Funes, Lupiáñez, & Humphreys, 2010a; Notebaert & Verguts, 2008; Verbruggen, et al., 2005, Experiment 2; Wendt, Kluwe, & Peters, 2006). One way to explain that is based on the idea that different conflict types involve different control resolution strategies (Egner, 2008), therefore, when the conflict type changes across consecutive trials the control strategy activated to solve the first type of conflict is no longer useful to solve the following different type of conflict. From that idea, one might think that when only one conflict type is presented, general SC effects can be found, regardless of whether stimulus feature repeats or not. However, controversial findings have been reported. Some studies have shown that SC effects are specific even to the stimulus, thus, when they change across trials, no SC effects are found (Fernández-Duque & Knight, 2008; Spapé & Hommel, 2008). For example, Fernández-Duque & Knight (2008) did not observe any transfer of SC effects between the number and the color-word versions of Stroop conflict. In this case, the explanation made by the authors was based on memory instances. According to them, when experiencing and resolving conflict, the control resolution is bounded with the context where it takes place. Then, when the same context repeats, it primes that control resolution.

On the other side, other studies have found across-contexts SC effects (Freitas, et al., 2007; Kunde & Wühr, 2006)..For example, in Kunde & Wühr study (2006), they combined a prime-target and a Simon tasks. It is noteworthy that these two tasks shared the level where conflict arises from, since in both cases the conflict takes place at response layers. Similarly, the flanker and Stroop combination included in Freitas et al. study (2007), also shared the nature of the conflict, that is, in both cases the conflict arises between two perceptual dimensions.

In an attempt to clarify that situation, Notebaert and Verguts (2008) suggested that observing general or specific SC effects might depend on whether the two combined conflicting situations share or not the task-relevant information. Besides, they also argue that when they share the same task-irrelevant information, one might also find general SC effects, but the response-stimulus interval has to be short for that to happen (Notebaert & Soetens, 2006; Notebaert, Soetens, & Melis, 2001).

Similarly, the conflict type specificity or generality of PC effects does not seem to be that consistent. For example, PC effects have been found to be general to conflict type (Funes, et al., 2010b; Torres-Quesada, et al., 2013), since they transferred from the conflict where they were created (Simon) to a different conflict (Spatial Stroop) where the proportion of congruent and incongruent trials was neutral (50%-50%). However, several studies have found evidence that PC effects can behave in a quite specific manner, the so called context-specific proportion congruent effects (Crump, Gong, & Milliken, 2008; Crump, Vaquero, & Milliken 2008; Jacoby, Lindsay, & Hessels, 2003). In these studies, proportion of congruency is manipulated independently for two sets of stimuli or contexts that are intermixed at random within a block of trials. Therefore, and critically, in these studies the overall proportion of congruent and incongruent trials is kept at .50. However, particular items (Jacoby, et al., 2003) or contexts (Cañadas, Rodríguez-Bailón, Milliken, & Lupiáñez, in press; Crump, et al., 2006) entail a high (or low) proportion of congruent trials, whereas other items or contexts entail a low (or high) proportion of congruent trials. The key result is again larger congruency effects for the items or contexts associated with a high proportion of congruent trials. Once again, those effects can be accounted for based on a memory-attention account. That is, the attentional control strategy of biasing the system toward the enhancement of task-relevant information as result of high proportion of conflict situations is encoded with the context with larger proportion of incongruent trials (e.g., location). Then, when the context repeats, it primes that strategy, thus leading to context-specific effects. That view has been further supported by a recent study that showed how activity in medial superior parietal lobe, related to voluntary attentional shift, correlated with context-specific proportion effects, that is, larger activity when interference was reduced in high conflict context. Besides, that was coupled with larger activity on areas in charge of processing the task-relevant information (King, Korb, & Egner, 2012).

This property of SC and PC effect to be either specific vs. general across conflict types and/or contexts has been used to speculate about whether they are reflexions of the same or different mechanisms. Those studies showing that both effects behave in opposite manner (Funes et al., 2010) have concluded that this favour the view that these two effects reflect different mechanisms. On the other side, those studies that found that both effects, that is, SC and PC effects, are context specific, assume that the same mechanism might account for both of them (Blais & Bunge, 2010). However, the question of whether those effects are actually reflecting the same mechanism is still a highly discussed issue at present and constitutes a main motivation of the present thesis.

1.2. Individual differences in cognitive control

When talking about individual differences on cognitive control, we should specify whether we refer to differences: 1) within a person depending on, for example, context, moment of the day, etc; 2) between people basing on stable individual differences (i.e. working memory, fluid intelligent, etc); 3) or between group variations (i.e., age, clinical aspects such as schizophrenia, anxiety, etc). Those individual differences produce varieties in the way cognitive control is implemented, the strategies used to resolve it, and even neural correlates. As examples of intra-individual differences we can cite studies showing different cognitive control resolutions depending on emotional state (i.e., Pacheco-Unguetti, Acosta, Lupiáñez, Román, & Derakshan, 2012; van Steenbergen, Band, & Hommel, 2010), motivation and reward (Braem, Verguts, Roggeman, & Notebaert, 2012; Locke & Braver, 2008), context (Crump, et al., 2006; Funes, et al., 2010b), etc. Similarly, some results indicate that cognitive control can also vary depending on stable personal traits such as working memory and fluid intelligent (i.e., Kane & Engle, 2003) or trait anxiety (Bishop, 2009; Fales, et al., 2008). For group differences, several studies have shown conflict monitoring impairments in patients with esquizophrenia (Alain, McNeely, He, Christensen, & West, 2002; Kerns, et al., 2005; Völter, et al., 2012); similarly, aging studies have reported cognitive control differences, both in elderly (i. e., Czernochowski, Nessler, & Friedman, 2010) and children (Rueda, Posner, & Rothbart, 2005; Rueda, Rothbart, McCandliss, & Posner, 2005). Others studies have even showed age differences in cognitive control depending on whether the conflict resolution involved emotional or non-emotional stimuli, showing deficits restricted to non-emotional (cognitive) conflict (Monti, Weintraub, & Egner, 2010).

Recently, cognitive control individual differences have been studied using neuroimaging techniques. For example, Egner (2011) showed an area involved in conflict control, ventrolateral prefrontal cortex, whose activity accounted for approximately 40 percent of the variance in across subjects SC effects measured behaviorally. In the same lab, a very recent study has shown that there are brain areas associated to domain-general conflict-control processes that vary across subjects, whereas domain-specific conflict-control areas are more consistent across subjects (Jiang & Egner, 2013). Finally, using tracktography, Wit and colleagues (de Wit, Watson, Harsay, Cohen, & van de Vijver, 2012) found that the strength of dissociable corticostriatal fiber tracts predicts differences on vulnerability toward task-irrelevant information capture, the tendency to over-relying on habits or different ways to implement cognitive control.

Therefore, it is important to keep in mind that individual differences play a significant role on cognitive control processes and we should consider them to have a complete picture of cognitive control. In fact, we believe that intra-individual differences allow us to study the impact of a given factor on cognitive control differences, stable traits permit finding out which aspects of cognitive control are more susceptible to individual particularities, and group differences let us to look at the relatively independence of cognitive control processes. Furthermore, future research should focus on studying when and which cognitive control processes are mainly driven by across subjects mechanisms or, by contrary, which ones are more susceptible to individual particularities.

2. Cognitive Control Models and neural correlates

Cognitive control models can be grouped in: 1) models proposing a unitary view of cognitive control, thus suggesting a single general mechanism; 2) models suggesting a plural conception of cognitive control.

2.1. Single control mechanism Views

Within the models proposing a unitary view of cognitive control, the most prominent one is the *Conflict Monitoring Theory (CMT)*, developed by Botvinick and colleagues (2001; 1999). According to it, cognitive control is divided into two components: the conflict-monitoring component, implemented by the anterior cingulated cortex (ACC), that detects and evaluates on-going information for potential response conflict, and the strategic control component, related to dorsolateral prefrontal cortex (DLPFC), which in turn resolves conflict by reinforcing top-down biasing processes associated with the current task set (Botvinick, et al., 2001). Besides, the

CMT can explain SC effects. Thus, when facing an incongruent trial, conflict is detected and control is recruited, therefore, when the next trial is also incongruent, there is no need to re-activate control, observing a benefit on reaction times and accuracy compared to when the previous trial is congruent

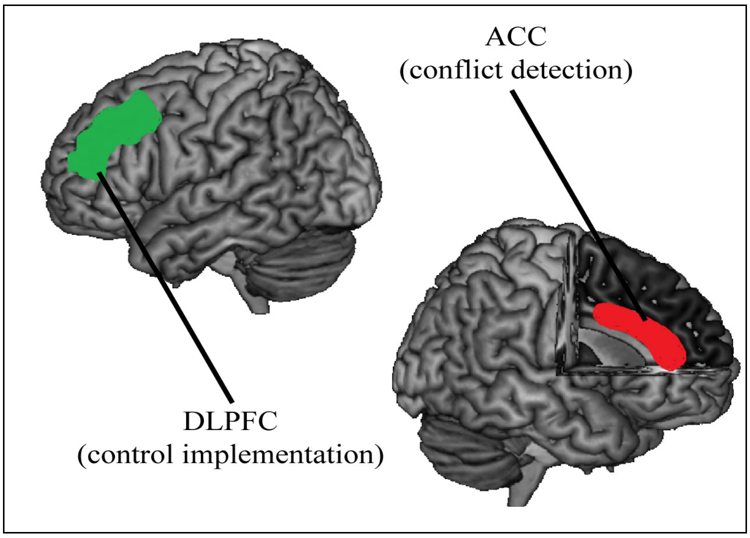

Figure 2. Dorsolateral prefrontal cortex (DLPFC) and Anterior Cingulate Cortex (ACC) neural locations.

The importance of this theory is that it proposes for the first time "how" the system knows when to intervene to bias the bottom-up processing route. However, this model does not explain how the system knows "where" to intervene, since it assumes that control implementation is applied regardless of the conflict nature. That is the weakness of the model since, as it has been shown in the empirical section above (1.1.), cognitive control can be specific to conflict nature.

Other authors have tried to account for that weakness. For example, Blais and colleagues (2007) recently proposed a modification to the CMT in which the conflict detector mechanism operates at the item or the context level, which allows the system to know where control is needed, that is, how the system knows where control adjustments are required. Similarly, Vergust & Notebaert in their hybrid learning-conflict model (2008, 2009) also suggest a proposal of how the system knows where to apply control. That model conceptualizes cognitive control as the result of interactions between feature binding and conflict detection processes. According to them, the conflict signal is used by the system as an indicator of when task-relevant associations should be strength (that is, association between the stimulus and the task-relevant response). Such a mechanism would lead to an improvement in performance on subsequent trials where conflict is again detected (since binding had previously taken place, in a subsequent detection of conflict the system already “knows” how to implement control). Similarly to the conflict monitoring theory (CMT), the hybrid learning account (Verguts & Notebaert, 2008, 2009) proposes the medial frontal cortex (mainly ACC) as the area related to conflict detection and DLPFC to control implementation. However, the difference with the CMT is that those areas are not directly connected. The hybrid model adds the locus coeruleus (LC), which would be in charge of releasing noradrenaline. That releasing enhances the binding of currently active representations, which tend to be task-relevant, therefore, enhancing learning between task-relevant units and stimulus. To do so, LC receives input from ACC (indicating that conflict has been registered), as a result the LC places more emphasis on the task-relevant route by sending outputs to DLPFC to bias information processing in favor or the task-relevant information in posterior areas. Therefore, MFC affects DLPFC indirectly through LC.

2.2. Multiple control mechanisms Views

However, unitary models cannot explain some of the results presented in previous sections. For example, they cannot explain some findings indicating that control implementation might have different temporal dynamics depending on whether control implementation is measured in a trial-by-trial or block level basis (i.e., Funes et al., 2010b). Similarly, they either can’t explain why in some situations control is applied in a specific (Crump, et al., 2006; Crump, et al., 2008; Funes, et al., 2010a) or general (Freitas, et al., 2007; Funes, et al., 2010b; Kleiman, Hassin, & Trope, 2013; Kunde & Wühr, 2006) manner. In an attempt to resolve those questions, some models suggesting a **multiple cognitive control mechanisms view** has been proposed. Next we will describe some of them, distinguishing between the control mechanisms presented: I. Different control mechanisms for different control temporal dynamics; II. Different mechanisms to solve different conflict types; III. Different mechanisms to solve different conflict domains such emotional versus cognitive conflicts.

I. Different control mechanisms for different control temporal dynamics.

One of the first models proposed to account for different temporal control implementations was the *Dual Model of Cognitive Control* developed by Braver and colleagues (Braver, Gray, & Burgess, 2007; De Pisapia & Braver, 2006). This model suggests that cognitive control consists of at least two sub-systems: a reactive mechanism based on conflict detection over a short-time scale (on the order of milliseconds) that resolves conflict after experiencing it, therefore, after stimulus onset, and a second mechanism driven by long time-scale conflict detection (on the order of several seconds or minutes) and characterized by the sustained active maintenance of task-set information which allow to reduce conflict previous to stimulus onset. Besides, they proposed the same key areas than the CMT, that is, ACC and PFC, but adding, within each of them, two separate units that show transient activity in the case of reactive and sustained activity in the case of proactive control. Although, initially it was proposed for attentional control tasks (De Pisapia & Braver, 2006), its final version is based on working memory tasks (Braver, Gray, & Burgess, 2007). Besides, the applicability of the model has also been tested using working memory tasks (e.g., Braver, Cole, & Yarkoni, 2010; Braver, Paxton, Locke, & Barch, 2009). Therefore, we believe that an attentional control model is needed to account for the results found when using interference tasks.

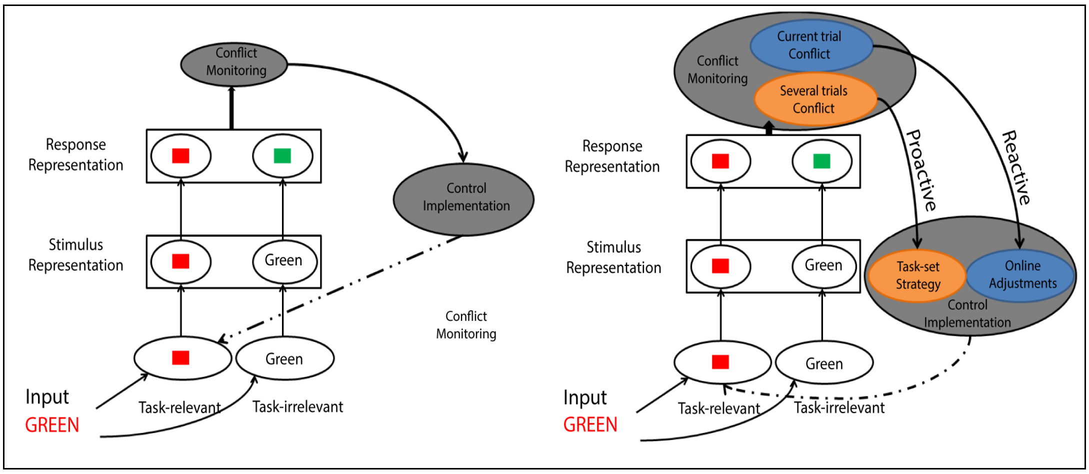

Figure 3. The two most prominent models in cognitive control defending an unitary view (left panel) or a plural conception of cognitive control (right panel). **Left panel:** The *conflict monitoring theory* (Botvinick et al., 2001) showing that the conflict present in a task such as Stroop task is detected by a conflict monitoring unit and send it to a control unit in charge of implementing control, by enhancing task-relevant units. **Right panel:** The *dual model of cognitive control* developed by Braver (2007) which defined two units for conflict detection and two unit of control implementation, differentiated for their temporal dynamics. Specifically, conflict can be detected in the current trial, that is, in the order of milliseconds, resulting in online control adjustments, or registered as a result of several conflicting situations (in the order of seconds time scale) resulting in a task-set strategy maintained over time. In both cases, control produces the enhancement of task-relevant information.

Similarly, Dosenbach et al., (2008; 2007; 2006) proposed a different model composed by two different brain control networks with different temporal functioning: a fronto-parietal (FP) and a cingulo-opercular (CO) networks. The FP network acts over short time scale, performing control adjustments in a trial-to-trial basis. It comprises dorsolateral prefrontal cortex (dlPFC) and dorsal frontal cortex (dFC), inferior parietal lobe (IPL), intraparietal sulcus (IPS), precuneus and midcingulate cortex (mCC). By contrary, the CO network acts over the task epoch and it is in charge of task-set maintenance. It counts with dorsal anterior cingulate and superior medial frontal cortex (dACC/msFC), anterior insula and frontal operculum (aI/fO), anterior prefrontal cortex (aPFC) and thalamus. Besides, they also highlighted the role of the cerebellum as an emisor of error codes for both networks, through dlPFC and IPL connections for the fronto-parietal network and through thalamus connections for the cingulo-opercular network.

In the attentional field, that reactive and proactive possible differentiation of control mechanisms has been done by studying sequential congruent (SC effects) and proportion congruent effects described beforehand (PC effects). In general, SC effects are considered a reflection of a reactive control mechanism (Correa, Capucci, Nobre, & Lupiáñez, 2010; Egner, 2007; Egner, Ely, & Grinband, 2010; Funes, et al., 2010b; Grandjean, et al., 2012), while PC effects have been considered a sustained control form (Grandjean, et al., 2012; Krug & Carter, 2012; West & Bailey, 2012). Therefore, any dissociation between them can be considered as dissociation between those two forms of control. Evidence supporting that idea comes from a behavioral study that showed dissociation between SC and PC effects (Funes, et al., 2010b). Similarly, the neural correlates of the transient or reactive control understood as the benefit observed on incongruent trials when the previous trial is also incongruent (SC effects) have been extensively studied (Durston, et al., 2003; Egner & Hirsch, 2005a; 2005b; Kerns, et al., 2004). As it has been said, there is a consensus proposing dorsal anterior cingulate cortex (dACC) as the chore for conflict detection and dorsolateral prefrontal cortex (dlPFC) for reactive control implementation. However, very few studies have been focused on the neural correlates of proactive control understood as a sustained strategy implemented in low proportion congruent trials blocks, when conflict is supposed to be high (PC effects) (Carter, et al., 2000; Grandjean, et al., 2012; Krug & Carter, 2012;

Wilk, Ezekiel, & Morton, 2012). An additional problem of most of these studies is that they did not directly compare the areas showing transient versus sustained activity. In fact, most of them studied proactive control as the transient activation for incongruent trials modulated by proportion of congruency, that is, depending on whether the context was low conflict (high proportion of congruent trials) or high conflict (low proportion of congruent trials). For those studies, they observed ACC activations for incongruent versus congruent trials when collapsing proportion congruent conditions, but non PFC activations (Carter, et al., 2000; Grandjean, et al., 2012). On the other hand, Krug and Carter (2012) did test sustained activity by contrasting low conflict versus high conflict contexts and found medial DLPFC showing greater activity for high conflict contexts than for low conflict contexts. However, only one study have used an hybrid event-related/mixed block design which allows contrasting both areas showing transient activity from areas showing sustained activity (Wilk et al., 2012). In that study, ACC, anterior insula and inferior parietal cortex activations indicating general conflict processing were reported, as activations in superior frontal gyrus associated to sustained control (high conflict context).

II. Different mechanisms to solve different conflict types

As it has been mentioned, several studies have showed that control can act in a conflict-type specific manner, that is, only resolving one type of conflict and not other (e.g., Funes, et al., 2010a, 2010b; Notebaert & Verguts, 2008). To account for those findings, a proposal based on the existence of different control loops to solve different forms of conflict has been suggested (Egner, 2008). Similarly, and also motivated for those findings and proposal, some researchers have looked for the existence of separate neural correlates of control depending on the conflict involved.

On the one hand, some studies have shown different brain areas for different conflict types (e.g., Egner, et al., 2007; Jiang & Egner, 2013; Liu, Banich, Jacobson, & Tanabe, 2004). In general, those studies report different areas associated to, for example, Simon (more related to premotor and medial frontal areas) and Stroop (associated to more parietal areas). Both suggest that those differences in neural correlates point out the fact that conflict types are different in nature and involve different control strategies. Thus, Simon is a response conflict that might cause the inhibition of the incompatible response, while Stroop is a perceptual conflict whose resolution might involve the enhancement of task-relevant features processing. In this line, a very recent TMS study has confirmed that dissociation by showing that when the premotor area was transiently inactivated by TMS, Simon conflict resolution was unable. By contrary, when the pulse was applied in the inferior parietal lobe, Spatial Stroop conflict resolution was the process affected (Soutschek, Taylor, Müller, & Schubert, 2013). Therefore, it seems that there are areas specific to non-emotional conflict types.

III. Different mechanisms to solve different conflict domains such emotional versus cognitive conflicts

Regarding to differences in control implementation depending on conflict domain such as cognitive and emotional conflict, some important issues have been approached while other remains unclear. Initially, some experts from the emotional field suggested that the mechanisms underlying both cognitive control and emotional regulation could be similar, since studies focused on emotional control such as reappraisal have found a similar brain circuitry with some common areas within the prefrontal cortex than the ones reported for cognitive control (Ochsner, Silvers, & Buhle, 2012). However, when talking about emotional control, one can distinguish between the control of emotion impact using cognitive mechanisms (i.e., reappraisal, which deliberately changes the meaning of an emotional stimulus; see Ochsner & Gross, 2005) and regulation understood as the control of conflicting emotional stimuli. Therefore, using a cognitive strategy to resolve emotional conflict would explain why the same areas have been found. Thus, some authors have tried to dissociate the neural correlates of emotional and cognitive conflict-control processes when using emotional and non-emotional distracters, and compared whether the brain areas involved were similar. In that case, the conflict type was the same, but the stimuli used involved either emotional conflict or non-emotional conflict. Some studies have shown the very same areas for both emotional and non-emotional conflicts (Chechko, et al., 2012; Chiew & Braver, 2011), with those areas showing a higher degree of activation for emotional conflict. By contrary, other studies have provided evidence for a neural distinction between circuits involved in detecting and resolving non-emotional and emotional conflict (Egner, Etkin, Gale, & Hirsch, 2008; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006; Maier & di Pellegrino, 2012; Mohanty, et al., 2007; Monti, et al., 2010). Interestingly, they showed shared neural correlates for emotional and non-emotional control in dACC, as the area in charge of detecting conflict (Egner, et al., 2008; Etkin, et al., 2006; Hass, Omura, Constable, & Canli, 2006), with emotional conflict detection also involving amygdala (Egner, et al., 2008; Etkin, et al., 2006), but they showed different areas involved in control implementation, specifically, rostral ACC (rACC) for emotional (Egner, et al., 2008; Etkin, et al., 2006; Maier & di Pellegrino, 2012) and dlPFC for non-emotional control (Egner et al., 2008). In fact, Maier and Pellegrino (2012) showed that patients with rACC lesion did not show SC effects when the task involved emotional stimuli, but they did show SC effects when the task involve neutral stimuli. Besides differences between the control strategies used for emotional and non-emotional control resolution have been found. Specifically, resolving non-emotional conflict involved the enhancement of task-relevant information processing in sensory cortices, while resolving emotional conflict resulted in the inhibition of amygdala responses toward task-irrelevant information (Egner et al., 2008).

Similar to cognitive control, most of the studies on emotional control have been focused on transient modes of control, with almost none looking at the neural correlates of proactive control comparing emotional and non-emotional conflict. There is only one study that has sought proactive control areas under emotional conflict conditions (Krug & Carter, 2012). However, since it doesn't count with a comparable non-emotional condition, one cannot draw strong conclusions regarding emotional and non-emotional brain differences in proactive control. This issue will be addressed in the present thesis.

2.3. Alternative theories to cognitive control effects

As we have said, the majority of the previous research and theoretical approaches on cognitive control have focused on SC and PC effects, assuming that what they reflect are attentional forms of control (regardless of the number of mechanisms). That is, they assume that tasks manipulations (interpreted as conflict occurring) produce the bias of selective attention (i.e., attention to task-relevant or task-irrelevant information). However, there are other theories arguing that both SC and PC effects can be explained by other processes, completely different to cognitive control, specifically by *pure memory-learning based processes*, such as binding, contingency learning, frequency accounts, memory-based expectancies and high-order sequence learning (for a review see Schmidt, in press). Next, we will describe briefly some of those accounts.

From a *binding* aproach, some authors have suggested (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003) that interference tasks present different types of feature repetitions in their design, which leads to different response times. That is, complete repetitions (i.e., word and color of the previous trial repeats in the current trials) and complete alternations (i.e., word and color do not match across trials) result in faster reaction times than partial repetitions (i.e., color changes and word repeats), since the latest involve binding cost. That is, when some feature repeats across consecutive trials, the previous instance is retrieved, but since the other feature changes, that leads to the activation of an incorrect response, which has to be overcome, causing a slow-down on reaction times. Given that complete alternations and repetitions can be only present on congruent-congruent or incongruent-incongruent transitions, whereas partial repetitions are present on congruent-incongruent ones and vice versa, feature repetitions can explain SC effects themselves and PC effects since, obviously, they would be more frequent in a high proportion of incongruent context. Nevertheless, several studies have observed SC effects when controlling for feature repetitions (e. g., Funes, et al., 2010a; Verbruggen, Notebaert, Liefooghe, & Vandierendonck, 2006), suggesting that binding can play a role, but it is not the only factor that produces SC effects (Egner, 2007).

Similarly, from a *Contingency learning* (i.e., stimulus-response association learning), it has been argued that unbalanced presentation of stimulus can produce contingencies effects. For example, in an attempt to control for feature repetitions, authors have used tasks including more than two stimulus/response-choices. The problem is that by doing that different contingencies for congruent and incongruent trials are induced, mainly by presenting congruent trials above chance. That is, if blue, red, yellow and brown are the choices, for congruent trials there are only four possible options while for incongruent trials the possible options go up until twelve, leading to an overrepresentation of incongruent trials, which in turn makes them more predictive of their responses than incongruent trials. In general, highly contingent (predictive) stimuli lead to faster responses than low contingent ones (non predictive). Similarly, when manipulating the proportion of congruency different item *frequencies* are also introduced. Thus, on high proportion congruent conditions, specific congruent items might repeat more frequently than incongruent ones, while on high proportion incongruent conditions, specific incongruent items might repeat more frequently than congruent ones (Jacoby, et al., 2003). Some authors suggest that participants learn the correlations between word and color when they are presented frequently (i.e., incongruent trials). That is, if blue written in red is frequently presented in an incongruent context, the relevant answer “red” is highly correlated to that stimulus, however, if blue written in red is highly presented in a congruent context the irrelevant answer “blue” is highly correlated with the stimulus.

On the other hand, from *memory based expectancy* account (Schmidt & De Houwer, 2011), authors argue that memory encoding processes are different for incongruent (two potential responses need to be encoded) and congruent trials (one response has to be encoded). Due to those differences, when the level of congruency changes across trials, the system has to be reconfigured in order to accomplish a new encoding process for the current trial. This leads to a switch cost similar to cost measured in switching tasks. This would explain why congruent-congruent and incongruent-incongruent transitions are faster than congruent-incongruent and incongruent-ones.

Finally, according to the *high-order sequence learning account*, participants might learn sequences of congruent and incongruent trials, resulting in faster responses when congruency repeats across several consecutive trials (several congruent or incongruent trials in a row) and responses slow down when the current trial changes regarding to the previous ones. Those results have been interpreted in two ways: one based on conflict adaptation accounts, that is, the system “learns” to bias attention toward relevant or irrelevant information as a function of congruency sequences (Clayson & Larson, 2011; Durston, et al., 2003), and another based on temporal expectancies, (Schmidt, in press). The latter is based on the idea that participants not only learn about what to respond, but when to respond. Upon retrieval, the information encoded helps participants to anticipate when a response can be made, and when the anticipating respond is correct, participants are especially faster. Given that congruent trials have a fast response (less conflict), in mostly congruent trial contexts participants get into a fast pace of responding, with large penalties for incongruent infrequent trials. Therefore, interference effects are large. By contrary, responses for individual incongruent trials are slower (conflict needs to be resolved). Therefore, even if responses are less slow in mostly incongruent trials (because they are frequent and participant might relax their response threshold), incongruent trials are still not that fast than congruent trials, and congruent trials are not so fast since they are infrequent and participants might slow down their responses to them. That results in a reduced interference effect.

Nevertheless, those explanations cannot account for some forms of SC and PC effects, for example, when partial repetitions are controlled or when PC effects are observed in trials that have not been presented before (Torres-Quesada, et al., 2013).

In summary, although several models have been proposed to account for the controversial results described in the previous section (1.1.), none of them can explain all the findings. Therefore, in the present thesis we will try to analyze further and measure the extent to which pure cognitive control processes separated from other forms of bottom up processes might explain SC and PC effects. Finally we will try to integrate our results and existing ones, as well as some ideas described in the models proposed at present, and suggest a theoretical model that would explain the weakness of the described models.

CHAPTER 2

Motivation and aims

A vast body of research has been carried out during the past decade on cognitive control, allowing a better understanding of this function, and leading to the proposal of several models. Some of them conceptualize cognitive control as a single general mechanism able to resolve any kind of conflict situation (i.e., Botvinick, et al., 2001; Verguts & Notebaert, 2008, 2009). By contrary, other models have suggested that cognitive control is composed of several control mechanisms, which are different in nature (Braver, et al., 2007) or depend on the conflict to be resolved (Egner, 2008).

A common way to study cognitive control in the lab is by using interference tasks. In those tasks, conflict situations are created from the overlap between relevant and irrelevant dimensions, which lead to the activation of, respectively, the relevant response needed for successful performance and incompatible responses that interfere with the relevant response. Thus, interference (or congruency) effects are an index of conflict. Likewise, any factor that reduces interference effects is considered as a form of control. Thus, most researchers have used sequential congruent (SC) and proportion congruent (PC) effects as effects reflecting cognitive control mechanisms. However, not everyone agrees regarding the kind of cognitive control that they reflect.

Most researchers describe SC effects as the benefit of encountering a previous incongruent trial. Once conflict has been resolved on the previous trial, control implementation is still active on the current incongruent trial and therefore conflict will be reduced with no further need for re-recruitment of control (observing faster RTs and higher accuracy). This is carried out online, on a trial-by-trial basis, in reaction to encountering conflict, i.e., in a reactive manner. However, for PC effects the explanation is not that straightforward. For some researches, PC effects are only the sum of SC effects (i.e., Blais, et al., 2007; Botvinick, et al., 2001). That is, PC effects are typically observed when proportion of congruent and incongruent trials is manipulated, having contexts where congruent trials are more frequent and other contexts where incongruent trials are frequent. When incongruent trials are frequent, smaller congruency effects are observed compared to when incongruent trials are rare. However, since in those contexts with a high proportion of incongruent trials the incongruent-incongruent transitions are also more frequent than in contexts of a low proportion of incongruent trials, the overall reduction of congruency effects can be simply explained on the basis of SC effects. By contrary, other authors have defined PC effects as the reflection of a task-set strategy created as the result of experiencing certain level of conflict (e.g., Cohen, Dunbar, & McClelland, 1990). This strategy is conceived as being proactive (preparatory) and sustained over a period of time. Only recent papers using neuroimaging techniques tried to study whether PC effects are the result of sustained processes by testing whether there are brain areas associated to sustained control in high conflict contexts (i.e., Grandjean, et al., 2012; Krug & Carter, 2012; Wilk, et al., 2012).

In an attempt to distinguish between those two possible explanations of PC effects, Funes et al. (2010b) showed a dissociation between SC and that PC effects based on the fact that they were differentially affected by conflict type. Specifically, their results showed that PC effects were observed regardless of the conflict type. Thus, the effect actually transferred from one conflict type where proportion of congruent and incongruent trials was manipulated, and therefore PC effects are expected, to a conflict where the proportion of congruent trials was neutral. Interestingly, they also found that SC effects were specific to conflict type, suggesting that the dissociation between the two effects based on whether they were specific or general to conflict type might indicate that the nature of the mechanisms underlying them is different. However, other studies have also found that PC effects can be context specific (Crump, et al.2006; 2009; 2008), which might contradict the previous dissociation and suggest that SC and PC effects reflect the same mechanism. Therefore, PC and SC effects might be different reflections of the same mechanism, which leads to a single cognitive control conception.

As a result of these discussions, over the past years a plural conception of cognitive control has started to get support suggesting that control resolution does not result from the action of general mechanism as suggested by unitary views. Instead, cognitive control could be divided into different control resolution mechanisms depending on conflict type or into different control mechanisms depending on whether control is applied reactively or proactively (i.e., Egner, 2008; Funes, 2010b). Supporting evidence comes from neuroimaging studies (e.g., Egner, et al., 2007; Egner, et al., 2008), group differences (e.g., Czernochowski, et al., 2010; Monti, et al.r, 2010), etc. However, the only model presented to account for a dual conception of cognitive control is the Dual Model of Cognitive control developed by Braver (2007) and it is working memory based. Therefore, we believe it is really important to articulate a model of attentional cognitive control where the findings on this field could be articulate on. .

To that end, the main aim of the present thesis is to thoroughly study attentional cognitive control and its constituting mechanisms. To do so, we used three main approaches: behavioral, group differences (aging) and neuroimaging approaches. Several experimental series were carried out within one of these approaches to elucidate whether cognitive control is composed by one or several mechanisms, which will allow a big picture of that function to emerge.

Behavioral Approach. The starting question was testing the two alternative models of cognitive control by using interference tasks: a single reactive general model of cognitive control (i.e. Botvinick et al., 2001) and a dual conception of cognitive control (Braver et al., 2007). With that purpose in mind we run three behavioral experimental series. In the three of them, the basic idea was to dissociate SC and PC effects. As explained beforehand, SC effects are considered to be the result of reactive/transient control, whereas PC effects are considered the result of proactive/sustained mechanisms of cognitive control. However, no clear evidence for these claims has been provided in the literature.

In *Experimental series I*, we followed Funes et al.' idea (2010b) of using conflict type specificity as a tool to dissociate SC and PC effects. Besides, we also wanted to test whether PC effects were in fact sustained by testing whether they transfer to a subsequent phase (i.e, to a different time episode). To do so, participants performed a task with three phases. In two phases (pre and post-training phases) Simon and Spatial Stroop were randomly intermixed and the proportion of congruent and incongruent trials was neutral (50/50). In the middle training phase only Simon was presented and the proportion of congruency was manipulated with some participants being trained with a high proportion of Simon congruent trials, and the other half being trained with a low proportion of Simon congruent trials. We tested whether PC effects created on the training phase transferred to the post-training phase and whether it transferred regardless of conflict type. That would indicate that PC effects are general and sustained. Similarly, we also wanted to test whether SC effects on the post-training phase were conflict-type specific. In the case of finding that, we will provide some more evidence suggesting that SC and PC effects reflect different mechanisms based on their different influence by conflict type.

However, showing that two effects are modulated differentially for the same factor (e.g., conflict-type specificity) is not sufficient for claiming that there are different mechanisms underlying them. In fact, one might argue that the same process could works differentially, in a general or conflict-specific way, depending on different circumstances; therefore, SC and PC effects might still be reflections of the same mechanism.

In *Experimental series II and III*, we used a different strategy to show PC effects in the absent of SC effects. As it has been explained beforehand, this is a quite difficult issue, since the manipulation of the proportion of congruent and incongruent trials within a block of trials has embedded the fact that incongruent-incongruent transitions are biased. That is, in a context where incongruent trials are frequent, obviously incongruent-incongruent trials transitions are also more frequent compared to contexts where incongruent trials are rare. In order to avoid this problem we look for a situation where there are no SC effects, and still aimed for observing PC effects in this situation. As described in the introduction, it has been consistently shown that SC effects disappear when conflict type alternate (i.e., Simon incongruent- Spatial Stroop incongruent). Therefore, we used a paradigm in which Simon and Spatial Stroop were randomly intermixed within the same block of trials, but the proportion of congruency was only manipulated for one of the conflict types. By doing so, in Experimental series II we looked for a PC effect, but crucially, only on conflict alternation trials, where SC effects were absent.

In *Experimental series III* the same strategy was used, but we also extended our understanding of these “pure” PC effects, observed where SC effects are absent. Previous studies have shown that PC effects are modulated by the percentage of proportion of congruency manipulation, being larger when there are larger differences between high and low proportions (e.g., 80-20) than when these are smaller (e.g., 60-40). Since those previous studies did not rule out SC effects, it is not possible to be sure that this modulation of the PC effect is not simply the larger present of SC effects for 80-20 conditions compared to the 60-40 one. Besides, we also wanted to see whether our data would vary as a function of the conflict type on which the proportion of congruency is manipulated. That is, in our previous studies we always manipulated the proportion of congruency on Simon, leaving neutral Spatial Stroop trials. As shown in the introduction, previous studies have shown that Simon and Spatial Stroop are different in nature and they even have different neural locations. Therefore, we explored whether pure PC effects vary depending on conflict type. In order to do so, we also varied (between participants) whether the percentage of congruent trials was manipulated for either Simon or Stroop.

In *Experimental series IV* we used a **group differences (aging) approach** to see whether cognitive control is made of different mechanisms. As mentioned in the introduction, several studies have shown group differences regarding reactive vs. proactive control mechanisms (e.g., Czernochowski, et al., 2010; Monti, et al., 2010). In our case, we run one study to investigate whether younger and older adults show different SC and pure PC effects, which would indicate that those effects rely on different mechanisms, which are differently affected by age. Besides that main goal, we wanted to test whether other processes related to cognitive control could be affected by normal aging. Specifically, we distinguish between task-irrelevant processing that produce early incompatible response capture, conflict detection, and control implementation. Within control implementation, we tested reactive and proactive mechanisms. We used a variant of the paradigm developed with the first approach, which allowed us to tease apart SC (reactive) and PC (proactive) effects. Furthermore, we used distributional analyses of both RT and accuracy, in order to further dissociate the different control mechanisms. As explained in the introduction, those analyses were based on the activation-suppression model (Ridderinkhof, 2002a, 2002b) according to which congruency effects should be studied as a function of response speed, since it is the only way to tease apart the contribution of early automatic response capture and selective suppression processes to the overall congruency effects.

Finally, in *Experimental series V*, we used **neuroimaging** to study the neural correlates of proactive control. Neuroimaging is a useful tool for this goal since, if one assumes that proactive control is a sustained strategy, it allows to study unique sustained activity in high conflict conditions (that is, conditions where proactive control is supposedly recruited). As we have mentioned previously, sustained proactive control reflected by PC effects has not been extensively studied (as far as we know only few studies have done it, i.e., Grandjean et al., 2012; Krug & Carter, 2012; Wilk et al., 2012), while reactive control, as reflected by SC effects, has been broadly studied (e.g., Egner & Hish, 2005a, 2005b; Kerns et al., 2004). Therefore, we wanted to see whether our results would show similar areas reported for reactive control. Besides, we also wanted to test whether proactive control is domain-specific or domain-general and, once more, compare it with previous results on domain-general or specific reactive control (Egner, et al., 2008; Etkin, et al., 2006). We run one experiment with fMRI to test the neural correlates of proactive control and investigate whether they map onto the same areas reported for reactive control mechanism (i.e., SC effects). To do so, participants performed a Stroop-like task, one cognitive and one emotional, while they were in the scanner. In these tasks, there were cognitive and emotional blocks where the proportion of congruency was alternatively manipulated (having blocks with high proportion and others with low proportion). For proactive control, we tested which areas were active in low proportion of incongruent trials block and whether they were different for cognitive and emotional conflict.

Each experimental series is presented as an article itself. Some of them are accepted for publication or are currently under review. Therefore, each experimental series has its own introduction, method and discussion, some of which might seem repetitive when seen together as part of the thesis. We will nevertheless conclude with a global summary of the main results and a General Discussion to interpret them. Finally, we will close this thesis by briefly describing how I personally understand attentional cognitive control and I will propose a model in an attempt to provide a structure made of its basic mechanisms.

CHAPTER 3

Experimental series

1. Experimental series I

Dissociating Proportion Congruent and Conflict Adaptation effects in a Simon-Stroop procedure

Published work:

Torres-Quesada, M., Funes, M. J., & Lupiáñez, J. (2013). Dissociating Proportion Congruent and Conflict Adaptation effects in a Simon-Stroop procedure. *Acta Psychologica, 142*(2), 203-210.

Abstract:

Proportion Congruent and Conflict Adaptation are two well-known effects associated with cognitive control. A critical open question is whether they reflect the same or separate cognitive control mechanisms. In this experiment, in a training phase we introduced a proportion congruency manipulation for one conflict type (i.e. Simon), whereas in pre-training and post-training phases two conflict types (e.g. Simon and Spatial Stroop) were displayed with the same incongruent-to-congruent ratio. The results supported the sustained nature of the proportion congruent effect, as it transferred from the training to the post-training phase. Furthermore, this transfer generalized to both conflict types. By contrast, the conflict adaptation effect was specific to conflict type, as it was only observed when the same conflict type (either Simon or Stroop) was presented on two consecutive trials (no effect was observed on conflict type alternation trials). Results are interpreted as supporting the reactive and proactive control mechanisms distinction.

1.1. Introduction

This manuscript focuses on the construct of cognitive control. The main function of cognitive control is to ensure that behaviour unfolds in line with task goals. In many contexts goal-driven behaviour requires responses that are driven by the selection of relevant sources of information amidst competing sources of distraction. For this reason, the mechanisms underlying distractor interference have become a central issue in the study of cognitive control. Generally speaking, the aim of such studies is to understand the control processes that modulate the processing of irrelevant sources of information.

Two behavioural effects in particular have played an important role in the cognitive control literature; conflict adaptation effects (Gratton, et al., 1992) and proportion congruent effects (Lowe & Mitterer, 1982). An important issue in the study of cognitive control is whether these two effects have the same or different causes. It isn't clear whether proportion congruency effects are caused by a mechanism different from the mechanisms that could produce conflict adaptation effects. The primary aim of this manuscript is to address this outstanding issue.

A common strategy used to study cognitive control is to measure performance in interference tasks. For example, in the classical Stroop color-naming task (for a review see Macleod, 1991) participants are required to name the colour in which color words are displayed. Response times (RTs) are reliably slower for trials where the name of the printed word is incongruent with its color (e.g., the word RED printed in green) compared to trials where the word and color are congruent (e.g., the word RED printed in red). This difference in performance provides a measure of the contribution of irrelevant word reading to performance, with greater amounts of word reading leading to larger differences in performance between congruent and incongruent trials (i.e., larger interference). Similarly, in the Simon task people are required to respond to a non-spatial dimension of target stimuli (e.g., color), which are presented, say, to the left or right of fixation by pressing response keys lateralized to the left or right (Simon & Craft, 1972; Simon, et al., 1973; Simon & Small, 1969). Although target location is irrelevant for the task, people respond more quickly and accurately to targets appearing on the same side as the response location (e.g., a left target requiring a left hand response) than to targets appearing on the side opposite the response location (e.g., a left target requiring a right hand response). In this case, the difference in performance for these two trial types provides a measure of the contribution of irrelevant spatial processing to performance, with greater amounts of spatial processing leading to a larger Simon effect.

The fact that Stroop and Simon effects are driven by the processing of task-irrelevant stimulus dimensions suggests that the processing of these irrelevant stimulus dimensions occurs automatically and is difficult to prevent. However, these effects can be subjected to modulation, as conflict adaptation (CA) and proportion congruent (PC) effects reveal.

1.1.1. Measuring cognitive control: Conflict adaptation

The CA effect is defined by congruency effects that are smaller on a current trial when preceded by an incongruent trial than when preceded by a congruent trial (Gratton, et al., 1992), and have been explained by different approaches. According to the “Control Monitoring Theory” (Botvinick, et al., 2001) the detection of conflict on incongruent trials by the anterior cingulate cortex (ACC), leads to the recruitment of control by the activation of the dorsolateral prefrontal cortex (DLPFC), which will recruit others areas responsible to implement control by reducing the interference from an irrelevant distractor. Consequently, when the following trial is also incongruent, the cognitive control system is already activated and prepared to handle interference from the upcoming irrelevant distractor, with the outcome of a reduced congruency effect.

However, this theory has been challenged by several authors who explain CA effects as the result of mere priming and/or learning processes (Hommel, et al., 2004; Mayr, et al., 2003; Nieuwenhuis, et al., 2006). Specifically, they pointed out that congruent followed by congruent trials (cC transitions) or incongruent followed by incongruent trials (iI transitions) can include complete repetitions of the full event (target + response). In contrast, this does not occurs in mixed transitions (i.e. incongruent followed by congruent trials (iC) or congruent followed by incongruent trials (cI)), where only partial repetitions can occur. Note that CA effects are usually due to improved performance for cC compared to iC transitions and for iI compared to cI transitions. Therefore, taking into account that responses are faster in complete repetitions, according to the priming and/or learning processes CA could be due to repetition priming speeding up cC and iI trials. In fact, when considering the contribution of all those 4 possible transitions, Schalaghecken & Martini (2012) showed that CA effects were driven mostly by faster responses on cC trials relative to iC, and less by faster responses on iI trials relative to cI.

In an attempt to reconciliate both reinforcement learning and conflict monitoring accounts, hybrid learning-conflict models have been proposed (Davelaar & Stevens, 2009; Verguts & Notebaert, 2008, 2009), highlighting the idea that cognitive control results from interactions between binding processes and conflict detection, for example, by conflict indicating where binding should be applied (Verguts & Notebaert, 2008, 2009).

1.1.2. Measuring cognitive control: Proportion Congruent effect

Another well-known effect reflecting cognitive control adjustments to task demands is the PC effect. This effect is measured by manipulating the relative proportions of congruent and incongruent trials within an experimental block. The magnitude of the congruency effect varies with the proportion of congruent trials, being larger in the context of a high proportion of congruent trials than in the context of a low proportion of congruent trials (e.g., Carter, et al., 2000; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; West & Baylis, 1998). This modulatory effect is most commonly attributed to the adoption of a sustained strategy or task set, probably implemented after having experienced the level of conflict encountered on the first few trials in a block. This task set produces tonic changes in processing by, for example, altering the 'weighting' of word-reading relative to color-naming (e.g. Cohen, Dunbar, & McClelland, 1990).

Similarly to CA effects, alternative accounts of the PC effects have been proposed. For example, according to Risko et al. (2008), in line with the priming and binding proposals described beforehand for CA effects (Hommel, et al., 2004; Mayr, et al., 2003; Nieuwenhuis, et al., 2006), suggested that the different ratio of complete repetitions/alternations to partial repetitions of features, also present in high vs. low proportion congruent blocks of trials explained the observed PC effect.

Furthermore, recent studies have shown that PC effects can also be observed under conditions in which a sustained strategy for all trials within a block cannot possibly explain the effect. In these studies, proportion congruent is manipulated independently for two sets of stimuli or contexts that are intermixed at random within a block of trials (Crump, et al., 2006; 2008; Jacoby, et al., 2003). Critically, in these studies the overall proportion of congruent and incongruent trials is kept at .50. Even though, particular items (Jacoby, et al., 2003) or contexts (Cañadas, et al., in press; Crump, et al., 2006) entail a high (or low) proportion of congruent trials, whereas other items or contexts entail a low (or high) proportion of congruent trials. The key result is again larger congruency effects for the items or contexts associated with a high proportion of congruent trials. Interestingly, as the type of item or context is manipulated randomly from trial to trial, the effect cannot be explained on the basis of a general, sustained, strategic attentional control set. Instead, the effect must be explained by reference to processes initiated at onset of the stimulus that perhaps cue the retrieval of prior memory episodes involving similar items/contexts. In turn, the cognitive control operations engaged on the current trial may be those that are retrieved as part of the memory representation of similar prior trials (see also Mayr, et al., 2003).

1.1.3. Conflict adaptation and proportion congruent effects: the same or different mechanisms?

A still unsolved question is whether the two above described forms of cognitive control adjustments (CA and PC effects), are reflections of the same or different control mechanisms. According to the above-described Conflict Monitoring account there is no need for sustained strategic control to explain PC effects. Instead, PC effects can be explained by the same transient or reactive mechanism proposed to account for CA effects. By this view, in a high conflict condition (low proportion of congruent trials), incongruent trials are very frequent, both as current and previous trials. Consequently, the number of iI transitions (incongruent trials preceded by incongruent trials) increases, leading to an overall reduction of interference effects.

An alternative view is that CA and PC effects tap separate control mechanisms (De Pisapia & Braver, 2006; Dosenbach, et al., 2008), one responsible for transient shifts of control and the other responsible for more sustained forms of control. For example, De Pisapia and Braver (2006) propose the Dual Mechanisms of Control framework, a computational model with two separate mechanisms. On the one side, they propose a reactive mechanism responsible of CA effects through transient activation of prefrontal cortex (PFC) based on conflict detected in ACC over a short-time scale (in the order of milliseconds). A second mechanism would be responsible for PC effects, and is characterized by the sustained active maintenance of task-set information in a separate PFC module, which is driven by long time-scale conflict detected in a separate ACC unit (in the order of several seconds or minutes).

In agreement with this approach, Funes et al. (2010b), recently reported a behavioural dissociation between CA and PC effects in the context of conflict tasks, and concluded that they reflect different mechanisms. Concretely, they used a paradigm in which participants were to respond to up/down pointing arrows by pressing a left or right key. Arrows could be randomly presented either in the horizontal axis (to the left or to the right of fixation, in which case Simon interference was observed), or in the vertical axis (above or below fixation, in which case Spatial Stroop was observed). They manipulated the proportion of congruent trials for just one conflict type (Simon), leaving neutral (i.e., 50% congruent and 50% incongruent) the overall congruency ratio on the other conflict type (Spatial Stroop). The Simon and Stroop conflict trials were randomly presented within the same block of trials and participant had to perform the same task on all of them (i.e., to press a left-right key depending on whether the arrows pointed up or down). Importantly, a PC effect was observed for both Simon and Spatial Stroop despite manipulating proportion congruent for Simon trials only. At the same time, the CA effect was present only when the same type of conflict repeated on consecutive trials (i.e., they were observed from Simon to Simon and from Stroop to Stroop trials, but not from Simon to Stroop or from Stroop to Simon trials). This conflict-type specificity of CA effects has been consistently observed with different paradigms (Egner, et al., 2007; Funes, et al., 2010a; Funes, et al., 2010b; Kiesel, Kunde, & Hoffmann, 2006; Verbruggen, et al., 2005; Wendt, et al., 2006).

Thus, PC effects generalized in Funes et al. (2010b) study across different conflict types combined within a single task, while CA effects seems to be conflict type specific. This dissociation was interpreted as evidence of different mechanisms underlying the two effects. However, Funes et al study (2010b) measured PC effects under proportion of congruency manipulations, that is, under over-represented cC transitions for the high proportion congruent condition and iI transitions for the low proportion congruent condition. Furthermore, they measured PC effects on-line with the same trials with which the proportion of congruency was manipulated. Therefore, although it is assumed that PC effects are the results of the application of a sustained control set, there is no evidence for their sustained nature in this study.

Therefore, in the present experiment we define two main goals. The first one is to show whether we can find evidence of PC effects reflecting a genuine sustained control strategy. In that sense, if a PC effect reflects the activation of a control set that can be sustained over a substantial time period, then it ought to be possible to measure the generalization of such a PC effect beyond the block of trials in which PC is manipulated, in a subsequent block of trials on which the PC is kept neutral. Thus, we investigated whether this across block transfer effect occurs, and for how long it lasts.

Our second goal is to test further whether PC and CA effects can be dissociated in a more qualitative manner, thus reflecting different mechanisms at their basis. Concretely, we study whether the across block transfer of the PC effect will be general, generalizing to both conflict types, in contrast to the CA effect, which will be conflict-specific. Furthermore, given that there is no actual manipulation of the proportion congruency in the transfer block, any observed PC effect (as manipulated in the previous block) could not be explained on the basis of different proportion of transitions of cC, cI, iI and iC for the high vs. low proportion of congruent trials conditions, or to differences in the ratio of complete repetitions/alternation vs. partial repetitions associated to the different types of transitions.

To achieve these two goals, we introduced a modification of Funes et al's paradigm (2010b). In particular, the experiment had three phases; pre-training, training and post-training. In the critical training phase, only Simon conflict type trials were presented (i.e., only trials on the horizontal axis, left or right of fixation). Proportion congruent was manipulated for these trials, with half of the participants receiving mostly congruent and the other half receiving mostly incongruent trials. In the pre-training and the post-training phases, both Simon and Stroop conflict types (i.e., trials on both the horizontal and vertical axes) were presented, but without a manipulation of proportion congruent. With this procedure we were able to break our goals into contrastable questions: 1) Will there be a sustained component to the PC effect that transfers from the training to the post-training phase?; 2) If such a transfer occurs, how long will it persist into the post-training phase?; and 3) Will the PC effect that transfers to the post-training phase be specific to the conflict type manipulated in the training phase or will it generalize to both conflict types?

1.2. Method

1.2.1. Participants

Thirty-six undergraduate psychology students (4 males) from the University of Granada participated in the experiment. Their ages ranged from 18 to 29 years (with a mean age of 21.72 years). Four of the participants were left handed. All of them had normal or corrected to normal color vision and were naive as to the purpose of the experiment. They all participated voluntarily and received credits for their Psychology courses.

1.2.2. Apparatus and Stimuli

Participants were tested on a Pentium computer running E-prime software (Schneider, Eschman, & Zuccolotto, 2002a, 2002b), and sat in front of the computer screen at a viewing distance of about 57 cm. Stimuli were presented on a 15-inch color Samsung monitor. All the stimuli consisted of white arrows pointing either up or down, and subtending 0.54° of visual angle in width and 1.08° in length. The target could appear in one of four possible locations, either to the left, right, above or below fixation (a plus sign in the centre of the screen), forming the four vertices of an imaginary diamond. These four locations were equidistant to fixation (4.32º). Responses were made by pressing either the “v” key (left response) on the keyboard with the index finger of the left hand or the “m” key (right response) with the index finger of the right hand.

1.2.3. Procedure

Participants were instructed to make left/right key presses in response to the up/down direction of an arrow. Half the participants responded to the “up” direction by pressing the letter “v” (left response) with the index finger of their left hand and to the “down” direction by pressing the letter “m” (right response) with the index finger of their right hand. The opposite mapping was used for the other participants. For targets appearing on the vertical axis, that is, above or below fixation a pure Spatial Stroop effect (i.e., Stimulus-Stimulus interference) was measured. In contrast, for targets appearing on the horizontal axis, that is, left or right of fixation, a pure Simon effect (i.e., Stimulus-

Response interference) was measured. Within each block of the pre- and post-training phases, half of the trials were Simon conflict trials and the other half were of Spatial Stroop conflict trials. Only Simon trials were included in the training phase. Trials were congruent whenever the arrow location corresponded with the arrow direction (in the case of Spatial Stroop trials) or the arrow location corresponded with the response location (in the case of Simon trials). On the other hand, incongruent trials were defined as those where the arrow location did not correspond with the arrow direction or the response location (for Spatial Stroop and Simon, respectively). The instructions stressed the need to respond as fast as possible while trying to avoid error. Participants were asked to maintain fixation at the centre of the screen before the target was presented.

The sequence of events on each trial was as follows. The fixation point was displayed for 750 ms, after which the target was displayed for 100 ms. Following offset of the target, the fixation point remained alone on the screen until participants' response or for 1500 ms if there was no response. Auditory feedback (a 500 Hz, 50 ms computer-generated tone) was given on error trials, or on trials in which no response was made within 2000 ms. Trials were grouped in blocks and presented randomly within each block. The experiment stopped between blocks. Participants were instructed to rest for a few seconds between blocks, and then resume the experiment by pressing the space bar.

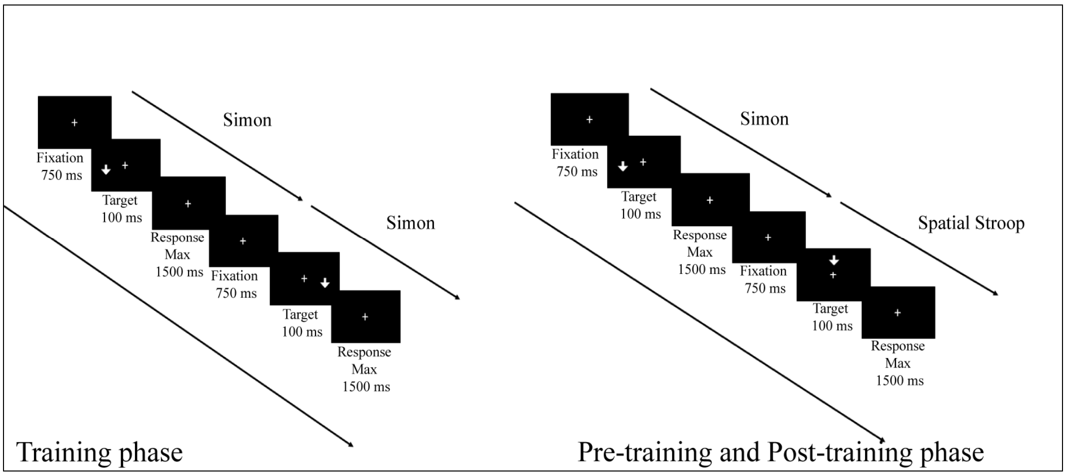

Figure 1. Sequence of events along two consecutive trials. On the left side of the figure, there is an example of the training phase, in which just Simon conflict was displayed (within the horizontal axis). On the right side of the figure, an example of the pre-training and post-training phase is presented. In those phases either Simon (within the horizontal axis) or Spatial Stroop stimuli (within the vertical axis) were randomly presented.

1.2.4. Design

The experiment consisted of 16 practice trials (not included in the statistical analysis), followed by 7 blocks of 64 experimental trials each. The experimental trials were divided in three phases: one block of pre-training trials, two blocks of training trials, and four blocks of post-training trials.

For the training phase, only one within-subject variable was manipulated, congruency, which took two possible values (congruent and incongruent), as only Simon trials were presented. In addition, a between-group variable was also manipulated, proportion congruent. In the high proportion congruent condition, 75% of the trials were congruent and 25% of the trials were incongruent, while in the low proportion congruent condition, 25% of the trials were congruent and 75% of the trials were incongruent. The factorial combination of these two variables (congruency and proportion congruent) formed our four experimental conditions.

For the pre-training and post-training phases, Simon and Stroop trials were intermixed within each block of trials, with congruent and incongruent trials being equally represented for both conflict types. Thus, the combination of two within-subjects variables, conflict type (Spatial Stroop vs. Simon) and congruency (congruent vs. incongruent), led to four experimental conditions. Importantly, although proportion congruent for both conflict types in the pre and post-training phases was always .50, group was included in the analysis of the post-training phase to investigate the transfer from the training phase.

In addition to these variables, we recoded sequential effects offline by creating two additional within-subjects variables (previous congruency and conflict type shift). The previous congruency variable was created to code the level of congruency encountered on the previous trial, and took two possible levels, congruent and incongruent. The conflict type shift coded whether the type of conflict encountered on the current trial constituted a repetition or an alternation of the kind of conflict encountered on the previous trial. Conflict type repetition trials consisted of a Spatial Stroop trial followed by another Spatial Stroop trial (both appearing along the vertical axis), or a Simon trial followed by another Simon trial (both appearing along the horizontal axis). Conflict type alternation trials consisted of any Spatial Stroop in the vertical axis preceded by a Simon trial in the horizontal axis or vice versa.

1.3. Results

Several analyses were conducted on mean reaction times (RTs) and error rates. For the mean RTs, error trials and trials with RT either shorter or longer than 2.5 standard deviations from the mean were excluded, which constituted 6.0 % and 2.8 % of the overall trials, respectively. Furthermore, trials following an error and the first trial of each block were also excluded, which eliminated a further 6.2% of the trials. For the analysis of error rates only the first trial of each block and trials following an error were excluded, which constituted 7.6 % of the trials. Interactions were analysed using planned comparisons that followed a priori hypotheses.

1.3.1. Pre-training phase

First, we analyzed the pre-training phase to confirm that there were no differences between the high and low proportion congruent groups in the congruency effect prior to implementing the proportion congruent manipulation in the training phase.

To do so, we conducted a mixed 2 x 2 x 2 ANOVA on mean RTs and error rates, with the variables conflict type and congruency as within participants factors, and proportion congruent as a between participants factor. There was a significant main effect of congruency, $F(1,34)=51.02$, $p<.001$, with larger RTs for incongruent trials (553 ms) than for congruent trials (523 ms), and a significant main effect of conflict type, $F(1,34)=25.6$, $p<.001$, with larger RTs for Spatial Stroop (547 ms) than for Simon trials (529 ms). Importantly, the interaction between proportion congruent and congruency was not significant ($F<1$, with a congruency effect of 31 ms and 30 ms in the high and low proportion of congruency conflict conditions respectively).

In the analysis of error rates, there was only a main effect of congruency, $F(1, 34) =8.03$, $p=.008$, with a larger error rate for incongruent trials (.13) than for congruent trials (.09).

1.3.2. Training phase

In this phase, the main objective was to test whether the manipulation of proportion congruent on Simon trials would produce the usual PC effect, and more important, whether PC and CA effects within the training phase would be independent of each other. To this end, we carried out a 2 x 2 x 2 mixed ANOVA on RTs and error rates, including previous congruency and congruency as within participant factors and proportion congruent as a between participant factor.

In the analysis of RTs, there was a significant main effect of congruency, *F*(1, 34) =33.00, p<.001, with RTs being faster for congruent (509 ms) than for incongruent trials (550 ms). This congruency effect was modulated by previous congruency, *F*(1,34)=69.2, p<.001, showing the typical conflict adaptation pattern, that is, larger congruency effects for previous congruent trials [*F*(1,34)=83.82, p<.001, 77 ms] than for previous incongruent trials (*F*<1, 5 ms). The proportion congruent by congruency interaction was also significant, *F*(1,34)=6.33, p=.017, with the typical pattern of congruency effects observed, that is, larger congruency effects for the high proportion congruent condition [*F*(1,34)=44.49, p<.001, 67 ms] than for the low proportion congruent condition [*F*(1,34)=2.11, p=.15,, 15 ms]. Importantly, the three-way interaction involving proportion congruent, congruency, and previous congruency was not significant (F<1; see Figure 2).

The analysis of error rates revealed a similar pattern. There was a significant main effect of congruency, *F*(1,34)=10.24, p=.003, with a larger error rate for incongruent trials (.09) than for congruent trials (.05). Once more, the congruency effect was modulated by both previous congruency and proportion congruent. In the first case, we observed the usual CA effect, with a congruency effect after congruent trials [*F*(1,34)=27.21, p<.001, .11 effect], but not after incongruent trials, [*F*(1,34)=3.1, p=.087, -.02]. In the second case, we observed the usual PC effects pattern, *F*(1,34)=14.08, p<.001, with a significant congruency effect in the high proportion congruent condition [*F*(1,34)=24.16, p<.001, .09], but not in the low proportion congruent condition (*F*<1, -.01). The three-way interaction again did not reach significance, *F*(1,34)=3.48, p=.071.

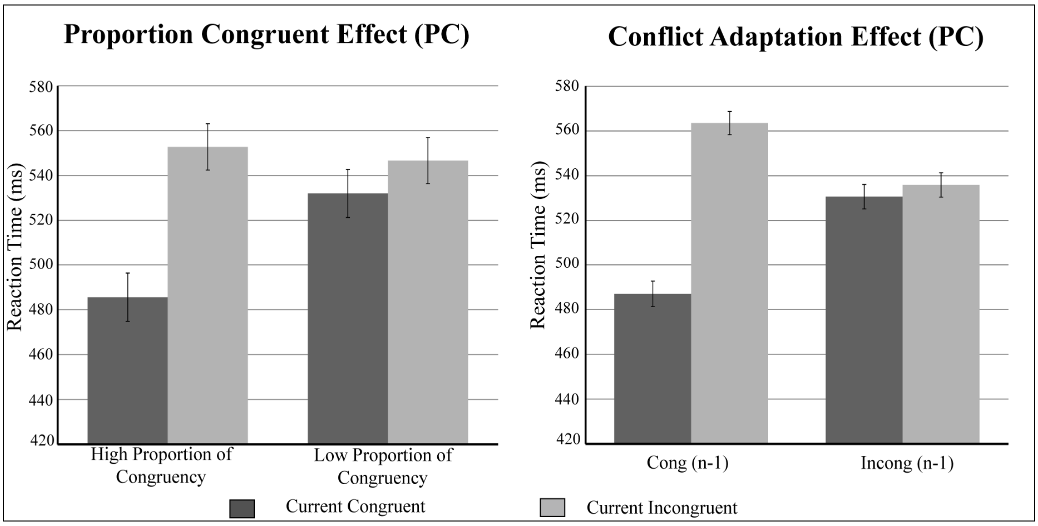

Figure 2. Mean reaction times for congruent and incongruent trials, depending on high vs. low proportion of congruency and previous congruency conditions, during the training phase. That is, proportion congruent and conflict adaptation effects respectively

1.3.3. Post-training phase

Focusing on the post-training phase, one aim was to test whether PC effects would transfer from the training phase to the post-training phase, and whether such transfer would take place independently of conflict type. Moreover, we also wanted to test how long the transfer would last and, once more, whether the transfer was independent of CA effects.

To do so, we first carried out a general 2 x 2 x 2 x 2 x 2 mixed ANOVA on mean RTs with conflict type, shift of conflict type, previous congruency and congruency as within participant factors and proportion congruent in the training phase as a between participant factor. A corresponding ANOVA was then carried out on error rates.

In the analysis of RTs, we first found a significant interaction between proportion congruent and congruency [$F(1,34)=6.83$, p=.013], with a larger congruency effect (31 ms) when the proportion of congruent trials in the preceding training phase was high [$F(1,34)=48.64$, p<.0001] compared to when it was low [$F(1,34)=10.75$, p<.005, 14 ms]. This interaction was not modulated either by shift of conflict type or by conflict type (F<1 in both cases; see Figure 3). Second, we found a significant CA effect (i.e., a congruency x previous congruency interaction), $F(1,34)=11.39$, p=.002, which, in contrast to the PC effect, was significantly modulated by shift of conflict type, *F*(1,34)=11.34, p<.005. Concretely, CA effects were observed only on conflict type repetitions across consecutive trials [*F*(1,34)=26.7, p<.0001, with a CA effect of 41 ms] while a non-significant effect [*F*(1,34)=1.13, p=.295, 7 ms] was obtained when conflict type alternated across consecutive trials (Figure 3). Finally, this general ANOVA revealed that CA and PC effects did not interact (F<1).

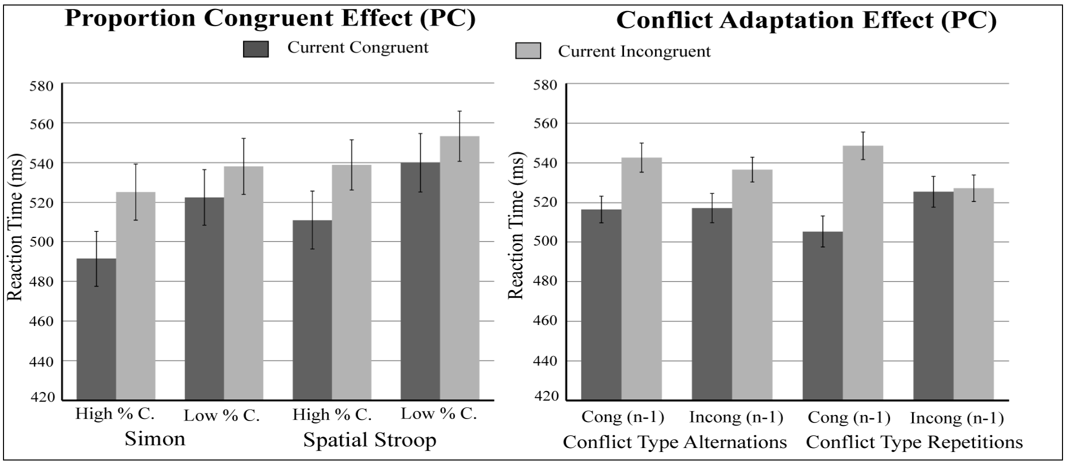

Figure 3. Mean reaction times for congruent and incongruent trials, depending on proportion of congruency (high vs. low proportion conditions) and conflict type (Simon vs. Spatial Stroop) when analysing proportion congruent effects; and shift of conflict type (alternation vs. repetition conflict type across consecutive trials) and previous congruency when analysing conflict adaptation effects, during post-training phase. As it shown, proportion congruent effects are independent of conflict type, while conflict adaptation effects are specific.

Besides, we wanted to confirm that the PC effects found were not due to mere group differences in latency or in RTs distribution. To do so, we compared the overall RTs for both groups and observed that mean RTs were slower for the low proportion congruent trials group (538 ms) than for the high proportion congruent trials group (517 ms). However, those differences were not significant, F(1,34)=1.32, p=.258. To analyze the RTs distribution, we carried out a bin analysis for the post-training phase including bin (1,2,3,4, from 25% fastest to 25% slowest responses), conflict type (Simon and Spatial Stroop) and congruency (congruent vs. incongruent) as within participant factors and proportion of congruency as between factor. The results showed the typical interaction between bin and congruency, F(3,102)=10.42, p<.001. However, that interaction was not modulated by high vs. low proportion congruent trials group, F(3,102)=1.11, p=.35. Indeed, the interaction between bin and congruency was significant for both groups. Concretely, for the high proportion of congruent trials group, F(1,34)=4.40, p=.043, congruency effects for bin 1,2,3 and 4 were 38ms, 32ms, 23ms and 18ms respectively. Similarly, for the low proportion of congruent trials group, F(1,34)=14.21, p<.001, congruency effects were 31ms, 19ms, 7ms and -9ms for bin 1,2,3 and 4 respectively. Apart from that, we again observed an interaction between congruency and proportion of congruency, F(1,34)=4.59, p=.039, showing smaller congruency effect for the low proportion congruent trials group (12ms) than for the high proportion one (28ms). Therefore, both groups showed the typical reduction in the congruency effect due to slower RTs, but low proportion congruent trials group showed an additional reduction in its congruency effect potentially due to the transfer of a cognitive control mechanism.

Having confirmed the PC effects in the post-training phase, independent of conflict type and CA effects, we wanted to test the duration of this transfer effect. To do so, we carried out several planned comparison. First, in an analysis of the post-training phase that included block, congruency, and conflict type as within participant factors and proportion congruent as a between participant factor, a planned comparison showed a significant linear change across block in the PC effect (i.e., the proportion congruent by congruency interaction), *F*(1,34)=5.71, p=.022, which was independent of conflict type [*F*(1,34)=2.05, p=.16].

To determine when exactly the PC effect disappeared, planned comparisons showed a significant PC effect in the first post-training block that was only marginal in the second block [*F*(1,34)=9.63, p<.005, with a 22 ms PC effect, and *F*(1,34)=3.54, p=.07, with a 21 ms PC effect, in the two blocks respectively]. No significant PC effect was observed in the following blocks (7 ms and 3 ms, *F*<1 in both cases) (see Figure 4, where task factor is collapsed). Importantly, once again whether the PC effect was observed or not was independent of conflict type in all blocks (p>.14 in all cases).

The analysis of error rates showed two complex interactions. One of these interactions involved conflict type, congruency, proportion congruent and conflict type shift, *F*(1,34)=9.59, p<.005, showing that the PC effect was only present in Simon conflict when conflict type repeated across consecutive trials [*F*(1,34)=8.79, p=.005, .07 effect]. The second of these interactions involved conflict type, congruency, proportion congruent and previous congruency, *F*(1,34)=10.74, p<.005, showing that the PC effect was observed only for Simon conflict trials when the previous trial was incongruent

[*F*(1,34)=7.01, p=.012; .06 effect]. Regarding the CA effect, we found a significant interaction between previous congruency and congruency, *F*(1,34)=6.7, p=.014, that was modulated by conflict type shift, *F*(1,34)= 23.64, p<.001, observing a significant CA effect for conflict type repetition trials [*F*(1,34)=22.1, p<.001,.07], but not for the conflict type alternation condition (F<1, -.01).

More specific analyses on error rates were not possible due to insufficient error observations.

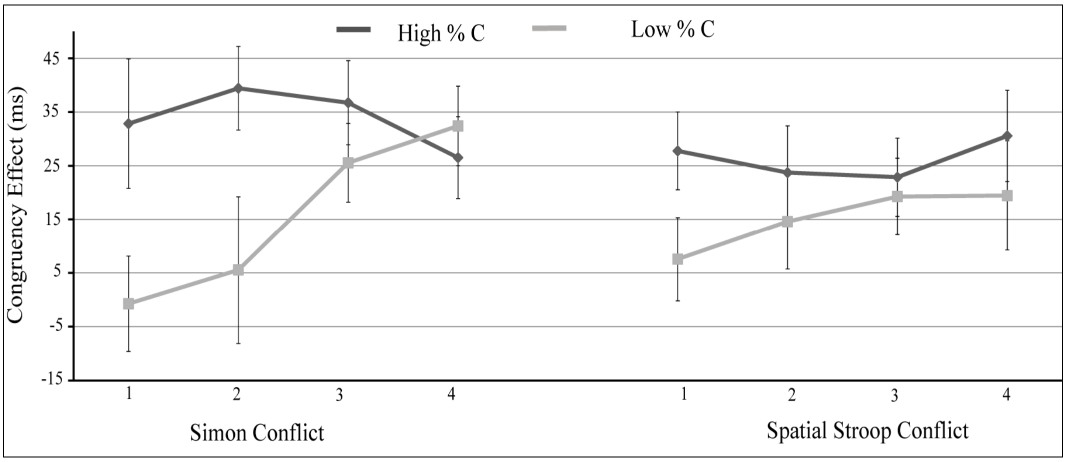

Figura 4. Mean reaction times on congruency effect (incongruent trials minus congruent ones) as a function of proportion of congruency and along the four blocks of the post-training phase, for both Simon and Spatial Stroop conflict types (high % C: high proportion of congruent trials; low % C: low proportion of congruent trials).

1.4. Discussion

The current experiment is to our knowledge the first demonstration that PC effects can be observed as transferring from one block where proportion congruency is manipulated to a following block where proportion congruency is actually not manipulated. Therefore the main conclusion of the present study is that PC, at least under the conditions used here, can be the reflection of a genuine sustained mode of cognitive control. Consequently, we provide further evidence that PC and CA effects can be determined by separate processes within the context of conflict tasks.

Importantly, our results clearly showed that the PC effect found in the post-training phase cannot be explained as a by-product of CA effects. As it has been explained in the Introduction, PC effects have been interpreted (Botvinick, et al., 2001) as a result of several CA effects situations, that is, larger number of iI transitions in the low proportion of congruent trials condition explained the reduction in the congruency effect compared to the high proportion of congruent trials condition. Besides, PC effects cannot be accounted either in terms of differential representations of feature repetitions, alternations or partial repetitions for the different types of transitions (cC, cI, iI, iC), in the high and low proportion congruent conditions, as suggested by Risko et al (2008). Thus, we obtained a significant PC effect in a subsequent and contextually different block of trials, on which the proportion of congruent and incongruent trials, was kept at 50%.

It is very important to note that the observed generalization of PC effect, even if similar to the one observed in Funes et al. study (2010b), with our new procedure extended to a different point in time, as the learning of the proportion congruent manipulation occurs at one point in time (the training phase) and the effect of PC is measured at a later point in time (in the post-training phase). This transfer of the PC effect from training to post-training followed a linear trend across blocks, with the largest effect in the first block decreasing gradually until it disappeared entirely in the last two blocks. Altogether, this finding is consistent with the idea that a sustained-proactive control set developed during the training phase was maintained at the beginning of the post-training phase, but decayed with time as participants experienced the lack of congruency bias. Thus, we can conclude that this finding constitutes new and direct evidence supporting a *strategic and sustained* nature of PC effects.

Furthermore, the pattern of results in turn offers four pieces of evidence against the unitary view of PC and CA effects. First, this result eliminates any explanation of the effect based on the accumulated consequences of CA effects across conditions with unequal frequencies of trial type transitions. Those findings constitutes a clearer evidence of independence than the results of Funes et al. (2010b), where PC and CA effects were measured in the context of proportion congruent manipulations, and therefore in a situation where the ratio of cC, cI, iI and iC transitions was not equally distributed. Second, we obtained a behavioral dissociation between the two effects in that the PC effect transferred in a general manner to the other conflict type in the post-training phase, while CA effects were specific to the conflict type experienced on the previous trial. This finding also constitutes an extension of the results of Funes et al. (2010b), where PC effects generalized across conflict types that were randomly mixed within the same block. Finally, there was no indication in the overall ANOVA of a significant interaction involving PC and CA effects. Together, these results offer a strong argument against the unitary view of PC and CA effects.

We believe the findings of the present experiment are important because they provide evidence for the sustained and proactive nature of at least one component of the PC effect, which to our knowledge has not been clearly confirmed in the context of conflict tasks. Consequently, the results constitute clear evidence against alternative accounts of the PC effect, as a by-product of CA effects.

Given the specificity of CA effects reported here, it is worth noting that domain-general CA effects have been observed elsewhere (Freitas, et al., 2007; Kunde & Wühr, 2006). Importantly, however, those domain-general CA effects were observed with overlapping conflict types. For example, in the Kunde et al. study (2006) the tasks used were both based on spatial codes. Concretely, they used a prime-target paradigm and Simon paradigm where, in both cases, conflict arises from an overlap between spatial dimensions (stimulus and response locations). Therefore, although two tasks were used, both involved the very same conflict type. The same can be said of the Freitas et al. study (2007) where Flanker and Stroop tasks were used. In those tasks, conflict arises from an overlap between stimulus irrelevant and relevant dimensions of the tasks, and therefore just one conflict type was presented. It follows then that CA effect are conflict type specific (Funes, et al., 2010a). Therefore, in order to show real conflict type specific CA effects, truly independent conflict types have to be used (Kornblum, et al., 1990). With that idea, we used Stimulus-Stimulus (SS) or Spatial Stroop interference, and Stimulus-Response (SR) or Simon interference, two distinct conflict types that have been dissociated in prior work on the basis of differences in how they are affected by spatial and temporal attention (Correa, et al., 2010; Egner, et al., 2007; Lupiáñez & Funes, 2005).

A more challenging issue is raised by the fact that, as discussed in the introduction, domain-specific, rather than general, PC effects have been reported recently (Cañadas, et al., in press; Crump, et al., 2006; 2008; Fernández-Duque & Knight, 2008). One way to resolve this apparent contradiction to the observed results is to assume that the PC effect may arise from at least two different sources. On some occasions, participants may rely on the retrieval of item or contextual cues to respond to a given stimulus, thus being specific, i.e., leading to ISPC, CSPC, and/or Conflict Specific PC effects (Fernández-Duque & Knight, 2008). On other occasions, the task conditions might work against the learning of associations between specific contexts/items and cognitive control processes, in which case PC effects might be driven only by a sustained and proactive control set, as observed in our experiment. By this view, then, one component of the PC effect may be truly sustained, proactive, and strategic in nature, while another component is stimulus-driven and automatic, rapidly triggered by the stimuli or the context itself. In any case, we believe that both forms of PC effects are independent from CA effects. For the general and sustained one is pretty straightforward to think so since it is defined by different characteristics. However, for the specific and transient one some concern might arise since, by definition, it shares similar qualities with CA effects. Briefly, we have shown that even when PC effects are specific and transient they can be observed in the absent of CA effects. This constitutes clear evidence that both effects are independent from each other even when they are defined by the same characteristics.

Future research is needed to delimitate which are the key conditions that make people to rely on the proactive-sustained mechanism or on the retrieval of control processes triggered by item or contextual cues to produce PC effects. It will be important that future research investigate whether individual differences can bias the system to use one of these forms of control more than the others.

1.5. Conclusions

The broad implication of the present research is that cognitive control is expressed in performance by a set of distinct mechanisms. This conclusion follows from the fact that more than a single control mechanism is needed to explain both conflict adaptation and proportion congruency effects. It is a question of future research to investigate which mechanism is particularly involved in controlling the way we adapt to the different demands of control. In this endeavour we believe that apart from looking for factors related to the task, such as the saliency vs. homogeneity of the conflict types, future research should look for factors related to individual differences in control processing. Thus, a growing number of studies are elucidating important differences across individuals in executive control functions (see Braver, 2012; Braver, et al., 2010 for a review; Egner, 2011). In that sense a recent study has shown how individuals with high working memory capacity or fluid intelligence are more prone to use a proactive control mechanism to perform a working memory task, as compared to people scoring low in those measures, who are more prone to rely on the reactive control mechanism to perform the same task (Burgess & Braver, 2010). Similar to that and within the context of the present PCE and CA dissociation, we have recently found evidence showing a consistent relation between individual bias to focus on local vs. global features of the stimuli, and the specificity/generality of the PC effect in a task similar to the one used in Funes (2010b). Thus, we found that the better are people to perceive the global form of a stimuli the more prone they are to show a general PC effect across conflict types (Funes, Torres-Quesada, Montoro-Membila, & Lupiáñez, 2010).

Finally, another promising line of research would be to use neuroimaging techniques with an individual differences approach (Egner, 2011). It will be interesting to investigate the brain circuits that are active when participants produce PC effects to dissociate those that are conflict type specific from those that are conflict type general. This brain information would help us to better understand the complex brain architecture responsible for cognitive control.

2. Experimental Series II

Proportion Congruent effects in the absence of Sequential Congruent effects: the very same mechanism cannot explain both.

Unpublished work (under review):

Torres-Quesada, M., Milliken, B., Lupiáñez, J., & Funes, M. J. (2013). Proportion Congruent effects in the absence of Sequential Congruent effects: the very same mechanism cannot explain both. *Psicologica* (under review).

Abstract:

A debated question in the cognitive control field is whether cognitive control is best conceptualized as a collection of distinct control mechanisms or a single general purpose mechanism. In an attempt to answer this question, previous studies have dissociated two well-known effects related to cognitive control: sequential congruence and proportion congruent effects. In the present experiment, we pursued a similar goal by using a different strategy: to test whether proportion congruent effects can be present in conditions where sequential congruence effects are absent. We used a paradigm in which two conflict types are randomly intermixed (Simon and Spatial Stroop) and the proportion of congruency is manipulated for one conflict type and kept neutral for the other conflict type. Our results showed that in conflict type alternation trials, where sequential congruence effects were absent, proportion congruent effects were still present. It can be concluded that, at least under certain circumstances, sequential congruence and proportion congruent effects can be independent of each other and specific to the conflict type.

2.1. Introduction

Cognitive control can be defined as a set of processes that allows behavior to adapt flexibly in response to our goals. To study cognitive control in the lab, interference tasks are often used. These tasks introduce conflict between goals and actions afforded by the stimuli, and allow researchers to study how these conflicts are solved. For example, in the classical Stroop color-naming task (for a review see Macleod, 1991) participants are required to name the color in which color words are displayed. Response times (RTs) are reliably slower for trials in which the name of the printed word is incongruent with its color (e.g., the word RED printed in green) compared to trials in which the word and color are congruent (e.g., the word RED printed in red). This difference in performance (which is known as a congruency effect) provides a measure of the contribution of irrelevant word reading to performance, with greater amounts of word reading leading to larger differences in performance between congruent and incongruent trials (i.e., larger interference). In more general terms, incongruent trials constitute a conflict for the system, and congruency effects reflect the time that the system needs to implement control and resolve the conflict.

Two particular contexts that produce dynamic variation in congruency effects have been used often to study cognitive control. On the one hand, sequential congruent (SC) effects are defined by a reduction in the congruency effect on a current trial when preceded by an incongruent trial compared to when preceded by a congruent trial (Botvinick, et al., 1999; Gratton, et al., 1992; Kerns, et al., 2004; Kunde & Wühr, 2006; Riggio, et al., 2012). On the other hand, proportion congruent (PC) effects are measured by manipulating the relative proportions of congruent and incongruent trials within an experimental block. The magnitude of the congruency effect varies with the proportion of congruent trials, being larger in the context of a high proportion of congruent trials than in the context of a low proportion of congruent trials (e.g., Carter, et al., 2000; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; West & Baylis, 1998).

Some prominent theories have argued that SC and PC effects are the very same process (Blais, et al., 2007; Botvinick, et al., 2001; Verguts & Notebaert, 2008). Specifically, they argue that both SC and PC effects are the result of a single reactive cognitive control system, which first detects and evaluates on-going information for potential response conflict and then resolves that conflict by reinforcing top-down biasing processes associated with the current task set. Thus, it is not surprising to observe a reduction in congruency effects in blocks with a low proportion of congruent trials, as these blocks also have a high proportion of iI transitions (i.e., incongruent trials preceded by incongruent trials). This way, the mechanism that produces the SC effect could also produce the PC effect.

In other words, it is logic that sequential congruent effects produce proportion congruent effects since having a context with high proportion of incongruent trials necessary leads to frequent incongruent-incongruent transitions. However, this does not necessarily lead to the conclusion that PC effects are actually SC effects in disguise. In fact, recent studies in our lab have questioned that argument by showing behavioural dissociations between SC and PC effects within the context of conflict tasks (Funes, et al., 2010b; Torres-Quesada, et al., 2013). For example, Funes et al. (2010b) reported an experiment in which sequential effects were specific to conflict type (they disappeared when conflict type changed between Stroop and Simon across consecutive trials), but PC effects were not specific to conflict type (i.e., PC effects transferred from one conflict type to the other).

The finding that SC effects were conflict type specific in this study has proved to be a quite stable defining property of SC effects, as it has been found consistently across many studies and labs using a variety of different conflict types (for a review see Egner, et al., 2007; Notebaert & Verguts, 2008; Wendt, et al., 2006). In contrast, the conflict type generality of PC effects appears to be less consistent. In fact, under some conditions PC effects have been shown to be item and/or context specific within the same conflict type (Crump, et al., 2006; 2008; Jacoby, et al., 2003). In these studies, proportion congruent is manipulated independently for two sets of stimuli (Jacoby, et al., 2003) or for two contexts (Cañadas, et al., in press; Crump, et al., 2006), such that one set of items or one context is associated with a high (or low) proportion of congruent trials, whereas another set of items or context is associated with a low (or high) proportion of congruent trials. The key result is again larger congruency effects for the items or contexts associated with a high proportion of congruent trials.

In any case, dissociating the two effects on the basis of the way they act under certain conditions (i.e., being either conflict-type specific or general) does not rule out the fact that, in nature, sequential congruent effects might be embedded in proportion congruent effects, with the very same mechanism underlying both. Therefore, in the current paper we looked for a stronger source of evidence which could clearly show that proportion congruent effects ought to be explained by a mechanism different from the mechanism underlying SC effects. Based on the robust finding that SC effects are completely absent on conflict type alternations (Egner, et al., 2007; Funes, et al., 2010a; Wendt, et al., 2006), we investigated whether PC effects are present on conflict type alternation trials, where no SC effects occur. If such a result were to be found, it would constitute a strong piece of evidence that PC effects can be caused by a different mechanism than SC effects.

2.2. Method

2.2.1. Participants

Forty-eight undergraduate psychology students (36 females; 5 left handed) from the University of Granada and McMaster University participated in the experiment. Their ages ranged from 17 to 31 (with a mean age of 20). All had normal or corrected to normal vision, were naive to the purpose of the experiment, and received course credit for participation. The experiment was conducted in accordance with the ethical guidelines laid down by the Department of Experimental Psychology, University of Granada, and the McMaster University Research Ethics Board.

2.2.2. Apparatus and Stimuli

Participants were tested on a Pentium computer running E-prime software (Schneider, et al., 2002a, 2002b), and responded to stimuli presented on a 15-inch color Samsung monitor at a viewing distance of about 57 cm. All the stimuli consisted of white arrows pointing either up or down, and subtending 0.54° of visual angle in width and 1.08° in length. The target could appear in one of four possible locations; left, right, above or below fixation (a plus sign in the centre of the screen). The four target locations were equidistant to fixation (4.32°). Responses were made by pressing either the “v” key (left response) on the keyboard with the index finger of the left hand or the “m” key (right response) with the index finger of the right hand.

2.2.3. Procedure

Participants were instructed to make left/right key presses in response to the up/down direction of an arrow. Half the participants responded to the “up” direction by pressing the letter “v” (left response) with the index finger of their left hand and to the “down” direction by pressing the letter “m” (right response) with the index finger of their right hand. The opposite mapping was used for the other participants. For targets appearing on the vertical axis, that is, above or below fixation, a pure Spatial Stroop effect (i.e., stimulus-stimulus interference) was measured. In contrast, for targets appearing on the horizontal axis, that is, left or right of fixation, a pure Simon effect (i.e., stimulus-response interference) was measured. Within each block, half of the trials were Simon conflict trials and the other half were Spatial Stroop conflict trials. Trials were congruent whenever the arrow location corresponded with the arrow direction (in the case of Spatial Stroop trials) or with the response location (in the case of Simon trials). On the other hand, incongruent trials were defined as those where the arrow location did not correspond with the arrow direction or the response location (for Spatial Stroop and Simon, respectively). The instructions stressed the need to respond as fast as possible while trying to avoid error. Participants were asked to maintain fixation at the centre of the screen before the target was presented.

The sequence of events on each trial was as follows. The fixation point was displayed for 750 ms, after which the target was displayed for 100 ms. Following offset of the target, the fixation point remained alone on the screen until participants’ response or for 1500 ms if there was no response. Auditory feedback (a 500 Hz, 50 ms computer-generated tone) was given on error trials, or on trials in which no response was made within 1500 ms. The inter-trial-interval (ITI) was 1000 ms long. Trials were grouped in blocks and presented randomly within each block. The experiment stopped between blocks. Participants were instructed to rest for a few seconds between blocks, and then resume the experiment by pressing the space bar.

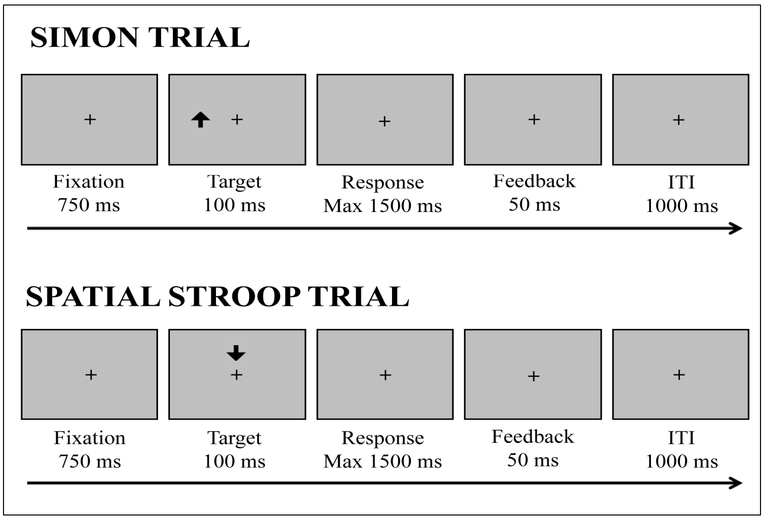

Figure 1. Sequence of events for Simon (top panel) and Stroop (bottom panel) trials. The two types of trials were randomly mixed within each block of trials. On Simon trials targets are presented to the left/right of the fixation cross, whereas on Spatial Stroop trials targets are presented above/below the fixation cross.

2.2.4. Design

The experiment consisted of 16 practice trials (not included in the statistical analysis), followed by 512 experimental trials. There were three within-participants factors: proportion congruent, conflict type, and congruency. Proportion congruent was manipulated within each block and applied only to the Simon trials. In the high proportion congruent condition, 75% of the Simon trials were congruent and 25% were incongruent, while in the low proportion congruent condition, 25% of the Simon trials were congruent and 75% were incongruent. Stroop trials were 50% congruent (and 50% incongruent) in all conditions. Importantly, Simon and Spatial Stroop trials were intermixed within each block of trials, with equal proportions of the two conflict types in each block.

The experimental trials within a block were divided into sequences within which the proportion congruent remained constant, but then proportion congruent varied between these sequences within-subject. We refer to the length of these sequences using the label transition length, and this transition length varied between three groups of participants. For one group, proportion congruent alternated every 32 trials (i.e., every block) from high proportion congruent to low proportion congruent or vice versa. For another group, the proportion congruent alternated every 64 trials (i.e., every two blocks). And for a final group, the proportion congruent alternated every 128 trials (i.e., every four blocks). Ultimately, this variable did not affect performance in any way, and so, although it was included in analyses, it will not be discussed further.

In addition to these variables, we recoded sequential effects offline by creating two additional within-subject variables (previous congruency and conflict type shift). The previous congruency variable was created to code the level of congruency encountered on the previous trial, and took two possible levels, congruent and incongruent. The conflict type shift coded whether the type of conflict encountered on the current trial constituted a repetition or an alternation of the kind of conflict encountered on the previous trial. Conflict type repetition trials consisted of a Spatial Stroop trial followed by another Spatial Stroop trial (both appearing along the vertical axis), or a Simon trial followed by another Simon trial (both appearing along the horizontal axis). Conflict type alternation trials consisted of any Spatial Stroop trial in the vertical axis preceded by a Simon trial in the horizontal axis or vice versa.

2.3. Results

Mean RTs for each condition were calculated after excluding RTs more than 2.5 standard deviations from the overall mean, and RTs on trials in which an error was made. This procedure eliminated 2.3% and 6.6% of the trials, respectively. Furthermore, trials following an error and the first trial of each block were also excluded, which eliminated a further 10% of the trials from the analysis of RTs. For the analysis on error rates, only the first trial of each block and trials following an error were excluded. Separate ANOVAs were carried out to analyse PC effects and SC effects to test our predictions.

2.3.1. SC effects

To analyse SC effects, mean RTs and error rates were submitted to separate ANOVAs that included conflict type shift, previous congruency and congruency as within participant factors, and transition length as a between participants factor. In the analysis of RTs, there was a significant main effect of congruency, $F(1,46)=167.94$, $p<.001$, which interacted with previous congruency, $F(1,46)=87.86$, $p<.001$, revealing the typical sequential congruence pattern. More important, this interaction was modulated by conflict type shift, *F*(1,46)=161.44, p<.001. To analyse this interaction further, separate analyses were conducted for the two conflict type shift conditions. For conflict type repeated trials, the SC effect (i.e., the congruency by previous congruency interaction) was significant, *F*(1,46)=185.55, p<.001, with a 67 ms congruency effect for previous congruent trials and a -8 ms congruency effect for previous incongruent trials. In contrast, for conflict type alternation trials, the SC effect was not significant (F<1), with a congruency effect of approximately 33 ms for both previous congruent and previous incongruent trials (see Figure 2).

In the analysis of error rates, there was also a significant main effect of congruency, *F*(1,46)=50.76, p<.001, with a higher error rate for incongruent trials (.09) than for congruent trials (.05). This effect was modulated by previous congruency, *F*(1,46)=60.88, p<.001, and, as in the RT analysis, this SC effect was also modulated by conflict type shift, *F*(1,46)= 32.22, p<.001. The SC effect was significant for conflict type repeated trials, *F*(1,46)=56.45, p<.001 with .10 and -.01 congruency effects for previous congruent and incongruent trials, respectively. In contrast, the SC effect was not significant for conflict type alternation trials (*F*<1, with a .05 congruency effect for both previous trial types).

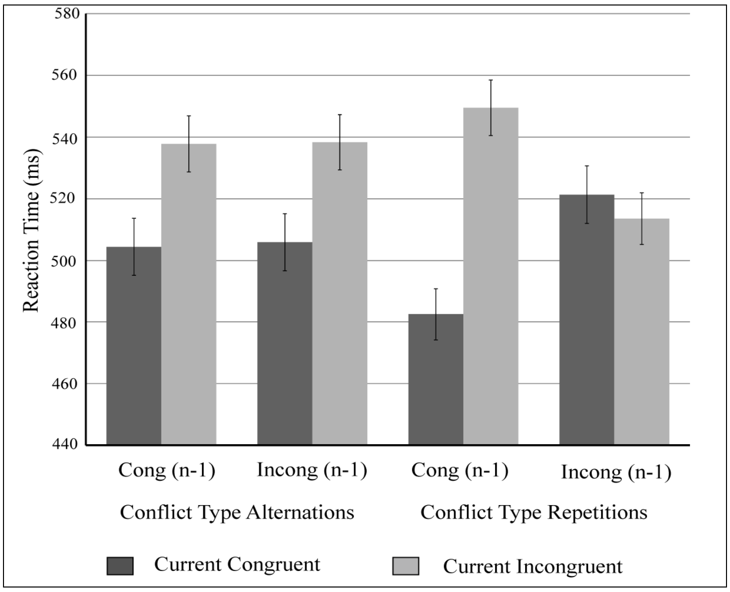

Figure 2. Reaction times for congruent and incongruent trials as a function of previous congruency [previous congruent (cong-1) vs. previous incongruent (incong-1)] and shift of conflict type (alternation or repetition of conflict type across consecutive trials). Note that sequential congruent effects are only observed for conflict type repetition trials.

2.3.2. PC effects in the absence of SC effects.

Next, we examined whether the proportion congruent effect occurred in the absence of SC effects. The ANOVAs included proportion congruent, conflict type and congruency as within participant factors and transition length as a between participants factor. Importantly, we performed these analyses exclusively on conflict-type alternation trials[1], as the above analyses showed clearly that sequential congruent effects are completely absent on these trials (see Figure 3).

In the analysis of RTs, the key finding was a significant interaction between congruency, proportion congruent, and conflict type, *F*(1,44)=16.38, p<.001. Separate analyses for the two conflict types revealed a significant interaction between proportion congruent and congruency for the Simon conflict type, *F*(1,44)=17.86, p<.001, with congruency effects of 48 ms and 23 ms for the high and low proportion congruent conditions, respectively. In contrast, the proportion congruent by congruency interaction was not significant for the Spatial Stroop conflict type, *F*(1,44)=1.54, p=.225, with congruency effects of 28 ms and 35 ms for the high and low proportion congruent conditions, respectively.

The analysis of error rates revealed a similar pattern. There was a significant interaction between congruency, proportion congruent, and conflict type, *F*(1,44)=4.42, p=.04. Separate analyses for the two conflict types revealed a significant congruency by proportion congruent interaction for the Simon conflict type [*F*(1,44)=17.28, p<.001, with congruency effects of .11 and .05 for the high and low proportion congruent conditions, respectively], and a non-significant interaction for the Spatial Stroop conflict type [*F*(1,449=2.83, p=.099, with congruency effects of .04 and .02 for high and low proportion congruent conditions, respectively].

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[1] The same results were found for conflict type repetition trials, but we will not detail them since they were not relevant for our predictions and would therefore be redundant.

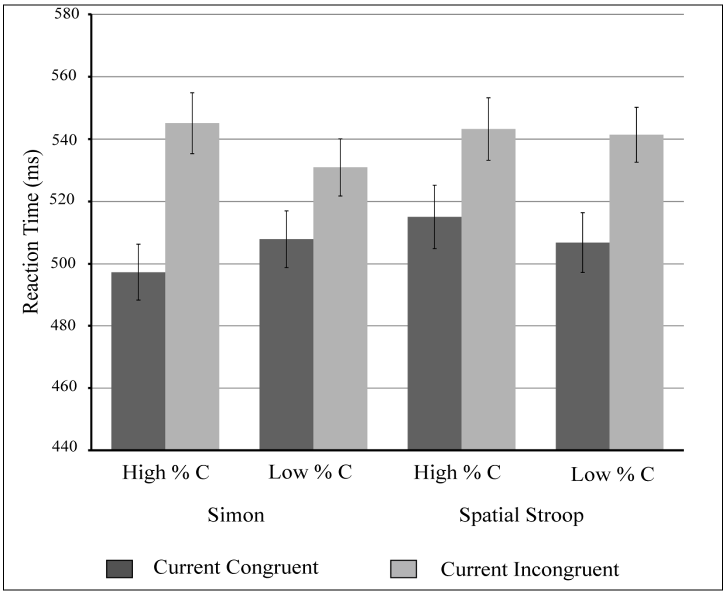

Figure 3. Reaction times for congruent and incongruent trials as a function of proportion congruency [high proportion of congruent trials (high % C) vs. low proportion of congruent trials (low % C)] and conflict type (Simon and Spatial Stroop), and only including in the analysis conflict type alternation trials (where sequential congruent effects are not present). Note that the observed PC effect was specific to the conflict type on which proportion of congruency was manipulated (i.e, Simon trials).

2.4. Discussion

The key research question addressed here was whether PC effects are caused by a different mechanism than SC effects. Our research strategy was to examine PC effects on conflict type alternations, as many prior studies have shown that SC effects disappear when conflict type alternates across consecutive trials (for a review see Egner, et al., 2007; Funes, et al., 2010a; Wendt, et al., 2006). Importantly, PC effects were indeed observed on conflict alternation trials, where no SC effects occurred. In other words, congruency effects measured on the horizontal axis (Simon) trials did not depend at all on whether the previous vertical axis (Stroop) trial was congruent or incongruent. At the same time, congruency effects measured on the horizontal axis (Simon) trials did depend on whether there were a lot or just a few congruent Simon trials in that particular block, even if in the previous trials the target appeared on the vertical axis, thus producing Stroop conflict. The implication is that the local context offered by the immediately preceding vertical axis trial had no influence on congruency effects, while the broader block-wide context offered by other horizontal axis trials did have an impact on performance.

We also observed that this PC effect was specific to conflict type, that is, it occurred only for the Simon conflict type trials for which proportion of congruency was manipulated. Therefore, in contrast to the pattern observed in two other recent studies (Funes, et al., 2010b; Torres-Quesada, et al., 2013), both PC and SC effects in the present study were specific to conflict type. Nonetheless, the conclusion we draw here is similar to that drawn in those prior studies; the two effects must be caused by separate processes. Here, this conclusion follows from the finding that one effect can be observed in the absence of the other.

However, the fact that PC effects are different from SC effects, does not mean that they are independent since the manipulation of the proportion congruent necessarily leads to different sequential congruent situations. Nevertheless, our data clearly show that there are PC effects that cannot be explained by the very same mechanism than SC effects, since they occurred in the absent of SC effects. For that reason, we believe the present procedure and strategy for analysis can be used as a tool to measure pure PC effects. That is, in this paper we provide a procedure to separate PC effects that can be explained by SC effects from PC effects that cannot be explained on the basis of the accumulation of SC effects.

SC effects are commonly interpreted as the result of a reactive control mechanism. Specifically, when conflict is detected (i.e., on incongruent trials) a reactive control mechanism is recruited to implement control. If the preceding trial was also incongruent, the control mechanism would have already been engaged, and there is no need for reactivation, resulting in relatively efficient performance for incongruent-incongruent (iI) transitions (Botvinick, et al., 2001). By contrast, PC effects are often attributed to the adoption of a sustained or proactive strategy or task set, probably implemented after having experienced the level of conflict encountered on the first few trials in a block. This task set is assumed to produce tonic changes in processing by, for example, altering the 'weighting' of word-reading relative to color-naming (e.g. Cohen, et al., 1990).

The Dual Model of Cognitive Control recently proposed by Braver and colleagues (Braver, Gray, & Burgess, 2007; DePisapia & Braver, 2006), is consistent with that view of SC effect as reactive control and PC effects as proactive control. This model suggests that cognitive control consists of at least two sub-systems: a reactive mechanism that is recruited only when needed, that is, once interference is detected, and a second mechanism characterized by the sustained active maintenance of task-set information, allowing the anticipation and prevention of interference before it occurs. Therefore, the present results constitute a novel source of support for a dual conception of cognitive control. In line with the reactive/proactive control distinction in the DMC model of Braver and colleagues (2007), we propose that a proactive form of control in which a task set is sustained across time is responsible for the PC effect observed here, whereas a reactive form of control may be responsible for the SC effect.

No matter whether we entertain the cognitive control account of SC and PC effects presented here, or other different approaches based on memory and learning processes (for a review see Bugg & Crump, 2012; Schmidt, in press), it is important to highlight the critical contribution of the present results: regardless of the nature of the underlying mechanism, PC effects cannot be fully explained by the same mechanism that accounts for SC effects. Therefore, previous approaches suggesting that PC effects are fully explained by SC effects need to be revised. Future research should keep in mind that there can be some PC effects that are a by-product of the accumulation of SC effects, but they are other PC effects that are not, and therefore must be different in nature.

In summary, the present experiment show that proportion congruent effects are observed in the absent of sequential congruency effects, suggesting that different mechanisms must underlie the two effects. We believe that cognitive control theories can account for the present findings but we do not deny that other learning and memory-based mechanisms can also contribute to the explanation of the same data. Therefore, more research is needed to understand the contribution of each mechanism to sequential congruency and proportion congruent effects.

3. Experimental Series III

Proportion Congruent effects in the absence of Sequential Congruent effects: Analyzing their properties

Unpublished work (in preparation).

Torres-Quesada, Lupiáñez, J., Milliken, B. & Funes, M. J.

Abstract:

Proportion congruent (PC) effects are the overall reduction of interference effects when most trials in a block are incongruent. PC effects are usually modulated by the level of proportion of congruency, being larger with extreme differences between high vs. low congruent conditions (e.g.,80% -20%incongruent) than for more intermediate differences (e.g. 60%-40% incongruent) (Logan & Zbofroff, 1979; Blais et al., 2010). However, some authors claimed that both PC effects themselves, and their modulation by the level of proportion of congruency, can be explained in terms of the same reactive cognitive control mechanism that is responsible of Sequential Congruency effects (e.g., Botvinick et al., 2001). In fact, in most previous studies there was a systematic confounding between the level of proportion of congruent trials and the proportion of transitions of incongruent trials followed by incongruent ones. In the present study we ruled out such confounding to directly test whether PC effects can still be measured in the absence of SC effects. Once confirmed, we studied the properties of this pure form of PC effects, whether they act in a conflict-type specific or general manner, and whether PC effects gradually decrease as a function of the specific proportion of congruency that is manipulated (80% vs. 70% vs. 60%). Our results showed significant PC effects in the absence of SC effects, which replicate our previous findings (Torres-Quesada et al., under review), and effect that can be conflict-type general or specific, depending on the nature of conflict type where they were produced, and, importantly, modulated by the level of the proportion congruent manipulation, decreasing as the absolute percentage of incongruent trials decreases.

3.1. Introduction

In the past years, a large body of studies investigates cognitive control processes necessary to allow behavior to adapt flexibly in response to our goals.
To do so, researchers have mostly used interference tasks, where a task-irrelevant dimension of the stimulus is presented together with a task-relevant dimension of the stimulus. The task-irrelevant dimension can be congruent or incongruent with the relevant one, thus facilitating or interfering performance. For example, in the classical Stroop color-naming task (for a review see Macleod, 1991) participants are required to name the colour in which colour words are displayed. In incongruent trials (e.g. the word RED printed in green), where the name of the printed word (task-irrelevant dimension) is incongruent with its color (task-relevant dimension), response times (RTs) are reliably slower and less accurate compared to congruent trials (e.g., the word RED printed in red) where the word and color are congruent. In this task, the conflict created is perceptual since the interference is produced from an overlap between the relevant and the irrelevant dimensions of the stimulus. Differences between performance on incongruent minus congruent trials are called congruency effects. In addition to the Stroop task, many forms of conflicting situations have been extensively used. The Simon task, constitutes an example where the conflict arise between the stimulus irrelevant dimension and the response. Specifically, in that task stimuli appear left or right to the fixation cross and they require a left or right hand response. Conflict arises when the stimulus location and the required response location are opposite or incongruent.

One well known finding regarding congruency effects is that they can be systematically modulated by the relative proportion of congruent and incongruent trials within an experimental block or session. Concretely, the magnitude of the congruency effects is larger in the context of a high proportion of congruent trials than in the context of a low proportion of congruent trials (e.g. Carter, et al., 2000; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; West & Baylis, 1998). This phenomenon is broadly known as Proportion Congruent (PC) effect.

PC effects have been initially interpreted as a reflexion of a sustained or proactive strategy or task set, probably implemented after having experienced the level of conflict encountered on the first few trials in a block. This task set might produce tonic changes in processing by, for example, altering the ‘weighting’ of word-reading relative to color-naming (e.g. Cohen, et al., 1990). However, alternative interpretations have also being proposed. According to the prominent Conflict Monitoring Theory (Botvinick, et al., 2001) PC effects won’t be the reflexion of a proactive or sustained mode of cognitive control, but instead, they can be explained based on transient deflexions of cognitive control across consecutive trials. Thus, PC effects would result from the accumulation of reactive, sequential congruency effects (e.g., Gratton, et al., 1992). Sequential congruency effects are the reduction of congruency effects on the current trial following a previous incongruent trial. Thus, the finding of smaller congruency effects on those blocks with a high proportion of incongruent trials could be explained by the fact that on those conditions, there are many trials preceded by incongruent ones. Finally, a third main explanation of PC effects comes from learning and memory based accounts (i.e., Risko, et al., 2008; Schmidt, in press). According to those theories, PC effects can be explained as learning of connections between a given stimulus and response based on its contingency. For example, the response of an incongruent Stroop-color name word (e.g., the word red written in blue ink) will be better predicted in high incongruent contexts (e.g., when read red the “blue” response will be automatically activated) than in low incongruent ones since in the former the incongruent stimulus is more frequent and its associated response is more trained. Besides, that learning process could also include information about where the stimulus appear (i.e., context) and when (i.e. temporal learning). Therefore, if the high proportion condition is associated to a certain location, the location will predict the more predictive response, leading to faster reaction times.

Much recent research is being done to disentangle between these alternative explanations of PC effects, or at least to catch light about the task conditions that makes each of these potential processes to be the one that most contribute to performance. For example, Funes et al. (2010) directly tested within a single task, whether PC effects and SC effects can be behaviourally dissociated. They showed that when manipulating the proportion of congruency in just one conflict type (i.e. Simon), PC effects transferred from one conflict type to another (Spatial Stroop) on which the proportion of congruency was neutral. However, SC effects behaved the opposite way, that is, they were conflict type specific, as they completely disappeared when conflict type alternated on consecutive trials. On that study, PC effects were interpreted as proactive, able to produce a task-set strategy that, once activated, was applied generally, regardless of conflict type. In another recent study (Torres-Quesada, et al., 2013) we have found further evidence favouring the view that PC effects can be the reflexion of a proactive and sustained mode of cognitive control, since PC effects, due to the manipulation of proportion congruent during a training phase, were transferred to a subsequent phase where the proportion of congruent and incongruent trials was even and where the type of stimuli and conflict type was different. Since PC effects were observed across phases that involved different conflict-types (from Simon to Spatial Stroop) and different contexts (horizontal context to vertical context), this last result is difficult to reconciliate with the idea that PC effects can be totally accounted by a learning-memory process.

Nevertheless, there is also numerous studies showing that PC effects are not always congruent with a general and sustained mode of control (Crump, et al., 2006; 2008; Jacoby, et al., 2003). In this group of studies, proportion congruent is manipulated independently for two sets of stimuli or contexts that are intermixed at random within a block of trials. Critically, if stimulus set or context is not considered the overall proportion of congruent and incongruent trials is kept at .50. However, particular items (Jacoby, et al., 2003) or contexts (Crump, et al., 2006) entail a high (or low) proportion of congruent trials, whereas other items or contexts entail a low (or high) proportion of congruent trials. The key result is again larger congruency effects for the items or contexts associated with a high proportion of congruent trials. As the type of item or context is manipulated randomly from trial to trial, the effect cannot be explained on the basis of a general, sustained, strategic attentional control set. Instead, the effect must be explained by reference to more reactive or online processes initiated at onset of the stimulus that perhaps cue the retrieval of prior memory episodes involving similar items/contexts. Therefore, those arguments would support a reactive view of PC effects.

In summary, the literature reviewed so far shows that the nature of PC effects seems compelling. Thus, on some occasions PC effects behave in a form congruent with a proactive and sustained mode of cognitive control that can generalize across items, contexts and conflict types and transferred to subsequent neutral phases. However, on other occasions PC effects have been also shown to behave specific to items, contexts and conflict types, that is, more congruent with a reactive/learning mode of control. Consequently, the distinction between PC and SC effects based on their ability to generalize or being specific across items, context or conflict types (e.g. Funes et al., 2010), seem not sufficient to test whether both effects tap the very same, partly the same or completely different control mechanisms.

One possibility is that PC effects are usually produced by the joint contribution of several processes. In a recent study we have used an alternative logic to put apart and to dissociate the different processes that might contribute to PC effects (Torres-Quesada, Milliken, Lupiáñez, & Funes, under review). To that end, we aimed at testing whether PC effects can be still measured under the very same conditions where SC effects have systematically proved to be completely absent. Therefore, we hypothesized that if PC effects were only the reflection of the same reactive cognitive control system responsible of SC effects, as suggested by several authors (Blais, et al., 2007; Botvinick, et al., 2001) then PC effects should be completely absent whenever SC are prevented. Apart from replicating our previous work (Funes, et al., 2010a; Funes, et al., 2010b) and showing that SC effects were completely abolished on conflict type alternations, we found that PC effects were still present on the very same conflict type alternation transitions, that is, under conditions were SC were absent (Torres-Quesada, Lupiáñez, Milliken & Funes, under review). A second finding was that the PC effect found on conflict type alternations behaved specific to conflict type, that is, it was only present for the type of conflict on which the PC manipulation was introduced (Simon) but not for the other form of conflict (Spatial Stroop) for which the ratio of congruent to incongruent trials was kept neutral. Thus, even if PC effects behaved specific across conflict types in that experiment (similar to SC effects), they still were present in the absence of SC effects. These last findings seem to conclusively indicate that PC effects cannot be just the reflexion of the same mechanism responsible of SC effects.

The aim of the present study was to replicate and extend this last finding, to better understand the nature of this pure form of PC effects, independent of SC effects. Previous work have shown that PC effects are increased gradually as the difference between high-low proportion congruent manipulation becomes more extreme, that is, PC effects are gradually larger for extreme frequencies of congruency (e.g. when comparing conditions with 80 vs. 20% of congruent trials) than for more intermediate frequencies (i.e., Blais & Bunge, 2010; Logan & Zbrodoff, 1979). However, in all previous studies such frequency effect on PC effects has been always studied on conditions where PC effects could not be dissociated from SC effects. One straightforward question is whether such sensitivity of PC effects to gradually increase with parametrical increases in the proportion of congruent trials would still be present on “pure” measures of PC effects, that is, on those conditions where PC effects can be measured independently of SC effects. Therefore one main manipulation included in the two experiments of the present study was the manipulation of the different percentage of congruent trials across groups ranging from extreme to more intermediate differences between high and low proportion congruent conditions (i.e. 80-20, 70-30 and 60-40 % congruent trials). We will test whether such percentage manipulation can also modulate PC effects in the absence of SC effects.

A second main question of the present research was to further examine the extent to which PC effects can transfer from one conflict type to another, and whether this new measure of pure PC effects (independent from SC effects on conflict alternation trials; Torres-Quesada et al., under review) depends on the degree of transfer across conflict types or whether it is independent of that factor. In all of our previous studies where we combined two conflict types, we have always manipulated the proportion of congruency on Simon conflict while leaving neutral the Stroop conflict. On the other side, we have never studied the generalization of PC effects across conflict types when the proportion of congruency is manipulated on spatial Stroop rather than on Simon. To that end, in experiment 1 the proportion of congruency was manipulated on Simon trials (with 50% congruent on spatial Stroop trials), whereas in experiment 2 the proportion of congruency was manipulated on spatial Stroop trials (while leaving neutral Simon ones). On the one side, this manipulation will allow us to further explore the transfer ability of PC across conflict types in both directions, but also, and more importantly, to test whether pure PC effects, that is, PC effects in the absence of SC effects, are dependent on such transfer ability across conflict types. To that end we will teste whether PC effects transfer across conflicts, and how this transfer is related with the presence of “pure” PC effects.

3.2. Experiment one

3.2.1. Method

3.2.1.1. Participants

A twenty-four undergraduate psychology students from the University of Granada and forty-eight from the McMaster University participated in the experiment (61 females; 9 left handed). Their mean age was 20.61. All of them had normal or corrected to normal vision and were naive as to the purpose of the experiment. They all participated voluntarily and received credits for participation. Informed consent was obtained from all individuals prior to beginning participation in the investigation following guidelines set forth by the Psychology Department of both University of Granada and McMaster University on the Use of Human Subjects.

3.2.1.2. Apparatus and Stimuli

Participants were tested on a Pentium computer running E-prime software (Schneider, Eschman, & Zuccolotto, 2002a, 2002b), and sat in front of the computer screen at a viewing distance of about 57 cm. Stimuli were presented on a 15-inch color Samsung monitor. All the stimuli consisted of white arrows pointing either up or down, and subtending 0.54° of visual angle in width and 1.08° in length. The target could appear in one of four possible locations, at 4.32° away from fixation (a plus sign in the centre of the screen), either to its left, right, above or below it. Responses were made by pressing either the “v” key (left response) on the keyboard with the index finger of the left hand or the “m” key (right response) with the index finger of the right hand.

3.2.1.3. Procedure

Participants were instructed to make left/right key presses in response to the up/down direction of the target arrow. Half the participants responded to the “up” direction by pressing the letter “v” (left response) with the index finger of their left hand and to the “down” direction by pressing the letter “m” (right response) with the index finger of their right hand. The opposite mapping was used for the other participants. For targets appearing on the vertical axis, that is, above or below fixation, a pure Spatial Stroop effect (i.e., Stimulus-Stimulus interference) was measured. In contrast, for targets appearing on the horizontal axis, that is, left or right of fixation, a pure Simon effect (i.e., Stimulus-Response interference) was measured. Within each block half of the trials were Simon conflict trials and the other half were of Spatial Stroop conflict trials. Trials were congruent whenever the arrow location corresponded with the arrow direction (in the case of Spatial Stroop trials) or the arrow location corresponded with the response location (in the case of Simon trials). On the other hand, incongruent trials were defined as those where the arrow location did not correspond with the arrow direction or the response location (for Spatial Stroop and Simon, respectively). The instructions stressed the need to respond as fast as possible while trying to avoid error. Participants were asked to maintain fixation at the centre of the screen before the target was presented.

The sequence of events on each trial was as follows. The fixation point was displayed for 750 ms, after which the target was displayed for 100 ms. Following offset of the target, the fixation point remained alone on the screen until participants' response or for 1500 ms if there was no response. Auditory feedback (a 500 Hz, 50 ms computer-generated tone) was given on error trials, or on trials in which no response was made within 1500 ms. The inter-trial-interval (ITI) was 1000 ms long. Trials were grouped in blocks and presented randomly within each block. The experiment stopped between blocks. Participants were instructed to rest for a few seconds between blocks, and then resume the experiment by pressing the space bar.

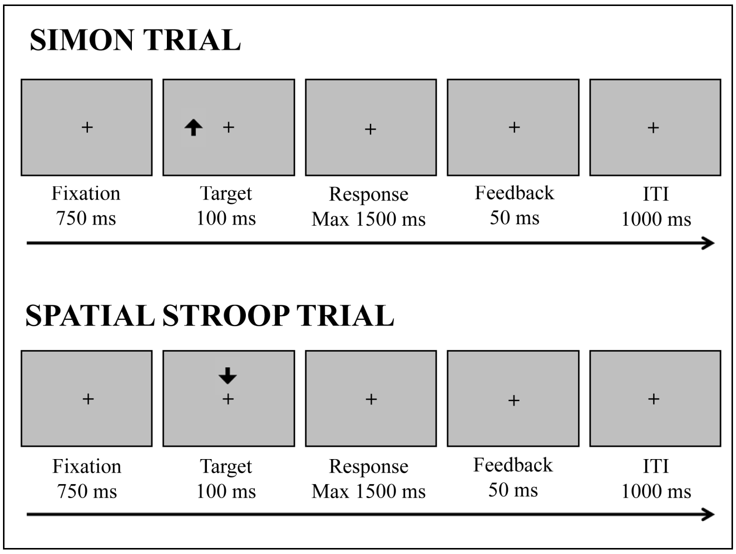

Figure 1. Sequence of events for Simon (top panel) and Stroop (bottom panel) trials. The two types of trials were randomly mixed within each block of trials. On Simon trials targets are presented to the left/right of the fixation cross, whereas on Spatial Stroop trials targets are presented above/below the fixation cross.

3.2.1.4. Design

The experiment consisted of 16 familiarization trials (not included in the statistical analysis), followed by 640 experimental trials. Those experimental trials were divided into 5 different phases: the high and the low proportion congruent manipulation phases were preceded and followed by other neutrally congruent phases in order to reduce strategic carry-over effects between the high and low proportion congruent phases. Concretely, a first neutral block of trials (64 trials), preceded one (either high or low) proportion congruent phase (108 trials), which was followed by a second neutral phase, (128 trials), then a second proportion congruent manipulation phase (180 trials), and finally a third neutral phase (128 trials). The neutral phases were not included in the analysis.

There were 3 within-participants factors: proportion of congruency (high vs. low), conflict type (Simon vs. Spatial Stroop) and congruency (congruent vs. incongruent); and one between participant factors, level of proportion of congruency. Proportion of congruency was manipulated within each block and only for the Simon conflict type, while it was neutral for Spatial Stroop conflict (equal number of congruent and incongruent spatial stroop trials). This factor had two levels: high vs. low proportion congruent levels. The order of high vs. low proportion congruent blocks was counterbalanced across participants, that is, half of them were first exposed with the high proportion of congruency, and the other half received first the low proportion block. Besides, Simon and Spatial Stroop trials were intermixed within each block of trials, being equally represented within each block.

Moreover, there were three proportion of congruency levels: For 1/3 of the participants, proportion of congruency in Simon trials was manipulated in a ratio of 80 to 20. That is, in the high proportion congruent condition, 80% of the Simon trials were congruent and 20% of the trials were incongruent, while in the low proportion congruent condition, 20% of the trials were congruent and 80% of the trials were incongruent. A 70 to 30 ratio of proportion congruent manipulation was applied to another 1/3 of participants and a 60 to 40 one for the last 1/3 of participants (important to note that those percentages were applied to both conflict type being manipulated conditions).

In addition to these variables, we recoded sequential effects offline by creating two additional within-subjects variables (previous congruency and conflict type shift). The previous congruency variable was created to code the level of congruency encountered on the previous trial, and took two possible levels, congruent and incongruent. The conflict type shift coded whether the type of conflict encountered on the current trial constituted a repetition or an alternation of the kind of conflict encountered on the previous trial. Conflict type repetition trials consisted of a Spatial Stroop trial followed by another Spatial Stroop trial (both appearing along the vertical axis), or a Simon trial followed by another Simon trial (both appearing along the horizontal axis). Conflict type alternation trials consisted of any Spatial Stroop in the vertical axis preceded by a Simon trial in the horizontal axis or vice versa.

3.2.2. Results

For the analysis of mean RTs, error trials, trials following an error and the first trial of each block were also excluded, which eliminated 16% of the trials. Besides, trials with RT either shorter or larger than 2.5 standard deviations from the mean were also ruled out from the analysis (3% of trials). For the analysis on error rates the first trial of each block and trials following an error were also ruled out, which constituted 10% of the trials. Besides, we also excluded participants whose error rates were larger than two standard deviations from the mean (a total of 3 participants).

Two ANOVAs were carried out on each dependent variable (mean RTs and error rates), one to analyse PC effects and another to analyse SC effects. For SC effects we included shift of conflict type, previous congruency and congruency as within participant factors. This analysis was done to test whether the specificity of SC across conflict types (the disappearance of SC on conflict type alternation trials) found in previous studies using a similar paradigm was also present in the current experiment. To further test whether PC effects can be measured independently of SC effects, separate ANOVAs were carried out for conflict type alternation trials and for conflict type repetition trials, including proportion congruent, conflict type and congruency as within participant factors, and level of proportion of congruency manipulation as between participant factors.

3.2.2.1. SC effects

For RTs, we found the typical 3-way interaction between shift of conflict type, previous congruency and congruency, F(1,66)=228.34, p<.001, showing a 86 ms significant SC effect when conflict type repeats across consecutive trials (F(1,66)=384.72, p<.001) and a complete absence of SC effect when conflict type alternated (-2ms, F<1 and) (See figure 2).

For error rates, we also found the 3-way interaction between shift of conflict type, previous congruency and congruency, F(1,66)=79.71, p<.001, with a significant SC effect for conflict type repetitions (.12 and F(1,66)=87.45, p<.001) which reversed for conflict type alternations (-.02 and F(1,66)=4.59, p=.036) (Figure 2).

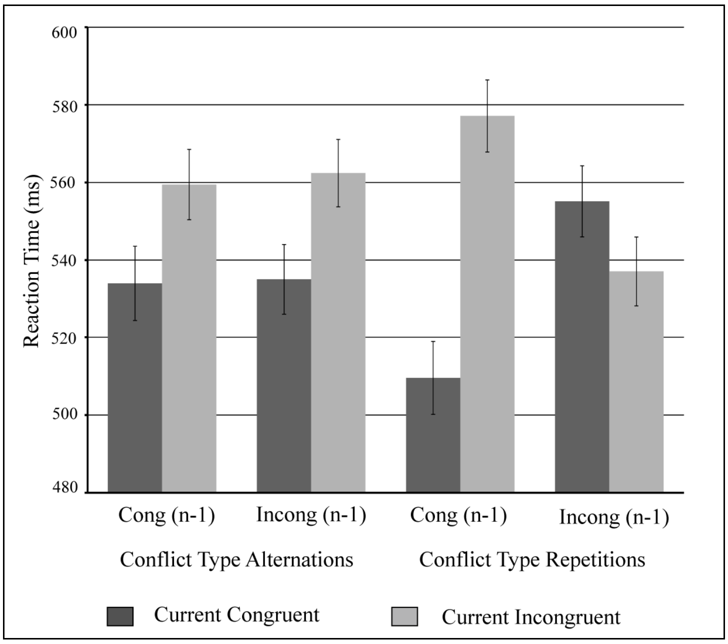

Figure 2. Mean reaction times for congruent and incongruent trials depending on previous congruency and shift of conflict type. Bars represent ±SEM.

3.2.2.2. PC effects

a. PC effects for conflict type repetitions

We found a significant interaction between proportion of congruency, conflict type and congruency, F(1,66)=40.17, p<.001. Specifically, our results showed significant PC effects for Simon trials, F(1,66)=68.64, p<.001, 58 ms) but not for Spatial Stroop trials (F<1 and approximately -3ms). The interaction between proportion of congruency, conflict type, congruency and level of proportion of congruency did not reach significance (F(2,66)=2.02, p=.141). However, as can be seen in Figure 3, PC effects in Simon type of conflict showed a significant linear reduction (F(1,66)=10.70, p=.002) when comparing 80-20 (94 ms), 70-30 (42 ms), and 60-40 condition (39 ms).

Regarding the analysis on error rates, we did find context-specific PC effects for conflict type repetition trials, F(1,66)=27.05, p<.001, with significant PC effects for Simon (.11, F(1,66)=34.43, p<.001) but no for Spatial Stroop (.02, F<1). That interaction was further modulated by level of proportion of congruency (F(2,66)=4.04, p=.022), due to a significant linear modulation of Simon PC effects (F(1,66)=10.44, p=.002) with .20, .07, 06 for 80-20, 70-30 and 60-40 conditions respectively.

b. *PC effects for conflict type alternations.*

We found a significant interaction between proportion of congruency, congruency and conflict type for conflict type alternation trials, F(1,66)=13.05, p<.001, Specifically, our results showed significant PC effects for Simon trials (F(1,66)=19.51, p<.001, 28 ms; but not for Spatial Stroop trials (F<1 and approximately -3ms (See figure 3). We also observed a significant interaction between proportion of congruency, conflict type, congruency and level of proportion of congruency, F(2,66)=3.20, p=.047, indicating a marginally significant linear reduction of PC effects for Simon conflict trials (F(1,66)=3.10, p=.083, with 44ms, 25ms and 17ms for 80-20, 70-30 and 60-40 conditions) but not for Spatial Stroop conflict trials (F<1) (Figure 3).

For error rates, we did not find any significant PC effect (proportion of congruency by congruency interaction F<1), neither modulated by conflict type (F(1,66)=1.23, p=.265).

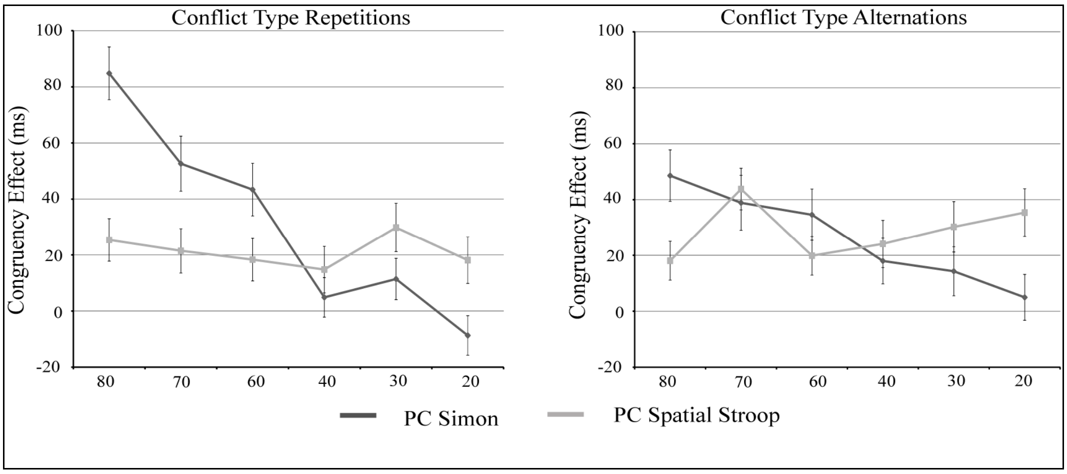

Figure 3. Congruency effects (RTs and SEM bars) as a function of proportion of congruency and conflict type, for conflict type repetitions trials (left pannel) and conflict type alternations trials (right pannel).

3.2.3. Discussion

As explained in the introduction, the first goal of the present research was to further test that PC effects can be present in the absence of SC effects. We first confirmed that SC effects were present when conflict type repeated while they were absent when conflict type alternates, thus replicating previous findings (Akçay & Hazeltine, 2011; Egner, 2008; Funes, et al., 2010a, 2010b; Notebaert & Verguts, 2008; Torres-Quesada, et al., 2013; Verbruggen, et al., 2005). Then, by separately analyzing PC effects on conflict type repetition and alternation trials, we confirmed that PC effects were present on conflict type repetitions (when SC effects were present) but also and more importantly, on conflict type alternations (when SC effects were prevented). In both conditions, PC effects behaved specific to the type of conflict on which the proportion manipulation was implemented, so that they were only obtained for Simon type of conflict trials but not for Spatial Stroop ones. These results replicate our previous work (Torres-Quesada et al., submitted). More important, the present study showed new evidence that these conflict type specific PC effects were modulated by the level of congruency, as they gradually increased with increases in the ratio in percentage of congruent trials. Thus, PC effects were smallest for the 60/40% congruent condition, were increased for the 70/30% condition, while they were the largest for the 80/20% congruent condition. More relevant for the aim of the present study was that such a modulation of PC effects was true even for PC effects found on conflict type alternation trials, that is, on the PC effects on which SC effects were absent. This finding is new and relevant as it shows for the first time that a "pure" form of PC effects is also sensitive to increases in percentage of congruency. As described in the introduction, previous research studying the gradual modulation of PC effects by different ratio in percentage (Blais & Bunge, 2010; Logan & Zbrodoff, 1979) could not dissociate whether such an modulation on PC was due to differences in the ratio of incongruent trials or to differences in the ratio incongruent trials followed by incongruent ones, that is, to SC effects. The process dissociation strategy used in the present experiment allows us to conclude that such a modulation can occur independently of SC effects.

3.3. <u>Experiment two</u>

As described in the introduction, a final aim of the present research was further understand the relationship between "pure" PC effects (those obtained in the absence of

SC effects) and their ability to generalize across conflict types. Until now, we have found that pure PC effects were only found on the type of conflict on which the proportion of congruency manipulation was included, that is, they were conflict type specific (Torres-Quesada, et al., submitted; experiment 1 in the present study). In experiment two we analyze this relationship further, in a situation where the proportion of congruency was manipulated on spatial Stroop trials,

3.3.1. Method

3.3.1.1. Participants

Seventy-two undergraduate psychology students from the University of Granada participated in the experiment (64 females; 11 left handed). Their mean age was 22 years old. All of them had normal or corrected to normal vision and were naive as to the purpose of the experiment. They all participated voluntarily and received credits for participation. Informed consent was obtained from all individuals prior to beginning participation in the investigation following guidelines set forth by the Psychology Department of both University of Granada and McMaster University on the Use of Human Subjects.

3.3.1.2. Procedure and Design

The same than experiment one apart from the conflict type where the proportion of congruency was manipulated. In this experiment the different conditions of proportion of congruency were manipulated on Spatial Stroop trials while for Simon Conflict trials the proportion of congruency was kept at neutral for all conditions.

3.3.2. Results

We applied the same filters than in experiment one. Therefore, for the analysis of mean RTs we excluded a total of 18% trials and for the analysis on error rates a 9% of the trials were excluded. Besides, we also ruled out three participants with error rates above two standard deviations from the mean.

We carried the same analysis than on experiment one, that is, two ANOVAs on RTs and error rates, one for CA effects including shift of conflict type, previous congruency, congruency and percentage of manipulation, and another for PC effects, including proportion of congruency, conflict type, congruency and percentage of manipulation only in conflict type alternation trials.

3.3.2.1. SC effects

For RTs, we again observed the typical 3-way interaction between shift of conflict type, previous congruency and congruency, F(1,66)=77.88, p<.001, showing a 72 ms significant SC effect when conflict type repeats across consecutive trials (F(1,66)=165, p<.001) and a null SC effect when conflict type alternated (F<1 and 3ms) (See figure 4).

For error rates, we found again a 3-way interaction between shift of conflict type, previous congruency and congruency, F(1,66)=38.75, p<.001, with SC effects for conflict type repetitions (.10 and F(1,66)=46.03, p<.001) and a null a SC effect for conflict type alternations (almost 0 and F<1) (Figure 4).

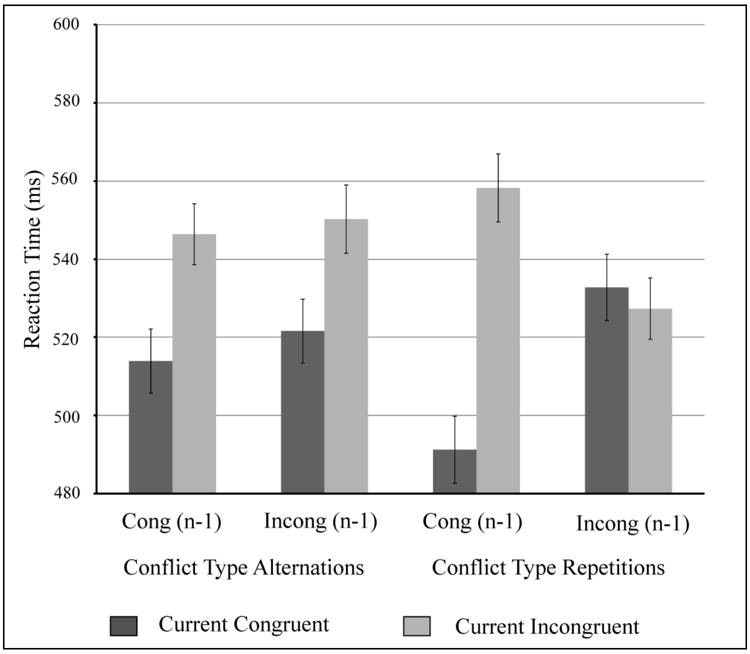

Figure 4. Mean reaction times for congruent and incongruent trials (SEM bars) depending on previous congruency and shift of conflict type.

3.3.2.2. PC effects

a. PC effects for conflict type repetition trials

The results found for conflict type repetition trials mirrored those found in experiment 1. First, we observed conflict-type specific PC effects, given the significant three-way interaction between proportion of congruency, congruency and conflict type, F(1,66)=40.43, p<.001. Thus, significant PC effects were only found for the conflict being manipulated (Spatial Stroop, 28 ms; F(1,66)=80.48, p<.001). Second, as we found in experiment 1, we observed that conflict-type specific PC effects were modulated by the level of proportion of congruency, F(2,66)=3.45, p=.037. Once again, there was a significant linear modulation of PC effects in the conflict being manipulated, F(1,66)=14.03, p<.001, observing 90ms, 55ms and 30 ms for 80-20, 70-30 and 60-40 conditions respectively, and no modulation for the neutral Simon conflict, (F<1).

The analysis on error rates also revealed a conflict-type specific PC effect F(1,66)=9.80, p=.003, with significant PC effects for Spatial Stroop (.05, F(1,66)=11.12, p=.001) but not for Simon (-.02, F<1). That interaction was not further modulated by the level of proportion of congruency (F(2,66)=2.28, p=.11), and PC effects for Spatial Stroop conflict did not change linearly (.09, .02 and .05).

b. PC effects for conflict type alternations

For RTs and conflict type alternation trials, we found a significant interaction between proportion of congruency and congruency, F(1,66)=19.60, p<.001. Interestingly and differently from experiment 1 such interaction was not further modulated by conflict type, F(1,66)=2.28, p=.136, and significant PC effects were obtained for both Spatial Stroop conflict trials (F(1,66)=19.74, p<.001; 27ms), and Simon conflict trials (F(1,66)=5.76, p=.019; 15ms). Finally, and also differently from experiment 1, the interaction between level of proportion of congruency, proportion of congruency, conflict type, and congruency did not achieved significance, F(1,66)=1.64, p=.201). However, separate analysis for each conflict type, showed that PC effects were similar across percentage conditions for Simon conflict (16ms, 16ms and 13 ms, for 80-20, 70-30 and 60-40 conditions respectively), while for Spatial Stroop there was a significant reduction of PC effects from 80-20 to 70-30 condition (F(1,66)=4.44, p=.034) and they kept the same from 70-30 to 60-40 condition (F<1; 47ms, 17ms and 16 ms, for 80-20, 70-30 and 60-40 conditions respectively).

On the analysis of error rates, any interaction reached significance. Thus, we did not find any significant PC effect (proportion of congruency by congruency interaction F<1), neither modulated by conflict type (F(1,66)=1.15, p=.287).

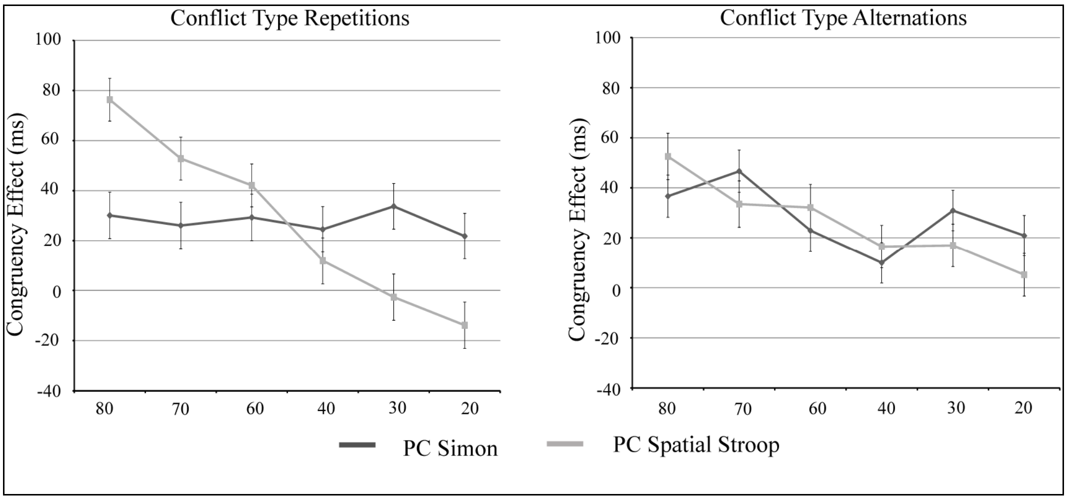

Figure 3. Congruency effects (RTs and SEM bars) as a function of proportion of congruency and conflict type, for conflict type repetitions trials (left pannel) and conflict type alternations trials (right pannel).

3.3.3. Discussion

As in experiment one, we confirmed that SC effects were only observed when conflict type repeated across consecutive trials. Therefore, to study whether PC effects can be present in the absence of SC effects we were interested in observing its occurrence on conflict type alternation trials. The findings of experiment 2 did confirm the existence of this form of “pure” PC effects, that is, PC effects on conditions where SC were absent. However, and differently to what we observed in experiment one, this pure form of PC effect was conflict type general, that is, it was observed for both types of conflict, that is, on Spatial Stroop trials, on which the proportion of congruency manipulation was included (on) but also for the type of conflict for which the proportion of congruency was even (Simon trials). However, for conflict type repetition trials, PC effects were conflict-specific, being present only in the type of conflict manipulated. Second, we tested whether PC effects varied along different percentage manipulation conditions. In both measures of PC effects (those measured together with SC effects and those measured in the absence of SC effects) , we observed that the modulation was confined to the conflict type where the proportion of congruency manipulation took place, that is, for Spatial Stroop type of conflict.

3.4. General Discussion

The main purpose of the present study is to better understand the nature of PC effects. As described in the introduction, different processes have been proposed to be responsible of such effects. Some views have proposed strategic, proactive and sustained cognitive control processes to account for PC effects (e.g., Braver, et al., 2007; Cohen, et al., 1990). Others, based on the confounding between different proportion of congruent trials with different proportion of sequences where incongruent trials are followed by other incongruent ones, have explain them based on more transient or reactive modes of cognitive control, concretely by the same reactive mechanism responsible of sequential congruency effects (SC) (Blais, et al., 2007; Botvinick, et al., 2001). Third, another group of researchers, based on the general confounding between different proportions of congruent trials and different proportion of stimuli and response repetitions, have proposed an alternative explanation of PC effects based on main principles of stimulus and stimulus-response learning and memory retrieval (Risko, et al., 2008; Schmidt, in press; Schmidt & Besner, 2008). However, as described above, the empirical evidence so far is not definitive to disentangle between these and other explanations of PC effects. Consequently more research is still needed to understand the main processes underlying PC effects.

One possibility pointed in the introduction is that PC effects might be caused by multiple processes and that the different requirements of the task at hand might modulate the relative contribution of different processes to PC effects.

In the present study we have followed a main strategy to put apart the different components of PC effects. More concretely we have randomly presented two conflict types (Simon and Spatial Stroop) within the same task, and we manipulated the proportion of congruency in just one of them while keeping it neutral for the other one. Previous results using this general paradigm have systematically showed that SC effects are only present for conflict type repetitions while completely disappeared when conflict alternated from one trial to the next one (Funes et al., 2010a; 2010b; Torres-Quesada et al., 2013,under review).

Based on that finding, the key question was whether PC effects would be present under those conditions where SC effects are systematically absent. This was recently tested in a previous study in our lab (Torres-Quesada et al., under review), thus showing significant PC effect for conflict type alternations. Such finding was interpreted as evidence that PC effects might be composed by other process apart from those responsible of SC effects. With this knowledge in mind the present study had two main aims. The first one was to replicate and extend such a finding, that is, the existence of PC in the absence of SC effect. Along two experiments we separately measured SC and PC effects on conflict type repetitions and on conflict type alternations. Apart from replicating the systematic disappearance of SC on conflict type alternations, PC effects were found both when measured on conflict type repetitions (concurrent with the presence of SC effects) but also, and more importantly, on conflict type alternations (in the absence of SC effects). This was true both in experiment 1, where the proportion of congruency manipulation affected the Simon type of conflict (while spatial Stroop conflict kept neutral) and in experiment 2, where the proportion manipulation affected the spatial Stroop conflict (while Simon conflict kept neutral). This finding constitutes a generalization to previous work, as this “pure” form of PC effects (independent of SC effects) had never been tested before when the proportion of congruency manipulation affected Spatial Stroop type of conflict. Taken together, we conclude that the finding of PC effects in the absence of SC effects is incompatible with those views that consider PC effects as a mere reflection of the same reactive mode of cognitive control responsible of SC effects. Other processes, apart from the ones responsible of SC effects might contribute to PC effects.

Once corroborated the robustness of this “pure” form of PC effects, the second aim of the present study was to better understand its nature. One first question was whether this PC effect obtained on conflict type alternations is general or specific to conflict type. As fully described in the introduction, previous studies using a similar paradigm as the one used here, have shown that on some occasions PC effects can transfer from Simon type of conflict to neutral intermixed Spatial Stroop trials, which can be interpreted as evidence of a proactive cognitive control mechanism (Funes et al., 2010b; Torres-Quesada et al., 2013). However, in our last study (Torres-Quesada, under review) we found PC effects which were specific to conflict type, that is, only present for Simon trials, the type of conflict on which the proportion of congruency manipulation took place. More importantly, in that occasion, pure PC effects (those measured on conflict type alternations) were also conflict type specific. This could indicate that this form of PC effects, being independent from SC effects, also behaves in a conflict-type specific manner.

In the present study we have explored this property of pure PC effects more extensively, by testing the transfer of pure PC effects not only from Simon trials to neutral Spatial Stroop ones (experiment 1), but also from Spatial Stroop trials to neutral Simon ones (experiment 2). Our data showed that PC effects measured on conflict type repetitions (where SC effects were present) were always specific to conflict type, that is, they were only found on the type of conflict on which the proportion manipulation took place.

This finding seem not surprising since, as we have previously said, PC effects measured on that condition might be mainly triggered by the mechanism responsible of SC effects, which are highly conflict-type specific. However, pure PC effects (on conflict type alternations, free of SC effects) behaved quite differently; they behaved conflict-type specific in experiment 1, that is, they were only found for Simon trials where the proportion of congruency manipulation took place, thus replicating our previous findings. However they behaved conflict-type general in experiment 2, that is, PC effects were present not only for Spatial Stroop trials but also for neutral Simon ones. This asymmetry in the ability to generalize from Stroop to Simon but not from Simon to Spatial Stroop, seem quite interesting. One potential explanation might come from the differences in the nature of the dimensional overlap that take place in Simon vs. Spatial Stroop. Thus, Simon is a conflict taking place at the level of the response (response conflict), therefore, its control resolution act at the level of response by inhibiting incompatible responses automatically active by task-irrelevant information. By contrary, Spatial Stroop conflict take place at an earlier perceptual stage of processing, and act over that stimuli processing by enhancing task-relevant information (Soutschek, et al., 2013). Since in our study Simon and Spatial Stroop share the same task-relevant information, when that strategy is enhanced as the result of PC manipulations on Spatial Stroop stimuli Simon conflict trials might be also benefited from that. However, the two forms of conflict do not share the automatic response capture by task-irrelevant information at the level of the response, therefore, applying control at that level to respond to the proportion of congruency manipulation applied on Simon, might not have large benefits to solve Spatial Stroop trials. Of course, more research is still needed to elucidate the conditions that facilitate or prevent transfer of PC effects across different types of conflicting situations.

Nevertheless, one main conclusion that can be made from the present result is that it might constitute an additional dissociation regarding the nature of SC and PC effects. Meanwhile SC effects behaved conflict-type specific in a systematic manner, pure PC effects sometimes behave specific while sometimes were able to transfer across conflict types.

Finally, a second question regarding the nature of this pure form of PC effects in this study was whether they would be modulated by the level of percentage of congruency effects. According to previous studies, PC effects are systematically modulated by the actual level of proportion of congruent trials (e.g. Blais et al., 2010; Logan & Zbrodoff, 1979). However, as discussed in the introduction in those studies SC effects were again confounded with PC effects, making difficult to rule out the possibility that such an effect was due to a the reduction of the overall SC effects within each condition. Therefore, the finding of a larger PC effects on a 80% vs.20% incongruent condition compared to a 60%-40% one, would be explain for a larger presence of incongruent followed by incongruent transitions, compared to a condition with 60% of incongruent trials.

With the process dissociation strategy proposed in this study we have dissociated whether pure measures of PC effects (free from sequential effects) are also sensitive to the level of proportion of congruency. To test that we presented different percentage manipulations across different groups going from extreme percentage conditions like 80-20 to more intermediate ones such as 70-30 and 60-40 percentage. Our results showed that the PC effects modulation across proportion congruent levels can take place even when controlling for SC effects, that is, they modulated PC effects not only on the conflict type repetition condition but also when conflict types alternated. It is true that such an effect was stronger on experiment 1, than in experiment 2. However, an interesting common result found in both experiments is that such modulation of PC effects by the level of percentage of congruent trials was only observed for the type of conflict for which the manipulation took place. As can be observed in figure 5, the linear reduction of PC effects with the reduction of congruency percentage only took place for Simon trials in experiment 1 and for Stroop trials in experiment 2, indicating that this kind of manipulation cannot transfer across conflict types.

To conclude, in the present study we tested whether PC effects can be independent from SC effects, by showing PC effects in the absence of SC effects. Second, we study the nature of such pure form of PC effects. We found that meanwhile SC effects were always conflict type specific, PC effects were able to generalize across conflict types on certain conditions. Finally we also found that the level of proportion of congruency could modulate this “pure” form of PC effects (in the absence of SC effects). Altogether, the present study provides relevant evidence showing that PC effects are a complex phenomenon that probably depend on different mechanisms and cannot be explained exclusively based on the same reactive cognitive control mechanism responsible of SC effects.

4. Experimental Series IV

A process-specific approach in the study of normal aging deficits on cognitive control: what does deteriorate with age?

Unpublished work (in preparation.)

Torres-Quesada, M., Lupiáñez, J., Ródenas, E. & Funes, M.J.

Abstract:

It is well known that cognitive control deteriorates with age as previous studies have suggested by showing increased congruency effects on older adults when performing interference tasks such as the color-naming Stroop task (e.g., Belleville, Rouleau, & van der Linden, 2006; Rush, Barch, & Braver, 2006). However, cognitive control is a complex function that includes several processes. Then, what does exactly deteriorate with age? Controversial results have been found when elucidating which process deficits underlie general increased congruency effect (e.g., Nessler, Friedman, Johnson, & Bersick, 2007; West & Alain, 2000). One possible reason is that the contribution of those processes to cognitive control deterioration has been done separately, that is, without testing all the processes within the same paradigm. Therefore, the main goal of the present experiment was the study of normal aging impact on several measures of related with cognitive control in the same talk. We focused on the following processes: automatic response capture by irrelevant-information, which actually creates the conflict that will have to be resolved; conflict detection; and control implementation (reactive control both within trial and across trials, and proactive control, as a task-set strategy). Our results showed larger automatic response capture effects when facing a stimulus-response conflict (Simon) but not for stimulus-stimulus conflict (Spatial Stroop). Similarly, older adults also showed larger detection effects for both conflicts. However, for control implementation, they only showed difficulties on inhibiting the early automatic response capture (reactive within control trials), but not on neither reactive control across trials nor proactive control. In conclusion, it seems that older adults are more vulnerable to irrelevant information, especially when it affected stimulus-response conflict type. However, they seem spared in their ability to implement cognitive control both across trials and as a task-set strategy.

4.1. Introduction

The fact that executive functions decrease with normal aging is well established in the literature (i.e., Band, Ridderinkhof, & Segalowitz, 2002; Braver, et al., 2001). It is also well known that the term *executive function* includes several cognitive processes, which have their own particular dynamic, functioning, and components (Diamond, 2013). Thus, an approach based on general cognitive deficits (i.e., decreased on information processing; Salthouse, 1996; Salthouse & Babcock, 1991) without differentiating process-specific deficits can give an uncompleted picture of how exactly executive functions decline with aging (Verhaeghen, Cerella, & Basak, 2006).

Within executive functions, cognitive control is one key part that plays a crucial role in our daily life. Specifically, it allows us to carry out any wished action by maintaining the action goal, enhancing the relevant information and inhibiting irrelevant information present in the environment. Besides, cognitive control is also composed by more than one process. According to top-down control models (i.e., Botvinick, et al., 2001; Botvinick, et al., 1999) several processes can be differentiated in cognitive control: at least a) conflict detection and monitoring processes which evaluate ongoing information, detect conflict and send the information for recruiting control; and b) control processes in charge of implementing control.

In the laboratory, cognitive control processes have been studied using interference tasks such as the classical Stroop color-word task, in which participants have to name the ink color of a word while ignoring its meaning (e.g., red written in green). When the ink color and the word match (congruent trials), responses are fast. By contrary, when the ink color and the word do not match (incongruent trials) responses slow down. That happens because task-irrelevant and task-relevant information active incompatible responses, therefore, the system needs time to select the appropriate response among the incompatible ones. The difference between congruent and incongruent trials is called congruency effect and reflects, on correct trials, the time that the system needs to overcome the conflict produced by the overlapping between the task-relevant and irrelevant dimension of the stimulus, leading to opposite responses.

Other interference tasks used to study cognitive control processes are the Simon, Spatial Stroop or Flanker tasks. In the Simon task participants have to response to a certain dimension of a given stimulus with the left or right hand. Crucially, the stimulus can be displayed left or right to a centered fixation cross, causing interference when both location and response hand do not match, in spite of stimulus location being completely irrelevant for the task. In the Spatial Stroop task an arrow (or a word denoting a location) can appear above or below fixation, pointing up or down. In this task, interference arises when the direction (or meaning) and the location of the arrow mismatch (e.g., an arrow pointing down appears above fixation). Finally, in the flanker task participants have to response to a central target flanked by distracters. Once more, the interference arise when the target and the flankers do not active the same responses (e.g., the target has to be responded with the left hand and distracters elicit the right hand response). Importantly, the different interference tasks do not share the same dimensional overlap from which interference arises. Thus, for example, the Simon task involves the overlapping of an irrelevant stimulus feature and response location whereas the Spatial Stroop task involves the overlapping between relevant and irrelevant stimulus features, as highlighted by Kornblum in his taxanomy (Kornblum, et al., 1990).

Any reduction of congruency effects in any of these tasks is interpreted as the result of the allocation of control since the impact of conflict is reduced. There are two laboratory manipulations that lead to effects consisting in such reduction on congruency effects: sequential congruent (SC) and proportion congruent (PC) effects. In the first case, the congruency effect is reduced on the current trial after facing an incongruent trial as compared to the situation where the previous trial is congruent. That is explained by a conflict adaptation mechanism that enhances task-relevant information after encountering conflict in the previous trial. If the current trial is also incongruent, the conflict between task-relevant and irrelevant information is weaker since the processing of task-irrelevant information is reduced due to the focusing of attention on the relevant information. Several studies have shown that those effects are specific to conflict type, that is, they only occur when conflict type repeats across consecutive trials but they disappear when conflict type alternates (Akçay & Hazeltine, 2011; Egner, et al., 2007; Funes, et al., 2010a, 2010b; Notebaert & Verguts, 2008; Torres-Quesada, et al., 2013; Verbruggen, et al., 2005, Experiment 2; Wendt, et al., 2006).

On the other hand, PC effects are observed in contexts where the proportion of congruent and incongruent trials is manipulated, in a way that high proportion congruent contexts, in which congruent trials are highly frequent, lead to rely on automatic processes not differentiating between relevant and irrelevant information, resulting in fast responses for congruent trials but very slow responses for incongruent trials. As a result, large congruency effects are observed. By contrary, in low proportion congruent contexts, where incongruent trials are highly frequent, attention is constantly biased toward task-relevant information, resulting in not much benefit on congruent trials and reduced conflict experienced on incongruent trials, which lead to an overall reduction on congruency effects.

Although in principle PC can be theoretically considered as different from SC effects, they could likely arise from the accumulation of SC effects. In fact, cognitive control models have interpreted PC effects as the results of SC effects (Botvinick, et al., 2001; 1999), focusing on the fact that in contexts where incongruent trials are frequent (high conflict contexts), they are also frequent in the previous trials, and therefore incongruent-incongruent transitions are most common. Therefore, the overall reduction on congruency effects might be simply the sum of all the SC effects that have taken place within the high conflict context. However, recent studies have dissociated PC and SC effects, by showing that, while SC effects are typically specific to conflict type, PC effects can be general to conflict type (Funes, et al., 2010b; Torres-Quesada, et al., 2013). More importantly, a previous work in our lab showed PC effects in the absent of SC effects (Torres-Quesada, Milliken, Lupiáñez, & Funes,under review). We created a paradigm in which two conflict types are randomly intermixed within a block (i.e., Simon and Spatial Stroop) and the proportion of congruency is manipulated in only one of them (e.g., Simon). Then, the existence of pure PC effects can be tested on trials where conflict type alternates across consecutive trials, because, as it has been extensively proved, SC effects are absent in those trials. If PC effects are observed under those conditions, then they cannot be explained by the accumulation of SC effects.

Importantly, once dissociated, PC and SC effects have been proposed to reflect two different cognitive control mechanisms: one reactive, which acts at the same time of response, therefore, after stimulus onset, and one proactive that allows preparation for conflict resolution before response, therefore, before stimulus onset (Braver, et al., 2007; Torres-Quesada, et al., 2013). Based on that conception, SC effects can be defined as carry-over effects of reactive control processes (reactive processes itself is the correct conflict resolution within the trial) while PC effects reflect proactive control processes.

Because of that hierarchical organization of processes and sub-processes, when studying age-related deficits it is really important to differentiate between the different processes and specify which one is affected and to which degree. In this line, several experiments have been carried out to study process-specific deficits on normal aging, going beyond the general larger interference (i.e., larger congruency effects) typically observed in older adults (i.e., Andrés, Guerrini, Phillips, & Perfect, 2008; Belleville, Rouleau, & van der Linden, 2006; Rush, Barch, & Braver, 2006). For example, some ERPs studies have found age-related deficits on conflict detection and monitoring processes, but not on control implementation (i.e., Eppinger, Kray, Mecklinger, & John, 2007; R. West & Alain, 2000). By contrary, other studies have observed intact conflict detection but impaired control implementation (i. e., Nessler, Friedman, Johnson, & Bersick, 2007; Sharp, Scott, Mehta, & Wise, 2006). More specifically, other studies have tried to tease apart whether the problem in control implementation might depend on the type of cognitive control mechanism, finding a larger tendency in older adults to rely on reactive rather than proactive mechanisms (Braver & West, 2008; Czernochowski, et al., 2010). Nevertheless, other studies that have used SC effects as reflections of reactive control mechanisms, have not found age-related differences (Puccioni & Vallesi, 2012; West & Moore, 2005). From this variety of results, one can conclude that the frame of cognitive control normal aging is quite complex and general conclusions are difficult to be drawn, being necessary an attempt to put all the results together in order to get a big picture of how cognitive control is affected by age. This is the general goal of the present paper.

With this aim in mind, in the present experiment we tested whether normal aging affects cognitive control and, more importantly, which specific process or processes are affected. To do so, two groups (older and younger adults) performed a task where two conflict types were presented (Simon and Spatial Stroop), and the proportion of congruency was manipulated in one of them. This procedure allows the measurement of three processes involved in cognitive control: task-related information processing; detection of conflict; and control implementation. Any differences on those processes between groups will indicate age differences in cognitive control but their implications will be different depending on the process being affected.

In the *processing of task-related information*, one can distinguish between task-relevant and task-irrelevant information processing. The former is voluntary, since it is necessary for a successful performance. However, the latter is unwished and involuntary, since it can interfere with performance. Therefore, attention is selectively biased toward task-relevant information for its processing while attention is involuntary captured by task-irrelevant information. Due to these voluntary and involuntary attentional processes, more than one response are active, resulting in several incompatible response options. As it has been explained, that situation causes conflict. One would expect that conflict strength will vary as a function of the magnitude of the task-relevant or task-irrelevant processing. Thus, if task-relevant is enhanced, the processing of task-irrelevant information will have less impact. Similarly, when task-irrelevant is inhibited, there is nothing that could interfere with the response associated to the task-relevant information. Although those are considered selective attention processes, rather than part of the cognitive control function per se, they are indirectly related to it, since the conflict to be resolved by applying control depend on the overlapping between those sources of information (see Funes, Lupiáñez, & Milliken, 2008).

To study task-related information processing, we specifically tested whether task-irrelevant information processing was stronger than task-relevant information, i.e., whether attentional capture by the irrelevant information was larger than the selective attention toward the relevant information. This situation would be reflected on larger congruency effects right after stimulus presentation since irrelevant information processing will lead to fast errors on incongruent trials and fast correct responses on congruent trials. With this purpose, we used the activation-suppression model (Ridderinkhof, 2002). According to it, congruency effects can be explained by the existence of both an early automatic response capture toward irrelevant information (reflected, as we have just explained, on larger early congruency effects) and a later controlled suppression mechanism (that allows the suppression of irrelevant information and, in turn, favors the processing of task-relevant information, resulting on a reduction of congruency effects as a function of response speed since that suppression mechanism needs time to build-up). The activation-suppression model uses distributional analysis of congruency effects to expose their dynamics, which would be masked otherwise by overall measures of mean interference effects.

The second process we wanted to study was *conflict detection and conflict monitoring*, in charge of evaluating information processing and detecting conflict, so that once conflict is detected a signal for control recruitment is created. For testing this process, we used the different sequences of congruent and incongruent trials. As explained above, encountering an incongruent trial produce the bias of attention toward relevant information; hence, the benefit of congruent irrelevant information will be smaller for the following trial. Similarly, encountering a congruent trial relax the system allowing to rely on task-irrelevant information. Therefore, if the following trial is incongruent, the conflict experience will be larger compared to when the previous trials is incongruent. With this idea in mind, we focused on incongruent trials in high conflict situations, that is, on incongruent trials preceded by congruent trials.

The last process to be studied was *control implementation*, a process in charge of applying different strategies to resolve conflict. Following previous literature we differentiated between two control implementation processes, reactive and proactive mechanisms (Braver, et al., 2007; Funes, et al., 2010b; Torres-Quesada, et al., 2013). The difference between them is their temporal dynamic, thus, reactive control is applied after stimulus onset whereas proactive control acts before stimulus onset. Moreover, we also distinguish between reactive control applied within the same trial (that is, after stimulus onset) and reactive control applied across trials (as a kind of a carry-over effect found when reactive control has been recently implemented in the previous trials).

For reactive control within the same trial, we focused again on the activation-suppression model but on the selective suppression part, since it reflects how conflict is reactively resolved within the trial by suppressing initial response capture. For reactive control across trials we focused on sequential congruent effects. As it has been explained beforehand, SC effects are the benefit observed on incongruent trials when the previous trial is also incongruent. Finally, to study proactive control we used proportion congruent (PC) effects, which are observed on contexts where conflict is frequent (high proportion of incongruent trials) compared to contexts where it is rare (low proportion of incongruent trials). However, in order to exclude the contribution of SC effects in these analyses, we analyzed PC effects exclusively on trials where conflict type alternated (where no SC effects are observed) (Torres-Quesada, et al., submitted).

In summary, we tested how cognitive control declines with age by studying age-related deficits on each of the processes involved in cognitive control. To do so, we studied the performance of two groups (older and younger adults) in an interference task developed in a way that allow us to measure: task-irrelevant processing by looking at congruency effects at fast responses (which will indicate the strength of automatic response capture by irrelevant information); detection of conflict by looking at the conflict registered after congruent trials; and control implementation. In the latter we will study three different control adjustments: a reactive mechanism understood as the suppression of the irrelevant information within the same trial, hence, reflected on slower responses; a second reactive one across trials, measured by the reduction of congruency effects after an incongruent trials; and proactive control measure as the reduction of congruency effects when incongruent trials are frequent. Any differences on those processes between groups will indicate age differences in cognitive control but their implications will be different depending on the process being affected.

4.2. Method

4.2.1. Participants

Thirty-eight older adults recruited through Birmingham University (12; 5 females; 1 left handed) and University of Granada (20; 11 females; all right handed) participated in the study. Possible neuropsychogical deficits were controlled. Their ages ranged from 57 to 75 (with a mean age of 67.39 years). Besides, thirty-eight younger adults (23 females; 2 left handed) participated in the experiment, with a mean age of 24.5 years.

All participants had normal or corrected to normal vision, were naive as to the purpose of the experiment, and gave written consent following the ethics for human subject research of the Experimental Psychology department of University of Granada and School of Psychology of Birmingham University. Both committees guaranteed the fulfilment of the Helsinki Declaration for human experimentation.

4.2.2. Apparatus, Task and Procedure

Participants were tested on a Pentium computer running E-prime software (Schneider, Eschman, & Zuccolotto, 2002a, 2002b), and responded to stimuli presented on a 15-inch color Samsung monitor at a viewing distance of about 57 cm. All the stimuli consisted of white arrows pointing either up or down, and subtending 0.54° of visual angle in width and 1.08° in length. The target could appear in one of four possible locations; left, right, above or below fixation (a plus sign in the centre of the screen). The four target locations were equidistant to fixation (4.32°). Responses were made by pressing either the “v” key (left response) on the keyboard with the index finger of the left hand or the “m” key (right response) with the index finger of the right hand.

Participants were instructed to make left/right key presses in response to the up/down direction of an arrow. Half the participants responded to the “up” direction by pressing the letter “v” (left response) with the index finger of their left hand and to the “down” direction by pressing the letter “m” (right response) with the index finger of their right hand. The opposite mapping was used for the other participants. For targets appearing on the vertical axis, that is, above or below fixation, a pure Spatial Stroop effect (i.e., stimulus-stimulus interference) was measured. In contrast, for targets appearing on the horizontal axis, that is, left or right of fixation, a pure Simon effect (i.e., stimulus-response interference) was measured. Within each block, half of the trials were Simon conflict trials and the other half were Spatial Stroop conflict trials. Trials were congruent whenever the arrow location corresponded with the arrow direction (in the case of Spatial Stroop trials) or with the response location (in the case of Simon trials). On the other hand, incongruent trials were defined as those where the arrow location did not correspond with the arrow direction or the response location (for Spatial Stroop and Simon, respectively). The instructions stressed the need to respond as fast as possible while trying to avoid errors. Participants were asked to maintain fixation at the centre of the screen before the target was presented.

The sequence of events on each trial was as follows. The fixation point was displayed for 750 ms, after which the target was displayed for 200 ms. Following offset of the target, the fixation point remained alone on the screen until participants’ response or for 2000 ms if no response was given. Auditory feedback (a 500 Hz, 50 ms computer-generated tone) was given on error trials, or on trials in which no response was made within 2000 ms. The inter-trial-interval (ITI) was 1500 ms long. Trials were grouped in blocks and presented randomly within each block. The experiment stopped between blocks. Participants were instructed to rest for a few seconds between blocks, and then resume the experiment by pressing the space bar.

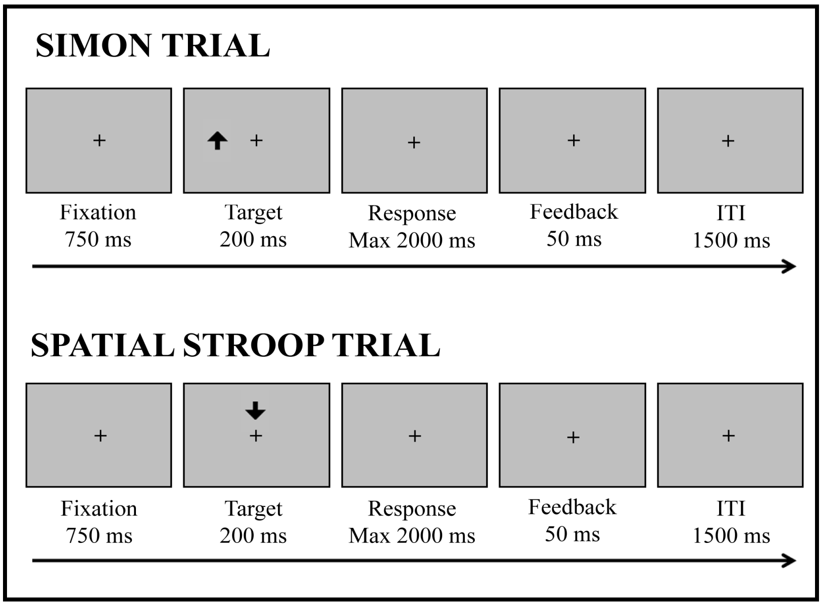

Figure 1. Sequence of events for Simon (top panel) and Stroop (bottom panel) trials. The two types of trials were randomly mixed within each block of trials. On Simon trials targets are presented to the left/right of the fixation cross, whereas on Spatial Stroop trials targets are presented above/below the fixation cross.

The experiment consisted of 32 practice trials (not included in the statistical analysis), followed by 512 experimental trials. There were three within-participants factors: proportion congruency, conflict type, and congruency; and one between-participant factor: age group (older versus younger adults). Proportion congruency was manipulated within each block (changing between high and low proportion congruent on alternating blocks) but only for on conflict type (for the other always being 50% congruent). The proportion of congruency alternated between high and low across blocks, counterbalancing the starting condition (high or low) across subjects. Besides, the conflict where proportion congruent alternated between high and low was manipulated between participants. For some participants Simon was manipulated and Spatial Stroop was always 50% neutral and for other participants Stroop was manipulated and Simon was always 50% congruent[2]. Therefore, in the high proportion congruent condition, 75% of the manipulated conflict trials were congruent and 25% were incongruent, while in the low proportion congruent condition, 25% of the manipulated conflict trials were congruent and 75% were incongruent. By contrary, the non-manipulated conflict trials were 50% congruent (and 50% incongruent) in all conditions. Importantly, Simon and Spatial Stroop trials were intermixed within each block of trials, with equal proportions of the two conflict types in each block.

In addition to these variables, we recoded sequential effects offline by creating two additional within-subject variables (previous congruency and conflict type shift). The previous congruency variable was created to code the level of congruency encountered on the previous trial, and took two possible levels, congruent and incongruent. The conflict type shift coded whether the type of conflict encountered on the current trial constituted a repetition or an alternation of the kind of conflict encountered on the previous trial. Conflict type repetition trials consisted of a Spatial Stroop trial followed by another Spatial Stroop trial (i.e., both appearing along the vertical axis), or a Simon trial followed by another Simon trial (i.e., both appearing along the horizontal axis). Conflict type alternation trials consisted of any Spatial Stroop trial in the vertical axis preceded by a Simon trial in the horizontal axis or vice versa.

4.2.3. Data Analysis

Different filters were applied depending on the kind of analysis to be performed. For standard ANOVAs on RTs analysis, errors, trials after an error and first trial of each block were excluded (16.26%). From the remained trials, RTs above or below 2.5 standard deviations from the overall mean for each participant were also ruled out (2.46%). On the other hand, for error rates analysis, just post error trials and the first trial of each block were eliminated (10.73%). Besides, subjects with a mean error rate above 2.5 standard deviation from the mean of the group were excluded, leaving apart only one older adult subject. For the distributional RT analysis, we only eliminated the error, post error trials and first trial of each block, and for the distributional error rate

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[2] Originally, the two conditions, where the proportion of congruent trials was manipulated for Simon and not for Stroop or vice versa, were run as separate experiments. However, for the sake of simplicity and since no big differences were observed between experiments, we included this factor as a between participants variable in the same general analysis.

analysis, similarly to the standard analysis, we only ruled out post error trials and the first trial of each block. Those filters were applied after computing bins. Besides, for the distributional analysis we had to exclude two subjects due to empty cells on some conditions.

4.2.4. Design

As it has been mentioned in the previous section, we used a complex paradigm that allows us to tease apart several processes. Thus, by selecting which factors will be included in the analysis, we were able to extract the conditions implicated in the process we wanted to study. Therefore, the analysis performed was completely guided by our theoretical approach.

In sum, we divided our analysis and predictions on five results sections: 1) *congruency effects,* to study general age-related interference effects (both on RTs and error rates); 2) *task-irrelevant capture,* based on distributional analysis on error rates depending on response speed to study automatic response capture; 3) *sequential congruent effects* (both on RTs and error rates) to study *conflict detection* (congruency effects preceded by congruent trials) and *reactive control implementation across trials* (congruency effects preceded by incongruent trials); 4) *reactive control within trial,* based on distributional analysis on RTs to study selective suppression; and 5) *pure proportion congruent effects* (both on RTs and error rates) to study proactive control.

For the distributional analysis for analysis 2 and 4 we computed five bins per subject per condition, that is, we ordered reaction times from fastest to slowest for each subject and for each factorial combination of conflict type and congruency, and divided them in 5 different bins.

4.3. <u>Results</u>

4.3.1. Congruency effects

To study general differences between older and younger adults on congruency effects, which will indicate that a sub-cognitive control process is altered, we performed a mixed ANOVA including Conflict type, Congruency, Age group and Manipulated conflict, with the last two variables as between participants factors.

For RTs, a main effect of Age group, F(1,61)=62.61, p<.001, indicating slower reaction times for older (659 ms) than for younger adults (510 ms). As expected, we observed a

Congruency by Age group interaction, F(1,61)=18.91, p<.001, with larger interference effects for the older adult group (57 ms) compared to the younger adult group (30 ms). Moreover, this interaction was modulated by Conflict type, F(1,61)=9.93, p=.003. Planned comparisons showed that differences between Age groups were larger for Simon conflict (F(1,61)=21.83, p<.001 and 39 ms) than for Spatial Stroop conflict (F(1,65)=4.94, p=.03 and 15 ms), although it was significant in both cases. Interestingly, those differences between groups varied depending on the Manipulated conflict (F(1,61)=5.42, p=.023). Thus, they were confined to the condition where Spatial Stroop was manipulated since planned comparisons in that condition showed a significant interaction (F(1,61)=18.82, p<.001) between Conflict type, Congruency and Age group, but no when Simon was manipulated (F<1) [3].

For error rates, no main groups differences were found (F(1,61)=2.28, p=.136). However, mirroring RTs, we did observed a Congruency x Age group interaction, F(1,61)=7.10, p=.010, indicating larger congruency effects for older (.06) than for younger (.03) adults. Once again, that latter interaction was modulated by Conflict type, F(1,61)=8.74, p=.004, with larger differences between older and younger adults for Simon conflict type (F(1,61)=9.74, p=.003 and .05 errors) than for Spatial Stroop (F<1 and almost no differences). In this case, there was not 4 way interaction (F<1), observing larger differences for Simon conflict type between age groups for both when Simon and Spatial Stroop were the Manipulated conflicts.

4.3.2. Task-irrelevant capture (Automatic Response Capture)

To test task-irrelevant response capture we performed a distributional analysis on error rates. To do so, we carried out an ANOVA on error rates including Congruency, Conflict type, Bin, Age group and Manipulated conflict, with the last two variables as

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[3] To rule out the possibility that the previous results were due to overall differences between age group in reaction times, we performed the same analysis but using proportional reaction times as dependent factor (i.e., each reaction time of each subject was divided by the general mean of that subject). Once again, we observed a congruency by age group interaction, F(1,61)=7.05, p=.01, with larger congruency effects for older (.09) than for younger adults (.06). That interaction was further modulated by conflict type, F(1,61)=8.99, p=.004, due to larger differences between groups for Simon conflict type (F(1,61)=13.31, p<.001 and 04 differences) than for Spatial Stroop (F<1 and.01). As for RTs, those larger differences were restricted to the condition where Spatial Stroop conflict was the manipulated conflict, as indicated by the significant interaction between congruency, conflict type, age group and manipulated conflict (F(1,61)=5.85, p<.018).

between participants factors. Results indicated an interaction between Conflict type and Congruency modulated by Bin, F(4,236)=7.59, p<.001, showing larger congruency effects for Simon than for Spatial Stroop at early bins (.18 and .10 Simon, .06 and .009 Spatial Stroop error rates respectively for bin one and bin two; after bin 2 performance got to almost no congruency effects for both conflict types). Moreover, that interaction was modulated by the Manipulated conflict (F(4,236)=3.35, p=.011), indicating even larger congruency effects at early bins for Simon than for Spatial Stroop conflict when Spatial Stroop was the conflict being manipulated.

The Bin x Conflict type x Congrueny interaction was also modulated by Age group, F(4,236)=4.20, p=.003. Focusing on the first bin, where the strongest response capture took place, we can observe no differences between conflict types for the younger group (F<1, with .13 and .12 error rates for Simon and Spatial Stroop conflict types respectively). However, there are significant differences between conflict types in the older group, F(1,61)=19.99, p<.001, with .24 and .09 error rates for Simon and Spatial Stroop respectively.

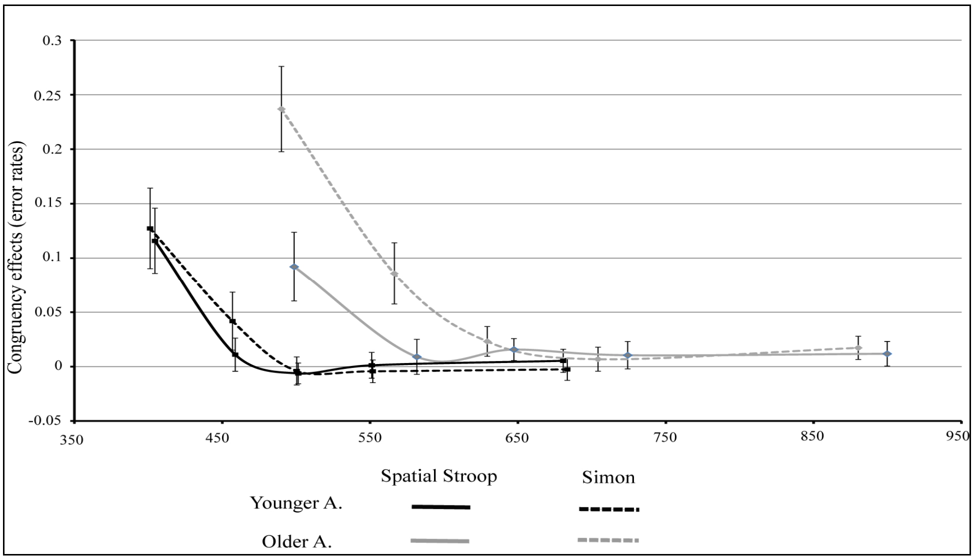

Figure 2. Congruency effects on error rates (incongruent-congruent trials) as a function of response speed for the factorial combination of conflict type and age group (Simon-younger adults; Simon-older adults; Spatial Stroop-younger adults; Spatial Stroop-older adults) (±S.E.M.).

4.3.3. Sequential congruent effects: Conflict detection and Reactive control across trials.

To study group differences in conflict detection, we analyzed incongruent trials when they are preceded by congruent trials. Similarly, for reactive control implementation across trials we based on sequential congruent effects, focusing on incongruent-incongruent sequences in conflict type repetition trials.

To do so, we performed an ANOVA including Previous Congruency, Congruency, Age group and Manipulated conflict, with the last two variables as between participants factors, but only on consecutive conflict type repetition trials (note that, as described in the introduction, SC effects only occurs when the same conflict type repeats on consecutive trials).

For RTs, results showed the typical pattern of SC effects, F(1,61)=256.21, p<.001, with large and significant congruency effects when the previous trial is congruent (F(1,61)=236.07, p<.001; 83 ms) and no congruency effects when the previous trial is incongruent (F<1; 0 ms). Interestingly, SC effects were modulated by Age group, F(1,61)=29.93, p<.001, indicating that SC were larger for the older (111 ms) than for the younger (54 ms) group. It is important to highlight that both groups differed in their congruency effects after congruent trials, F(1,61)=25.15, p<.001, but no after incongruent trials, F<1, indicating that both showed similar control implementation after incongruent trials but older group had larger congruency effects after congruent trials. Besides, Conflict type or Manipulated conflict did not modulated that last interaction (F(1,63)=2.15, p=.148, and F<1, respectively).

Mirroring RTs results, error rates also showed SC effects (F(1,63)=42.69, p<.001) modulated by Age group (F(1,61)=5.53, p=.022). Once again, the modulation of SC effects by Age group was mainly due to larger congruency effects after congruent trials for the older (.11) than for the younger group (.05), F(1,61)=8.66, p=.005, and no differences in congruency effects between age groups when previous trials was incongruent (F<1, approximately 0 errors in both cases). As for RTs, neither Conflict type (F<1) nor Manipulated conflict (F(1,63)=1.82, p=.182) modulated this interaction.

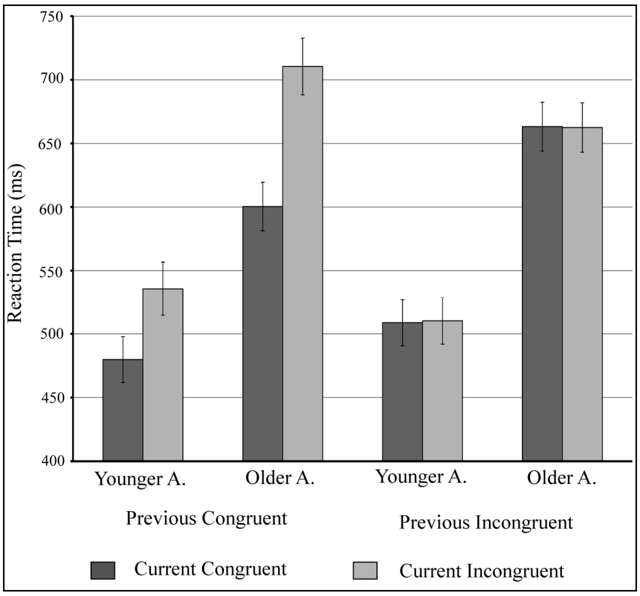

Figure 3. Reaction times for congruent and incongruent current trials as a function of Age group and Previous Congruency (±S.E.M.).

4.3.4. Reactive control within trial (Selective suppression mechanism)

For reactive control implementation within the trial, and following Ridderinkhoff activation-suppresion model (2002), we plotted congruency effects as a function of response speed and focused on late bins (where suppression mechanism takes place). To do so, we carried out the same ANOVA performed previously (section two) including Bin, Conflict type, Congruency, Age group and Manipulated conflict, but on RTs as dependent factor. There was a significant interaction between Bin, Conflict type, Congruency and Age group, F(4,236)=7.54, p<.001. As it is shown in the figure 4, the two age groups were differentially influenced by bin. For the older group, there was a significant reduction of congruency effects for Spatial Stroop conflict (F(1,59)=9.73, p=.003; 40 ms and 21 ms for bin one and five respectively) and a significant linear increse for Simon conflict (F(1,59)=5.44, p=.023; 46 ms and 78 ms for bin one and five respectively). However, for the younger group variations of congruency effects across bins were smaller and not significant (F(1,59)=1.17, p<.28 and 33 ms and 22 ms bin one and five resectively for Simon conflict type; F<1 and 33 ms and 39 ms bin one and five for Spatial Stroop conflict type).

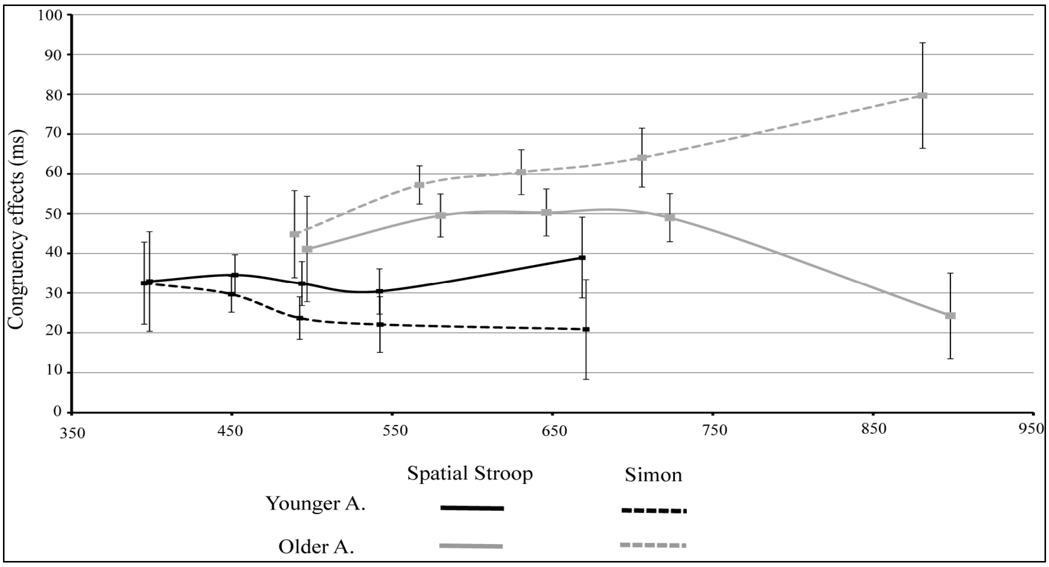

Figure 4. Congruency effects on error rates (incongruent-congruent trials) as a function of response speed for the factorial combination of conflict type and age group (Simon-younger adults; Simon-older adults; Spatial Stroop-younger adults; Spatial Stroop-older adults (±S.E.M.).

4.3.5. Proactive control (Proportion Congruent Effects)

Finally, we analyzed proactive control focusing on proportion congruent effects. To study PC effects in contexts where they are not confounded with SC effects, we focused on conflict type alternation trials (where no SC effects are observed) and performed an ANOVA including Proportion of congruency, Manipulation of conflict type (manipulated versus neutral), Congruency Age group and Manipulated conflict, with the last two variables as between participants factors. As expected, we observed a significant Proportion of congruency by Congruency interaction, F(1,61)=7.46, p=.008, with larger congruency effects in the high proportion of congruent trials (F(1,61)=150.43, p<.001; 54ms) compared to the low proportion of congruent trials condition (F(1,61)=167.10, p<.001; 44 ms). Although the Proportion of congruency x Congruency x Manipulated conflict interaction did not reach significance (F(1,61)=1.94, p=.169, PC effects were only significant for the conflict where proportion congruency manipulation took place (F(1,61)=6.17, p=.016; 16 ms PC effect) and not for the condition where the proportion of congruency was neutral (F<1; 4 ms PC effects). Interestingly, that specific PC effects were not modulated by either age group (F<1) or manipulated conflict (F<1).

For error rates we did not observe any proportion congruent effects since the interaction between Proportion of congruency and Congruency was not significant (F<1).

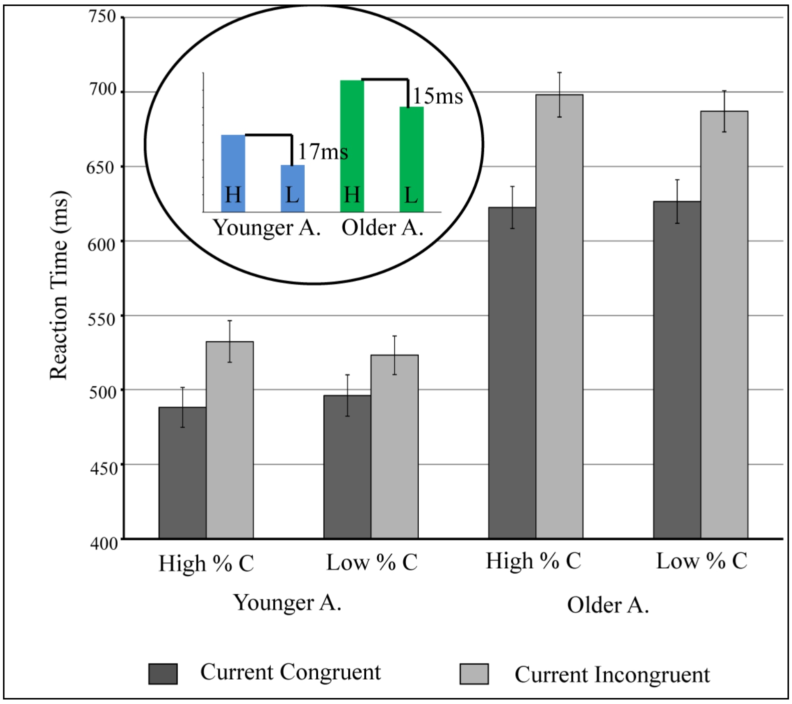

Figure 5. Reaction Times for congruent and incongruent trials as a function of proportion congruent conditions, for older and younger adult groups and only including conflict-type alternations trials. Bars represent ±S.E.M Blue and green color bars represent congruency effects (ms) as a function of high (H) and low (L) proportion congruent conditions; and the overall PC effects for older and younger adults

4.4. Discussion

In the present study we tested the effect of aging on cognitive control. However, and most importantly, we studied normal aging impact on each of the sub-processes that composed cognitive control. We believe that considering the different sub-processes separately is necessary in order to be able to draw comprehensive conclusions about how cognitive control deteriorates with age and, therefore, be able to create accurate approaches to diminish the deficits associated to aging. With that purpose in mind, we first checked that the usually observed larger interference in the elderly could be measured with our procedure. Then, we distinguished three main processes involved in cognitive control that might underlie the observed larger interference: task-irrelevant capture (response automatic capture), which leads to the present conflict, conflict detection and control implementation (reactive within and across trials, and proactive).

4.4.1. Congruency effects

As in previous studies, we observed larger congruency effects for older compared to younger adults (i.e., Puccioni & Vallesi, 2012). Interestingly, those increased congruency effects were larger for Simon conflict type than for Spatial Stroop conflict type, but only for the condition where Spatial Stroop proportion of congruency was manipulated. Observing stronger congruency effects for Simon than for Spatial Stroop is a typical finding maybe related to the different nature of the Simon and Spatial Stroop interference (i.e., different dimensional overlap; see Kornblum, et al., 1990). The fact that this tendency to suffer stronger interference from Simon conflict is vanished when the proportion of Simon congruency is manipulated could be explained by the manipulation of proportion congruent itself. That is, that manipulation could have produced a proactive control strategy active before stimulus onset, resulting in less Simon congruency effects.

4.4.2. Task-irrelevant capture (automatic response capture).

Once we confirmed that there were age differences in congruency effects, we were interested on the specific deficits underlying them, specifically, whether the larger interference was due to larger attentional capture by task-irrelevant information or were rather driven by deficits on cognitive control-related processes. According to Ridderinkhof activation-suppression model (2002), the strength of automatic response capture (which is typically driven by task-irrelevant information) is reflected on fast errors. That is, as task-irrelevant processing is not inhibited at the fastest responses, larger error rates are observed on incongruent trials and lower error rates on congruent trials. This only occurs on early bins, however, since with more time the impact of task-irrelevant information is suppressed. Therefore, we focused on the error rates at early bins to study differences in automatic response capture between older and younger adults. We observed greater congruency effects for older than for younger adults but only for the Simon conflict type. For Spatial Stroop the two groups showed similar congruency effects. Those findings suggested that older adults showed stronger capture by task-irrelevant information than younger adults, but only for Simon conflict type.

Therefore, age groups differences in automatic response capture are confined to Simon conflict. As stated above, Simon and Spatial Stroop are different in nature. Based on task-irrelevant dimensions, for Simon there are two irrelevant sources, the location of the arrow and the location of the response. By contrary, Spatial Stroop has only one irrelevant dimension, the location of the arrow. Besides, in Simon the task-irrelevant response location actually involves the motor automatic response whereas Spatial Stroop only involves perceptual interference. That is, it seems than when the task-irrelevant dimension involves the automatic response (Simon) older adults showed larger capture than when the task-irrelevant dimension is perceptual, and therefore the automatic response is not directly active.

4.4.3. Sequential congruent effects: Conflict detection and Reactive control across trials.

We also tested possible deficits on conflict detection processes, by focusing on different congruency effects after congruent trials. As stated in the introduction, when facing a congruent trial the system somehow relaxes and operates in an automatic and less effortful way, thus relying more on task-irrelevant information. Consequently, when the following trial is incongruent a higher conflict is experienced, and attention needs to be biased from task-irrelevant information toward task-relevant information to perform the task successfully. Our results showed that older adults had increased congruency effects after congruent trials indicating that they register higher levels of conflict. That finding corroborates previous studies showing higher sensitivity to response conflict levels in older compared to younger adults (i.e., Czernochowski, et al., 2010; Nessler, et al., 2007), as indicated by increased amplitude in a medial frontal negativity (MFN) ERP component, associated to response conflict detection. Given that larger congruency effects after congruent trials are found both for Spatial Stroop and Simon, while automatic response capture by task-irrelevant information is restricted to Simon, one cannot conclude that the latter factor is driven by the former. Thus, we cannot argue that due to stronger task-irrelevant capture, older adults showed larger congruency effects after congruent trials. Instead, it seems that older adults show higher response conflict regardless of conflict nature.

The next process to be tested was control implementation. As we said, we distinguished between three control implementation processes: two reactive ones (one within the trial and another across trials) and a proactive one. For the reactive control across trials, also measured with sequential congruent effects, there were no differences between age groups, as congruency effects after incongruent trials were similarly reduced to 0 ms in both groups. To the extent that a reduction on congruency effects after incongruent trials indicates the effectiveness of the bias of attention toward task-relevant information due to encountering conflict and implementing control in the previous trial, our results indicate that older adults do not show any deficit on reactive control implementation across trials.

4.4.4. Reactive control within trial (Selective suppression mechanism)

On the contrary, we did observed age groups differences in the implementation of reactive control within the trial. We assessed it by looking at congruency effects at late bins, again following the activation-suppresion model by Ridderinkhoff (2002). According to it, the suppression of the response capture by task-irrelevant information measured in early bins needs time to build up, and therefore a successful conflict resolution will be only reflected as smaller congruency effects at late bins. Since the usual interference tasks are nevertheless quite easy and with time no errors are committed, this conflict resolution is measured in RT (i.e., no differences in RT between congruent and incongruent trials on late bins). Our findings indicated that there were differences between groups and, once again, restricted to the Simon conflict type. Older adults showed normal suppression effects for Spatial Stroop (i.e., almost no difference between congruent and incongruent trials at late bins) but increased congruency effects for Simon conflict at late bins. Surprisingly, younger adults seem not to show modulation of the congruency effect by bins. The reason could be that the early automatic response capture by task-irrelevant information is actually resolved pretty fast, as it can be seen from the quick reduction on congruency effects from bin 1 to bin 2 on error rates. Therefore, there is nothing to be suppressed at late bins.

Once again, older adult deficits have been mainly found on Simon conflict type. As it has been mentioned beforehand, Simon and Stroop conflict Since arise from different conflict sources, that is, Simon from the overlapping between irrelevant information and response code and Spatial Stroop from the overlapping between irrelevant and relevant information. Therefore, our results indicate larger difficulties for older adults in dealing with stimulus-responses compatibility conflicts. To account for that vulnerability to Simon conflict, one can argue that since both conflicts have been located in different brain areas, the neural substrate related to Simon are more deteriorated with age. Specifically, Egner et al. showed (Egner, et al., 2007) that Simon was mainly related to pre-suplementary motor area activity while Stroop activations were related to more parietal locations. Besides, the frontal-lobe hypofunction hypothesis (i.e., Braver & Barch, 2002; West, 1996), cognitive processes supported by the prefrontal cortex suffer from an earlier and greater decline with respect to processes requiring non-frontal regions. Moreover, the neuroimaging literature has also shown that the differential pattern of brain activations across age groups particularly concerns the frontal lobes, with many studies showing an under-recruitment of frontal regions with aging (e.g. Gutches, Kensinger, & Schacter, 2007; Vallesi, McIntosh, & Stuss, 2009). Therefore, since Simon conflict has a more frontal location compared to Stroop, it is not surprising to find age-related deficits (possible due to frontal function decline). Another plausible explanation is related to the degree of inhibitory control involved on each conflict type. Previous studies have shown that aging deficits on inhibitory control might depend on the degree in which it is needed (e.g. Andrés, et al., 2008). Simon is a conflict that takes place at the moment of the response while Spatial Stroop arises at early stages of the processing, therefore, Simon could involve stronger inhibitory control since the inhibition has to take place at the same time than the conflict is occurring; thus, there is almost not time to prepare the inhibition of the motor response. Nevertheless, they are just possible explanations and future studies should to study in depth all the possibilities.

4.4.5. Proactive control (Proportion congruent effects)

Finally, there were no differences between young and older adults on proactive control implementation as measured by PC effects. It is important to highlight that we used a procedure and strategy of analysis by which PC effects were dissociated from SC effects, since we tested them in situations where SC effects were absent (Torres-Quesada, et al., under review). Our results replicate previous findings from a study also manipulating the proportion of congruent trials (Bélanger, Belleville, & Gauthier, 2010). In that study, healthy older adults showed comparable proactive conflict resolution than younger adults (understood as the strategy developed in contexts where incongruent trials are frequent and which, in turn, enhances task-relevant processing).

However, in this study PC effects were not dissociated from SC effects as we did in our study.

Furthermore, not many studies have used proportion of congruency manipulations as the way to study the effect of aging on proactive control. By contrary, different studies based on the Dual Model Theory have looked at age differences in reactive and control implementation (Braver, et al., 2001; Braver, et al., 2009; Paxton, Barch, Racine, & Braver, 2008; Paxton, Barch, Storandt, & Braver, 2006). Most of those studies have found a high tendency of older adults to rely on reactive control mechanisms more than on proactive ones. Does it mean that they show proactive impairments? The same authors argue that older adults do not show any proactive impairment since after task-strategy training, they switched to a conflict resolution strategy, going from a reactive one to a proactive one after intense training (Paxton, et al., 2008). Therefore, it seems that, and regardless of the paradigm, older adults can show proactive control adjustments. However, the differences between studies might be due to the task being used, or to the fact that older adults do not use proactive control by default. Given that this control strategy is more demanding, they might rely by default on reactive mechanisms, and only activate proactive mechanisms when either tasks demands, motivation or training clearly call for the activation of proactive mechanisms.

On the other hand, the studies showing larger tendency to use reactive than proactive control processes on older adults (Braver, et al., 2001; Braver, et al., 2009; Paxton, et al., 2008; Paxton, et al., 2006) have used tasks based on working memory processes while in our study and Bèlanger et al.'s one (2010) the task used was based on interference tasks, therefore, attentional cognitive control. Although tightly related, working memory and attentional cognitive control performance might involve some sub-processes differentially affected by age. Nevertheless, future research is needed to tease apart the differences between performance and working memory tasks regarding the use of proactive vs. reactive control in older adults.

4.5. <u>Conclusions</u>

Summarizing, our results indicate that older adults seem more sensitive to task-irrelevant information since they showed larger early response capture toward it and larger conflict detection experiences. Besides, they showed deficits only in on-line reactive control implementation when it takes place at the moment of response, that is, when understood as the suppression of task-irrelevant information. However, they did not show any deficit in control implementation when it takes place across trials, understood as the benefit of just having resolved conflict, which also enhances task-relevant information. Interestingly, they do not show any impairment of proactive control defined as the strategy developed under high frequent incongruent trials contexts.

5. Experimental Series V

Identifying common and dissociable neural substrates of proactive control over emotional vs. non-emotional conflict.

Unpublished work (submitted).

Torres-Quesada, M., Korb, F. M., Funes, M. J., Lupiáñez, J., &. Egner, T. (2013). Identifying neural common and dissociable substrates of proactive control over emotional vs. non-emotional conflict. *NeuroImage* (submitted).

Abstract:

Recent models of cognitive control distinguish between reactive and proactive mechanisms. Reactive control can be observed via phasic trial-by-trial performance adjustments in reaction to conflict ("Conflict Adaptation" [CA] effects: less interference following incongruent trials); and proactive control can be seen in sustained adjustments to the frequency of congruent relative to incongruent stimuli over longer sequences of trials ("Proportion Congruent" [PC] effects: less interference when incongruent trials are frequent). The neural correlates of CA effects have been extensively investigated and much evidence implies a partial dissociation between circuits involved in resolving cognitive (non-emotional) vs. emotional conflict. By contrast, the study of PC effects' neural correlates has received less attention and it is presently unknown whether there are dissociable neural mechanisms underpinning proactive emotional vs. non-emotional conflict-control processes. We addressed this question in a hybrid blocked/event-related functional magnetic resonance imaging (fMRI) study, which varied the proportion of congruent trials in emotional vs. non-emotional conflict tasks in different blocks of trials. Reliable behavioral PC effects were observed for both the non-emotional and emotional domains. At the neural level, we found domain-independent sustained control signals in a group of regions including the cingulo-opercular network, and sustained control signals exclusive to the non-emotional task in a different region of the anterior cingulate. Moreover, the left anterior insula/operculum was found to track conflict as a function of control-context exclusively in the emotional task context. These results suggest that, akin to reactive conflict-control, there are both overlapping and distinct neural substrates involved in the proactive control over emotional and non-emotional conflict.

5.1. Introduction

Cognitive control refers to processes that guide perceptual and motor selection in line with task goals, especially in the face of distraction from irrelevant stimuli or task-inappropriate response tendencies (Miller & Cohen, 2001). In many contexts goal-driven behaviour requires responses that are based on the selection of relevant sources of information amidst competing sources of distraction. For example, in the classic color-naming Stroop task (for a review see Macleod, 1991) participants are required to name the ink color in which color-words are displayed, and the meaning of the words can be congruent or incongruent with their ink color. Participants need to select the relevant information (the ink color) over the irrelevant information (word meaning) to perform successfully, which is rendered particularly difficult by the fact that word-reading is a highly practised process whereas color-naming is not. Therefore, response times (RTs) are reliably slower for trials where the meaning of the word stimulus is incongruent with its color (e.g. the word RED printed in green) compared to trials where the word and color are congruent (e.g., the word RED printed in red). The difference in performance between incongruent and congruent trials is called the congruency or conflict effect, and is used as an index of the relative success (or failure) to impose cognitive control and selectively process task-relevant versus –irrelevant information.

Various task parameters have been found to modulate congruency effects, including most notably trial-by-trial stimulus congruency transitions ('conflict adaptation' [CA] effects, for a review see Egner, 2007), and the frequency of congruent relative to incongruent stimuli over longer sequences of trials (‘proportion congruent’ [PC] effects, for a recent review, see Bugg & Crump, 2012). If certain lower-level feature repetition and stimulus-response learning effects are accounted for (Hommel, et al., 2004; Mayr, et al., 2003; Schmidt & Besner, 2008), both of these modulations are typically considered reflections of control processes. Concretely, CA effects are defined by congruency effects that are smaller on a current trial when preceded by an incongruent trial than by a congruent trial (Gratton, et al., 1992). This phenomenon has been interpreted to reflect a transient or reactive conflict-control process, where conflict generated during an incongruent trial leads to a compensatory up-regulation in top-down control that is observed in the form of reduced congruency effects on the following trial (Egner, 2007; Egner, et al., 2010). On the other hand, PC effects are measured by manipulating the relative proportions of congruent and incongruent trials within an experimental block. The magnitude of the congruency effect varies with the proportion of congruent trials, being larger in the context of a high proportion of congruent trials than in the context of a low proportion of congruent trials (e.g., Carter et al., 2000; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; West & Baylis, 1998). This effect is typically attributed to a strategic adoption of a higher level of sustained or proactive top-down control in response to encountering frequent conflict (i.e., when the proportion of incongruent trials is high) and a relaxation of control when conflict is rare (i.e., when the proportion of congruent trials is high) (Carter, et al., 2000; Krug & Carter, 2012).

Conflict adaptation effects and their neural correlates have been extensively investigated (e. g., Botvinick, et al., 1999; 2001; Durston et al., 2003; Egner & Hirsch, 2005a, 2005b; Kerns et al., 2004), with much evidence suggesting key roles for the dorsal anterior cingulate cortex (dACC) and the dorsolateral prefrontal cortex (dlPFC). Moreover, a number of studies have provided strong evidence for a distinction between circuits involved in detecting and resolving cognitive (non-emotional) conflict from those that detect and resolve emotional conflict (Egner, Etkin, Gale, & Hirsch, 2008; Etkin, et al., 2006; Maier & di Pellegrino, 2012; Mohanty, et al., 2007; Monti, et al., 2010). Specifically, whereas in non-emotional conflict adaptation, conflict appears to be detected in the dACC (Botvinick, et al., 1999; Kerns, et al., 2004) and subsequent control adjustments implemented by the lateral PFC (Egner &Hirsch, 2005a, 2005b; Kerns, et al., 2004) through biasing of stimulus processing in posterior sensory regions (Egner & Hirsch, 2005b), emotional conflict adaptation appears to also involve the dACC (and additionally the amygdala) in detecting conflict, but subsequent control adjustments have been mapped on to the pregenual, rostral ACC (rACC) inhibiting amygdala activation (Egner, et al., 2008; Etkin, et al., 2006; Krug & Carter, 2010; Maier & di Pellegrino, 2012).

Compared to CA effects, the neural correlates of PC effects have been studied less extensively (Carter, et al., 2000; Grandjean et al., 2012; Krug & Carter, 2012; Wilk, Ezekiel, & Morton, 2012). Given that this effect is assessed at the level of blocks of trials, neural signatures can be investigated both for a putative sustained control process (which would be more engaged in low PC than high PC blocks) as well as for phasic (event-based) conflict signals (i.e., the contrast between incongruent and congruent trials) as a function of block membership. In an early study, Carter and colleagues (2000) focused on the latter, and showed the ACC to track transient conflict signals to incongruent stimuli as modulated by the proportion of congruent trials (i.e., conflict signals were less pronounced under low PC than high PC conditions). More recent studies attempted to tease apart sustained and transient (stimulus-evoked) neural signatures in a single protocol, with one study reporting fronto-parietal activity, including dlPFC and ACC, tracking phasic conflict signals as a function of PC contexts, but no sustained activity varying across the different PC contexts (Grandjean, et al., 2012), and another one finding sustained control signals (low PC > high PC context) in the medial frontal cortex and phasic context-modulated conflict signals in the ACC, inferior frontal junction and anterior insula (Wilk, et al., 2012). Moreover, Krug and Carter (2012) investigated PC effects in the context of emotional conflict and also found medial and lateral PFC activation (plus right amygdala) to track phasic conflict signals modulated by PC, but they additionally reported (based on a separate model assessing only block-wise activation) higher sustained responses for low than high PC contexts in the right dlPFC.

The latter study raises the intriguing possibility that, akin to the distinction between non-emotional and emotional conflict adaptation mechanisms, there might also be distinct, domain-specific neural mechanisms involved in the sustained control mechanisms reflected by PC effects of non-emotional vs. emotional conflict. However, since that study consisted only of an emotional conflict task without a comparison condition of non-emotional conflict, it remains unknown whether emotional PC effects rely on distinct neural substrates from those of non-emotional conflict. Moreover, Krug and Carter (2012) used different models for assessing event-related and sustained activity instead of a hybrid block/event-related model (Dosenbach, et al., 2006; Petersen & Dubis, 2012) which leaves open the possibility that some frequent transient signals (like incongruent trials in a low PC condition) could have contributed to the sustained activity results, and vice-versa.

The main goal of the present study, therefore, was to investigate whether there are dissociable neural mechanisms involved in emotional vs. non-emotional PC effects by providing an appropriate comparison condition. To this end, participants performed two face-word Stroop tasks (cf. Egner, et al., 2008) - one using emotional stimuli and the other one non-emotional stimuli - while brain activity was recorded using functional magnetic resonance imaging (fMRI). The proportion of congruency was manipulated between blocks within each task, alternating between high and low PC conditions. This hybrid blocked/event-related design (Petersen & Dubis, 2012; Dosenbach et al., 2006) allowed us to identify regions uniquely involved in (1) sustained conflict-control signals varying as a function of proportion congruency across a block of trials, (2) phasic, event-based conflict processing (displaying greater activity for incongruent than congruent trials), and (3) the modulation of phasic conflict signals by sustained control (i.e., differences in event-related signals as a function of block). Most importantly, we could delineate (4) brain areas that displayed these activation profiles in a domain-specific fashion, by analyzing the interaction of conflict processing and conflict-control with task-domain (non-emotional vs. emotional).

5.2. Methods

5.2.1. Participants

Twenty-four right-handed volunteers gave written informed consent to participate in this study, which was approved by the Duke University Health System Institutional Review Board. All participants had normal or corrected-to-normal vision, and reported no current or history of neurological, psychiatric, or major medical disorder. They were reimbursed with $30 for their participation, which lasted approximately 90 minutes. The data of three participants were excluded due to incomplete scans (two participants) or high error percentage (one participant). The remaining twenty-one participants were 10 females and 11 males (mean age = 24.8; range = 19-34).

5.2.2. Stimuli

Stimuli were displayed on a back-projection screen that was viewed by participants via a mirror attached to the head-coil. This set-up simulated a viewing distance of approximately 80 cm, resulting in individual stimuli extending ~9 degrees horizontally and ~ 11 degrees vertically for the face-word task and ~ 10 degrees horizontally and ~ 12 degrees vertically for the localizer. For the face-word task, stimuli were presented using E-prime software (Psychology Software Tools, Pittsburgh, PA), and consisted of photographic gray-scale images displayed on a black background , depicting male or female faces posing either happy, fearful, or neutral emotional expressions (NimStim faces database, Tottenham et al., 2009). Face stimuli were cropped to remove any hair. The stimulus set consisted of 24 unique images, 12 males (3 happy, 3 fearful and 6 neutral faces) and 12 females (3 happy, 3 fearful and 6 neutral faces). Each stimulus was presented with a red-capital distracter word overlaid on the face (Figure 1). The word could be “MALE”, “FEMALE”, “HAPPY” or “FEAR”. For the localizer task, gray-scale pictures of faces or houses were presented on a gray background screen using MATLAB software (Mathworks Inc., Nantucket, MA). Face and house pictures for the localizer were obtained from an in-house collection.

5.2.3. Procedure

Participants performed two tasks during fMRI: a face-word interference task (including an emotional and a non-emotional version), which was performed first, and a subsequent standard localizer task to provide independent functional definitions of the fusiform face area (FFA; Kanwisher, McDermott, & Chun, 1997) and the amygdala as regions-of-interest (ROIs).The face-word task consisted of two blocks of 16 practice trials each (not included in the statistical analysis and performed outside the scanner), followed by 4 runs of the experimental task (each run comprised 2 blocks of 64 trials each, resulting in a total of 512 trials). The first two runs were of one block type (e.g., emotional blocks) and the other two runs were of the other type (e.g., non-emotional blocks), and this order was counterbalanced across participants. For the emotional blocks, 12 emotional faces were presented, 6 of them showing happy faces (3 males and 3 females) and the other 6 showing fearful faces (3 males and 3 females). For the non-emotional blocks, all the faces (6 males and 6 females) had neutral facial expressions. Like the faces, distracters were grouped by blocks: in emotional block, only happy and fear words were displayed, while in non-emotional blocks, only female and male words were presented. Stimuli were presented in a random order within each block, with the constraint that a given face image was never repeated across consecutive trials, in order to avoid potential confounds from repetition priming or feature integration effects

(Hommel, et al., 2004; Mayr, et al., 2003). Note also that the inclusion of a relatively large number of distinct face stimuli (12) in each task renders it highly unlikely that PC effects in this study would be mediated by stimulus-response learning (Bugg & Hutchison, 2012).

Participants were instructed to categorize the face stimuli while ignoring the word distracters. Specifically, they had to indicate whether the face was happy or fearful in the emotional task blocks, or whether the face was male or female in the non-emotional task blocks. Given the possible pairings between target face stimuli and distracter word labels, these tasks produced congruent and incongruent stimuli, akin to the classic Stroop task (Egner, et al., 2008). Specifically, the congruency factor arises from a match or mismatch between face and word stimuli, that is, when both indicate the same response (i.e. happy facial expression with a happy overlaid word) the trial is *congruent*, whereas when they do not (i.e. happy facial expression with a fear overlaid word) the trial is *incongruent*. Besides this congruency factor, the proportion of congruent and incongruent trials within block was manipulated, presenting 75% of congruent trials and 25% of incongruent for the *high proportion congruent condition*, and 75% of incongruent trials and 25% of congruent for the *low proportion congruent condition*. Moreover, proportion of congruency alternated across the 8 blocks, starting with the low PC condition (i.e., low PC, high PC, low PC, and so on); this order of blocks was found to be most effective in producing robust PC effects in behavioral pilot work.

Participants responded to the stimuli using their right hand index and middle fingers to press buttons on a MRI-compatible response box, which was vertically oriented on the participant's chest. Stimulus-response mappings were counterbalanced across participants. Since both the non-emotional and emotional tasks have the same response mappings, the associations between their factor levels (e.g., happy and female faces being responded with the same key) were also counterbalanced across participants.

Stimuli were presented for 750ms, followed by a jittered inter-trial interval (ITI) during which a fixation cross was displayed centrally on the screen. To facilitate optimal statistical segregation of blood-oxygenation-level- dependent (BOLD) signals across successive trials, the ITI was randomly drawn from a pseudo-exponential distribution, where 50% of interval lasted 2.5s, 25% lasted 3s, 16%lasted 3.5s and 9% lasted 4s (mean interval ~3s) At the beginning of each block, instructions indicating whether the subjects had to respond to the gender or to the expression of the faces were displayed for 7 seconds, and there were 3s intervals between blocks within each run.

The localizer task consisted of a 1-back task, where participants were required to push the right hand index finger response button whenever two identical stimuli were presented in a row. Twelve blocks of 15 stimuli each were presented, alternating between blocks where only faces were displayed and blocks where only houses were presented. Each stimulus appeared on the screen for 750ms, separated by a 250ms ITI, and a 10 sec fixation period between blocks.

5.2.4. Design

As outlined above, there were two types of task-domains used in the main experiment (emotional vs. non-emotional), a congruency factor with two levels (congruent vs. incongruent) and two proportion congruent conditions (low vs. high PC). The factorial combination of these 3 factors formed our eight experimental conditions. Because we modelled this task as a hybrid block/event-related design in the fMRI analysis (Petersen & Dubis, 2012; Dosenbach et al., 2006), the above 3 factors were employed in analysing event-related responses, while sustained, block-wise effects were assessed only for the PC and task-domain factors.

5.2.5. Image acquisition

Images were recorded on a 3T GE Signa EXCITE HD system using a standard head coil. Functional images were acquired parallel to the anterior-posterior commissure line with a T2*-weighted single-shot gradient EPI sequence of 30 contiguous axial slices (time repetition [TR] = 2,000 ms, time echo [TE] = 28 ms, flip angle = 90º, field of view = 192 mm, array size 64 x 64) with 3.5 mm thickness and 3 x 3 mm in plane-resolution. Structural images were acquired with a T1-weighted SPGR sequence using a 3D inversion recovery prepared sequence, recording 180 slices of 1 mm thickness in plane-resolution of 1 x 1 mm.

5.2.6. Image Preprocessing

All preprocessing and statistical analyses were carried out using SPM8 (http://www.fil.ion.ucl.ac.uk/spm/sofware/spm8.html). Functional data were slice-time corrected and spatially realigned to the first volume of the first run. The structural scan was co-registered to the functional images, and served to calculate transformation parameters for spatially warping functional images to the Montreal Neurological Institute (MNI) template brain (resampled voxel size: 2 mm^3). Finally, normalized functional images were spatially smoothed with an 8mm^3 Gaussian kernel. The first 5 volumes of each run were discarded prior to building and estimating the statistical models. In order to remove low-frequency confounds, data were high-pass filtered (128s). Temporal autocorrelations were estimated using restricted maximum likelihood estimates of variance components using a first-order autoregressive model (AR-1), and the resulting non-sphericity was used to form maximum likelihood estimates of the activations.

5.2.7. Image Analyses

Regressors for stimulus events (convolved with a canonical hemodynamic response function [HRF]) were created for each of the combinations of task-domain (emotional vs. non-emotional), PC (low vs. high PC) and congruency (congruent vs. incongruent) factors, resulting in a total of 8 different trial types/regressors. Additionally, sustained signals associated with the different proportion congruent conditions were modeled with HRF-convolved boxcar regressors spanning the whole block of trials. These sustained responses were modeled separately for low vs. high PC conditions as a function of task-domain, resulting in four different types of block regressors (low PC/non-emotional task, high PC/non-emotional task, low PC/emotional task, high PC/emotional task). Finally, we modeled error trials, the first trial of each block, and instruction screens as nuisance regressors. Note that, unlike in some previous studies of the PC effect (Carter et al., 2000; Krug & Carter, 2012), we here pursued a hybrid blocked/event-related analysis where both sustained and event-related regressors are incorporated into the same model. This allowed us to identify signal variance that is *uniquely* accounted for by either sustained or phasic regressors, because any shared variance between regressors will be assigned to the model's error term. This model was applied to each subject's data, followed by linear contrasts between events of interest.

Specifically, we computed the main effect of PC at the block level (*sustained control*), event-related congruency (*conflict processing*), and the interaction between congruency and PC (*conflict modulated by sustained control*), as well as the interactions between these contrasts and the task-domain factor (emotional vs. non-emotional). Group effects were assessed by submitting the individual SPMs for the above contrasts to voxel-wise *t*-tests at the group level, where subjects were treated as random effects.

To control for false-positive rates, combined voxel activation intensity and cluster extent thresholds corrected for multiple comparisons were determined by using 3dClustSim of the AFNI software suite (http://afni.nimh.nih.gov/afni/). Specifically, the program was used to run 10,000 Monte Carlo simulation taking into account the whole-brain search volume and the estimated smoothness of each axis of the respective group SPMs to generate probability estimates of a random field of noise producing a cluster of voxels of a given extent for a set of voxels passing a specific voxel-wise p-value threshold, which we set at $p<0.01$ for all analyses. Given this voxel-wise threshold, the simulations determined that cluster sizes of >177 and <323, depending on the specific analysis, corresponded to combined threshold of $p<0.05$ (whole-brain corrected). Following identification of activations that passed the whole-brain corrected thresholds for interaction effects, we followed up these analyses with ROI data extraction in order to determine the likely causes for each interaction effect (and to display the data patterns in graphical form). For this purpose, we employed Marbars software (http:marsbar.sourceforge.net) to extract the mean cluster activation values for each experimental condition and submitted the resulting values to statistical tests.

Finally, we also created functionally defined FFA and amygdala ROIs from the localizer task and used these to extract activation estimates for these regions during the main task. Given that the localizer data were independent of the main task, we employed more lenient statistical thresholds (voxel-wise $p<.005$, cluster extent=20). Since face-related activation in the amygdala was quite extensive, with activation clusters extending beyond the anatomical borders of this region, the functional amygdala ROI was furthermore masked with an anatomically defined amygdala ROI taken from the WFU pickatlas (http://fmri.wfubmc.edu/software/PickAtlas).

5.3. Results

5.3.1. Behavioral Data

Descriptive statistics for RT and error rate performance measures for each experimental condition are presented in **Table 1**. For the analysis of mean RTs, we excluded the first trial of each block, error trials and trials with excessively fast/slow responses (<150ms, >1500ms; excluding 9.4% of all trials). For the analysis of error rates only the first trial of each block was eliminated, which constituted 1.6 % of the trials. One repeated-measures ANOVA was carried out on each dependent variable (mean RTs and error rates), including task-domain (emotional vs. non-emotional), proportion congruent (high vs. low PC) and current trial congruency (congruent vs. incongruent) as within-participant factors. The RT data displayed a main effect of congruency, F(1,20)=25.60, p<.001, with slower RTs for incongruent trials (577ms) compared to congruent ones (555ms). The effect of congruency was furthermore modulated by proportion of congruency, F(1,20)=12.88, p<.005, indicating larger congruency effects for the high PC trials (31ms) compared to the low PC trials one (14ms). However, this PC by congruency interaction was similar for both the emotional and non-emotional task, since the overall 3-way interaction did not reach significance (F1,20)=1.07, p=.313.

Table 1. RTs and error rates with SD for each experimental condition

	High % C		Low % C	
	C	I	C	I
Emotional	564 (48)	597 (56)	556 (50)	568 (43)
	0.05 (0.05)	0.14 (0.08)	0.05 (0.05)	0.09 (0.06)
Non-Emotinal	547 (79)	575 (71)	551 (71)	567 (73)
	0.04 (0.04)	0.12 (0.11)	0.05 (0.05)	0.06 (0.05)

[1] C=Congruent, I=Incongruent, High % C=High proportion of congruent trials, Low % C=low proportion of congruent trials.

For error rates, we also observed a main effect of congruency, F(1,20)=36.18, p<.001, with higher error rates for incongruent (.10) than for congruent trials (.05). The congruency effect was modulated by the proportion of congruent trials (F(1,20)=17.26, p<.001), showing the typical pattern of larger congruency effects for high (.08) than for low (.02) proportion congruent conditions. Once more, task-domain, proportion congruency and congruency factors did not interact (F<1) (see **Figure 1 C** and **D**). In sum, we observed typical and reliable conflict and PC effects in both RT and accuracy and these effects did not vary reliably with task-domain. These behavioural results document that the experimental manipulations were effective in producing robust signatures of conflict (congruency effects) and control processes (PC effects), which sets the stage for interrogating the fMRI data for the neural substrates of these effects as a function of task-domain.

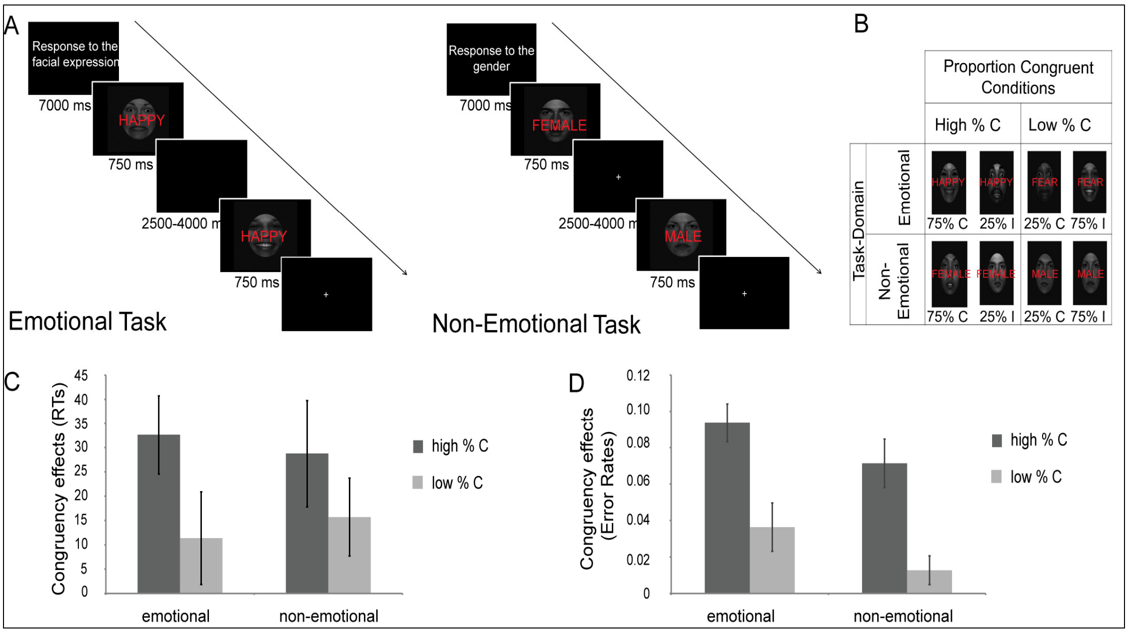

Figure 1. Experimental protocol, design, and behavioral results. (A) Instructions and two example trials are shown for the emotional (left panel) and non-emotional (right panel) tasks. (B) Manipulation of proportion congruent trials for each task-domain condition (C = congruent, I = incongruent). (C) Mean reaction times for congruency effects (incongruent minus congruent trial RT) (±S.E.M.) display the classic proportion congruent effect, that is, differences in reaction times between congruent and incongruent trials are smaller in the low proportion congruent ("low C") than in the high proportion congruent ("high C") condition, in both task-domains. (D) Mean error rates for congruency effects (±S.E.M.) also show typical proportion congruent effect.

5.3.2. fMRI data

The aim of the fMRI analyses was to reveal brain regions involved in either domain-general or domain-specific conflict-control processes. Specifically, we sought to identify regions involved in *sustained* conflict-control (that is, signals varying with the block-wise proportion of congruency), in *phasic* conflict processing (event-related signals displaying greater activity for incongruent than congruent trials), and in phasic conflict processing as modulated by sustained control (where congruency effects are modulated by the proportion congruent manipulation). Most importantly, we additionally searched for brain areas that displayed these activation profiles in a domain-specific fashion, by analyzing interactions of the above contrasts with task-domain (non-emotional vs. emotional). All reported activations passed whole-brain correction ($p<0.05$) via a combined voxel-height and cluster-extent threshold (see Methods) and are listed in **Table 2**. For any significant interaction effect results, mean cluster activation estimates were extracted (see Methods) and submitted to follow-up tests to determine the source of the interaction.

Table 2. fMRI Results

Anatomical area	**Hemisphere**	***x***	**y**	**z**	**Extent**	**Z_{max}**
Main Effect of Block (low % C> high % C)						
dACC	L/R	6	38	16	2307	5.29
Cingulated gyrus (posterior)	L/R	2	-16	36	491	4.00
Middle/Superior temporal gyrus	L	-58	-44	4	324	4.61
Superior temporal gyrus/inferior frontal gyrus/insula	R	40	10	-10	436	4.38
Superior temporal gyrus/inferior frontal gyrus/insula	L	-28	12	-8	334	4.33
Basal ganglia and thalamus	L/R	-8	6	16	561	3.98
Posterior areas (occipital, temporal, parietal)	L/R	14	-66	0	136830	5.75
Task x Block (low % C> high % C) interaction						
dACC	R	8	24	20	413	3.21
Task × Proportion Congruent (low % C> high % C) × Congruency interaction						
Insula/Inferior Frontal Gyrus	L	-34	24	2	705	3.38

[2] L=left, R=right; x, y, z = Montreal Neurological Institute (MNI) coordinates; Extent = number of voxels belonging to activated cluster; Z_{max} = z-score at peak activated voxel within the cluster.

5.3.2.1. Sustained conflict-control

To study the neural correlates of sustained conflict-control processes, we performed a main effect contrast of the (block-wise) PC factor, specifically contrasting low PC > high PC conditions, in order to identify regions that displayed higher sustained activity when incongruent trials were frequent (and behavioral conflict effects were small). We observed such sustained control-related signals in a large network of (mostly) medial cortical, as well as subcortical regions. Specifically, sustained activation was higher for blocks with a high incidence of incongruent trials in a large cluster of frontal medial activation, spanning bilateral ACC and ventromedial prefrontal cortex (vmPFC), as well as large clusters of activity in the mid-cingulate and the posterior cingulate cortex/cuneus regions (see **Figure 2A**). Additionally, we observed bilateral activations in the temporal lobe extending anteriorly into inferior frontal gyrus and insula (i.e., the frontal operculum), as well as extensive subcortical involvement as reflected in activation in the basal ganglia (caudate, putamen and globus pallidus) and the thalamus. Finally, we observed a large cluster of activity in ventral visual stream regions including bilateral parahippocampal gyrus, lingual gyrus and fusiform gyrus, as well as in the cerebellum.

The above analyses revealed higher tonic activation in the low PC condition (that is, when incongruent trials are frequent) than in the high PC condition in a wide array of cortical and subcortical areas. Next, we addressed the question as to whether we could also detect brain regions where these putative sustained control effects varied depending on whether the task involved overcoming emotional or non-emotional conflict. We tested this via a whole-brain interaction effect analysis involving the PC and task-domain factors. We detected a voxel cluster in the right dACC displaying a significant interaction between these factors (**Figure 2B**). A follow-up analysis of mean beta values in this cluster revealed that this interaction ($F(1,20)=18.79$, $p<.001$) was driven by the fact that the dACC showed sustained differential control-related activity for the non-emotional task (low > high proportion congruent trials, $F(1,20)=22.28$, $p<.001$) but not for the emotional one, where low and high proportion congruent conditions evoked similar levels of activity ($F<1$) (**Figure 2C**). Thus, this region of anterior cingulate cortex appeared to be involved in sustained (or proactive) control processes that were selective to the non-emotional task set. It should be noted though that the proportion congruent-related sustained ACC activity differences in the non-emotional task were driven in part by a relative deactivation during the “easy”, low control (high proportion congruent) condition. This would suggest a functional disengagement of this ACC region specific to the low-conflict blocks in the non-emotional task compared to the three other block conditions.

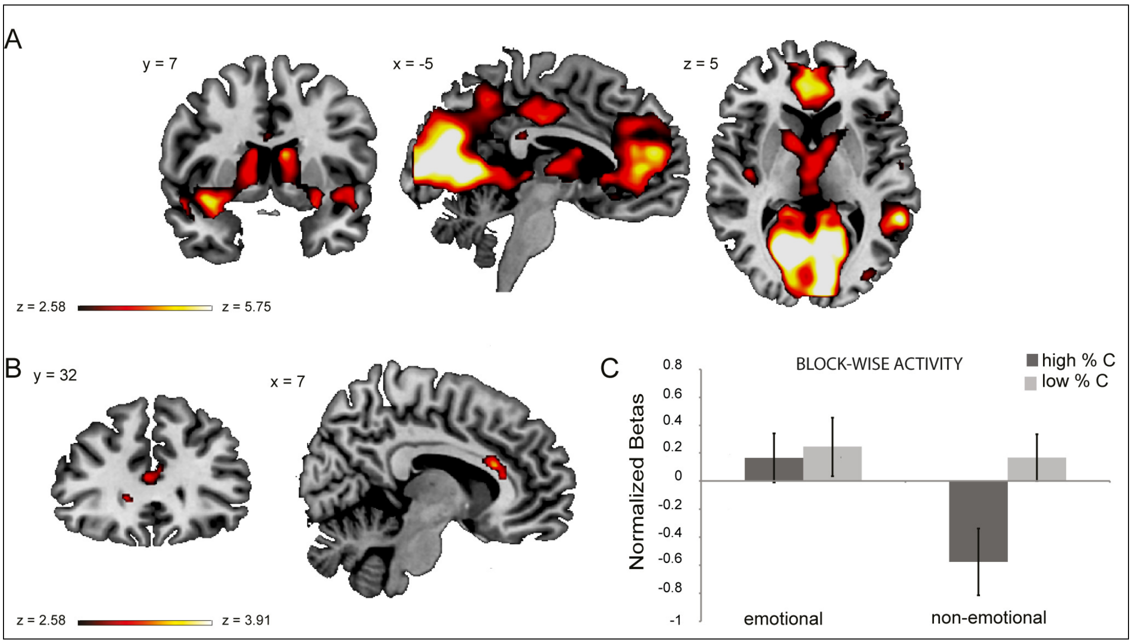

Figure 2. Neural substrates of sustained control and its interaction with task-domain (whole-brain corrected, p<0.05). (A) Brain regions exhibiting a main effect of block (low proportion congruent trials > high proportion congruent). (B) Brain regions displaying a sustained control × task domain interaction effect. (C) Mean activation estimates (±S.E.M.) for high and low proportion congruent trials blocks as a function of task-domain (emotional vs. non-emotional) are shown for the ACC activation cluster displayed in (B).

5.3.2.2. *Phasic conflict signals*

At whole-brain corrected threshold, we did not detect significant event-related effects of the congruency factor (incongruent > congruent trial contrast). This may seem surprising given that previous studies have frequently observed robust event-related conflict signals (incongruent > congruent trials) in the ACC and beyond (e.g. Botvinick et al., 1999; Kerns et al. 2004). However, a feasible cause for this null-finding is that in the hybrid block/event-related analysis we employ here, any signal variance that is shared between the sustained (block-wise) and any of the event-related regressors will not be attributed to either one of them. This is generally desirable because we are primarily interested in neural responses that are *uniquely* associated with either sustained control processes or phasic conflict-control signals. However, it comes at the cost of ignoring regions whose signals cannot be attributed exclusively to either phasic or sustained effects. This seems a likely scenario in the present study, particularly because in a manipulation of proportion congruency the block-wise proportion congruent regressors necessarily correlate quite closely with the incidence of congruent vs. incongruent trials. Therefore, some phasic effects of conflict (incongruent > congruent trials) may be shared with the sustained effects of proportion congruency (low > high proportion congruent blocks).

In order to corroborate this intuition, we re-analyzed the data in purely event-related models, which excluded the block-wise regressors coding for PC levels but included event regressors coding both for previous and current trial congruency (see e.g., Botvinick et al., 1999; Kerns et al., 2004; Egner & Hirsch, 2005a; 2005b). In line with our interpretation, this analysis did in fact reveal event-related conflict-driven activation (main effect of incongruent > congruent trials) in a large voxel-cluster covering bilateral dorsal anterior cingulate cortex (dACC) and stretching into the right pre-supplementary motor area (preSMA), as well as in additional clusters in the right inferior frontal gyrus and in right middle temporal gyrus (data not shown). Importantly, however, in none of these clusters were the event-related conflict signals modulated by task (all $p>0.1$), which replicates previous findings of common emotional and non-emotional conflict signals in the dACC in a study focusing on reactive conflict-control processes (Egner et al., 2008). These results indicate a domain-general role in conflict processing for these regions, which in the present design is expressed both in event-related and sustained responses (thus resulting in shared variance between event-related and blocked regressors).

5.3.2.3. Phasic conflict signals modulated by sustained conflict-control

To identify brain regions where phasic conflict-driven activations were modulated by sustained control context, we conducted a whole-brain proportion congruency by congruency interaction analysis. No activations in this analysis survived multiple comparisons corrections. We therefore next tested the 3-way interaction between phasic conflict processing, sustained control, and task-domain, in order to locate regions where the interaction between phasic conflict and sustained control might be specific to the emotional or non-emotional domain. Here, we observed a left-lateralized cluster of voxels spanning the inferior frontal gyrus and anterior insula, extending into middle frontal gyrus (**Figure 3A**). Follow-up analysis of beta values in this insula-centered cluster revealed that this 3-way interaction (F(1,20)=15.10, p<.001) was due to the fact that in the emotional task, conflict-related phasic activity (incongruent > congruent trials) was found in the high proportion congruent (F(1,20)=10.47, p<.005) but not in the low proportion congruent condition (F(1,20)=2.82, p=.109). By contrast, in the non-emotional task, neither proportion congruent condition was associated with significant congruency effects in this cluster (**Figure 3B**). In other words, the left anterior insula/operculum displayed conflict-related activity in a high PC context, that is, when incongruent trials are rare and (presumably) sustained control is low, but only in the emotional task, suggesting a domain-specific role in emotional conflict processing for this region.

Recall that we also observed anterior insula/operculum activity in our analysis of domain-general sustained control effects above. This raises the question as to whether the exact same region in the left insula/operculum uniquely contributes both to domain-general sustained control as well as to phasic emotional conflict processing. In order to explore this issue, we performed a conjunction analysis (see Nichols et al., 2005) across those two tests. As can be seen in **Figure 3C**, a partial overlap between these analyses showed that some aspects of the anterior insula/operculum were indeed involved in both sustained and phasic effects. This overlap, however, was complemented by clearly distinct foci that were uniquely associated with either domain-general proactive control or with context-dependent conflict tracking in the emotional task. Thus, we detected some anterior insula/opercular regions with a purely domain-general, sustained control activation profile, adjacent regions with a selectively phasic and emotional conflict-specific response profile, and finally an aspect of this region that displayed both of these characteristics.

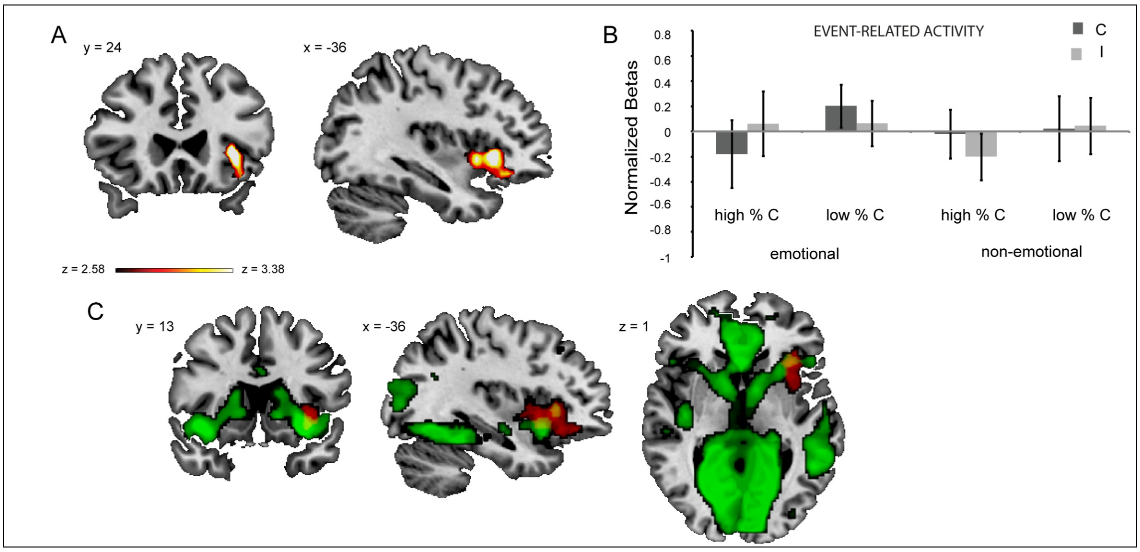

Figure 3. Context- and domain-dependent phasic conflict effects. (A) Brain regions displaying a task-domain × proportion congruent × congruency interaction effect (whole-brain corrected, p<0.05). (B) Mean activation estimates (± S.E.M.) for congruent and incongruent trials as a function of proportion congruency (high % C = high proportion of congruent trials, low % C = low proportion of congruent trials) and task-domain (emotional vs. non-emotional) are shown for the left anterior insula/operculum. (C) Conjunction map of the main effect of block (low proportion congruent > high proportion congruent, shown in green) and the interaction between task-domain, proportion of congruency and congruency (red), with partial overlap in anterior insula/operculum regions shown in yellow.

5.3.2.4. Regions of Interest Analyses

We carried out an independent localizer scan to define face-sensitive ROIs, in particular the FFA and amygdala, in order to test whether the processing of face stimuli was modulated by domain-dependent conflict-control processes. **Figure 4A** displays the FFA group activation map. We first tested whether any of our effects of interest were modulated by FFA laterality. Since we did not find any significant interaction involving this factor, we collapsed across left and right FFAs and analyzed the sustained activity effects as a function of task-domain and proportion congruency, and event-related activity as a function of task-domain × proportion congruency × congruency. We found a marginally significant main effect of proportion congruency on sustained activity (F(1,20)=4.19, p=.054), with greater activity for the low than for the high proportion congruent condition. Although block-wise activity was not modulated by task-domain (F(1,20)=2.19, p=.154), as can be seen in Figure 4, the block main effect was numerically larger for the non-emotional task than for the emotional task. Additionally, we observed a main effect of congruency on event-related activation (F(1,20)=6.26, p=.021) with larger activity for incongruent trials than for congruent trials, which was not modulated by task-domain (F<1) (**Figure 4B**). Thus, phasic FFA responses were susceptible to conflict between faces and word labels in both emotional and non-emotional tasks, and the FFA was also tonically more active under conditions of high sustained control (low proportion congruent > high proportion congruent).

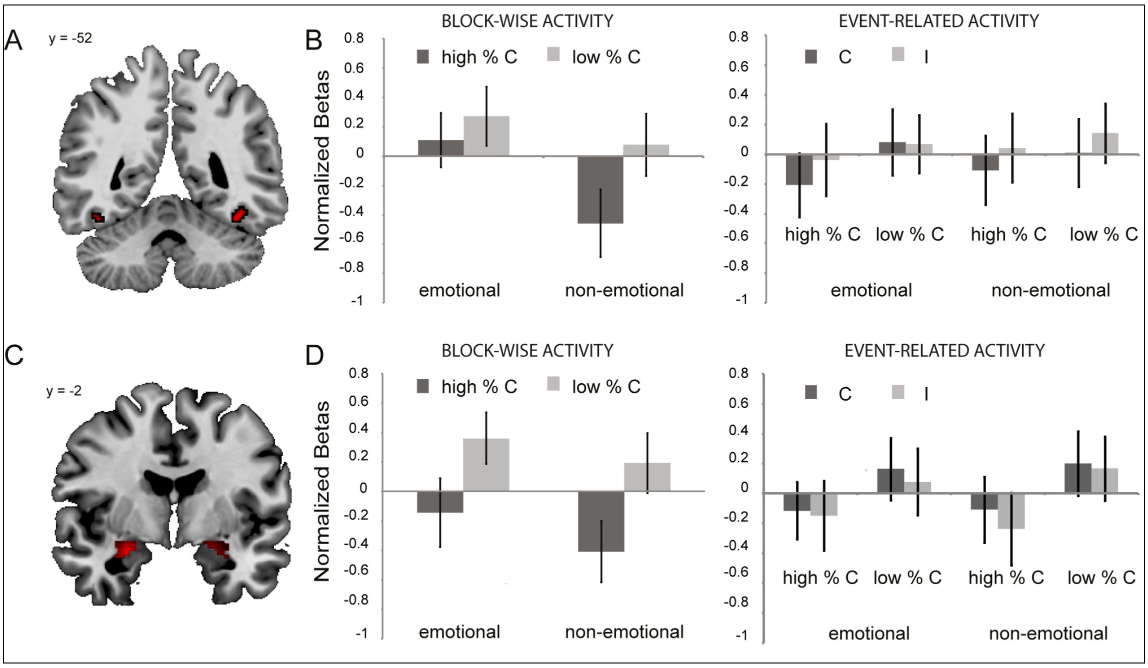

Figure 4. FFA and Amygdala ROI results. (A) Group FFA ROIs based on an independent localizer scan (p<.005, uncorrected, with cluster-extent threshold = 20 voxels). (B) high and low proportion congruent trial blocks mean activation estimates (± S. E. M.) as a function of task-domain (emotional and non-emotional); congruent and incongruent trials modulated by high and low proportion congruent trials conditions and task-domain mean activation estimates (± S. E. M.) (C). Group amygdala ROIs based on an independent localizer scan (p<.005, uncorrected, with cluster-extent threshold = 20 voxels). (D) high and low proportion congruent trial blocks mean activation estimates (± S. E. M.) as a function of task-domain (emotional and non-emotional).

The localizer task also fashioned us with functionally defined amygdala ROIs. Since these face-sensitive activation clusters extended beyond the anatomical confines of the amygdala proper, we masked the activations with an anatomically defined amygdala ROI (**Figure 4C**, see Methods). Mean activation estimates of the resultant clusters were submitted to the same analyses as the FFA ROIs. We observed a main effect of proportion congruency on sustained amygdala activity (F(1,20)=17.73, p<.001), due to greater activity for the low proportion congruent condition than for the high proportion congruent condition, and regardless of task-domain (F<1) (**Figure 4D**). Similarly, for the event-related ANOVA, we also observed a proportion congruent condition main effect (F(1,20)=5.12, p=.035), with larger activity for the low proportion congruent condition than for the high proportion one (that is, mirroring sustained activity). Surprisingly, this effect was neither modulated by task-domain (F<1) nor by congruency (F<1). In other words, the amygdala showed greater event-related activity for the low proportion congruent trials condition independently of whether these trials were congruent or incongruent, and emotional or non-emotional (Figure 4).

5.4. Discussion

In this study, we examined whether there are common and/or dissociable neural mechanisms involved in supporting emotional vs. non-emotional proactive conflict-control processes. To do so, we varied the source of conflict, between emotional and non-emotional, and assessed behavioral and neural effects of encountering and resolving conflict in a proportion congruent manipulation paradigm. In order to delineate brain regions that were uniquely involved in either sustained (block-wise) control processes or in event-related conflict processing (which may or may not be modulated by sustained control processes), we analyzed fMRI data in a hybrid blocked/event-related fashion. At the behavioral level, we observed reliable PC effects showing, as expected, larger congruency effects for the high proportion of congruent trials condition compared to the low proportion of congruent trials condition. Moreover, these effects did not interact with task-domain, as they were of comparable magnitude across the emotional and non-emotional tasks. At the neural level, we obtained three main results, which we will discuss in turn: first, we observed domain-general, sustained control-related activation in a large network of regions prominently including rostral ACC and ventromedial prefrontal cortex (vmPFC), mid-cingulate and posterior cingulate/cuneus cortex, temporal areas spanning into inferior frontal gyrus and insula, and occipital areas; second, we found a dACC cluster showing domain-specific sustained control activity for the non-emotional task; third, we observed phasic conflict-driven activations modulated by control context (i.e., higher conflict signals in the high proportion congruent condition where sustained control is expected to be low) in left anterior insula/operculum, which was specific to the emotional task.

PC effects have been interpreted as a reflection of proactive control (e.g., Braver, 2012; Carter, 2000), that is, as a sustained strategy whereby top-down control (attention to task-relevant stimulus features) is maintained at high levels when encountering a high incidence of conflict, but is disengaged when conflict is rare. In neural terms, proactive control (in contexts where conflict is frequent) has been envisaged as sustained levels of elevated activation in regions involved in implementing said control (Braver et al., 2007; Krug and Carter, 2012). We observed domain-general activity corresponding to this response profile in a large network of regions including anterior and posterior medial cortices, anterior insula/frontal operculum, the basal ganglia/thalamus, and visual cortex. We infer that these regions are involved in domain-general proactive control processes, either as source regions of control signals (a likely role for the anterior regions in this network) or as targets of such biasing (a probable role for the visual regions involved).

The finding that the anterior insula/operculum, aspects of the ACC, and the thalamus were implicated in sustained task-set maintenance in the present study is highly compatible with previous findings from hybrid blocked/event-related studies across many different task contexts. In particular, Dosenbach and colleagues (2008; 2007; 2006) analyzed a number of such data sets and proposed two core control networks with differing temporal dynamics: a fronto-parietal network that acts over short time scales (e.g., performing control adjustments on a trial-by-trial basis) and a cingulo-opercular (CO) network that sustains top-down task-sets over extended temporal epochs. The present results support the latter network's purported role in proactive control, and we extend the previous literature by showing that this network acts in a domain-general fashion, supporting sustained control both over non-emotional and emotional conflict. Further in line with these findings, a recent imaging study using the PC paradigm in a non-emotional task context observed sustained control activation to be centered on the medial frontal cortex (Wilk et al., 2012). In addition to these anterior activations of regions putatively involved in extended conflict-control processes, we also observed sustained activations in posterior visual processing areas, indicating that stimulus processing is enhanced in high control conditions, presumably as a result of top-down biasing (e.g., Egner & Hirsch, 2005b). Interestingly, those block-wise activations were task-independent, suggesting that control over stimulus processing might be applied in equal measures for both types of conflict. This finding also chimes with data from Wilk and colleagues (2012) who reported sustained activity in the fusiform gyrus during high PC blocks in a non-emotional context.

However, in addition to these domain-general sustained control signals, we also observed task-specific sustained control activity in a dorsal area of the ACC where proactive control signals were exclusive to the non-emotional task. This region is located caudally and dorsally to pregenual ACC areas previously associated with reactive control processes in the emotional domain (Etkin et al., 2006; Egner et al., 2008) but somewhat ventral and rostral to the ACC regions typically found to express conflict-related signals in non-emotional tasks (e.g. Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). A possible role for this region in sustaining proactive control processes is intriguing, and some precedence for this suggestion can in fact be found in the literature. For instance, Aarts and colleagues (2008) found this region to be activated by informative (relative to uninformative) cues indicating the congruency of subsequent Stroop stimuli, thus indicating a role in proactive control processes. A parallel with respect to the sustained nature of the ACC activation we observed in the present study can be found in Kouneiher et al. (2009: see also Egner, 2009) who argued that this anterior aspect of the dACC is involved in supporting temporally extended task motivation. Finally, given that the low proportion congruent condition is associated with a high incidence of incongruent trials, it is also possible that this (quite anterior) ACC region in question is in fact involved in conflict-monitoring over long time-scales (as opposed to more posterior ACC regions dedicated to monitoring conflict over shorter time-scales), as has been hypothesized by De Pisapia and Braver (2006). Why any of these possible functional roles for this region would be exclusive to the non-emotional conflict task, however, is presently unclear.

Thirdly, we also observed phasic conflict-driven activations in the (left) anterior insula/operculum, which showed greater activity for incongruent trials than for congruent trials when incongruent trials were rare (and behavioral conflict was at its highest level). This response profile has previously been interpreted as reflecting conflict processing as modulated by sustained control (e.g., Carter et al., 2000): when sustained control is high (in the low proportion congruent blocks) no conflict signals are observed, but when proactive control is low or absent (in the high proportion congruent blocks) infrequent incongruent trials elicit high conflict, which is reflected in the activation profile of these brain regions. The anterior insula/operculum has in fact reported to display this response pattern both in non-emotional (Carter et al., 2000; Grandjean et al., 2012; Wilk et al., 2012) and emotional task contexts (Krug & Carter, 2012). Importantly, the present study, being the first to directly contrast PC effects between emotional and non-emotional tasks, was able to test whether this region shows preferential conflict-tracking responses in either context. Our results document that phasic, control-modulated conflict signals in the left anterior insula/operculum were in fact specific to the emotional task context, suggesting a domain-specific role in emotional conflict-tracking for this region.

The anterior insula is a paralimbic cortical region that is considered to be a core component of affective processing systems in the human brain (e. g., Kober, et al., 2008; Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012). In line with the present findings, previous studies have documented phasic insula responses to salient emotional distracter stimuli (e.g., Dolcos & McCarthy, 2006) and a recent study by Chechko and colleagues (2012) has in fact observed stronger left anterior insula responses to emotional than non-emotional conflict in a face-word Stroop task analogous to the one employed in the present study, suggesting a preferential involvement of the insula in emotional conflict processing. The current results extend this finding by showing that the insula's response to emotional conflict furthermore displays a modulation by proactive control processes. One possible functional role of the insula in this regard is highlighted by a recent study suggesting that this region might integrate signals of cognitive demand with affective stimulus salience (Gu, Liu, Van Dam, Hof & Fan, 2013). Along similar lines, an intriguing speculative interpretation of the insula's role in the present study could rely on its involvement in a putative "salience network" (Seeley, et al., 2007) that facilitates the detection of important environmental stimuli (such as a rare incongruent trial in the context of a high proportion congruent block), and initiates attentional control signals in turn (Menon, 2010).

Finally, we analyzed face-sensitive regions of interest derived from an independent functional localizer task. Both the FFA and amygdala were tonically more active under conditions of high relative to low sustained conflict-control (i.e., in the low proportion congruent blocks), irrespective of task-domain. Additionally, the FFA also displayed higher event-related responses for incongruent than for congruent stimuli, again across both tasks, whereas the amygdala displayed generally increased stimulus-evoked responses during high control (low proportion congruency) blocks. These data are commensurate with the assumption that regions involved in the perceptual analysis of task-relevant stimulus information (i.e., faces) are subjects to sustained, proactive top-down biasing in the context of a high frequency of incongruent distracter information. In fact, both the FFA and amygdala have previously been found to be targets of top-down modulation by reactive (trial-by-trial) control in non-emotional and emotional conflict tasks, respectively (Egner & Hirsch, 2005a; Etkin et al., 2006; Egner et al., 2008). Although FFA activity in the present data set was not significantly modulated by task-domain, it was numerically stronger for the non-emotional than for the emotional task, which corresponds to previous findings concerning reactive conflict adaptation processes (Egner, et al., 2008). The lack of a task-domain effect in the amygdala, on the other hand, seems puzzling, given its well-established specialization for detecting emotionally salient stimuli (e.g. LeDoux, 1996) as well as previous findings in reactive control experiments (Etkin et al., 2006; Egner et al., 2008). One feasible explanation for this null-finding is that both tasks involved the continuous differentiation of facial features (to determine either gender or affect), which, given the amygdala's general responsiveness to face stimuli (e.g., Ishai, 2008), may have created a ceiling effect that did not allow us to detect a significant additional enhancement of amygdala activity in the emotional task context.

5.5. Conclusions

In summary, we present novel findings of a partial dissociation between neural mechanisms mediating proactive conflict-control in the emotional as compared to the non-emotional domain. Specifically, our results support the idea of a cingulo-opercular network involved in sustained, proactive control processes, and we extend this notion by showing that this network sustains top-down set regardless of whether the task involves control over non-emotional or emotional conflict. By contrast, domain-specific activations were observed in a region of the dACC that displayed sustained control-related activity exclusively in the non-emotional context, and in the left anterior insula, which tracked conflict as a function of control-context but did so exclusively in the emotional task context. The present data suggest that, akin to the domain of reactive conflict-control (Etkin et al., 2006; Egner et al., 2008), there are both overlapping and distinct neural substrates involved in the proactive control over emotional and non-emotional conflict.

CHAPTER 4

Summary of results

The main goal of the present thesis was to study attentional control, specifically, whether it was composed by one or several mechanisms, and their possible neural implementation.

As it has been explained beforehand, as tools to answer that question we have used two effects typically related to cognitive control: sequential congruent (SC) and proportion congruent (PC) effects. The first one is the reduction of congruency effects when the previous trial is incongruent compared to when it is congruent. By contrary, PC effects are the reduction of congruency effects in high conflict contexts, that is, in contexts with larger proportion of incongruent trials. If both effects can be dissociated would indicate that the mechanisms underling them are different. Therefore, on the basis on that idea we carried out all our experimental series, and used different approaches, behavioral, group (aging) and neural approaches, to dissociate the mechanisms underlying cognitive control. Next we will summary the main results of each approach.

1. Behavioral approach

Firstly, we studied whether SC and PC effects were different regarding to conflict-type specificity. A previous study showed that while SC effects are conflict-type specific, PC effects can be conflict-type general (Funes et al., 2010b). Thus, SC effects are only present when conflict type repeats across consecutive trials. By contrary, PC effects can transfer from the conflict where the proportion of congruency is manipulated to a different one with neutral proportion manipulation. In our *experimental series I*, we confirmed those results and extended them by showing that PC effects were transferred from a phase where only one conflict was presented (Simon) and manipulated its proportion of congruency, to a subsequent phase where two conflicts were presented (Simon and Spatial Stroop) with no proportion manipulation. By contrary, SC effects remained conflict-type specific. Therefore, we again showed dissociation between SC and PC effects based on their conflict-type specificity. Besides, we showed that PC effects constituted a sustained strategy since they transferred from one phase to a posterior one. From that studied we concluded that while SC effects reflect a more reactive mechanism that applies control after conflict is experienced (they are the results of a reaction to conflict), PC effects reflect a more proactive and sustained mechanism that recruits control in a more preparatory way, hence, before experiencing conflict.

However, the dissociation between the two effects on the basis of their specificity seems not that strong, since PC effects have also been shown to be specific. For example, Crump et al. (2006; 2008; 2009) found that when manipulating the proportion of congruency between locations (i.e. up associated to high proportion of congruent trials and down with low proportion of congruent trials), while keeping neutral the overall proportion of congruency, PC effects were also observed. Thus, participants applied a task-set strategy depending on the proportion congruent associated to each location. Then, they were task-set context dependent, showing context-specific proportion congruent (CSPFC) effects. Those results are better explained on the basis of a reactive mechanism. That is, the strategy is bound to a certain location, and that location is what retrieves the specific strategy. Therefore, conflict is resolve as a "reaction" to the context. To that point, one might argue that SC and CSPC effects reflect the same "reactive" mechanism, one to the conflict and another to the context. But we have shown that PC effects can also be general. Therefore, different evidence supporting the idea of SC and PC effects reflecting different mechanisms is needed.

With that purpose, we run *experimental series II* in which we showed PC effects in the absence of SC effects. To do so, we developed a novel way to analyze PC effects. We relied on the fact that SC effects are conflict-type specific, and therefore they are absent when conflict-type alternates. Then, by randomly intermixing different conflict types within the same block we could have incongruent-incongruent transitions alternating from different conflict types, where SC effects are absent. Besides, we manipulated only one conflict type to produce PC effects and see whether they transfer to the other one. Importantly, we analyzed conflict-type alternation trials and found significant PC effects. However, those PC effects were specific to the conflict on which the proportion of congruent trials was manipulated. In conclusion, from that study we could argue that PC effects cannot be explained by the same reactive mechanism than SC effects, even when both are specific to conflict type.

From our two previous experimental series, we can conclude that PC effects has to be explained on the basis of a different mechanism than SC effects, but we do not know much about the nature of that mechanism. As we have mentioned beforehand, previous studies have investigated the nature of PC effects, looking at whether they are specific or general, but the majority of those studies have SC effects confounded with PC effects. Similarly, other studies have gone further and tested whether PC effects are modulated by the percentage of proportion congruent manipulation (Logan & Zbodroff, 1979; Blais et al., 2010). However, they also have SC effects embedded on PC effects. Thus, we cannot be sure that those results are actually reflecting the nature of SC effects.

Therefore, in *experimental series III*, we wanted to study the nature of PC effects when they do not involved SC effects. Specifically, we firstly confirmed that PC effects were observed in the absence of SC effects, and secondly, we tested whether those "pure" PC effects were specific or general to conflict type. Importantly, we investigated whether they were modulated by the percentage of proportion congruent manipulation. Besides, we also studied whether the nature of PC effects were different depending on the conflict where they were created. That is, in our previous experiments we have manipulated Simon conflict while keeping neutral Spatial Stroop, and tested whether the transfer was from Simon to the Spatial Stroop conflict. However, in the present experimental series, we did both manipulations, that is, also manipulated the proportion of Spatial Stroop congruent trials, while leaving neutral Simon, to test whether PC effects transfer from Spatial Stroop to Simon. Our results showed, once more, PC effects in the absence of SC effects. Interestingly, pure PC effects were conflict-type specific when Simon conflict was the manipulated conflict (they were only present in Simon trials), while they were general when Spatial Stroop was the manipulated conflict (they were present in both Spatial Stroop and Simon conflict trials). Further more importantly, pure PC effects were modulated by the percentage of proportion congruent manipulation, being smaller for 60/40% manipulation, increased for 70/30% and larger for 80/20% manipulation. However, and quite intriguing, that modulation was conflict-type specific, even for general pure PC effects. That is, when Simon was the manipulated conflict, PC effects modulation took place on Simon conflict trials only. Similarly, when Spatial Stroop was the manipulated conflict, PC effects modulation was present only on Spatial Stroop conflict trials.

2. Group (aging) approach

A different way of studying whether SC and PC effects are different, and the nature of the mechanisms underlying them, is by analyzing how they vary depending of group differences as aging. That was the main goal of *experimental series IV*, in which we studied whether SC and PC effects are differently affected by normal aging. Besides, we also wanted to study the general impact of aging on attentional cognitive control. Importantly, we distinguished between different processes that contribute to the overall performance, since we believe that age-related deficits need to be delimited and studied in a process-specific approach. In *experimental series IV* we used a task that allowed us to distinguish between several processes directly or indirectly involved in attentional control. Thus, we were able to, as in previous experiments, tease apart pure PC effects (considered a task-set strategy that resolves conflict in a proactive manner) from SC effects (that are reactive in nature). Besides, we also used the activation-suppression model developed by Ridderinkhof (2002), which allowed us to tease apart the contribution of the automatic response capture by irrelevant information from the selective inhibition of that task-irrelevant related response. Therefore, we distinguished between 3 processes responsible for the overall outcome: automatic response capture (that produces conflict itself); detection of that conflict (in order to recruit control); and control implementation (that resolves conflict). Within the latter, we differentiated between reactive control (as the mechanism that resolve conflict after experiencing it, both within and across trials) and proactive control (as a preparatory task-set active before conflict is encountered). We observed that older adults showed larger automatic capture toward the task-irrelevant dimension, but restricted to Simon conflict. Besides, older adults also showed stronger response conflict than younger adults, that is, larger congruency effects, but in both cases conflict was indeed detected. Finally, older adults showed deficits on reactive control mechanisms within the trial (but only for Simon conflict), while the other two were similar to younger adults.

Thus, in this experiment we observed that older adults did not present any control impairment, since they showed comparable SC and PC effects. What it seems different is the impact of task-irrelevant information, since they are more strongly captured by it, it is harder for them to inhibit its impact (although, with time, they get to do it, as observed in an accurate resolution of conflict at late responses) and it causes a larger response conflict reaction. The fact that this is confined to Simon conflict and not to Spatial Stroop conflict is not surprising if one takes into account the nature of the conflict. Simon is a response conflict, while Spatial Stroop is a perceptual conflict. Therefore, if Simon is a response conflict, it is expected to find stronger automatic response capture compared to Spatial Stroop, where the automatic response is not the conflict itself but the indirect consequence of having processed task-irrelevant information. In fact, when doing Simon and Spatial Stroop, usually larger congruency effects are observed for Simon than for Spatial Stroop. If older adults are more driven by automatic behavior, that is, more sensitive to task-irrelevant information, one could expect to find even stronger capture by Simon for them. In reference to the suppression of task-irrelevant information, they actually do not show deficits since, as observed on error rates, they do not show error differences between congruent and incongruent trials, although they are slower for incongruent trials. That means that they need to be slower for being able to suppress task-irrelevant information. Besides, it is logical to find differences in Simon since they actually start from larger automatic capture. Therefore, it seems that older adults are more sensitive to task-irrelevant information, but they do not have deficits on dealing with it.

3. Neural approach

Finally, we used a neural approach to better understand the mechanisms underlying PC and SC effects. As we have explained in the introduction, the reactive mechanism reflected by SC effects has been extensively studied using fMRI techniques (e.g., Egner & Hirsch, 2005a; 2005b; Kerns, et al., 2004). However, little attention has been paid to the proactive mechanism reflected by PC effects (e.g., Carter, 2000; Granjean et al., 2012; Wilk et al., 2012; Krug & Carter, 2012). Therefore, in *experimental series V* we sought for brain areas associated to proactive control, hence, showing larger activity for high conflict contexts (high proportion of incongruent trials) where proactive control is recruited. Besides, we also wanted to test whether the same areas were involved for emotional and cognitive (non-emotional) conflict resolution. To do so, we sought for areas showing sustained activity during high conflict contexts, since proactive control is supposedly to be a sustained task-set strategy applied before stimulus onset, that is, in a preparatory fashion.

Our results showed larger extensive sustained activity in the high porprotion of incongruent trials condition, involving anterior cigulate cortex, cingulated gyrus, middle and superior temporal gyrus, inferior frontal gyrus, insula, basal ganglia and posterior areas. Interestingly, those activations were task general, that is, they did not depend of task domain. Besides, we also showed specific dorsal anterior cingulated cortex activations for the non-emotional task, showing greater activity for the high proportion of incongruent trials condition. Finally, we also found transient activity in the inferior frontal gyrus and insula for the emotional task and for incongruent trials in the low proportion of incongruent trials condition. That was interpreted as showing conflict detection activity.

Therefore, from our results we can conclude that proactive control reflected by PC effects involved extensive areas showing greater activity when control is recruited and regardless of task domain. Those areas involved posterior areas indicating that control is actually being applied by biasing posterior activity that results in an enhancement of task-related processing. Importantly, the areas we reported for proactive control were different from the areas typically related to reactive control measured by SC effects. Specifically, for reactive control prefrontal cortex activity has been reported (e.g., Egner & Hirsch, 2005a; Kerns, et al., 2004). Therefore, our findings might indicate that proactive control recruit different areas than reactive control, supporting a dual conception of cognitive control.

CHAPTER 5

Discussion

After summarizing the results of the experimental series, next we will try to integrate them with the current literature about cognitive and emotional control. First, we will discuss whether there is one general control mechanism or several ones, and the evidence supporting those views. Secondly, we will present four possible characteristics of control implementation, that is, whether control is reactive or proactive, transient or sustained, specific or general (i.e., local or global control implementation), and on the basis of which mechanism can be applied (i.e., task-relevant enhancement or task-irrelevant inhibition). Finally, we will present some evidences about the neural correlates of control.

1. Several control mechanisms?

The main goal of the present thesis was to elucidate whether only one or more control mechanisms underlay attentional cognitive control. According to unitary views (i.e., Botvinick, et al., 2001; Verguts & Notebaert, 2008, 2009), cognitive control is a single mechanism that resolves every kind of conflict, regardless of its nature (perceptual, motor, etc) or its domain (emotional vs. non-emotional). Our results challenge that conception by showing clear dissociations between two effects, considered reflections of different control mechanisms: sequential congruent (SC) and proportion congruent (PC) effects. Specifically, we have dissociated those effects in different manners. First, we have shown that, while SC effects are specific to conflict type, that is, they disappear when conflict type alternates across consecutive trials, PC effects can be conflict-general, that is, they are observed in the conflict where proportion of congruency manipulation takes place and, interestingly, sometimes also in the conflict where the proportion of congruency is neutral (Experimental series I). Those results are in line with previous works carried out in our lab (Funes, et al., 2010b; Funes, Torres-Quesada, Montoro-Membila, & Lupiáñez, 2010).

However, one can argue that claiming both effects as independent based on their specificity is not sufficient and strong evidence. In fact, several studies have shown that, on one hand, PC effects can be item-specific (i.e., Blais & Bunge, 2010; Blais, et al., 2007; Jacoby, et al., 2003) and context-specific (i.e., Crump, et al., 2006; Crump & Milliken, 2009; Crump, et al., 2008), and on the other hand, that SC effect can be general (Freitas, et al., 2007; Kleiman, et al., 2013; Kunde & Wühr, 2006), challenging that general-specific dissociation. In an attempt to overcome that critic, we used a different approach where we again dissociated both effects but now showing that PC effects were present in the absent of SC effects. To do so, we developed a new analysis protocol that allowed us to find situations where SC effects are absent. As we said, this finding is really important since the proportion of congruency manipulation has embedded the unbalanced frequency of incongruent-incongruent transitions. That is, in high frequent incongruent contexts, the number of incongruent-incongruent transitions is higher than in low frequent incongruent contexts. Thus, getting rid of SC effects is crucial to actually argue that PC effects are different from SC effects. We resolved this problem presenting PC effects in the absent of SC effects. Specifically, since it has been extensively proved, SC effects disappear when conflict type alternates across consecutive trials (Akçay & Hazeltine, 2011; Egner, et al., 2007; Notebaert & Verguts, 2008; Verbruggen, et al., 2005, Experiment 2; Wendt, et al., 2006). Therefore, by showing PC effects on those SC effects-absent trials, as we did, we argued that PC effects and SC effects cannot be explained by the same mechanism. Interestingly, those PC effects were specific to conflict type, suggesting that being conflict-type specific or not has nothing to do with whether they reflect the same mechanism than SC effects or not. That finding was further confirmed in other experiments, where we again observed conflict-type specific PC effects in trials where SC effects were absent.

In conclusion, our results support the idea of several control mechanisms, at least, one reactive (underlying SC effects) and one proactive (underlaying PC effects). Therefore, we achieved the same conclusion that Braver et al.' Dual Model of Cognitive Control (2007) and extended it to the attentional control field.

2. Characteristics of control mechanisms

Once the two mechanisms are dissociated, it is important to understand how those control mechanisms work, whether they are different regarding to conflict type (specific or general), their neural basis, etc. Specifically, in this section we will try to understand the concepts typically used in cognitive control (i.e., reactive and proactive, transient and sustained, specific and general, task-irrelevant inhibition and task-relevant enhancing) in the attentional control field and analyze whether they can be applied to the mechanisms that we have claimed as different control forms (the mechanisms reflected by SC effects and PC effects).

2.1. Reactive versus Proactive

Based on the Dual Model of Cognitive Control (Braver, et al., 2007) a reactive mechanism can be conceived as online conflict resolution adjustments made at the moment of the response, that is, after stimulus onset; whereas a proactive mechanism can be conceived as a preparatory strategy that takes place before stimulus onset. Typically, SC effects are considered a reflection of reactive control (e.g., Correa, Rao, & Nobre, 2009; Egner, 2007; Egner, et al., 2010; Grandjean, et al., 2012) while PC effects can be considered a task-set strategy that resolves conflict proactively (e.g., Grandjean, et al., 2012; Krug & Carter, 2012; R. West & Bailey, 2012). However, although these two forms of control are somehow assumed in the attentional control domain, there is not a model based on interference tasks that defines whether reactive and proactive mechanisms are reflected by SC and PC effects. Nevertheless it is important to know whether that assumption is true.

Obviously, to study whether conflict resolution in SC effects is a reactive mechanism and conflict resolution in PC effects is a proactive mechanism, on the basis of when control is applyed, one should test whether SC and PC effects occurs after or previous to stimulus onset. Behavioral approaches make difficult to draw conclusions of this nature (Czernochowski et al., 2010). For example, from our behavioural data in the present thesis, we cannot be sure about whether SC effects reflect a reactive mechanism and PC effects a proactive one, since we don’t know when control is actually applyed. Therefore, other techniques, such as electrophysiology or fMRI, will be better tools to study reactive and proactive mechanisms. Obviously, fully covering this issue with all these techniques is beyond the focus of the present thesis but we will present a few experiments that support our assumptions of SC effects as reactive and PC effects as proactive mechanisms.

Regarding SC effects as reflecting control resolution after stimulus onset, some studies have tested the modulation of a transient after-stimulus-presentation component, medial frontal negativity (MFN), related to conflict detection (i.e., Czernochoski et al., 2010; Nessler et al., 2007; Nessler et al., 2010), showing that when the previous trial is incongruent the amplitude of MFN decreased (Czernochoski et al., 2010; Nessler et al., 2007). Therefore, they suggested that the conflict is reduced due to control implementation as result of having experienced conflict. However, evidence supporting the idea of PC effects as control adjustments applied before stimulus onsets is hard to find. In fact, the vast majority of studies interested on proactive control as a preparatory strategy have used a cued-conflict paradigm, in which a cue can be informative of the upcoming conflict level (e.g., congruent or incongruent; easy or hard, etc). Authors of those studies reason that any activity present during the cue-stimulus onset period is indicative of a preparatory strategy. For example, Correa et al. (2009), using EEG, studied how reactive and proactive control forms modulated a component related to conflict detection (N2). They observed modulations of N2 by both reactive (as measured by SC effects) and proactive control (as measured by a precue indicating congruency), but the two modulations were temporally and spatially different. Interestingly, they observed that N2 showed up earlier when proactive control was engaged, indicating that this control is in fact a preparatory strategy that speeds up conflict processing and control resolution.

Other studies using fMRI have also studied proactive control by testing the brain activity between cue and stimulus onset. However, the results of those studies are controversial, since some of them show preparatory activity in conflict-related areas such anterior cingulate cortex (e.g., Sohn, Albert, Jung, Carter, & Anderson, 2007), while other did find activity on different areas (e.g., Luks, Simpson, Dale, & Hough, 2007). Besides, other studies highlighted the need to differentiate between task-general cues and task-specific cues (Stern, Wager, Egner, Hirsch, & Mangels, 2007), since without doing that results can be interpreted as reflecting a general attentional set (i.e., being prepared to attend something) and not as reflecting a conflict-resolution task-set (e.g., being ready to pay greater attention to color). And even more importantly, those authors also highlighted the fact that brain activity found during cue-stimulus period should be correlated to behavioral conflict resolution measures, to confirm that the brain activity is truly reflecting a preparatory strategy that results in better conflict resolution.

In summary, it seems that SC effects reflect a reactive control mechanism applied after stimulus processing. However, we cannot claim that PC effects reflect a proactive mechanism that applies control before stimulus onset since there are not studies testing that hypothesis. But we think that the reason for the lack of these studies is the very own nature of PC effects. That is, the locus of these effects is perhaps after certain level of conflict is encountered, therefore, within a block of trials there is only one situation that could reflect the change from a reactive way of resolving conflict to a proactive way of resolving conflict. From that moment on, the basal state of the system has actually changed, remained in a "preparatory" mood until the level of conflict change to a low one. Therefore, we believe that a better strategy to see whether PC effects reflect a proactive mechanism might be to look for evidence of sustained control underlying PC effects. This topic will be discussed in the next section.

2.2. Transient versus Sustained

The terms transient and sustained control forms are also commonly used in the cognitive control literature and can be coupled with transient/reactive and sustained/proactive. Obviously, a transient process is active for a brief period of time while a sustained process is on for a certain period of time. The question is whether reactive control mechanism has to be transient and whether proactive one has to be sustained. Logically, one might reason that reactive control, which acts after conflict is detected, is a transient mechanism that it is on during the time conflict is being resolved but once it is resolved, the mechanism is off again. By contrary, a proactive mechanism would be something more sustained since it is a preparatory strategy that keeps the control strategy active for a longer period of time. In this line, one might reason that in proactive control participants' basal state change from "neutral" to a preparatory sustained conflict-control mood, sustained over a period of time, allowing participants to be ready for conflict resolution. Supporting the associations reactive/transient and proactive/sustained, the Dual Model of Cognitive Control (Braver, et al., 2007) showed transient activations in ACC and prefrontal cortex associated to reactive conflict detection and control resolution and sustained activations within the same areas associated to proactive conflict-control.

Therefore, if PC effects reflect a proactive mechanism, they should be mediated by sustained functioning of this mechanism; whereas if SC effects reflect a reactive mechanism, they should be mediated by transient activation of this mechanism. Evidence from PC effects reflecting a sustained control strategy come from our results in experimental series I, where we showed PC effects transfer from one phase to a subsequent phase, that is, sustained over time. Besides, we also showed in experimental series V that PC effects are related to sustained activity when proactive control is involved (high conflict contexts). Interesting, our results showed sustained activity in areas related not only to control implementation, but to conflict detection (e.g., ACC) and stimulus processing (e.g., ventral visual areas). Those results suggest that proactive control involves the sustained work of several areas in order to resolve conflict, which will be explained in more detailed in the section "neural correlates of the defined control mechanisms".

Apart from our studies, not many studies in the field of attentional control have shown clear evidence for the action of a control mechanism in a sustained way. Using neuroimaging, only few studies found significant sustained activity related to proactive control (as far as we know, Krug & Carter, 2012; Wilk, et al., 2012). We believe this type of evidence is clearly needed since, as we have mentioned in the introduction, PC effects has been interpreted as reflecting a mechanism different from a sustained task-set strategy that result in task-relevant enhancing. Therefore, by showing that they are different to SC effects (then to reactive mechanism) as we have done, and that are sustained over time, seems can be derived from our results, would support the idea that PC effects are the reflection of a task-set strategy that allows to be "prepared" previously to stimulus onset.

For SC effects reflecting a transient mechanism, many studies have reported greater transient activity in incongruent-incongruent transitions than in congruent-incongruent transitions (e.g., Egner, 2007; Egner, et al., 2010; Egner, et al., 2008; Egner & Hirsch, 2005b; Wilk, et al., 2012). It is important to highlight that SC effects are considered a carry-over effect of the reactive mechanism on trial n-1 that affect trial n. For example, Scherbaum and collegues (2010) showed EEG data indicating continuous within-trial readjustments of control in the occurrence of conflict, and interestingly, the dynamics of these within-trial readjustments depended on previously experienced conflict, indicating a carryover of previous readjustments to the next trial.

Then an important question is how long that carry-over effect lasts. One might think that it will be active until next stimulus onset. Therefore, it would be "sustained" over that inter-stimulus interval (no matter its length). By contrary, it can also be the case that it will be active after stimulus onset and decays right after, being completely transient. One can find controversial results in the literature supporting both views. According to Egner et al. (2010), SC effects show up shortly after stimulus onset and decay with time. In fact, they did not observe significant SC effects beyond 2,500–3,000 ms ISI. Similalry, other studies have reported SC effects only when using short RSI-intervarls (Notebaert & Soetens, 2006; Notebaert, et al., 2001). By contrary, Notebaert et al. (2006) varied RSIs between 50 and 200 ms and reported significant SC effects only at the longer interval. On the other hand, Wühr and Ansorge (Wühr & Ansorge, 2005) had ISI lengths of 1,250 and 5,750 ms and reported higher SC effects magnitudes at the shorter than at the longer ISI, but still observed SC effects at an ISI of 5,750 ms. Even more, other studies have shown SC effects when they are separated by another trial, that is, n-2 to n SC effects (Fernández-Duque & Knight, 2008). The differences results had led some authors (e.g., Egner, et al., 2010) to suggest that the rate of decay of the SC effects would vary as a function of the mean duration and overall distribution of ISI/RSI intervals.

One might argue that the use of SC effects to study reactive and transient control mechanism could not be as appropriate since, by definition, they are consider to be the carry over effect of applying control in n-1. Therefore, to study pure reactive control mechanism the analysis should be based on n trials, that is, when conflict is resolve for the first time. A way of doing so is by the activation-suppression model (Ridderinkhof, 2002a, 2002b) where conflict resolution is divided into early response capture, reflected on fast errors, and selective suppression of the irrelevant information (reflected on late reduction of interference effects), which reflect control implementation. That is what we did in experimental series IV, where we differentiated between control resolution within the trials and control resolution as a carry-over from the previous trial. If SC effects are the carry-over effect of a pure reactive mechanism, we expect that SC effect reflect the same reactive mechanism. However that interpretation seems challenged by our results since older adults showed differences compared to younger adults regarding reactive control implementation within the trial but not regarding SC effects (across trials). Yet, even if older adults showed differences on reactive control within the trial, they actually resolved conflict as reflected by error rates (no differences between congruent and incongruent trials on error rates in late bins). It seems that they needed longer time to resolve conflict, but they were able to finally resolve it. Therefore, since they did not have deficit on proper reactive control mechanism reflected on current trial, neither on SC effects, that would support the idea that both reactive mechanisms are in fact the same reactive mechanism, but SC effects are the carry-over effect of that mechanism affecting the next trial.

In summary, although further research is needed, proactive control as reflected by pure PC effects seems to be sustained (at least in our experimental series). By contrary, it seems that the reactive control mechanism is transient, that is, is active during the time conflict is present. Besides, it might be more appropriately or more precisely measured at the moment conflict is being resolved, hence, during the current trial. Similarly, it seems that SC effects are the result of resolving conflict previously. However, they have been shown shortly after previous response (that is, conflict resolution) and long after it, (e.g., conflict resolution of n-2 can affect conflict resolution on n). But it is not clear whether this evidence for sustained SC effects. We believe that it depends on several factors: length of the interval, priming processes, and different feature integration processes. We argue that priming effects drive those situations. Firstly, if the interval is short, the action of the reactive mechanism has not decayed, influencing the following trials (Notebaert & Soetens, 2006; Notebaert, et al., 2001). However, when the interval is longer, but the following trial involved the same control resolution type, that control type is primed (i.e., priming of control processes; a type of prime of a higher level than priming of feature repetitions). Finally, if that control process has been bound with stimulus features of the trial, when the same feature repeats, it helps to retrieves the bound control processes. We can speculate further by suggesting that, possibly, that feature integration process is modulated by individual differences, resulting in domain-general or domain-specific control processes. In fact, recent studies have highlighted the importance of considering individual differences on conflict-control processes (Jiang & Egner, 2013).

2.3. Specific versus General

Another important aspect of cognitive control is whether it acts locally or in a more general way, and whether reactive and proactive mechanisms can actually be applied in both ways. When reviewing the existing literature, we see that there is evidence supporting reactive specific and general control, and proactive specific and general control.

For example, reactive mechanisms as reflected by SC effects have been extensively found to be conflict specific (Akçay & Hazeltine, 2011; Egner, et al., 2007; Funes, et al., 2010a; Notebaert & Verguts, 2008; Verbruggen, et al., 2005, Experiment 2; Wendt, et al., 2006). Similarly, our results in experimental series I, II, III and IV confirmed that, since we found that SC effects disappeared when conflict type alternated across consecutive trials. However, when not really different conflict types are manipulated, specific and general SC effects have been found: specific to the context (Fernández-Duque & Knight, 2008; Spapé & Hommel, 2008) or general to tasks (Freitas, et al., 2007; Kleiman, et al., 2013; Kunde & Wühr, 2006).

Regarding PC effects, previous studies have shown that they can be conflict-type general (e.g., Funes, et al., 2010b; Funes, et al., 2010), which was further supported by our results from experimental series I and part B of experimental series III. But they can also be conflict-type specific, as indicated in our results from experimental series II, III (part A) and IV. Apart from being conflict-type specific or general, when only one conflict type is presented, other studies have found both item-specific (Blais, et al., 2007; Jacoby, et al., 2003) and context-specific (Cañadas, et al., in press; Crump, et al., 2006; Crump & Milliken, 2009; Crump, et al., 2008; King, et al., 2012) PC effects, and item general within context PC effects (Crump & Milliken, 2009). Therefore, it seems that: 1) PC and SC effects can act locally or in a more general way; and 2) the degree to which they are locally applied varies (conflict, context, and item). The pertinent question is on which factors cause depend the different local vs. general control implementation, but the answer to this question remains unknown at present. Therefore, we will speculate some possibilities based on the nature of the control mechanisms itself, that is, on whether they are a “prepared” control strategy applied before stimulus onset or a reactive control resolution applied at the moment of encountering conflict.

In the case of PC effects, we suggest that one possible factor that influences the control implementation before conflict takes place is the strategy that participants “learn”, that is, what they try to pay attention to during the task, such as response to the color of the stimuli when it appears above location (i.e., context-specific strategy) or to response to the color of the stimuli in general (i.e., broader strategy apply to every stimulus), resulting in different levels of proactive mechanisms (from item level to a broader level). For example, Cañadas et al. (Experiemt 2, in press) showed context- or item-specific proportion congruent effects depending on the instructions given to participants. That is, in that experiment faces served as context for the manipulation of proportion of congruency at two levels: individual items (i.e., different specific faces were associated to different proportion of congruency) and group level (i.e., different proportion of congruency depending on the gender group of faces). PC effects were individual-specific when the instructions emphasized paying attention to single items, while PC effects were group-specific when the instructions emphasized paying attention to the group.

The key question here is what makes participants to apply a more specific strategy or a broader one. We thought that one possible reason would be how they conceive the context where PC effects are created. That is, in paradigms with two different contexts, if the applied strategy is associated to one context and not to the other, participants might “learn” to apply the strategy in a context-specific manner. That logic would explain Crump et al.’s results (2006; 2009; 2008). It will also explain our results. Thus, although we found conflict-specific effects, a problem of our paradigms is that conflict-type is confounded with context, hence, Simon appears on the horizontal axis (i.e., one conflict-one context) and Spatial Stroop on the vertical axis (different conflict-different context). Therefore, a context change is also a conflict-type change. Therefore, on the basis that different contexts might produce specificity by inducing different strategies depending on the context, we thought that by presenting one general context, participants will learn a general strategy since there is no way of segregating the strategy. To test that idea, we run one experiment where Simon and Spatial Stroop were presented but, instead of presenting them separately in the horizontal and vertical axis as we have done previously, stimuli were displayed at the four corners of the screen. By doing so, both tasks where presented simultaneously in the same trial, without context differentiation. Crucially, we manipulated the proportion of congruency on one conflict (e.g., Simon) and tested whether it transferred to the other conflict where the proportion was neutral. Our results indicated PC effects only for the conflict manipulated. Thus, we observed specificity even when the context was the same for both conflict types (Torres-Quesada, Funes, & Lupiáñez, 2011).

We then thought that, perhaps, the way of considering conflicts as the same or different depends on the context, but considering it as an explicitly induced general context. Thus, by encouraging participants to conceive both conflicts as belonging to the same context they will categorize them as similar, which will induce them to learn a strategy useful for both conflicts (i.e., broad strategy). By contrary, if participants segregate both conflicts as different contexts, that will prevent them from learning a broad strategy. To do so, we presented Simon (in the horizontal axis) and Spatial Stroop (in the vertical axis) intermixed within a trial, with the proportion of congruency manipulated only for one conflict. We instructed participants that the stimuli would appear at four locations, and then explicitly indicated the four locations on the screen. For the "global" participants, the four locations were indicated drawing an imaginary circle on the screen (as belonging to the same context), whereas for the "local" participants, we indicated them by a cross in which horizontal and vertical axis where explicitly drawn with the finger on the screen (as belonging to different contexts). We observed that participants showing general PC effects were the ones for which a global context induction was made, whereas participants showing specific PC effects where the ones for which two contexts differentiation was induce (local induction) (Funes, et al., 2010)-

Another hypothesis regarding what makes participants to resolve conflict in a specific or more general manner, on the basis of the strategy they apply, is related to individual differences. As a first idea, we thought that the global or local tendency of participants to process information might actually modulate the way they apply control. With that idea, in the experiment we just described, we also tested participant's global/local tendency to process information. Interestingly, we found that the tendency to apply control in a general manner correlated with participants' tendency to process information based on global rather than on local attentional focus. As one can expect, people showing larger global focus tendency also showed more general PC effects, suggesting that those people might actually create a broad strategy to resolve conflict. But that correlation was observed only in the group that was globally induced, so maybe we just measured the sensibility to that manipulation. Therefore, more research is needed investigating individual differences regarding the application of control in a more specific vs. general way.

On the other hand, SC effects can also be, as we have mentioned, item, context and conflict specific. However, in this case the reason is not the strategy applied, since there is no strategy. Besides, control is applied at the response time, so the mechanism is completely different to the previous one. What does it modulate specific SC effects? We tried to study that issue by testing whether SC effects were item-specific, context-specific or conflict-specific. To do so, we again used the paradigm described beforehand where the stimuli were displayed at the four corners of the screen, thus, presenting both conflict types within the same context. Besides, the stimuli could be arrows pointing up or down, or the word “ARRIBA” (up, in Spanish) or “ABAJO” (down, in Spanish), with 50% congruent and incongruent trials (50% arrows and 50% words stimuli, i.e., everything at random). Interestingly, we observed SC effects for mixed stimuli trials (e.g. arrow-word) but only within the same conflict-type (e.g. from Simon to Simon, or from Stroop to Stroop). Therefore, it seems that SC effects were conflict-type but not stimulus-type or context-specific (Marino, Luna, Torres-Quesada, Funes, & Lupiáñez, 2013).

As one might have noticed, when studying the specificity of both effects we observed that conflict-type plays a central role. Thus, in PC effects, in the absence of explicit global inductions to make participants create a broad strategy, PC effects were specific to conflict type. Similarly, SC effects were also specific to conflict-type. Why is conflict-type so special? We will argue in the next sub-section that different conflict types possibly involve different ways of applying control, which would be reflected on specific control resolutions (i.e., enhancing task-relevant dimensions). In some cases conflicts share some dimensions, for example, task-relevant dimension. Thus, if the control resolution is based on that shared dimension, it will be useful for both conflicts, observing a transfer of that conflict resolution to other, thus leading to general effects. In any case, we will explain it in more detailed in the following section. However, we have to highlight that this conflict-specific control resolution mechanism is more likely to affect only the reactive mechanism, but not proactive mechanisms. That is, since the proactive mechanism is applied before stimulus onset, the “strategy applied” is likely not to rely on the type of conflict resolved. However, since the reactive mechanism takes place after stimulus onset, thus, after experiencing conflict, thinking that the control resolution will depend on the conflict type is pretty logical. Therefore, we argue that it seems more likely that proactive control level of applicability (item, context or conflict) depend on participant's information processing (induced or as individual differences).

On the other hand, if we assume that conflict type plays an important and independent role in reactive control implementation, when there is only one conflict, what will we expect to find? In the case of SC effects, we suggest the factor driving specificity when there is only one conflict type would be the information encoded at the time of previous conflict resolution. Feature integration theories argue that the information present in a given trial (item, context, etc) is bound with the response to that stimulus (Hommel, 2004; Hommel, et al., 2004). Besides, hybrid conflict learning-memory accounts (i.e., Davelaar & Stevens, 2009; Verguts & Notebaert, 2008, 2009) suggest that the conflict-resolution process is actually bound with active units present at the moment of conflict. Therefore, it is plausible to thing that active units can include irrelevant trial information such as location. Then, when conflict is experienced, the conflict-resolution process and other trial information are bound together. If the same trial information is repeated, conflict-resolution is retrieved, producing specific SC effects (Spapé & Hommel, 2008). However, previous findings also showed general SC effects when using same conflict but different "items" or "contexts" (Freitas, et al., 2007; Kunde & Wühr, 2006). What is happening in that case? That question remains unresolved. Perhaps, as we have suggested beforehand, individual differences play an important role. Similar to PC effects strategy, the way participants process information (i.e., more global or local) might modulate the feature integration process, and thus might modulate whether SC effects under same conflict type are specific or general to the stimulus feature (item or context).

In summary, in this section we have highlighted the idea that conflict type plays an important role in control implementation, possibly because it actually leads to different control resolution strategies (or event conflict-type mechanisms). But that will affect only to the reactive control mechanism. Besides, we have also highlighted the importance of individual differences at different learning levels. Quite speculatively, we have suggested that those individual differences might influence feature integration processes present between stimulus and control resolution process in SC effects. For PC effects, we have suggested and, initially confirmed in the lab, that individual differences might play a role in how abstract the strategy apply when performing the experiment. The idea is that personal ways of processing information, such as global or local processing, might modulate learning-processes. We think that this personal way approaching the task is automatic, and possibility due to previous experiences. In line with the role that individual differences play in domain general or specific control implementation, a recent study has even shown that domain general control application was related to different brain areas depending on the participant (Jiang & Egner, 2013).

2.4. Task-irrelevant inhibition versus Task-relevant enhance

As we have described in the previous section, we believe that conflict type is actually influencing control mechanisms themselves, but not only because it is encoded within the trial information, but as an independent factor. In fact, the idea that the control mechanism that is applied will depend on conflict type has been already suggested (Egner, 2008; Egner, et al., 2007; Soutschek, et al., 2013). Specifically, S-R or Simon interference has been related to the inhibition of the incompatible response active by task-irrelevant information while S-S or Spatial Stroop interference has been related to the enhancement of task-relevant information (Soutschek, et al., 2013). Supporting that idea, a very recent study showed that if one disrupts the functioning of areas related to different conflict types (i.e., Simon and Spatial Stroop), control implementation is actually differentially impaired, being affected the one whose neural correlated was impaired but not the other conflict (i.e., Simon but not Spatial Stroop was affected when disrupting presuplementary motor area) (Soutschek, et al., 2013).

We suggested that this conflict-type control specificity is principally observed in the reactive control mechanism. In fact, we observed specific SC effects in our experiments series I, II, III and IV. In those studies, Simon and Spatial Stroop were ramdonly intermixed within a block. That strong specificity can be explained based on the idea that they are different conflict types, that is, Simon is a response conflict type and Spatial Stroop a perceptual conflict type, hence they take place at different processing levels (or representational levels). Therefore, resolving Simon conflict results in the inhibition of the incompatible response representation (conflict type control process), while resolving Spatial Stroop results in the enhancement of the stimulus-relevant dimension at the stimulus representation level. In other words, resolving one does not help resolving the other. Supporting that idea, several studies have shown general SC effects when using different conflict, but importantly, using conflicts that actually arise from the same level of processing (Freitas, et al., 2007; Kunde & Wühr, 2006). For example, Freitas et al. (2007) used flanker and Stroop tasks, which can be considered perceptual conflicts since they come from an overlap between task-relevant and irrelevant stimulus dimensions. Similarly, Kunde and Wühr (2006) used prime-target and Simon tasks, which are response conflicts since the conflict takes place at the response representation layer.

By contrary, some studies have argued that finding general conflict-type SC effects depend on whether they share or not the same task-relevant dimensions (Notebaert & Verguts, 2008), regardless of conflict level. In fact, in that study they also used similar response conflicts (i.e., Simon and SNARC) but observed specific SC effects when they did not show the same task-relevant dimension. Specifically, participants had to make different judgment on each task (i.e., respond to italic dimension or color dimension), performing different operation on the two sets of stimuli As an explanation of that result, other authors argue that the source of information itself, even when they are different, does not defined the domains of control. According to them, what it is relevant is the salience of the boundary between the two tasks that determines the boundaries of control processes (Hazeltine, Lightman, Schwarb, & Schumacher, 2011). Supporting that idea, they showed that when the task-relevant information involved different modalities, even when it is the same conflict, control is applied locally. Besides, we suggest that when different modalities are present in the task-relevant dimension, different neural circuits are involved, then even if the control resolution level is the same, it does not affect the same "representation" (i.e., enhancing color processing is different than enhancing italic processing). Supporting that idea, previous research focusing on emotional and non-emotional sequential conflict effects have found that control implementation involved and act over different areas depending on the conflict domain. Specifically, Egner & Hirsch (2005b) showed dorsolateral prefrontal cortex activity that enhances posterior visual areas activity such as fusiform gyrus when task-relevant information involved face processing in detriment of word reading (task-irrelevant). However, activity in the rostral part of the anterior cingulate cortex inhibiting amygdale responses was found when conflict involved the processing of emotional expression in detriment of the processing of emotional words. Whether the importance of the modality as control level boundary is related to task-relevant or task-irrelevant information remains unclear, but perhaps it will depend on the type of conflict itself.

We suggested before that proactive control is less affected by that conflict-type control specificity, but we found conflict-type specific PC effects in our experimental series II, III (experiment one) and IV. Importantly, those results cannot be explained by a reactive mechanism similar to SC effects since they were absent. Similarly, how do we explain then results in experimental series I and experimental series III (experiment two) where we observed conflict general PC effects using very similar paradigms? and the global/local induction experiment where we again used similar paradigms and found general PC effects? We argue that this depends on the “strategy that is learned”. As said before, individual differences and the paradigm itself can modulate the way we apply control. Therefore, if the strategy is not broad, we are driven by a conflict-type control resolution strategy. However, if the strategy used is broader, it might actually enhance task-relevant instructions, hence, the task-relevant information that shares the conflict we use (i.e., arrow direction).

The fact that in our experimental series I only one conflict was presented could be explained why participants applied a broader strategy, that is, a task-general one. We suggest that participants might adopt that “broad” approach for two reasons. Firstly, because different contexts are not presented, therefore, they could not “learn” to segregate control implementation depending on the context. Secondly, , it seems reasonable that performing such an easy task during 128 trials lead people to actually “learn” the best strategy, which is the task-related one, and try to drive behavior by that learning (that is, changing from goal directed to habit control of action). By contrary, in the other experimental series, Simon and Spatial Stroop were intermixed within the block, which does not allow learning a goal-directed strategy since it actually changes from one trial to other. But in that case, when Spatial Stroop was manipulated, PC transferred to Simon conflict. If the paradigm itself induced a conflict-type specific strategy and we indeed found conflict-type specific effects when Simon was the conflict manipulated, why did we observe general PC effects when Spatial Stroop was the conflict being manipulated? In that case a conflict-type control strategy might have also been "learned", which in Spatital Stroop is the enhancement of task-relevant information. Since Simon and Spatial Stroop share the same task-relevant dimensions, that is, in both cases the direction of the arrow is the relevant dimension, the fact that task-relevant dimension is enhanced due to the Spatial Stroop control strategy affects also to Simon conflict. That would explain our results

In summary, we have suggested that the way control is applied (or what control is applied) depend on conflict-type itself. Besides, we also suggested that it directly affects the reactive control mechanism, but less directly the proactive one. However, other factors such as individual differences and modality of task-dimensions play a role, also contributing to the impact of that conflict-type control specificity.

3. Neural correlates of the defined control mechanisms

In the previous section we have claimed that there are two types of control mechanisms depending on when control is applied, reactive and proactive mechanisms. Besides, we have suggested that reactive control mechanisms perform transient control adjustments while proactive ones implement more sustained ones. Besides, we also indicated that control adjustments might be different in nature and seem to depend on the conflict-type that is resolved. But how are all those mechanisms implemented in the brain? As we have said, there is not a unified model of dual attentional control, but several studies related to this field have tried to clarify the neural correlates involved in attentional control. Therefore, next we will provide existing neural evidences that support and try to articulate them in an attentional control neural arquitecture.

Anterior Cingulate cortex (ACC) and prefrontal cortex (PFC) are typically related to attentional control. Specifically, it is well established that conflict detection is carried out by the ACC (i.e., Botvinick, et al., 2001; Kerns et al., 2004), which sends a signal indicating the need of control recruitment, implemented in the PFC. But are those areas similarly recruited for reactive and proactive control mechanisms? A way of studying this issue is by testing how the areas involved in incongruent trials varied as a function of the previous trials (reactive control) or the general proportion of incongruent trials (proactive control). When studying reactive control, results confirmed that dorsal ACC is involved in conflict detection since it is more active for congruent-incongruent transitions than for incongruent-incongruent transitions (e.g., Botvinick et al., 1999; Kerns et al., 2004). Besides, there is also evidence of increased activity in dorsolateral prefrontal cortex (DLPFC) (e.g., Botvinick,1999; Egner & Hirsch, 2005a; 2005b; Kerns et al., 2004) and posterior processing regions in incongruent-incongruent transitions (e.g., Egner & Hirsch, 2005b). Therefore, it seems that for the reactive control mechanism, once conflict is detected by dACC, triggers control implementation by the DLPFC, which in turn applies control by biasing processing in posterior areas. However, if one claims that there are two control mechanisms, does it mean that different neural areas should be involved? Based on the dual model of cognitive control (Braver et al., 2007), there is no need for different brain areas being involved, but the same areas showing different temporal dynamics. Specifically, they suggested ACC and PFC activations respectively for conflict detection and control implementation that were similar for reactive and proactive mechanisms, but with different temporal dynamics, i.e., transient (short time scale) and sustained (long time scale) respectively.

On the attentional control field, the few studies that have sought for proactive control related activity using PC effects have not found clear results (e.g., Grandjeand et al., 2012; Krug & Carter, 2012; Carter et al., 2000; Wilk et al., 2012). Due to this lack of evidence for proactive attentional control, we tested neural correlates of PC effects in our experimental series V. Specifically we sought for areas showing either unique sustained activity or unique transient activity. Based on our results, we suggest that proactive control is mainly correlated to areas showing sustained activity, since we just observed significant activations for the high conflict versus low conflict block contrast (reflecting control sustained activity) and not for incongruent versus congruent trials in high conflict block (reflecting control transient activity). Thus, we observed: extensive medial frontal activations, including ACC, ventromedial prefrontal cortex (vmPFC), and middle and posterior cingulate areas, spanning into cuneus regions; middle temporal activations extending frontally to the inferior frontal gyrus and anterior insula (i.e., frontal operculum); and ventral visual areas such as lingual gyrus, fusiform gyrus and parahippocampal gyrus; and subcortical regions such basal ganglia/thalamus, and cerebellum.

Previous work using hybrid model and tracking sustained activity have involved some of the previous areas reported. Specifically, Dosenbach et al. (2008; 2007; 2006) described a cingulo-opecular network that acts over a sustained period of time and is related to task-set control. That network includes similar areas than the ones found in our experiment, that is, ACC, medial superior frontal areas and anterior insula/frontal operculum. Besides, Wilk et al. (2012) showed sustained activity in visual areas such as the fusiform gyrus, supporting the idea of visual areas as target of control implementation (Egner e& Hirsch, 2005b; Wilk, et al., 2012). That is, they are more active in high conflict conditions since task-relevant processing is enhanced, which reduce the impact of interference on performance. Interestingly, we extended previous results since we showed that proactive control reflected by that brain areas network was task-independent, that is, present for both emotional and non-emotional task.

Therefore, considering those anterior and posterior medial activations and ventral visual regions, we suggest that proactive control, at least the one reflected by PC effects, involved several processes that are implemented with an anterior-to-posterior neural organization. We propose the following neural and process organization. First, ACC monitors performance, especially in situations that are likely to lead to conflict (e.g., when there is high proportion of incongruent trials). That area send information to medial areas such as the ventromedial prefrontal cortex, that keep active the task-set strategy, in an attempt to reinforce it (i.e., to implement control over that highly conflict situation). Finally, that task-strategy is implemented by acting over visual areas. To do so, vmPFC sends the information to mid- and posterior cingulated, which biases areas (visual areas) by enhancing task-relevant processing.

Since ACC has been related to transient conflict processing, one might be wonder its exact contribution to sustained conflict-control processes. We believe that ACC plays a general role in monitoring performance (signaling that the situation is “difficult” and the system has to be prepared for any event that might interference performance), regardless of whether it is transiently or rather sustained. For example, some authors have argued that increased ACC activity might reflect greater control demands, reporting increased ACC activity for probe trials indicating that ACC is “prepared” for recruiting control in case of needed (Braver, et al., 2007; Cole & Schneider, 2007). Similarly, studies using a cue paradigm have found greater ACC activity in the cue-stimulus onset period, which can also be interpreted as a preparatory state (Sohn, et al., 2007). And more interestingly, studies testing neural modulations during and after training a cognitive skill have shown that ACC activity increased after training, suggesting that when something is learnt, therefore more automatic, the need of monitoring the behavior and be ready to implement control is actually higher (Fincham & Anderson, 2006).

However, ACC activations have been also related to specific forms of conflict and not to a general monitoring function. Specifically, several studies have shown ACC involvement in conflict produced at the response layer as Simon, while being absent for perceptual conflict types as Stroop (Egner, et al., 2007; Liston, Matalon, Hare, Davidson, & Casey, 2006; Liu, et al., 2004). Therefore, does it means that ACC neither detect nor monitor conflict? We suggest that this is the key issue. Influenced by conflict monitoring theory (Botvinick et al., 2001), conflict detection and monitoring processes have been considered the same or simultaneous processes. But are they? Studies indicating different neural correlated depending on conflict type might indicate that conflict detection seems conflict type specific. Supporting that idea, a recent study has shown that TMS application on different neural locations produced conflict-specific resolution deficits. That is, disrupting pre-suplementary area, which is typically related to response conflict, (Egner, et al., 2007; Garavan, Ross, Kaufman, & Stein, 2003; Liu, et al., 2004; Luks, et al, 2007), affected Simon resolution (response conflict); while disrupting inferior parietal gyrus affected Stroop resolution (perceptual conflict) (Soutschek, et al., 2013).

Therefore, one might argue that ACC is actually monitoring performance and searching for any factor that might interference with performance, but no detecting conflict, a process that rather seems to be carried out by conflict-type specific areas. But why does ACC show up for response conflict but not for perceptual conflict if in both cases conflict monitoring is taking place? We argue that conflict monitoring, in general, takes place at the output layer since every influence at different levels of processing (stimulus and response) will result in the activation of an incompatible response that competes with relevant one in the output layer. If conflict takes place at the response layer, that competition is stronger because the incompatible response that interferes with the compatible response is strongly active compared to a perceptual conflict, whose incompatible response is less active since it comes from a different layer and possible decayed as a function of time. Supporting the idea of ACC as an area with a behavior monitoring function, a recent review on ACC functions (Gasquoine, 2013) has considered it as a mechanism reacting to any difficult cognitive and physical states that require additional effortful cognitive control. Specifically, they remarked that ACC monitors the emotional salience of stimuli in conjuction with orbitofrontal cortex, exerts control over the autonomic nervous systems with insular cortex and modulates cognitive activity in dorsolateral frontal cortex.

However, those are mere speculations and more research is needed to clarify whether ACC has a broader function such monitoring behavior or a more specific one such as conflict detection.

We also found extensive activations involving ventromedial prefrontal areas (vmPFC) and argued that they are related to task-set strategy maintenance. Interesting, these areas has been associated to goal-directed behavior (e.g., de Wit, Corlett, Aitken, Dickinson, & Fletcher, 2009; de Wit, et al., 2012; Tanaka, Balleine, & O'Doherty, 2008), being more active under conditions where only goal-directed action and not habitual action was possible. Other studies have shown that caudate is engaged during goal-directed action (Tanaka, et al., 2008); that it is strongly interconnected with vmPFC (Draganski, et al., 2008; Lehéricy, et al., 2004); and, even more, that white matter integrity in those connections underlies individual differences in the balance between goal-directed and habitual action control (de Wit, et al., 2012). In our experiment, we also observed caudate activations, apart from the mentioned vmPFC activations. Therefore, it seems that participants were goal-directed driven in the high conflict condition, which suggest that participants are constantly controlling their behavior in order to perform the task (which is their goal). However, we speculate that those activations might be modulated along the experiment. Specifically, we believe that action would be goal-directed at the beginning of the block since the task has just started, but after a while, a task-set strategy is learn, which mean that behavior will be rather more controlled by habitual action. That suggestion is supported by the observed basal ganglia activations involving putamen and globus pallidus, apart from caudate. Some studies have reported putamen and globus pallidus in instrumental learning (e.g., Brovelli, Nazarian, Meunier, & Boussaoud, 2011; Tricomi, Balleine, & O'Doherty, 2009). For example, Tricomi et al.

(2009) found a region in the posterior putamen extending into the globus pallidus that became increasingly sensitive to stimuli that were associated with a particular behavioral response, consistent with a potential role in S–R learning. Therefore, taking all together, one can argue that what is happening is that during high conflict situations a proactive control strategy is learnt, which is reflected in vmPFC cortex and caudate activations as it is a goal-directed strategy (participants want to perform well), and putamen and globus pallidus activatios since they are actually “transforming” that goal-directed “strategy” into a more habitual learn response.

Apart from the previous reported activations, we also found sustained activity in basal ganglia, thalamus and cerebellum. As it has been argued, basal ganglia implications can be related to learning processes involve in the frequency of incongruent trials itself. That is, first participants translate the task instructions into brain actual responses. Since the task goal is more challenged in a high conflict situation because the frequent present of irrelevant information might lead to incompatible responses, the involvement of that goal-directed implementation is higher in that condition. As mentioned, the caudate is related to those processes (Tanaka, et al., 2008). We suggested that after some trials participants might “learn” to keep active that task-set strategy, that is, to translate into habitual behavior (which is reflected by putamen and globus pallidus activations (e.g., Brovelli, et al., 2011; Tricomi, et al., 2009). And what is the role of cerebellum and thalamus? According to Dosenbach et al. (2006; 2007; 2008) cerebellum is the area in charge of error processing (Fietz et al., 1996). Interestingly, that area is also connected to thalamus, regions characterized by error related (feedback and adjustments) activity. Thus, both work together for optimizing performance by “tuning” control (that is, checking the results of control application and modulate control to achieve better performance).

Apart from that sustained domain-general activations, we also observed task-specific activations and, in some areas, transient activations. Thus, we did find a task-specific area showing sustained activity for non-emotional task, which involved a region of the ACC. As we explained in the discussion of experimental series V, we proposed several possibilities for that activation, although they are just speculations. One is related to predicting upcoming events. For instance, Aarts and colleagues (2008) found this region to be activated by informative (relative to uninformative) cues indicating the congruency of subsequent Stroop stimuli. Another explanation was proposed by Kouneiher et al. (2009: see also Egner, 2009) who argued that this anterior aspect of the dACC is involved in supporting temporally extended task motivation. Finally, given that the low proportion congruent condition is associated with a high incidence of incongruent trials, it is also possible that this (quite anterior) ACC region in question is in fact involved in conflict-monitoring over long time-scales (as opposed to more posterior ACC regions dedicated to monitoring conflict over shorter time-scales), as has been hypothesized by De Pisapia and Braver (2006). Nevertheless, as we have said, the exact role of that area and why it is restricted to non-emotionl task remained unclear.

Another area showing task-specific activity, but in this case transient, is the anterior insula/inferior frontal gyrus. Interestingly, it showed greater activity for incongruent than for congruent trials in the low conflict context, that is, when incongruent trials are rare, and only for emotional task. Previos estudies have interpreted that activity profile as reflecting conflict processing but modulated by sustained control (e.g., Carter et al., 2000), arguing that when sustained control is high (in the high proportion incongruent blocks) no conflict signals are observed, but when proactive control is low or absent (in the high proportion congruent blocks) infrequent incongruent trials elicit high conflict, which is reflected in the activation profile of these brain regions. The anterior insula/operculum has been in fact reported to display this response pattern both in non-emotional (Carter et al., 2000; Grandjean et al., 2012; Wilk et al., 2012) and emotional task contexts (Krug & Carter, 2012). The fact that anterior insula activiy is related to emotional task might be interpreted in term of a preferential involvement in emotional conflict processing. Suuporting that idea, a recent study by Chechko and colleagues (2012) has in fact observed anterior insula responses to emotional rather than non-emotional conflict in a face-word Stroop task analogous to the one employed in our Experimental Series V. We have suggested alternative views of the anterior insula, such as a region that might integrate signals of cognitive demand with affective stimulus salience (Gu, Liu, Van Dam, Hof & Fan, 2013), or being involved in a putative "salience network" (Seeley, et al., 2007) that facilitates the detection of important environmental stimuli (such as a rare incongruent trial in the context of a high proportion congruent block), and initiates attentional control signals in turn (Menon, 2010).

In summary, we can argue that reactive and proactive mechanisms are implemented by different neural areas (which might be considered different brain networks). Based on previous results, reactive control is related to dACC and lateral prefrontal cortex transient activations (e.g, Egner & Hirsch, 2005a; 2005b; Kerns, et al., 2004), while, based on our own results, proactive control seems more related to medial anterior and posterior frontal sustained activations. Interestingly, in both cases, conflict detection or monitoring is implemented by ACC, which seems domain-general (Egner & Hirsch, 2005b), while control implementation can be more specific of the task-domain in the case of reactive control, but general in the case of proactive control. Thus, for reactive control, control implementation is more related to prefrontal cortex that acts over posterior areas resulting in task-relevant enhance of information processing (Egner & Hirsch, 2005b), while emotional conflict is more related to rostral ACC as a control area that inhibit amygdala activity (Egner & Hirsch, 2005b). However, for proactive control, control implementation and its application seem domain-general.

Nevertheless, those are ideas of neural differences between reactive and proactive control mechanisms should be further confirmed by studies directly comparing both control mechanisms, and using hybrid blocked/event-related models, since they allow to find areas exclusively showing transient or sustained activations.

CHAPTER 6

Conclusions

In 1980, Normal & Shallice model defined control as the function in charge of selecting the information relevant for the task among the irrelevant. That function was described as general, that is, independent of the information nature. During the last decade, several studies on the cognitive control field have tried to go further on the knowledge of cognitive control functioning but has kept the idea of domain-general system (i.e. Botvinick, et al., 2001c; Kerns, et al., 2004). However, over the past five years, some studies have challenged that view suggesting a more domain-specific modular organization (Egner, 2008; Egner, et al., 2007; Funes, et al., 2010a; Wendt, et al., 2006). From these studies, there is a need to change the view of cognitive control as a general function able to cope with every kind of conflict nature. We have described several of those findings (including ours) and tried to provide a big picture of (attentional) control knowledge at present. To end up this thesis, we will present a model as theoretical proposal able to explain the majority of the existing results. It is important to highlight that the model presented is a mere theoretical attempt of summarizing the ideas we have discussed along the present thesis and give them a model organization. Therefore, it is a completely personal view of how attentional control might work. Besides, it includes proposal and ideas from different models, which will be highlighted. Finally, the way that the model has been built up is by trying to give an answer to the questions that I believe important in the understanding of attentional control: when, how, why, where and what control is applied.

1. Why control is applied

As it has been explained, there are different situations where we need to control our behavior in order to pursuit our goals. Therefore, we need a mechanism that helps us to be successful and actually achieve our goals. Thus, the reason why control is applied is simple: to be successful in what we wish to do.

2. When, what, where and how control is applied

The question about when control is applied was already answered by Botvinick et al. in their conflict monitoring model (2001). Thus, control is applied whenever conflict is detected.

Besides, they also suggested that control is applied by enhancing task-relevant information and regardless of conflict type. However, as it has been seen, several studies have shown that conflict type can be related with specific control implementation processes, reflected in both different neural basis and different ways of applying it (e.g., Egner, 2010; Liu et al., 2006). In fact, Egner already suggested the existence of conflict-control type specific loops that might work in parallel (Egner, 2008). Besides, our results show that conflcit-type specific effects are the most common finding, suggesting that the conflict-control type specific proposal is the most likely one.

However, other studies plus our, have suggested that control implementation can be also different depending on when control is applied (in a reactive or proactive manner). Then, the pertinent questions are whether those attentional mechanisms depending on conflicit-type are different from the ones depending on when control is applied. I believe so. Thus, I believe that control is conflict-type specic, having different control mechanisms depending on the conflict (i.e., reponse conflict or perceptual conflict). Besides, I also believe that control acts differently depending on when it is applied, distinguishing between reactively (i.e., within the trial and after stimulus onset) and proactively (i.e., as a preparatory task-set that is applied before stimulus onset). However, I suggest that while conflict-type mechanisms are several mechanisms (as many as conflict type), there is only one mechanism for “control implementation time”, with different temporal states, one reactive, which is the default one and allows conflict resolution being driven by the conflict-control loops, and a proactive one that biased control implementation from that reactive mood to a more sustained one that acts over the task demands unit (which will modify the inpu layer, hence, stimulus processin before they actually show up).

Basing on those ideas, next I will describe the model, first, describing how control is implemented within a trial and later, how control is implemented as a task-set strategy and how the systems reaches that state. For those ideas I have based on, apart from the models already mentioned, the activation-supression model developed by Ridderinkof (2002) and Verguts & Notebaert model (2008;2009), to describe how conflict arises and how it is implemented within a trial.

Translating that into experimental situations, we specified two conflict types to account for conflict-type specificity (e.g., Simon or Spatial Stroop). In both cases, participants have to respond to the direction of the arrow (task-relevant dimension) while ignoring the task-irrelevant information (e.g., location, response, etc). In a given trial, the task-relevant dimension of the stimulus displayed is processed by the task-relevant route, while the task-irrelevant dimension is processed by the automatic route. Within them there are different levels of processing: first, the perceptual information is processed (stimulus representation), and second, the responses related to each route are also processed (response representation). Since the automatic route is highly trained, therefore the connections along layers are stronger, the response associated to it reaches the output layer before the relevant response, which is actually slow (activation-suppression model, Ridderinkhof, 2002). Due to that, both responses are active in the output layer, competing for being the executed response (competition represented by a curve line ending in a circle, which indicates inhibitory processes within it). However, apart from the interference due to response competition in the output layer, conflict takes place at different level of processing depending on the conflict type. Thus, for Spatial Stroop, conflict takes place at the stimulus representation level when the task-relevant and task-irrelevant dimension of the stimulus interfere since, as it is shown in the figure, it is the first level where the information represented in both routes actually leads to incompatible representations. For Simon, that situation does not happen until the response representation, where for the first time in the processing, the representations related to the different routes are different. This conflict-type specific detection triggers online conflict-type specific adjustments, which actually act over the output layer where the compatible and incompatible responses are both active, biasing the response execution competition. Besides, the way of resolving conflict is also conflict-type specific. Thus, as some authors have argued, response conflict leads to the inhibition of the task-irrelevant information and the perceptual conflict to the enhancement of the task-relevant information. I suggest that control is not applied directly on the representations, but on the output layer, inhibiting incompatible response in response conflict and enhancing compatible response for perceptual conflict. The competition and control action in that output layer might be reflected on longer reaction times, which goes in the same line that the action of the selective mechanism described in the activation-suppression model (Ridderinkhof, 2002).However, the effect of biasing reponse competition does impact representations (differently depending on conflcit type). For perceptual conflict and following Verguts and Notebaert model (2008; 2009), when the compatible response is the executed response the connections between stimulus representation and task-relevant response representation are enhanced. Therefore, in subsequent trials those connections are stronger (leading to SC effects). However, for response conflict, the inhibition of the incompatible response of a given trial leads to the inhibition of its corresponding response representation. Therefore, in the subsequent trial, that representation is already inhibited, leading to SC effects. But as it can be inferred from it, the benefits of having resolved conflict in the previous trial are only visible when the next trial involves the same conflict type. That would explain conflict-type specific SC effects.

Resolving control within a trial means applying control after stimulus onset, that is, in a reactive way. But control is not applied like that constantly. By contrary, previous conflict experiences modulate conflict resolution and control implementation. According to the dual model of cognitive control (Braver et al., 2007) control can also be applied before stimulus onset. How do we change from one to other? We argue that reactive conflict-control experiences are registered in what we have called interference level. Thus, on each trial and after conflict resolution, the interference present depends on the response representations, that is, indirectly as a result of the strength of connections between represensations (perceptual conflict), and directly of the strength of the response representations for response conflict. However, representations change constantly due to the outcome of the response competition at the output layer (accuracy information), then, due to control implementation reactively. Therefore, the interference unit is registering the level of interference present, how often control implementation is needed, etc. I speculate that interference level unit is nothing more but the conflict monitoring unit extensively described. Thus, the information of conflict-control experiences is registered and used to monitor performance. And as suggested in the introduction, ACC is actually the neural area in charge of that.

To answer how control implementation moves from a reactive way to a proactive one, I argue that is the result of an accumulative process. That is, resolving conflict in a reactive manner when conflict is actually frequent might be costly for the system, since the control implementation has to be engaged constantly. Therefore, I propose that at some point and as a result of that accumulation, a tonic change (called switch control implementation mood) takes place and moved the unit of control implementation in the output layer (that is, control implementation applied when conflict is experienced) toward the control modulation in input layer, specifically, by influencing tasks-demand unit that will change the representations within the routes before stimulus onset, eliminating the recruitment of control on a trial-to-trial basis. However, there is the need of keeping it active, therefore, when conflict is not frequent, that strategy is costly. When I say "influencing task-demands" unit I refer to enhance task-demands, hence, potentianting instructions (what we have been told to do or want to do).

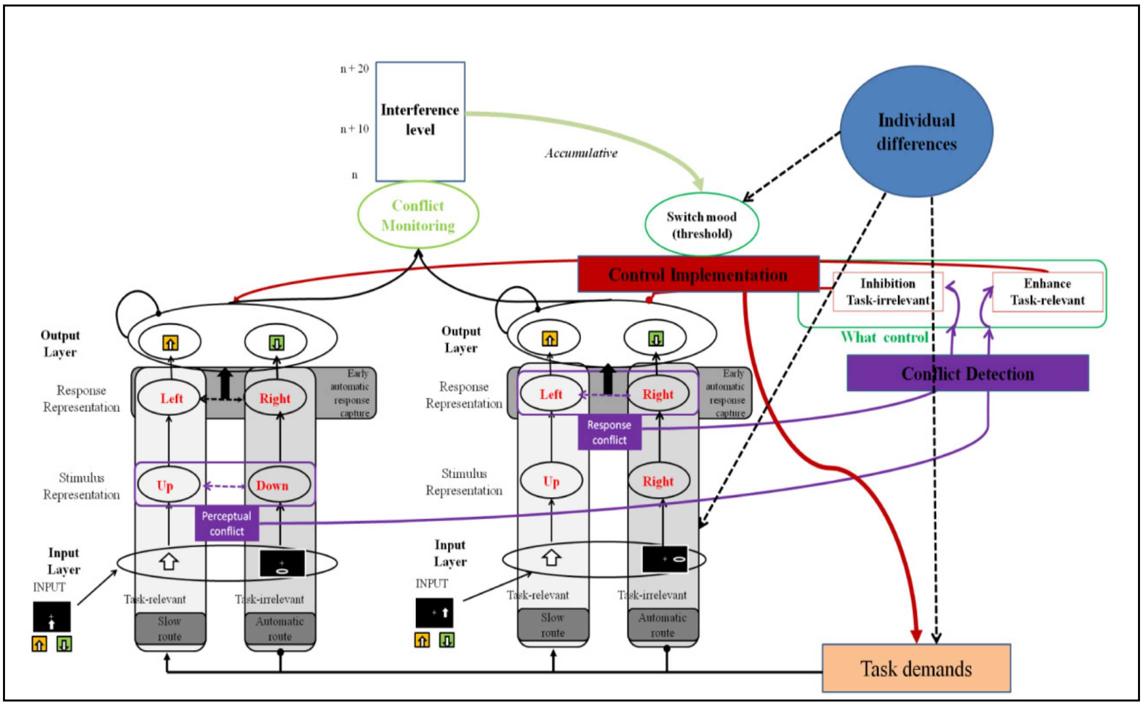

Figure 1. Attentional control model

But when does the switch from reactive to proactive take place? I believe that it is modulated by individual differences, since the threshold that indicates when recruiting conflict constantly or keeping active as a sustained control strategy will be different depending on, for example, cognitive resources (i.e., fluid intelligent), whether participants realize that keeping a sustained strategy is useful because conflict is frequent, global or local approaches, etc. In fact, I believe that individual differences play an important role at different levels of the presented conflict-control functioning: 1) at the task-demands units, that is, the way participants actually "understand" instructions (i.e., one might understand that he has to respond to the arrow, while other might understand that he has to respond to the arrow which is going to appear at different locations (so he is already segregating contexts); 2) switch control implementation mood, that explain individual differences found in tendency for a reactive or a proactive control implementation (i.e., Braver studies on aging, fluid intelligent, etc); 3) strength of the automatic route (e.g., how "trained" is that route or how relevant), that actually explains our own results for older adults.

The reason for ending my thesis in that way is that I believe that the study of specific effects and processes have to be contextualized in a bigger picture of the mechanism or function that is the scope of the study. By doing that everyone can share the same information, without being too specific, and contribute to the creation of that big picture. Similarly, the issues that remain unresolved can be highlighted and authors can suggest some directions for future researches.

Hopefully, I have achieved that goal.

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