Doctoral Dissertation

Función Ejecutiva y Control Inhibitorio en el Bilingüe

(Executive Function and Inhibitory Control in Bilingualism)

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Tesis doctoral presentada por María Julia Morales Castillo, en el Departamento de Psicología Experimental, para aspirar al grado de Doctor Internacional en el Programa Oficial de Doctorado de Psicología de la Universidad de Granada.

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Los Directores de Tesis: **La Doctoranda:**

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GRACIAS…

… a todos los que, de una u otra forma, han hecho posible este trabajo y, especialmente, a los que durante este trayecto han confiado en mí más que yo misma:

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A mi familia. Por apoyarme sin condiciones, por aceptar mis ausencias; por enseñarme a dudar y, sobre todo, a buscar las respuestas.

Introductory Note

The content of this doctoral dissertation has been drawn up according to the regulations of the University of Granada to obtain the International Doctorate Mention in the Psychology Doctoral Program. According to this, the majority of the thesis has been written in English. Specifically, in Chapter I a theoretical introduction to the subject of the investigation is presented in Spanish. Next, Chapter II contains a summary of the theoretical background written in English. Finally, the empirical chapters (Chapter III) and the general discussion (Chapter IV) proceeds in English.

Capítulo I. INTRODUCCIÓN Y OBJETIVOS

Actualmente, más de la mitad de la población mundial es bilingüe, es decir, utiliza dos idiomas de forma cotidiana. El concepto "bilingüismo" es un término heterogéneo que aglutina un amplio número de experiencias. Atendiendo a distintas variables como la frecuencia, el contexto de uso y la competencia en cada uno de los idiomas, podríamos determinar que existen tantos tipos de bilingüismo como bilingües (Grosjean, 2013). Además, si consideramos que el uso y la competencia en cada idioma suelen variar a lo largo del ciclo vital de cada persona, las tipologías se multiplican. A pesar de esta variabilidad, existe un aspecto común a cada bilingüe: todos tienen un único cerebro con el que coordinar y controlar sus idiomas. Esta necesidad de control entre idiomas ha motivado, en los últimos años, numerosas investigaciones orientadas a conocer los efectos que manejar varias lenguas produce sobre procesos cognitivos no verbales. La mayoría de los estudios coinciden en que, más allá de las evidentes ventajas comunicativas, el bilingüismo beneficia el funcionamiento cognitivo.

La base de estos estudios radica en que las personas bilingües se encuentran con situaciones de la vida cotidiana en las que deben seleccionar y cambiar de lengua, evitando intrusiones léxicas entre idiomas. Este fenómeno ha llamado la atención de psicolingüistas, psicólogos cognitivos y neurocientíficos que han investigado cómo se organizan los idiomas en el cerebro bilingüe. Aunque se han propuesto diferentes modelos de control de idiomas, todos concuerdan en que los bilingües activan de forma simultánea sus dos idiomas incluso cuando solo emplean uno de ellos (para revisiones véase Dijkstra, 2005; Kroll, Dussias, Bogulski y Valdés, 2012). En consecuencia, es necesario utilizar algún mecanismo que permita organizar los idiomas de forma eficiente. Este mecanismo se encargaría de seleccionar el sistema requerido según las demandas de la situación y del contexto, controlando que no se produzcan intrusiones e interferencias del idioma que no es necesario en ese momento.

Una de las opiniones más extendidas es que este mecanismo de selección y control de idiomas no es exclusivo al lenguaje, sino que también es el encargado, a nivel general, de seleccionar y controlar el flujo de información en nuestro cerebro. La idea subyacente es que el entrenamiento en una competencia específica puede transferirse a otras que comparten funciones cognitivas relacionadas (p. ej., Bialystok y Depape, 2009; Schellenberg y Moreno, 2004; Schellenberg, 2006). Por tanto, la necesidad continuada de resolver la competición entre idiomas podría repercutir en actividades que impliquen procesos de control similares, más allá de las meramente lingüísticas. Efectivamente, aunque los procesos implicados aún no se han definido con precisión, los resultados apuntan a que el uso cotidiano de varios idiomas beneficia el control cognitivo (o, al menos, alguno de sus componentes). Esta idea se apoya en múltiples evidencias que han encontrado superioridad bilingüe en tareas que implican resolver conflicto o controlar estímulos que compiten entre sí, tanto en niños (p. ej., Adi-Japha, Berberich-Artzi y Libnawi, 2010; Bialystok y Martin, 2004; Bialystok y Senman, 2004; Bialystok, 1999, 2010; Carlson y Meltzoff, 2008), como en adultos (p. ej., Colzato et al., 2008; Costa, Hernández, Costa-Faidella y Sebastián-Gallés, 2009; Costa, Hernández y Sebastián-Gallés, 2008) y ancianos (p. ej., Bialystok, Craik, Klein y Viswanathan, 2004).

No obstante, los resultados encontrados hasta la fecha no dejan de ser controvertidos. Mientras que unas investigaciones encuentran beneficios bilingües en procesos evaluados por determinadas tareas, otras no consiguen replicar estos resultados (véanse, por ejemplo, las recientes revisiones de Hilchey y Klein, 2011; Kroll y Bialystok, 2013; Paap y Greenberg, 2013). Aunque no existe consenso, la naturaleza de estas inconsistencias se atribuye a diversos motivos, como problemas en la identificación de los mecanismos de control propuestos para la selección y el control de idiomas (Costa et al., 2009), la variabilidad de la experiencia bilingüe entre las muestras de los distintos estudios (Green y Abutalebi, 2013) o, incluso, a que las ventajas bilingües son el resultado de características demográficas asociadas al bilingüismo pero no directamente relacionadas con el control de idiomas, como una historia de inmigración o multiculturalismo (Paap y Greenberg, 2013).

Nuestro trabajo se centra en investigar la naturaleza y la dinámica de los mecanismos cognitivos modulados por el bilingüismo. Identificar los procesos beneficiados por la experiencia bilingüe nos permitiría profundizar en el conocimiento de la cognición humana por dos vías principales. En primer lugar, permitiría contrastar los modelos propuestos sobre los mecanismos de selección y control de idiomas en los bilingües. El hecho de que los bilingües mejoren determinados procesos cognitivos debido exclusivamente a la necesidad de coordinación entre sus idiomas permite identificar los mecanismos que requieren mayor uso que en un entorno monolingüe. En segundo lugar, nos ayudaría a progresar en la comprensión de la naturaleza plástica de nuestro cerebro y la capacidad de transferencia de habilidades entrenadas en un campo determinado (p. ej., el lenguaje) a otros que requieren habilidades y/o procesos relacionados (p. ej., el control de acciones). Guiados por la idea de que la eficiencia del control cognitivo es producto de una red compuesta por distintos mecanismos, nos centraremos, más que en el estudio de componentes aislados, en investigar la influencia del bilingüismo sobre la coordinación de distintos procesos de control cognitivo, en diferentes experiencias bilingües y en distintas etapas del desarrollo.

Para esclarecer cuáles son los mecanismos potencialmente beneficiados por la experiencia bilingüe, es fundamental conocer primero cuáles son los procesos de control implicados en la selección del lenguaje. Por ello, en el primer apartado de la introducción revisaremos los principales modelos sobre selección y control de idiomas en el bilingüe. Estos modelos explican cómo se consigue resolver la interferencia generada por la competición entre dos idiomas activos y seleccionar el idioma deseado de acuerdo a las demandas del contexto y las intenciones del hablante (Costa y Caramazza, 1999; Dijkstra y van Heuven, 1998; Green y Abutalebi, 2013; Green, 1998; Meuter y Allport, 1999; Poulisse y Bongaerts, 1994). Dada su influencia en la investigación del control cognitivo en el bilingüismo, nos centraremos en los modelos de tipo inhibitorio, los cuales entienden que la interferencia causada por la activación simultánea de idiomas se resuelve a través de la supresión de las palabras o idiomas que compiten entre sí. A continuación, resumiremos brevemente las principales investigaciones que, guiadas por los modelos de control de idiomas, han evaluado las consecuencias del bilingüismo sobre los mecanismos de control cognitivo y, más concretamente, sobre el control inhibitorio. Haremos especial hincapié en los resultados inconsistentes que arrojan los distintos estudios, pues consideramos que constituyen un aspecto clave para comprender la raíz de los procesos modulados por el bilingüismo. En el tercer y cuarto apartados expondremos dos factores que pueden estar sesgando los resultados e interpretaciones de la investigación actual sobre bilingüismo y control cognitivo. Por un lado, el tercer apartado destacará la necesidad de adoptar una aproximación multivariada frente a la estrategia generalizada de estudiar los componentes de control ejecutivo de forma aislada. Nos centraremos en explicar la dinámica de los procesos de control cognitivo y cómo el bilingüismo puede afectar dicha coordinación, tanto en la edad adulta como en la infancia. Por otra parte, en el cuarto apartado subrayaremos la importancia de distinguir entre distintas situaciones bilingües, ya que cada una de ellas puede demandar diferentes procesos de control cognitivo. Si este es el caso, las consecuencias sobre la modulación de los circuitos encargados de la regulación y el control cognitivo podrían diferir según el contexto de uso de los idiomas. Para profundizar en este aspecto, en el siguiente apartado nos centraremos en el caso de la interpretación simultánea, pues supone un tipo muy particular de bilingüismo que implica mantener activos dos idiomas a la vez y, por tanto, sus demandas de control cognitivo difieren sustancialmente de otros tipos de bilingüismo. El conjunto de estudios de nuestra serie experimental tendrá como objetivo responder a las cuestiones que irán surgiendo a partir de los diferentes apartados de la introducción. No obstante, en un último apartado de la introducción describiremos específicamente la estructura y los objetivos de la serie experimental.

1.1. SELECCIÓN Y CONTROL DE IDIOMAS EN EL BILINGÜE

Las evidencias sobre la necesidad de ejercer control cognitivo cuando se manejan dos o más idiomas provienen de los estudios sobre compresión y producción del lenguaje. Aunque el objetivo del presente trabajo son los procesos de control cognitivo de carácter general (no restringidos al dominio verbal), para identificar cuáles son los mecanismos que participan en el control de idiomas, necesitamos conocer primero cómo se produce la selección y el control de idiomas en situaciones de bilingüismo. A continuación describimos las principales propuestas al respecto.

Los modelos psicolingüísticos proponen que, para expresar una idea o nombrar un objeto es necesario, en primer lugar, seleccionar la representación conceptual asociada a dicha idea u objeto, acceder posteriormente a las propiedades sintácticas y gramaticales de la palabra y después a la fonología adecuada para articularla (Caramazza, 1997; Levelt, Roelofs y Meyer, 1999). En el caso de los bilingües, la mayoría de los modelos de acceso léxico asumen que los dos idiomas comparten un único sistema semántico (Costa, Miozzo y Caramazza, 1999; De Bot, 1992; Kroll y Stewart, 1994; Poulisse y Bongaerts, 1994), el cual sirve para activar el sistema léxico de cada uno de los idiomas. Esto conlleva que el acceso a la representación léxica sea más costoso en los bilingües que en los monolingües, ya que la selección del concepto sirve para activar dos entradas léxicas diferenciadas, una para cada idioma.

Numerosas investigaciones han mostrado que los dos idiomas de un bilingüe se activan y compiten por la selección incluso cuando se utiliza solamente uno de ellos. Por ejemplo, el material presentado en un idioma afecta a la respuesta que se produce en el idioma alternativo cuando las palabras del idioma en uso comparten propiedades (léxicas, ortográficas, fonológicas o gramaticales) con palabras del idioma alternativo. Estos resultados se han encontrado en tareas con homógrafos (Beauvillain y Grainger, 1987; De Groot, Delmaar y Lupker, 2000; Dijkstra, Grainger y Heuven, 1999; Dijkstra, van Jaarsveld y Brinke, 1998; Macizo, Bajo y Martín, 2010; Schwartz y Kroll, 2006), cognados (Costa, Caramazza y Sebastián-Gallés, 2000; Dijkstra et al., 1999; Gollan, Forster y Frost, 1997; Lemhöfer y Dijkstra, 2004; pero véase De Groot y Nas, 1991) o estudios de género gramatical (Morales, Paolieri y Bajo, 2011). Así, en las tareas de decisión léxica que requieren la lectura de una palabra en solo uno de los idiomas, se leen más despacio las palabas homógrafas (palabras que se escriben igual en dos idiomas pero tienen significado diferente; por ejemplo, *pie* en inglés -“tarta”- y español) que las palabras control (Dijkstra et al., 1999; Macizo et al., 2010).

Otra fuente importante de evidencias proviene de estudios que indican que los bilingües muestran interferencia entre idiomas en tareas tipo Stroop (Stroop, 1935). En el paradigma estándar, ampliamente utilizado para evaluar procesos de resolución de interferencia (véase Macleod, 1991), los participantes deben nombrar el color de la tinta de una palabra que, a su vez, representa el nombre de un color. El efecto de interferencia (o efecto Stroop) se manifiesta en respuestas más lentas cuando el color de la tinta es diferente al que representa la palabra (p. ej., si aparece la palabra "verde" escrita en azul, el participante debe decir "azul") que cuando la palabra y su color coinciden. Estas respuestas más lentas estarían reflejando la necesidad de suprimir la respuesta prepotente de leer el texto. En la adaptación bilingüe de la tarea, la palabra se presenta en un idioma y la denominación del color debe hacerse en el otro (p. ej., aparece la palabra española "verde" escrita en azul y el participante debe decir "*blue*"-en inglés-). El hecho de que los bilingües muestren también el efecto Stroop entre idiomas (Chen y Ho, 1986; Zied et al., 2004) indica que los dos idiomas están compitiendo entre sí, aunque solo uno de ellos es necesario para resolver la tarea.

Este conjunto de resultados coincide en señalar que existe activación conjunta de ambos idiomas, incluso cuando uno de los idiomas no es relevante para la tarea. En consecuencia, la activación no selectiva de idiomas desencadena un proceso de competición a la hora de seleccionar las entradas léxicas correspondientes al idioma requerido (Dijkstra, 2005; Hoshino y Thierry, 2011; Kroll y Stewart, 1994; Kroll, Sumutka y Schwartz, 2005; Macizo et al., 2010; Marian y Spivey, 2003a, 2003b). Por tanto, la producción lingüística podría verse dificultada por la interferencia que se produce entre ambos idiomas. Sin embargo, los bilingües consiguen una ejecución fluida en el idioma elegido sin intrusiones del otro sistema lingüístico. ¿Cómo consiguen resolver la interferencia producida por la co-activación de idiomas? ¿Qué ocurre con el idioma no seleccionado? Los principales modelos propuestos para explicar el control y la selección de idiomas en bilingües asumen que es preciso ejercer algún tipo de control sobre la atención para dirigirla hacia el idioma seleccionado. Sin embargo, las dos aproximaciones principales difieren en cuanto al supuesto de que la selección de idiomas se produzca, o no, mediante algún tipo de control inhibitorio.

La perspectiva no inhibitoria defiende que, a pesar de que se produzca co-activación de los dos idiomas, la selección se basa en el grado de activación de los candidatos léxicos (Costa y Caramazza, 1999; Costa et al., 1999; Costa, 2005; Poulisse y Bongaerts, 1994). Por ejemplo, Costa (Costa y Caramazza, 1999; Costa et al., 1999; Costa, 2005) propone que la competición no llega a producirse porque solo se consideran las palabras del idioma objetivo para la selección léxica y, por tanto, son las únicas que compiten por la selección. Así, si un bilingüe español-inglés desea hablar en español solamente competirán por la selección los lemas en español. Una segunda propuesta defiende que la selección se produce en términos de activación (Poulisse y Bongaerts, 1994). Los autores proponen que las entradas léxicas de ambos idiomas se tienen en consideración durante la selección, pero ésta se produce a través de distintos niveles de activación. Desde esta aproximación, el sistema léxico del idioma en uso se activa en mayor grado que el idioma alternativo. Por tanto, la entrada léxica requerida se selecciona al aumentar los niveles de activación de la lengua objetivo respecto al idioma irrelevante. Desde estas perspectivas, se asume que los bilingües son sensibles a claves contextuales que indican el idioma apropiado de uso. Las claves del idioma se representan al mismo nivel que las características conceptuales. Por tanto, las claves de idioma dirigirán la activación a las representaciones léxicas o de lema solamente en el idioma relevante. Por tanto, la selección de idioma se produce de forma temprana, ya que las claves contextuales permiten reducir la activación de los candidatos del idioma alternativo antes de que lleguen a competir.

Por otra parte, las aproximaciones más influyentes sobre los mecanismos de control cognitivo en el procesamiento del lenguaje en el bilingüismo asignan un papel fundamental al control inhibitorio en la selección de idiomas. De acuerdo con estas propuestas, existiría un mecanismo inhibitorio encargado de reducir la accesibilidad al sistema de lenguaje no requerido. Así pues, la selección de los lemas asociados en el idioma objetivo se produciría mediante la supresión de las entradas léxicas del idioma irrelevante, evitándose intrusiones del mismo (Abutalebi y Green, 2008; Green, 1998; Levy, Mcveigh, Marful y Anderson, 2007; Macizo et al., 2010; Meuter y Allport, 1999). Existen dos modelos principales que se basan en este tipo de procesos: el modelo de Activación Interactiva Bilingüe (Dijkstra y van Heuven, 1998) y el modelo de Control Inhibitorio (Green, 1998), que describimos a continuación.

En primer lugar, el modelo de Activación Interactiva Bilingüe (*Bilingual Interactive Activation model*; *BIA*, Dijkstra y van Heuven, 1998; van Heuven, Dijkstra y Grainger, 1998) asume la existencia de un único sistema léxico que integra los dos idiomas. Está compuesto por cuatro niveles de representación: características de letras, letras, palabras y nodos de idiomas. Los dos primeros activan los candidatos léxicos en ambos idiomas que, a su vez, activan los nodos de idioma de la lengua correspondiente según el contexto. La selección de idiomas se lleva a cabo por un proceso interactivo de activación e inhibición (véase Figura 1). La competición de las representaciones ocurre tanto en un idioma como entre idiomas y se resuelve mediante un mecanismo de inhibición lateral. Esto es, las representaciones más activas inhiben a las entradas léxicas del mismo idioma, de manera que la selección de una respuesta determinada reduce la probabilidad de seleccionar respuestas vecinas. Al mismo tiempo, los nodos de idioma activados según el contexto se encargarían de inhibir las entradas léxicas el idioma alternativo.

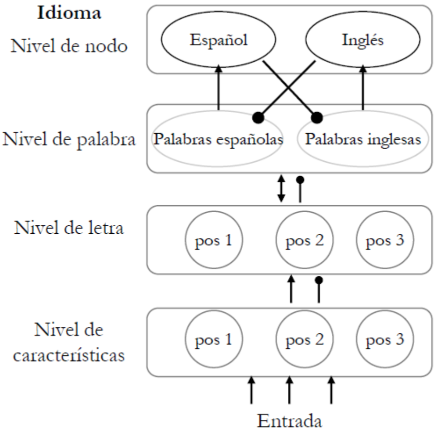

Figura 1. *Modelo de Activación Interactiva Bilingüe (BIA). Las conexiones excitatorias se indican mediante flechas (la punta de las flechas señala la dirección hacia la que se expande la activación), las conexiones inhibitorias se representan mediante líneas terminadas en círculos. Nótese que, aunque se presentan dos conjuntos de unidades de palabras, una por cada idioma, durante el procesamiento todas las palabras compiten entre sí a través de conexiones inhibitorias laterales que representan un léxico integrado.*

Pero dentro de las teorías inhibitorias el modelo más influyente es el de Control Inhibitorio de Green (1998; véase Figura 2), ya que propone explícitamente que en el control de idiomas participan mecanismos de control ejecutivo de carácter general. El modelo se basa en la intervención del sistema atencional supervisor (SAS) descrito por Shallice (Norman y Shallice, 1986; Shallice y Burgess, 1996), que controla la activación de los esquemas competidores. De acuerdo con

Shallice, existe un SAS unitario, dependiente fundamentalmente de la corteza prefrontal, que dirige e interacciona con diferentes procesos cognitivos, llevando a cabo diferentes subprocesos, entre los que se encuentran la construcción o modificación de los esquemas existentes y la monitorización de la ejecución de acuerdo con los objetivos de las tareas. El SAS actúa, por tanto, como un mecanismo global integrador de distintos procesos cognitivos. La ampliación de Green (1998) sugiere que este sistema también dirigiría la activación de los esquemas competidores de lenguaje.

Los bilingües deben ejercer un control inhibitorio sobre el idioma no elegido para permitir que el sistema de lenguaje requerido sea el que guíe la ejecución. De este modo, el mecanismo que reduce la atención al sistema de lenguaje no relevante sería el mismo que se utiliza para coordinar otros dominios cognitivos. El modelo de Green (1998) asume que el bilingüismo tendría implicaciones sobre el procesamiento cognitivo general, debido a que el mecanismo fundamental de inhibición se entiende como un proceso central e independiente de dominio.

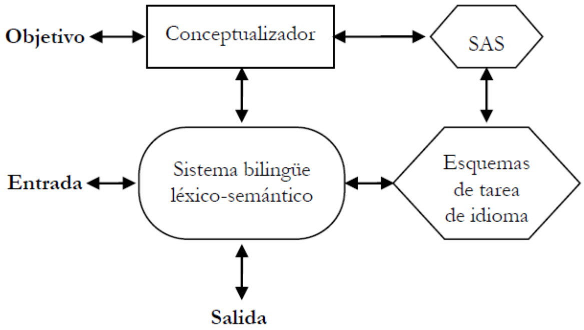

Figura 2. *Modelo de control Inhibitorio (Green, 1998). La regulación de las entradas (E) y salidas (S) del sistema léxico-semántico bilingüe en múltiples niveles de control se produce a través del Sistema Atencional Supervisor (SAS) que regula los esquemas de tarea de idioma que se aplica. El SAS se ve influido a su vez por un sistema de representación de conceptos que se recuperan de la memoria a largo plazo guiados por los objetivos (O) a alcanzar en la tarea. El "esquema de tarea de idioma" regula las S del sistema léxico-semántico alterando los niveles de activación de las representaciones en este sistema mediante la inhibición de las salidas del sistema (extraído y adaptado de Green, 1998).*

De acuerdo con esta perspectiva, al ejecutar una actividad en la que es necesario seleccionar un idioma determinado, la lengua irrelevante (entendida como estímulo distractor o ruido) se suprime en favor del sistema de lenguaje requerido, a fin de evitar interferencias. De este modo, los bilingües resuelven la competición entre idiomas a través de un mecanismo de inhibición activa que afecta a todas las representaciones del idioma no seleccionado. Los modelos inhibitorios consideran que las claves de idioma pueden contribuir a identificar los candidatos en el idioma objetivo en lugar de en el irrelevante, pero no son suficientes para eliminar la competición por la selección.

En resumen, en este apartado hemos revisado los principales modelos que tratan de explicar cómo consiguen los bilingües seleccionar el idioma adecuado al contexto en el que se encuentran. Aunque la idea de que los dos idiomas se activan simultáneamente está ampliamente aceptada, el debate se centra en distinguir si existe o no competición entre idiomas (véase Kroll y Gollan, en prensa, para una revisión). Desde las perspectivas no inhibitorias (p. ej., Costa et al., 1999) se argumenta que no existe competición, dado que la selección es específica del idioma y que, por tanto, las entradas alternativas en el idioma irrelevante no se tienen en cuenta como candidatas para la selección. Por el contrario, las teorías inhibitorias (p. ej., Green, 1998) defienden que los candidatos de ambos idiomas compiten por la selección y que, en consecuencia, es necesario ejercer inhibición sobre el idioma que no está en uso. Desde ambas perspectivas es necesario utilizar constantemente mecanismos de selección del lenguaje para mantener la activación de uno y evitar la interferencia del otro, aunque éstos sean de diferente naturaleza.

Si asumimos que los mecanismos de control ejecutivo encargados de resolver la selección en entornos lingüísticos son similares a los mecanismos de control que actúan en otras áreas cognitivas (p. ej., percepción, atención o acción; Abutalebi y

Green, 2007; Bialystok, 2001; Kan y Thompson-Schill, 2004) y que el entrenamiento de un mecanismo específico en la selección de idiomas puede transferirse a otras áreas que requieran el mismo mecanismo, la necesidad constante de control de idiomas incrementaría la capacidad de los bilingües en otras áreas que impliquen un procesamiento similar. De acuerdo con esta idea, tanto los modelos inhibitorios como los no inhibitorios darían lugar a predicciones distintas sobre cómo influiría un mecanismo de selección léxica sobre procesos cognitivos a nivel general (Kroll y Bialystok, 2013). Según los modelos inhibitorios, la selección ocurriría de forma tardía, una vez que los candidatos léxicos se han activado en ambos idiomas y dependería del nivel de competición (a mayor activación de los competidores en el idioma irrelevante, mayor será la inhibición ejercida). Desde esta perspectiva, los bilingües destacarían en tareas que impliquen resolver conflicto proveniente de alternativas que compiten entre sí una vez que dichas alternativas se encuentran disponibles. Por el contrario, en los modelos no inhibitorios la selección ocurriría de forma temprana, afectando a los mecanismos atencionales que se encargan de guiar la intención para escoger entre dos condiciones alternativas.

El presente trabajo parte de la idea de que la experiencia en una determinada actividad modula la ejecución en tareas que requieren procesos similares. En consecuencia, el estudio de los procesos de control cognitivo en bilingües supone un recurso en el que apoyar las perspectivas propuestas. Por otra parte, conocer la influencia de la experiencia bilingüe en el control cognitivo nos permite profundizar en la naturaleza, dinámica y plasticidad de la función ejecutiva. Guiados por la influencia de las teorías inhibitorias, numerosos estudios se han centrado en evaluar la capacidad de los bilingües para resolver tareas no verbales que implican resolución de conflicto (p. ej., Bialystok et al., 2005; Colzato et al., 2008; Costa et al., 2009, 2008; Lee Salvatierra y Rosselli, 2010). A pesar de la elevada cantidad de investigaciones realizadas hasta la fecha, aún no se conocen con exactitud los mecanismos implicados en el control de idiomas y el alcance de la influencia del bilingüismo en los mismos. En el siguiente apartado revisaremos los principales hallazgos en relación a la influencia del bilingüismo sobre el control cognitivo, y más concretamente sobre el control inhibitorio.

1.2. BILINGÜISMO Y CONTROL INHIBITORIO

La inhibición y el control ejecutivo

De acuerdo con los modelos inhibitorios de control de idiomas, los mecanismos globales de inhibición podrían estar directamente implicados en la selección de idiomas bilingüe. El control inhibitorio hace referencia a la capacidad de suprimir información o respuestas dominantes, automáticas o irrelevantes para la tarea (Miyake y Friedman, 2012; Miyake et al., 2000). De acuerdo con las principales teorías, la inhibición es uno de los componentes principales de la función ejecutiva[*], el cual se encarga de generar, mantener y ajustar un conjunto de estrategias dirigidas a procesar y alcanzar las metas de una tarea determinada (para revisiones recientes, véase Banich, 2009; Barkley, 2012; Jurado y Rosselli, 2007). La función ejecutiva estaría constituida por un conjunto de procesos, como la capacidad de actualización de información y la flexibilidad cognitiva (o cambio de set atencional), además del control inhibitorio (Miyake et al., 2000). Así, los distintos procesos se encargan de inhibir la información distractora, suprimir una respuesta prepotente o cambiar entre diferentes sets atencionales. Sin embargo, no existe acuerdo sobre los componentes específicos que constituyen la función ejecutiva, cómo operan y cuáles son los mecanismos que las subyacen (véase, por ejemplo, Braver, Paxton, Locke y Barch, 2009; Koechlin y Summerfield, 2007). Según la influyente teoría de Miyake (2000), la función ejecutiva tiene una naturaleza unitaria y diversa, ya que sus distintos componentes estarían relacionados entre sí, pero son relativamente independientes.

De acuerdo con los modelos inhibitorios de control de idiomas, las demandas de selección y cambio de idioma podrían estar directamente relacionadas con una capacidad general de control inhibitorio. Guiados por esta idea, los primeros estudios sobre la influencia del bilingüismo sobre procesos cognitivos

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[*] En este trabajo nos referiremos indistintamente a “control ejecutivo”, “función ejecutiva”, “control atencional” o “control cognitivo”.

generales se han centrado en investigar el control inhibitorio. Sin embargo, los bilingües también necesitan controlar cuál es el idioma más apropiado con diferentes interlocutores o situaciones, lo cual requiere la capacidad de cambiar entre idiomas. Por tanto, en los últimos años también se ha comenzado a investigar la influencia del bilingüismo en otros componentes aparte de la inhibición, como la capacidad de redirigir la atención y modificar los objetivos de la tarea (flexibilidad cognitiva o cambio de set atencional).

Para evaluar la influencia de la experiencia bilingüe sobre el control inhibitorio, las investigaciones se han servido de paradigmas atencionales usados tradicionalmente en el estudio de diferencias individuales en el control inhibitorio. Este es el caso de tareas que contienen información competitiva que debe ignorarse para la ejecución adecuada la tarea, como las tareas tipo Simon o de flancos (véase Figura 3). Las tareas de interferencia suelen componerse por estímulos asociados a una respuesta, presentados en ensayos congruentes e incongruentes. Mientras que en los ensayos congruentes toda la información del estímulo concuerda con la respuesta correcta, los ensayos incongruentes incluyen información competitiva, aunque irrelevante para resolver la tarea.

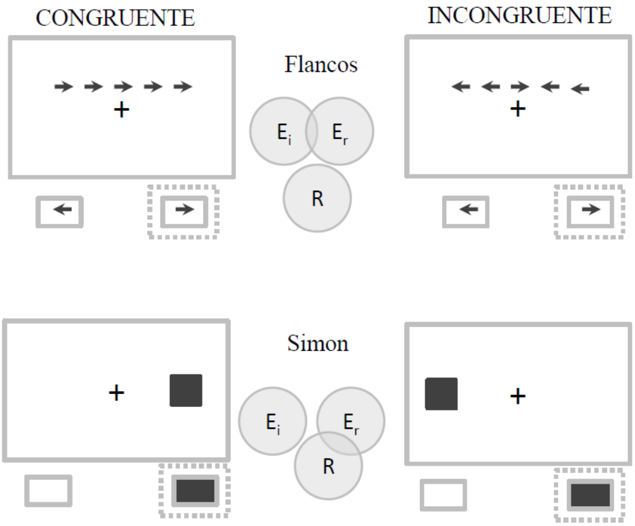

Figura 3. *Representación esquemática de las tareas de interferencia de flancos y Simon, respectivamente. En la tarea de flancos (arriba), cuando la dirección de las flechas circundantes (E_i) es congruente con la de la flecha central (E_r), existe compatibilidad E_i – E_r. Cuando la dirección de los flancos es incongruente con la de la flecha central, se produce incompatibilidad E_i – E_r. En la tarea Simon (abajo), cuando la característica del estímulo irrelevante para la tarea (E_i -el lugar-) coincide con el lugar de respuesta (R) asociado con la dimensión del estímulo relevante para la tarea (E_r -el color-) existe congruencia estímulo-respuesta (E_i –R). Cuando no hay correspondencia, se produce incongruencia E_i – R.*

Por ejemplo, en la tarea de flancos (Eriksen y Eriksen, 1974; Figura 3, arriba) los participantes deben responder a la dirección de una flecha (izquierda/derecha), rodeada por otras flechas (flancos) que pueden señalar en la misma dirección (ensayos congruentes) o en la contraria (ensayos incongruentes). En los ensayos incongruentes, la información de los flancos compite por la respuesta, lo que requiere suprimir la interferencia que éstos producen para responder adecuadamente. Por su parte, en la tarea Simon estándar (Figura 3, abajo) se pide a los participantes que asocien una respuesta a un estímulo determinado (p. ej.: “presionar la tecla derecha ante un estímulo rojo”; “presionar la tecla izquierda si el estímulo es verde”). Dado que el estímulo puede aparecer a la izquierda o a la derecha de la pantalla, en los ensayos incongruentes la respuesta asociada al estímulo compite con la tendencia motora prepotente de responder al lugar donde aparece el mismo. A pesar de que la localización del estímulo es irrelevante para la tarea, normalmente las respuestas son más rápidas si hay correspondencia entre localización del estímulo y de la respuesta (para revisiones, véase Proctor y Reeve, 1989; y un número especial de *Acta Psychologica* dedicado al efecto Simon, Mordkoff y Hazeltine, 2011). En esta tarea, la repuesta motora está asociada a una dimensión espacial del estímulo irrelevante para la tarea, lo que influye en la respuesta manual asociada a una característica que sí es relevante para la misma.

Estos paradigmas permiten obtener un índice de control de la interferencia a partir de la diferencia en los tiempos de reacción o número de aciertos entre los ensayos congruentes e incongruentes. Las diferencias más pequeñas entre ambos tipos de ensayos se relacionan con menor efecto de la interferencia producida por la información competidora, lo que a menudo se interpreta como mejor control inhibitorio (aunque en el siguiente apartado discutiremos interpretaciones alternativas). El efecto de interferencia en estas tareas, por tanto, permite evaluar diferencias individuales en control inhibitorio no dependiente del lenguaje. De hecho, múltiples estudios se han valido de ellas para evaluar modulaciones en la capacidad de control cognitivo derivadas del bilingüismo.

La ventaja ejecutiva bilingüe

Los primeros estudios sobre la influencia del bilingüismo en el control ejecutivo parten de la idea de que un mecanismo inhibitorio se encarga de seleccionar el idioma relevante para la situación, suprimiendo las entradas léxicas competidoras del idioma alternativo. En consecuencia, los bilingües ejercitarían este tipo de control de dos maneras. Por un lado, seleccionando un idioma e inhibiendo el otro y, por otra parte, inhibiendo los competidores del idioma irrelevante que podrían generar conflicto durante la producción o la comprensión del lenguaje. Asumiendo que la práctica intensiva de estos procesos entrena una capacidad general -no específica al dominio del lenguaje-, los bilingües serán menos vulnerables a la interferencia que los monolingües en tareas no verbales que implican mecanismos parecidos. Es decir, los bilingües serían más competentes al seleccionar la información relevante para la tarea en dominios no restringidos al lenguaje, suprimiendo la información competidora y distractora que podría generar conflicto.

Numerosos estudios han encontrado que los bilingües aventajan a los monolingües en tareas tipo Simon (Bialystok et al., 2005, 2004) y de flancos, a menudo insertada en la Tarea de

Redes Atencionales (*Attentional Network Test*; *ANT* -de Fan, McCandliss, Sommer, Raz y Posner, 2002- Costa et al., 2009, 2008; Tao, Marzecová, Taft, Asanowicz y Wodniecka, 2011), mostrando en ellas menor coste de interferencia que en monolingües. Además, este fenómeno aparece a lo largo del ciclo vital, ya que se han descrito ventajas bilingües tanto en niños (p. ej., Adi-Japha et al., 2010; Bialystok y Martin, 2004; Bialystok y Senman, 2004; Bialystok, 1999, 2010; Carlson y Meltzoff, 2008), como en adultos jóvenes (p. ej., Colzato et al., 2008; Costa et al., 2009, 2008) y mayores (p. ej., Bialystok et al., 2004).

Otros estudios han examinado la ejecución bilingüe en tareas que requieren capacidades inhibitorias y cambiar de tarea, pero no implican estímulos conflictivos. Dado que los bilingües a menudo necesitan cambiar de idioma, también deben implicar procesos de control implicados en cambiar de metas, inhibiendo el anterior objetivo y dirigiendo la atención hacia el nuevo. Esta función de cambio de set atencional normalmente se evalúa mediante procedimientos de cambio de tarea. En el paradigma estándar se presentan estímulos con varias características (p. ej., un cuadrado o un triángulo en color rojo o verde) y normalmente se incluyen bloques "puros", en los que el participante debe responder atendiendo solamente a una de las características (p. ej., el color o la forma) y bloques "mixtos", en los que el participante debe responder a una característica o a otra, de acuerdo a las instrucciones recibidas ensayo a ensayo. En estos bloques mixtos se producen dos tipos de ensayos: ensayos de repetición, en los que la tarea se repite en varios ensayos seguidos (p. ej.: color-color) y ensayos de cambio, en los que la tarea cambia entre un ensayo y el siguiente (p. ej.: color-forma). La diferencia entre los ensayos de repetición y los ensayos de cambio en los bloques mixtos se usa como medida de "coste de cambio", mientras que la diferencia entre los bloques mixtos y los bloques puros se usa como índice de "coste mixto". El primer índice (coste de cambio) evalúa la flexibilidad cognitiva o la resistencia a la interferencia proactiva que produce el ensayo anterior (Philipp, Kalinich, Koch y Schubotz, 2008). Refleja la capacidad de dejar de atender a las características del estímulo que indicaba el objetivo anterior (p. ej., color) y dirigir la atención hacia un nuevo objetivo (p. ej., forma). El segundo índice (coste mixto) evalúa la capacidad de mantener el control atencional en un contexto en el que se deben mantener activas varias tareas. Refleja la capacidad de cambiar continuamente los objetivos de la tarea frente a mantener un mismo objetivo. Los resultados en estas tareas han mostrado ventajas de los bilingües en el coste de cambio, pero no en el coste mixto (Prior y Gollan, 2011; Prior y Macwhinney, 2009; Soveri, Rodriguez-Fornells y Laine, 2011). Por tanto, el bilingüismo parece afectar a la capacidad de dirigir la atención hacia nuevos objetivos, lo cual, a su vez, requiere inhibir el objetivo previo y redirigir la atención hacia el nuevo.

En conjunto, los estudios sobre control inhibitorio apoyan la idea de que la selección y el control de idiomas estarían mediados por procesos de control ejecutivo general, lo que se ve reflejado en menores costes de interferencia en tareas no verbales y menores costes de cambio de tarea. No obstante, existen dos factores principales que cuestionan el papel modulador del bilingüismo sobre procesos de inhibición. En primer lugar, la superioridad bilingüe no se encuentra sistemáticamente. Las revisiones recientes coinciden en señalar numerosos estudios que no encuentran esta ventaja bilingüe en tareas que implican resolución de conflicto o flexibilidad cognitiva (Blumenfeld y Marian, 2013; Hernández, Martin, Barceló y Costa, 2013; Hilchey y Klein, 2011; Paap y Greenberg, 2013; Tao et al., 2011). En segundo lugar, la ejecución de los bilingües y los monolingües no solamente difiere en tareas que evalúan control inhibitorio. Por ejemplo, la superioridad bilingüe se extiende a tareas que implican memoria de trabajo (Bialystok et al., 2004; Luo, Craik, Moreno y Bialystok, 2013), creatividad (Hommel, Colzato, Fischer y Christoffels, 2011; Kharkhurin, 2010; Ricciardelli, 1992), resolución de problemas y flexibilidad cognitiva (p. ej., *dimensional card-sorting task*, Bialystok, Craik y Ruocco, 2006; Bialystok y Martin, 2004; Marzecová et al., 2013) o memoria episódica (Ljungberg, Hansson, Andrés, Josefsson y Nilsson, 2013).

Resumiendo, a los estudios que apoyan los modelos inhibitorios y encuentran que los bilingües superan a los monolingües en tareas que implican control cognitivo se contrapone otro conjunto de estudios en los que dichos beneficios son imprecisos o ausentes. Además, las diferencias encontradas entre bilingües y monolingües en tareas no inhibitorias sugieren que el bilingüismo puede influir sobre otros procesos cognitivos distintos de la inhibición. Estos aspectos ponen en duda, por una parte, que los mecanismos inhibitorios sean los responsables de la selección y el control de idiomas (o, al menos, que su uso se transfiera a otros dominios). Por otra parte, obligan a considerar la intervención de otros procesos cognitivos en el bilingüismo. Sin embargo, el carácter esquivo de la ventaja inhibitoria bilingüe podría estar simplemente reflejando diferentes aspectos del control inhibitorio.

Un problema en el estudio del control inhibitorio es que el término "inhibición" a menudo se emplea con demasiada laxitud, haciendo referencia a diferentes funciones y procesos (Friedman y Miyake, 2004). Por ejemplo, debemos tener en cuenta que, aunque las tareas empleadas en los experimentos descritos previamente requieren resolver el conflicto provocado por respuestas que compiten entre sí (como ocurre en la selección y control de idiomas según las propuestas inhibitorias), la naturaleza del conflicto que generan no es idéntica (véase Figura 3). Algunas tareas implican reducir el conflicto producido por la información del estímulo (supresión de interferencia), mientras que otras demandan la inhibición de una respuesta predominante ante el estímulo presentado (inhibición de respuesta). Por tanto, es importante distinguir entre tareas en las que el conflicto se deriva de características propias del estímulo (como en la tarea de flancos, en la que la flecha central señala en dirección opuesta a las flechas que la rodean) y tareas en las que el conflicto se deriva de las características de la respuesta (como en la tarea Simon, en la que el estímulo aparece en un lugar que está asociado a una respuesta diferente).

Los mecanismos de control de idiomas que intervendrían en el bilingüismo serían aquéllos relacionados con el tipo de conflicto que produce la co-activación de idiomas. En consecuencia, la ventaja bilingüe debería observarse específicamente en las tareas que requieren un mecanismo de resolución de conflicto similar al control de idiomas. Esta idea concuerda con las teorías de control atencional que defienden que los distintos procesos de control de conflicto son de naturaleza plástica y se modulan por la experiencia (Garavan, Hester, Murphy, Fassbender y Kelly, 2006) pero que también son independientes entre sí (Egner, Delano y Hirsch, 2007). Es decir, el entrenamiento en supresión de interferencia no afectaría al control de respuesta y viceversa.

Dado que el tipo de competición que se produce entre los dos idiomas, en el que un mismo objeto activa una entrada léxica para cada idioma, cabría esperar que el tipo de conflicto con el que se enfrentan los bilingües radique en procesos de supresión de interferencia más que en inhibición de respuesta. Efectivamente, los estudios que han tratado de disociar estos dos procesos inhibitorios demuestran que las ventajas bilingües están más estrechamente relacionadas con tareas que requieren ignorar información que compite entre sí y no cuando se requiere controlar una respuesta prepotente (Bialystok y Martin, 2004; Bialystok y Viswanathan, 2009; Blumenfeld y Marian, 2013;

Colzato et al., 2008; Esposito, Baker-Ward y Mueller, 2013; Martin-Rhee y Bialystok, 2008).

Por ejemplo, a nivel neural, Luk, Anderson, Craik, Grady y Bialystok (2010) examinaron, mediante imagen por resonancia magnética funcional (IRMf), la actividad cerebral asociada a diferentes componentes inhibitorios en bilingües y monolingües. Para ello emplearon una adaptación de la tarea de flancos que combina supresión de interferencia e inhibición de respuesta. Como en el paradigma estándar, hay ensayos congruentes e incongruentes. Se introducen también ensayos neutros, en los que la flecha está rodeada por rombos, estímulos que no producen interferencia con la tarea y, lo que es más interesante, ensayos NoGo, en los que el estímulo aparece flanqueado por aspas (X), que indican que no hay que responder en esos ensayos. Por tanto, los ensayos incongruentes requieren superar el conflicto producido por la información competitiva, mientras que los ensayos NoGo implican procesar la información de los flancos y utilizarla para parar la respuesta. En otras palabras, los ensayos incongruentes requieren supresión de interferencia, mientras que los ensayos NoGo implican inhibición de respuesta. Los autores no encontraron diferencias conductuales entre los grupos, pero sí encontraron diferencias en la activación cerebral. Aunque bilingües y monolingües empleaban regiones similares en los ensayos NoGo, activaron regiones diferentes para los ensayos congruentes e incongruentes. Mientras los monolingües activaron regiones del polo temporal izquierdo y de la región parietal superior izquierda para resolver la interferencia, los bilingües emplearon una red más extensa, que incluía regiones frontales y subcorticales bilaterales. De especial importancia es que esta red era la misma que ambos grupos activaban para inhibir la respuesta. Los autores interpretan estos datos como una prueba de que el efecto del bilingüismo sobre el control cognitivo se restringe a la supresión de interferencia y está ausente en la inhibición de respuesta, indicando que el manejar varios idiomas no afecta por igual todos los procesos inhibitorios. Estos resultados apoyan la idea de que la selección de idiomas demanda procesos de control cognitivo encargados de resolver la interferencia estímulo-estímulo (Blumenfeld y Marian, 2013). Por otra parte, encajan con las teorías atencionales, que defienden la importancia de distinguir entre distintos procesos de control (p. ej., Braver, 2012; Egner et al., 2007; Friedman y Miyake, 2004).

Sin embargo, aunque la ventaja inhibitoria parece observarse con mayor robustez en aquellas tareas que implican un control similar al requerido en la selección de idiomas, los resultados distan de ser consistentes. Son muchos los estudios que no consiguen encontrar ventaja bilingüe en, por ejemplo, tareas de flancos que implican supresión de interferencia (para una revisión, véase Hilchey y Klein, 2011). Una posible explicación a este fenómeno procede de las medidas neurofisiológicas. Estos estudios demuestran que, aun en ausencia de diferencias conductuales, bilingües y monolingües emplean circuitos diferentes al resolver tareas ejecutivas que requieren superar la interferencia. Por tanto, aunque la influencia del bilingüismo no siempre aparezca reflejada como mayor eficacia al resolver las tareas, los bilingües parecen emplear las redes neurales relacionadas con el control del conflicto de forma más eficiente, lo que apoyaría la idea del control inhibitorio (Abutalebi et al., 2012; Bialystok et al., 2005; Garbin et al., 2010; Kousaie y Phillips, 2012; Luk et al., 2010).

Por ejemplo, aunque Bialystok et al. (2005) no encontraron diferencias conductuales entre bilingües y monolingües en la ejecución de una tarea Simon, sí hallaron diferencias en la actividad neural asociada a la misma, medida mediante magnetoencefalografía (MEG). Se encontró que los bilingües (pero no los monolingües) mostraban una relación entre la rapidez de las respuestas (tanto en ensayos congruentes como en incongruentes) y la actividad en la corteza prefrontal izquierda y la corteza cingulada anterior (CCA), regiones asociadas con el procesamiento de las señales.

Además, es de especial relevancia que las medidas neurales de estudios centrados en el procesamiento del lenguaje en bilingües revelan que algunas de las regiones empleadas para evitar la interferencia entre idiomas son similares a las asociadas con mecanismos de control no verbal (para revisiones, véase Hervais-Adelman, Moser-Mercer y Golestani, 2011; Moreno, Rodriguez-Fornells y Laine, 2008; Rodriguez-Fornells, De Diego Balaguer y Münte, 2006). De hecho, la experiencia bilingüe media en las diferencias en los patrones de activación neural entre bilingües y monolingües (Garbin et al., 2010; Luk, Green, Abutalebi y Grady, 2012). Así, son varios los estudios que han mostrado una relación entre la ejecución de los bilingües al cambiar de idioma y la de tareas de cambio no verbal (Garbin et al., 2010; Prior y Gollan, 2011; Prior y Macwhinney, 2009), lo que sugiere que los procesos de control implicados son similares. Por ejemplo, Garbin y colaboradores (2010) observaron la activación cerebral de monolingües españoles y bilingües español-catalán mediante IRMf mientras ejecutaban una prueba no verbal de cambio de tarea y una tarea de cambio de idioma. Los resultados mostraron, por un lado, que solo los monolingües mostraban "coste de cambio" en la tarea no verbal. Por otro lado, bilingües y monolingües diferían en las regiones cerebrales asociadas con los ensayos de cambio y no cambio. Los monolingües empleaban principalmente la CCA y, además, en mayor magnitud que los bilingües, que empleaban también áreas relacionadas con el control de idiomas (corteza frontal inferior izquierda y estriado derecho). En la misma línea, Abutalebi y colaboradores (2012), emplearon una tarea de cambio de idioma y una tarea de flancos para examinar mediante IRMf las regiones asociadas con el control de idiomas y el control cognitivo, respectivamente. Encontraron que el efecto de conflicto en la tarea de flancos se reducía en los bilingües con la práctica, lo cual se asociaba a una reducción en la CCA. Además, observaron que la correlación entre el efecto de conflicto y la densidad en materia gris en la CCA era mayor en los bilingües que en los monolingües. Los resultados apoyan la idea de que la necesidad de manejar varios idiomas modula las redes neurales encargadas de resolver el conflicto.

En conjunto, los estudios neurofisiológicos apoyan la idea de que los bilingües emplean circuitos comunes para el control de idiomas y la resolución de conflicto a nivel general. Además, la ventaja bilingüe se relaciona con procesos de control inhibitorio, sugiriendo que el sistema atencional de los bilingües reacciona de una forma más eficiente en presencia de competición. Estos resultados apoyan la hipótesis inhibitoria y justificarían que la ventaja bilingüe no aparezca siempre en tareas inhibitorias. Sin embargo, los modelos inhibitorios no ofrecen ninguna explicación para las ventajas bilingües que se observan en tareas no inhibitorias. Por ejemplo, aparte del menor efecto de interferencia (p. ej., menores errores o tiempos de reacción en los ensayos incongruentes), los estudios con tareas de conflicto muestran que los bilingües son en general más rápidos contestando tanto a los ensayos congruentes como a los incongruentes (p. ej., Bialystok et al., 2006; Costa et al., 2008; Martin-Rhee y Bialystok, 2008; véase también Hilchey y Klein, 2011 para una revisión). Dado que este último efecto aparece solo en condiciones que requieren una elevada monitorización, quizás el control inhibitorio no es el principal responsable de las ventajas o, tal vez, no es el único mecanismo implicado.

Uno de los resultados más representativos en esta línea es el de Costa y colaboradores (2009), en el que compararon monolingües y bilingües en una tarea de flancos. En sus estudios, manipularon las demandas de monitorización de la tarea mediante la modificación de la proporción de ensayos congruentes e incongruentes. El razonamiento es que la presentación de ensayos congruentes e incongruentes en proporciones similares requiere cambiar constantemente entre situaciones de conflicto (incongruentes) y no conflicto (congruentes). Esto fuerza a los participantes a controlar constantemente las demandas de cada ensayo para poder seleccionar la respuesta adecuada. Por el contrario, cuando la proporción de ensayos congruentes e incongruentes está desequilibrada, los procesos de control estarán mucho menos implicados en la tarea, ya que hay poca variación de tipo de respuesta a lo largo de los ensayos. En las condiciones de baja monitorización (Experimento 1) los ensayos congruentes se presentaban en el 92% o el 8% de los ensayos, mientras que en las condiciones de alta monitorización (Experimento 2) lo hacían en el 75% y el 50% de las ocasiones. Los resultados indicaron que las diferencias entre bilingües y monolingües en el efecto de conflicto sólo aparecían cuando la tarea incluía una proporción similar de ensayos congruentes e incongruentes (las condiciones de alta monitorización). Además, bajo la condición de alta monitorización los bilingües eran más rápidos en general (tanto en los ensayos congruentes como en los incongruentes). Por un lado, esto podría indicar que las diferencias debidas a la experiencia lingüística no se restringen a las condiciones que implican conflicto (incongruentes) sino a la tarea en general. Por otro, que serían los procesos de monitorización los que deben estar implicados en la selección de idiomas.

Recientemente, Prior (2012) contrastó la capacidad de monitorización e inhibición en bilingües como procesos alternativos subyacentes a la ventaja bilingüe. En su estudio los participantes ejecutaron una tarea de cambio no verbal. La novedad de este estudio reside en que el coste de cambio se medía no en el ensayo siguiente, sino dos ensayos después. Por tanto, la inhibición se evaluaba comparando la ejecución en el último ensayo de una secuencia de ensayos ABA (p. ej., color-forma-color) con el último ensayo de una secuencia CBA (p. ej., tamaño-forma-color). El razonamiento es que en la secuencia ABA (color-forma-color) es necesario suprimir la respuesta al color en el segundo ensayo para reducir su interferencia proactiva. Por tanto, será más fácil contestar al tercer estímulo en la secuencia CBA. La monitorización se evaluó midiendo la atenuación de los efectos al introducir de forma inesperada un bloque "puro" (en el que siempre se realiza la misma tarea, por ejemplo, contestar al color) justo después de los bloques mixtos. La ejecución del último bloque (de atenuación) se usó para indicar la facilidad de los participantes para ajustar sus tiempos de reacción al descenso de demandas de monitorización en este bloque puro. Es decir, al principio del bloque de atenuación, los participantes continúan empleando los recursos cognitivos empleados en el bloque mixto que acaban realizar, lo que se manifiesta en tiempos de respuesta más lentos que los de un bloque puro esperado. Los procesos de monitorización se encargan de reajustar los recursos cognitivos conforme van avanzando los ensayos. El ajuste de recursos en ensayos más tempranos (manifestado en tiempos de reacción propios de un bloque puro) indica una monitorización más eficiente. Los resultados mostraron que los participantes bilingües tenían mayores costes en los ensayos ABA que los monolingües. Es decir, los bilingües ejercían mayor inhibición en la tarea sobre la característica no necesaria. Por el contrario, en el bloque de atenuación los dos grupos ajustaron su ejecución tras un número de ensayos similar, lo que sugiere que los bilingües no eran superiores que los monolingües ajustando su sistema de monitorización.

Otros estudios que han comparado la ejecución de bilingües y monolingües en tareas que requieren diferentes componentes del control ejecutivo enfatizan que otros procesos, como la capacidad de mantener las metas de la tarea, podrían subyacer a las ventajas bilingües. Así, Colzato y colaboradores (2008) evaluaron a un grupo de bilingües y otro de monolingües en una serie de experimentos que medían diferentes aspectos del control inhibitorio. Los resultados mostraron que no había diferencias en tiempos de reacción a la señal de parar la respuesta en la tarea de *stop-signal* (*stop-signal reaction time*; SSRT). La tarea de *stop-signal*, se ha usado ampliamente para evaluar inhibición de respuesta, pero sí mayor inhibición de retorno y parpadeo atencional en los bilingües comparados con los monolingües. La interpretación de los autores es que la ventaja bilingüe reside principalmente en una mayor capacidad de mantener el objetivo de la tarea, ya que no aparecen diferencias en la capacidad de supresión de respuesta, medida por la tarea *stop-signal,* y tanto el mayor parpadeo atencional como la inhibición de retorno pueden interpretarse como consecuencia de una mayor capacidad de mantener los objetivos de la tarea.

Conclusiones

En resumen, algunos estudios muestran mayor eficiencia de los bilingües en comparación con los monolingües en tareas que implican resolución de conflicto, lo que encajaría con la hipótesis inhibitoria. Por otra parte, los datos neuropsicológicos muestran diferencias funcionales derivadas del bilingüismo en la resolución de estas tareas, aún en ausencia de diferencias conductuales. Estos resultados indican que el manejo de varios idiomas produce diferencias en las redes neurales implicadas en la resolución de conflicto las cuales, además, están implicadas también en el control del lenguaje. No obstante, existen pruebas que no encajan completamente con las teorías inhibitorias, como los resultados diferenciales en tareas con distintas demandas de control inhibitorio (p. ej. control de interferencia, inhibición de respuesta), la dificultad de replicar la ventaja inhibitoria bilingüe y la observación de otros fenómenos como el menor tiempo de reacción global. Estos datos han llevado recientemente al desarrollo de propuestas alternativas que sugieren que la habilidad de manejar la competición y resolver la información competidora no sería la causa subyacente a la ventaja bilingüe. Desde esta aproximación, los mecanismos relacionados con la monitorización y mantenimiento de los objetivos de la tarea respaldarían la superioridad bilingüe encontrada en tareas atencionales (Colzato et al., 2008; Costa et al., 2009).

En el siguiente apartado examinaremos las propuestas que abordan los posibles factores responsables de las inconsistencias encontradas en los estudios previos y expondremos las circunstancias que pueden influir en los efectos encontrados, tratando de aportar coherencia al conjunto de investigaciones existentes. Concretamente, abordaremos dos factores que pueden estar sesgando las interpretaciones acerca de la relación entre control ejecutivo y bilingüismo. En primer lugar, destacaremos el hecho de que el bilingüismo debería estudiarse en el contexto de un sistema que modifica de forma dinámica la ejecución cognitiva y lingüística. Sin embargo, la mayoría de los estudios previos se centran en el estudio de componentes ejecutivos aislados y específicos (focalizándose principalmente en el control inhibitorio). Esta estrategia, si bien es positiva porque pretende identificar el papel concreto de cada mecanismo de control, impide captar posibles modulaciones sobre la dinámica entre diferentes mecanismos. En segundo lugar, es fundamental tener en cuenta que el bilingüismo no es una variable categórica. Como apuntábamos al principio de la introducción, los bilingües pueden y suelen diferir en aspectos socio-económicos, culturales, educacionales y, sobre todo, en factores lingüísticos como la competencia, la dominancia, o el contexto de uso de sus idiomas, por citar unos pocos. Las diferencias en estos factores, entre otros, podrían derivar en el empleo de diferentes estrategias para resolver la co-activación entre idiomas y, por ende, en diferentes demandas de recursos cognitivos. Por tanto, tratar de interpretar los numerosos estudios en este campo sin contemplar de forma explícita estas variables podría conducir a extraer conclusiones erróneas. Examinaremos a continuación estos factores y propondremos un enfoque alternativo para comprender la relación entre la experiencia bilingüe y la función ejecutiva.

1.3. LA NATURALEZA DINÁMICA DE LOS PROCESOS DE CONTROL COGNITIVO

En general, las investigaciones previas han observado el papel de cada componente de control ejecutivo de forma relativamente independiente, dando la impresión de que el bilingüismo afecta a procesos específicos y aislados. Esta aproximación fragmentada impide captar una característica fundamental del bilingüismo: es una experiencia que reestructura profundamente las redes neurocognitivas e influye de forma sustancial en la manera de procesar el lenguaje. Manejar varios idiomas es una experiencia que modula y reorganiza toda una red encargada de procesar el lenguaje. Por tanto, observar los cambios cognitivos derivados del bilingüismo centrándose en estudiar los componentes de forma aislada supone una forma muy sesgada de abordar el tema. Es por ello que las propuestas recientes sugieren que la causa de la ventaja bilingüe no radica en un único proceso, sino en la combinación dinámica de varios mecanismos de control cognitivo (Bialystok, Craik y Luk, 2012; Costa et al., 2009; Green y Abutalebi, 2013; Kroll y Bialystok, 2013). Así, proponen aproximaciones más globales, planteando que la ventaja bilingüe radica en diferencias en la "monitorización" (Costa et al., 2009), "coordinación" (Bialystok, 2011) o adaptación (Green y Abutalebi, 2013) entre distintos procesos de control cognitivo.

En consecuencia, parece fundamental abordar el estudio de los efectos moduladores de experiencia bilingüe sobre las redes de control cognitivo desde una perspectiva más holística, considerando que la función ejecutiva es más que la suma de cada componente. Ésta parece ser la aproximación de algunos modelos recientes sobre control cognitivo que enfatizan que distintos componentes de control ejecutivo dependen de un mecanismo común que permitiría a los individuos mantener las metas relevantes de la tarea y, así, activar los subprocesos adecuados para resolverla (Miyake y Friedman, 2012). En una revisión reciente de su modelo Miyake y Friedman (2012) proponen que la función ejecutiva debe estudiarse desde un marco de "unidad y diversidad" (véase Figura 4). De acuerdo con esta perspectiva, la función ejecutiva está compuesta por un mecanismo común y por componentes específicos (control inhibitorio, cambio de set atencional, actualización de información…). Cada componente principal de la función ejecutiva estaría, por tanto, formado por una habilidad propia (diversidad) y por una habilidad común a todas las funciones ejecutivas (unidad). La función ejecutiva común se relaciona con la capacidad de mantener activamente los objetivos de la tarea y la información relevante para la tarea y con usar esta información para dirigir de forma efectiva los procesos de menor nivel. Por tanto, la ventaja inhibitoria bilingüe podría ser el reflejo de la modulación de este factor común. En consecuencia, si el bilingüismo modifica el componente unitario de la función ejecutiva, modularía también el funcionamiento de los componentes de control no inhibitorios.

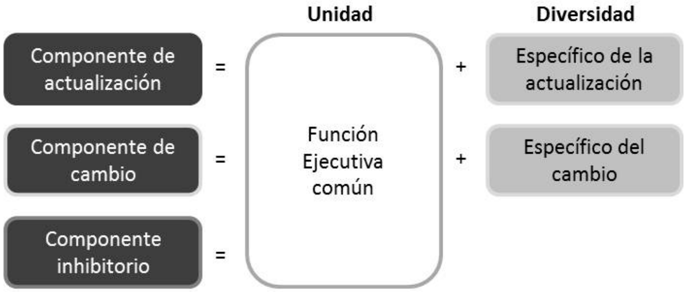

Figura 4. *(Adaptada de Miyake y Friedman, 2012). Representación esquemática de la unidad y diversidad de tres funciones ejecutivas. Cada función ejecutiva (p. ej. actualización) es el resultado de combinar una capacidad común a las tres funciones ejecutivas (p. ej., la capacidad específica de actualización).*

Por otra parte, otros mecanismos de control (aparte del inhibitorio) podrían participar para conseguir la máxima eficiencia durante la selección de idiomas. Por ejemplo, la selección del idioma planeado puede conllevar procesar las claves contextuales que proporcionan información sobre el idioma en que va a producirse la comunicación ("¿con quién estoy hablando?; "¿qué idioma habla mi interlocutor?; ¿estoy en casa o en el trabajo?", etc.). Desde esta perspectiva, los bilingües estarían constantemente monitorizando claves intra- y extra-lingüísticas para seleccionar con éxito el idioma adecuado para la compresión y la producción. Además, es necesario mantener activo el idioma planeado mientras se continúan procesando nuevas claves que puedan inducir el cambio de idioma (p. ej., Costa, La Heij y Navarrete, 2006; Costa, Santesteban y Ivanova, 2006; Finkbeiner, Almeida, Janssen y Caramazza, 2006;

Finkbeiner, Gollan y Caramazza, 2006; Philipp, Gade y Koch, 2007). La idea, por tanto, es que no tiene por qué haber un único proceso responsable, sino que el control de idiomas puede ser el resultado de la combinación dinámica entre distintos mecanismos de control (Bialystok et al., 2012; Costa et al., 2009; Costa, Santesteban, et al., 2006; Prior, 2012) que se modularía de acuerdo con las demandas de la situación (De Groot y Christoffels, 2006; Festman y Münte, 2012; Green y Abutalebi, 2013; Kroll y Bialystok, 2013). Es decir, un contexto interactivo bilingüe exige mantener el objetivo de hablar en un idioma determinado, pero también estar abierto a claves ambientales que indiquen la necesidad de cambiar a otro idioma. Por tanto, los diferentes procesos de control cognitivo deben colaborar para conseguir una comunicación adecuada y el aspecto común de la función ejecutiva propuesto por Miyake y Friedman podría ser el responsable de coordinar los distintos procesos implicados.

Esta idea podría explicar las evidencias tanto a favor de la mediación de procesos de control inhibitorio como de procesos de monitorización en la superioridad bilingüe que describimos en el apartado 1.2. Así, los bilingües muestran menores diferencias entre ensayos congruentes e incongruentes que los monolingües en tareas de conflicto, indicando que la ventaja bilingüe está relacionada con la capacidad de ignorar información irrelevante (mediante control inhibitorio o reactivo). Por otra parte, la mayor capacidad de los bilingües para ajustarse en contextos mixtos de ensayos congruentes e incongruentes en tareas de conflicto (Costa et al., 2009) junto con las diferencias encontradas en tareas de parpadeo atencional, cambio de tarea (Colzato et al., 2008; Garbin et al., 2010; Hernández, Costa y Humphreys, 2011; Hernández et al., 2013; Prior y Gollan, 2011; Prior y Macwhinney, 2009; Prior, 2012) o búsqueda visual (Hernández et al., 2011), que requieren mantener los objetivos de la tarea, sugieren que procesos de monitorización (control proactivo) pueden también subyacer a la ventaja bilingüe.

El papel de la coordinación entre procesos de control proactivo y reactivo en el control de idiomas se plantea implícitamente en el modelo de control inhibitorio de Green (Green, 1998), que asume que los esquemas de la tarea se activan proactivamente para dirigir el procesamiento. Asimismo, la hipótesis de control adaptativo propuesta recientemente por Green y Abutalebi (Green y Abutalebi, 2013) aborda explícitamente esta línea de pensamiento. Los autores proponen que los distintos procesos de control deben cooperar entre sí y adaptarse dependiendo de las demandas de la situación para conseguir la máxima eficiencia en la ejecución de una tarea, lo que conlleva cambios adaptativos en las regiones neurales y en los circuitos asociados a los mecanismos de control específicos. Por tanto, una situación que implica dos idiomas conllevaría la adaptación del circuito mediador en la cascada de procesos que conlleva el control de alternativas. Desde esta perspectiva, aunque procesos como el desvincularse y vincularse a una tarea puedan parecer contrapuestos, el ajuste adecuado entre ellos proporcionará mayor eficiencia en la ejecución. En consecuencia, las propuestas inhibitorias y no inhibitorias de control de idiomas no tienen por qué ser necesariamente excluyentes. Es más, las diferencias individuales en control cognitivo podrían comprenderse mejor examinando las diferencias de las dinámicas entre varias formas de control, en lugar de elaborando hipótesis más simples sobre cada modo de control por separado (Egner et al., 2007).

La propuesta de que diferentes mecanismos de control subyacen a la selección de idiomas puede enmarcarse en perspectivas teóricas atencionales que sugieren que la interacción entre distintos procesos cognitivos sería la responsable del control cognitivo. Por ejemplo, la teoría dual de mecanismos de control de Braver (p. ej., Braver, Gray y Burgess, 2007; Braver, 2012) propone dos procesos de control, proactivo y reactivo, que son relativamente independientes pero también complementarios. El control proactivo es un mecanismo atencional temprano que se encarga de seleccionar los objetivos de la tarea y mantenerlos activos de forma sostenida. Sirve para anticipar eventos venideros y previene al sistema de la interferencia, centrándose y seleccionando la alternativa adecuada antes de que se presente un competidor. En el caso de los bilingües, podría argumentarse que la selección del idioma adecuado para la comunicación requiere monitorizar el contexto en el que se va a producir la comunicación. El control reactivo, por su parte, se encarga de detectar y resolver la interferencia que aparece en una situación de conflicto. La ventaja del control proactivo es que utiliza con antelación las claves del contexto para adaptar la conducta al objetivo. Sin embargo, requiere muchos recursos de la memoria de trabajo para poder mantener dichos objetivos activos mientras se ejecuta la tarea. El control reactivo mantiene libre la memoria de trabajo para ejecutar otros aspectos de la tarea, pero tiene la desventaja de que las metas deben reactivarse cada vez que sea necesario y demanda mecanismos de detección de conflicto para detectar cuándo es necesario ejercer el control inhibitorio. Dado que vivimos en un mundo cambiante, a menudo es necesario mantener el contenido que es importante en un momento determinado (control proactivo o monitorización), sin dejar de ser sensible a nueva información potencialmente relevante que requiera cambiar a otros objetivos (control reactivo o inhibitorio). Por tanto, el ajuste adecuado de estos dos mecanismos de control permitiría alcanzar la máxima eficiencia en el desempeño de las tareas.

Los estudios previos han tratado de disociar la influencia del bilingüismo sobre distintos procesos de control inhibitorio como, por ejemplo, monitorización de conflicto y control de interferencia (Costa et al., 2009; Prior, 2012), supresión de interferencia e inhibición de respuesta (Bialystok y Martin, 2004; Bialystok y Viswanathan, 2009; Blumenfeld y Marian, 2013; Luk et al., 2010; Martin-Rhee y Bialystok, 2008) o inhibición activa y reactiva (Colzato et al., 2008). Sin embargo, no se ha investigado directamente si la experiencia bilingüe modula la coordinación entre diferentes procesos de control. Uno de los principales objetivos de nuestra investigación es, precisamente, conocer cómo influye la experiencia bilingüe en la cascada de procesos necesaria para resolver situaciones de conflicto. Para ello, en la primera serie experimental abordaremos la idea de que la combinación dinámica entre procesos de monitorización e inhibición influye en la resolución de la interferencia de la información distractora o competidora. En el Experimento 1 compararemos bilingües y monolingües en una versión AX de la tarea de ejecución continua (*continuous performance task*; AX-CPT) que requiere ajustar el control proactivo (monitorización) y reactivo (inhibición), para alcanzar una ejecución adecuada de la tarea. En el Experimento 2 evaluaremos las diferencias en el ajuste de ambos mecanismos observando los potenciales corticales (*event related potentials*, ERPs) asociados a la activación de las metas y objetivos y preparación de respuestas (control proactivo), así como a procesos de detección de conflicto y supresión de respuesta (control reactivo).

En la primera serie experimental evaluaremos la dinámica de los procesos de control ejecutivo en adultos jóvenes, cuando se encuentran en el pico de su desarrollo. Pero, ¿qué ocurre cuando estos componentes se están desarrollando? Durante la infancia, el bilingüismo podría afectar al desarrollo del aspecto específico de los componentes ejecutivos o, alternativamente, influir sobre el aspecto común entre los mismos mientras se están desarrollando. A continuación nos centraremos en describir los datos actuales sobre la influencia del bilingüismo sobre el desarrollo de la función ejecutiva en la niñez.

Bilingüismo y desarrollo de la función ejecutiva

La investigación indica que los niños bilingües desarrollan más temprano su capacidad de control cognitivo que los monolingües (Adi-Japha et al., 2010; Bialystok, Barac, Blaye y Poulin-Dubois, 2010; Bialystok, 2010; Carlson y Meltzoff, 2008; Yang, Yang y Lust, 2011). Como ocurre con los adultos, la mayoría de estudios se han centrado principalmente en el analizar procesos aislados (fundamentalmente la inhibición y flexibilidad cognitiva), con resultados similares. Los niños bilingües muestran menor coste de interferencia que los monolingües en tareas tipo Simon (Martin-Rhee y Bialystok, 2008) o de flancos (Engel de Abreu, Cruz-Santos, Tourinho, Martin y Bialystok, 2012; Yang et al., 2011). También puntúan mejor en tareas de flexibilidad cognitiva como la prueba de Cambio de Dimensión en la Clasificación de Tarjetas (*Dimensional Change Card Sort, DCCS* – de Frye, Zelazo y Palfai, 1995 – Bialystok y Martin, 2004; Bialystok y Viswanathan, 2009; Bialystok, 1999). Los escasos estudios que han evaluado hasta ahora la capacidad de actualización (o memoria de trabajo), no han encontrado diferencias entre grupos (Bialystok y Feng, 2009; Bonifacci, Giombini, Bellocchi y Contento, 2010; Engel de Abreu, 2011; pero véase Soliman, 2014). Las inconsistencias de los resultados también se asemejan a los estudios con adultos: algunos estudios no encuentran ventajas bilingües (Duñabeitia et al., 2013; Gathercole et al., 2014; Morton y Harper, 2007) mientras que otros describen que los niños bilingües son en general más rápidos respondiendo en las tareas de conflicto; esto es, muestran menores tiempos de reacción tanto en ensayos congruentes como incongruentes

(Martin-Rhee y Bialystok, 2008; Yang et al., 2011). La similitud de patrones de resultados entre niños y adultos parece sugerir, implícitamente, que la propuesta de que el bilingüismo influye sobre los procesos de monitorización o coordinación de recursos de control cognitivo también se puede aplicar desde las etapas tempranas de su desarrollo.

Recientemente, Bialystok (2011) evaluó de forma explícita la idea de que la experiencia reestructura las redes de control cognitivo en las etapas críticas de su desarrollo. Para ello, evaluó a niños bilingües y monolingües de 8 años en una tarea que requería la coordinación eficiente entre distintas funciones de control ejecutivo. Los niños tenían que llevar a cabo una tarea compleja de clasificación, en la que hacían juicios semánticos sobre estímulos presentados visual o auditivamente (p. ej., contestar "animal" cuando ven/escuchan un perro; o "instrumento musical" si ven/escuchan un piano). Cuando los estímulos se presentaban solamente en la modalidad visual o auditiva, la ejecución era similar en los dos grupos. Sin embargo, los niños bilingües superaron a los monolingües en la versión dual de la tarea. En este caso, los estímulos se presentaban en ambas modalidades simultáneamente. La versión dual requería mantener normas mentalmente para categorizar en cada modalidad (memoria de trabajo), atender a las características de clasificación del objetivo ignorando la otra modalidad (inhibición), y cambiar la atención a los distintos estímulos (cambio de set atencional). Aunque nada apunta a que los bilingües fueran más eficientes en alguno de los procesos aislados, su ejecución en la tarea dual (cuando debían coordinar los tres procesos) sí era mejor que la de los monolingües. Estos hallazgos sugieren que la necesidad de manejar dos sistemas de lenguaje diferentes mejora la coordinación de varios componentes ejecutivos.

Por otra parte, desde la perspectiva de la naturaleza unitaria y diversa de las funciones ejecutivas (Miyake y Friedman, 2012; Miyake et al., 2000), los niños bilingües deberían ser superiores también en memoria de trabajo, especialmente en condiciones en las que también participan otros componentes ejecutivos. Hay dos motivos que sostienen esta hipótesis. Primero, desde una perspectiva unitaria, si el efecto del bilingüismo observado en el control inhibitorio es fruto de modulaciones en el aspecto común, esta experiencia debería afectar a todos los componentes, incluyendo a la memoria de trabajo. En segundo lugar, la activación conjunta de ambos idiomas en los bilingües requiere la adaptación de varios procesos, no solo inhibición y selección. También es necesario, por ejemplo, mantener las representaciones del contexto, los interlocutores o el discurso, de modo que estos otros procesos implicados (p. ej., memoria de trabajo) también podrían modificarse. Por tanto, desde la hipótesis de control adaptativo, se predice que deben reajustarse junto con los otros dos componentes, lo cual debería poder observarse a través efectos en las interacciones entre los componentes ejecutivos. El bilingüismo nos proporciona una ventana única para evaluar la naturaleza unitaria y diversa de las funciones ejecutivas. Si durante el desarrollo cognitivo el aspecto específico de la memoria de trabajo se modifica por el bilingüismo (diversidad) deberíamos encontrar un efecto principal de memoria de trabajo en las manipulaciones sobre otros componentes ejecutivos. Si la memoria de trabajo se integra con otros componentes (unidad), la fuerza del efecto de la memoria de trabajo se modulará dependiendo de las demandas de otras componentes.

La segunda serie experimental del presente trabajo irá enfocada a evaluar cómo influye la experiencia bilingüe en el desarrollo de la función ejecutiva. A este fin, evaluaremos a niños en etapas críticas del desarrollo de las funciones ejecutivas en tareas que requieren una combinación eficiente entre varios componentes de control ejecutivo; específicamente, el control inhibitorio y la memoria de trabajo. Desde una perspectiva unitaria del desarrollo de las funciones ejecutivas, la experiencia bilingüe debería afectar de forma diferencial cada uno de estos componentes. Una perspectiva más global e interactiva comprendería que no se observen ventajas bilingües cuando analizamos cada componente por separado, pero sí cuando necesitan interactuar entre sí.

1.4. DIFERENTES EXPERIENCIAS BILINGÜES CONLLEVAN DIFERENTES PROCESOS COGNITIVOS

Otro de los factores señalados como responsables de la inconsistencia entre los estudios sobre la ventaja bilingüe es el hecho de que bajo la etiqueta “bilingüe” se engloba a un conjunto amplio de individuos. Tal y como apuntamos al principio de la introducción, los bilingües pueden variar en cuanto a la frecuencia y contexto de uso de sus idiomas, el nivel y edad de adquisición de cada idioma o la combinación de los mismos. Es cierto que la mayoría de los estudios descritos previamente tratan de paliar este factor centrándose en muestras de bilingües que han adquirido su segunda lengua de forma temprana (p. ej., antes de los 6 años de edad), tienen un nivel de competencia muy elevado y la practican regularmente en su vida cotidiana junto con su primera lengua (p. ej., un uso diario y alrededor del 50% del tiempo de exposición a idiomas). Sin embargo, aun cumpliendo estos requisitos, factores como la combinación de idiomas empleados, los factores socioeconómicos que han llevado al bilingüismo o el contexto de uso de cada uno ellos no se controlan fácilmente.

Por ejemplo, algunos estudios examinan el control cognitivo en bilingües con una combinación determinada de idiomas (p. ej., español-catalán; inglés-mandarín) mientras que otros escogen muestras con combinaciones diversas de lenguas. Las muestras también varían en cuanto a las condiciones sociales en que se producen las situaciones de bilingüismo (p. ej., historia de inmigración, residencia en un país/región con varios idiomas oficiales). Por otra parte, el contexto de uso de los idiomas puede diferir no solo entre los participantes de los distintos estudios, sino entre un mismo individuo, de modo que el control de la selección de idiomas podría resolverse ejerciendo diferentes procesos de control cognitivo.

Centrándose en el contexto de uso de los idiomas, algunos estudios han mostrado que diferentes experiencias de control de idiomas reclutan diferentes procesos de control cognitivo. Además, las distintas experiencias bilingües resultan en diferentes patrones de desempeño de tareas de control no verbal. Por ejemplo, Prior y Gollan (2011) seleccionaron a un grupo de monolingües angloparlantes, uno de bilingües que solían intercambiar sus idiomas con frecuencia de forma cotidiana (bilingües español-inglés) y otro de bilingües que no acostumbraban a cambiar entre sus idiomas (bilingües mandarín-inglés). Compararon la ejecución de los tres grupos en un paradigma de cambio de tarea y, además, los dos grupos de bilingües realizaron también una tarea de cambio de idioma, basada en el cambio de tarea. En este caso, los estímulos son números de un solo dígito (1-9) que los participantes deben nombrar tan rápido como sea posible en el idioma requerido por una señal (p. ej., una bandera estadounidense para el inglés, una bandera española para el español). Los autores encontraron que el grupo monolingüe y el mandarín-inglés mostraban costes de cambio similares en la tarea no verbal. Sin embargo, los bilingües español-inglés obtuvieron menor coste de cambio de tarea que los otros dos grupos y, además, los bilingües español-inglés experimentaban menor coste de cambio de idioma que los bilingües mandarín-inglés. Los resultados indican que los bilingües que suelen cambiar entre idiomas en su vida cotidiana son más eficientes en tareas no verbales que implican cambiar de tarea, que los bilingües que no lo hacen. Estos resultados sugieren que existe una relación entre la frecuencia de cambio entre idiomas y las ventajas bilingües en cambio de tarea.

Asimismo, Festman y colaboradores (Festman y Münte, 2012; Festman, Rodriguez-Fornells y Münte, 2010) demostraron que el control cognitivo varía según la capacidad de control de idiomas de los bilingües. Para ello, evaluaron a dos grupos de bilingües a los que clasificaron según su capacidad para controlar idiomas en una tarea de nombrado de dibujos. Seleccionaron a un grupo con "bajo control" (con un alto porcentaje de intrusiones indeseadas del otro idioma) y otro con "alto control" (con bajo porcentaje de intrusiones indeseadas). Compararon su ejecución en una serie de tareas ejecutivas (p. ej., tarea de flancos, tarea de clasificación de tarjetas de Wisconsin, torre de Hanoi, *Go/noGo*, atención dividida). Los resultados arrojaron que los participantes con alto control ejecutaban mejor tareas que requerían inhibición de respuesta, auto-regulación y resolución de problemas. Aunque no está clara la dirección de la relación entre funciones ejecutivas y capacidades de control de idiomas, estos resultados apoyan también la idea de que distintas formas de control de idiomas se asocian de forma diferente con el control cognitivo.

Por otra parte, Emmorey, Luk, Pyers y Bialystok (2008) analizaron el rol que juega la necesidad de seleccionar idiomas en las ventajas bilingües encontradas en la tarea de flancos. Para ello, compararon la ejecución de bilingües bimodales, bilingües unimodales (que utilizaban dos lenguas habladas) y monolingües de lengua hablada en una tarea de flancos. Aunque ambos grupos de bilingües deben coordinar dos idiomas, los bilingües bimodales no tienen por qué elegir entre sus idiomas para producir lenguaje (pueden hablar y signar a la vez) y, por tanto, no necesitan seleccionar continuamente entre sus lenguas, como ocurre entre los bilingües unimodales. En consecuencia, no existiría la misma demanda recurrente de procesos de control cognitivo que modularía los mismos. Efectivamente, solo los bilingües unimodales mostraron mejor ejecución en la tarea de flancos, mientras que los bilingües bimodales mostraron resultados similares a los bilingües. Estos resultados indican que el manejo de varios idiomas se produce en diferentes situaciones que demandan diferentes procesos de control cognitivo y, por tanto, podría conllevar diferentes modulaciones en las redes implicadas.

En línea con los resultados descritos, Green (Green y Abutalebi, 2013; Green, 2011) enfatiza que la necesidad de control de idiomas es fundamental para guiar a los bilingües en la adaptación de sus procesos de control cognitivo y en la modulación de las redes de control. En su hipótesis de control adaptativo (Green y Abutalebi, 2013) propone que los procesos de control de idiomas se adaptan según las demandas recurrentes que tienen lugar en los contextos en que interactúan. En consecuencia, destaca la importancia de identificar, por un lado, cuáles son los procesos de control que demanda cada contexto bilingüe y, por otro lado, cómo cada contexto modula las propiedades, coordinación y secuencia de activación de los procesos de control que requiere. Por ejemplo, de acuerdo con el patrón de conversación que tiene lugar entre los hablantes, describe los principales tipos de contexto de producción bilingüe. Así, un bilingüe puede estar expuesto a situaciones en que se habla un único idioma y nunca aparece el idioma alternativo; contextos de doble idioma (en los que se pueden producir cambios entre idiomas, por ejemplo al cambiar de interlocutor, pero no en una misma frase) y contextos de cambio de idioma (en los que los dos idiomas se intercalan en una misma intervención). Cada uno de estos contextos de interacción requeriría diferentes formas de coordinación entre los distintos mecanismos de control, lo cual repercutiría en diferentes modulaciones sobre su dinámica (véase Figura 5).

Por ejemplo, las situaciones en las que cada idioma se utiliza en contextos diferentes (por ejemplo, inglés en el trabajo y español en casa, sin que suelan alternarse los idiomas) requerirán de mantenimiento de objetivos y procesos de control de interferencia. Estos dos procesos se encargan, respectivamente, de dirigir la atención hacia el idioma elegido y de reducir la activación de los competidores del idioma alternativo. Por su parte, los contextos en los que se usan ambos idiomas (por ejemplo, cuando todos los interlocutores conocen los dos idiomas y suele cambiarse de idioma en una misma conversación, pero no en una misma frase) conllevarían la adaptación, por ejemplo, del circuito mediador en la cascada de procesos de control que conlleva el control de alternativas, dada la necesidad constante de decidir entre los dos idiomas.

	Contexto Interactivo		
Proceso de control	**Único idioma**	**Dos idiomas**	**Cambio de código**
Mantenimiento de objetivo	+	++	=
Control de interferencia: monitorización de conflicto y supresión de interferencia	+	++	=
Detección de claves salientes	=	+	=
Inhibición de respuesta selectiva	=	+	=
Vinculación a la tarea	=	+	=
Desvinculación a la tarea	=	+	=
Planificación oportunista	=	=	=

+ indica que el contexto incrementa las demandas de ese proceso de control (++ mayor demanda); = indica que el contexto es neutral

Figura 5. *Mecanismos de control propuestos por la hipótesis de control adaptativo y su relación con distintos contextos de interacción (extraído y adaptado de Green y Abutalebi, 2013).*

Para comprender los mecanismos de control que intervienen en la coordinación de idiomas es fundamental identificar las demandas cognitivas de los distintos contextos de comunicación. Tras evaluar la influencia del bilingüismo en la dinámica entre algunos de los procesos de control cognitivo, nuestro siguiente objetivo es conocer cómo se modulan las redes de control según la experiencia bilingüe. Para ello, nos planteamos qué ocurre en formas de bilingüismo que requieren el mantenimiento activo de dos idiomas simultáneamente, como la interpretación simultánea. Aunque no se trata de una forma cotidiana de bilingüismo, la interpretación simultánea supone una forma extremadamente demandante de control de idiomas. Interpretar implica comprender un mensaje en la lengua fuente, reformularlo y producirlo en la lengua meta. Dada su complejidad, los mecanismos implicados durante esta actividad deben diferir de los reclutados en una interacción bilingüe cotidiana. Identificar cómo se coordinan los procesos de control cognitivo requeridos para manejar una situación de interpretación simultánea puede permitirnos profundizar en el conocimiento de las distintas dinámicas de control lingüístico así como en el ajuste de los procesos de control cognitivo general. En el siguiente apartado revisaremos, en primer lugar, algunas propuestas sobre los mecanismos de control que requiere la interpretación simultánea. Posteriormente describiremos los principales hallazgos sobre la influencia de la misma en la dinámica de procesos de control cognitivo.

Función ejecutiva e interpretación simultánea

La interpretación simultánea es una actividad lingüística extremadamente compleja que implica la coocurrencia de múltiples procesos. Durante una sesión de interpretación simultánea, se presenta continuamente nueva información en la lengua fuente mientras que el intérprete está comprendiendo el mensaje y almacenando segmentos de información en su memoria. Al mismo tiempo, un segmento del mensaje presentado anteriormente se reformula mentalmente en la lengua meta mientras que se está articulando un segmento aún más temprano (p. ej., Gerver, 1976; Lambert, 1992; Padilla, Bajo, Cañas y Padilla, 1995). Si, como explicamos en el apartado anterior, en las condiciones cotidianas de bilingüismo ya es necesaria una coordinación eficiente de recursos de control cognitivo, la monitorización de los mismos en la interpretación simultánea debe ser aún más demandante. En este sentido, nuestro objetivo es identificar cuáles son los diferentes procesos de control ejecutivo que se modifican por el desempeño de una actividad que implica mantener dos idiomas activos simultáneamente sin que se produzcan intrusiones entre ellos.

El control de idiomas en la interpretación simultánea

Como vimos en el apartado 1.1., las teorías de selección y control de idiomas en el bilingüismo explican cómo se evita la interferencia entre idiomas en términos de inhibición o aumento/disminución de la activación de los idiomas. En la interpretación simultánea también es fundamental controlar los idiomas. Un requisito imprescindible es producir la información en la lengua meta sin que se produzca ninguna interferencia con la lengua fuente. La especial relevancia del control de idiomas en la interpretación simultánea se pone de manifiesto en los resultados de un estudio de Price, Green y Von Studnitz (1999). Mediante tomografía por emisión de positrones (*positron emission tomographic*; PET), los autores encontraron que la traducción de palabras en comparación con la lectura en su L1 y L2 incrementaba la actividad de áreas cerebrales como la CCA y regiones subcorticales relacionadas con el control de acciones.

Por tanto, sugieren la intervención de mecanismos de control durante la interpretación.

Sin embargo, es difícil conciliar los mecanismos de control implicados en la interpretación con los que proponen las aproximaciones inhibitorias sobre el control de idiomas. El principal motivo radica en que la interpretación requiere que ambos idiomas se mantengan activos simultáneamente mientras se ejecuta la tarea. Así, mientras que el reto para los bilingües[*] normalmente es reducir la activación del idioma no requerido, los intérpretes deben mantener ambos idiomas activos a la vez. Este hecho, presumiblemente, se traduce en la intervención de distintos procesos de control para cada situación. Los resultados empíricos corroboran esta idea, ya que muestran que los intérpretes, a diferencia de otros bilingües, emplean mecanismos diferentes de la inhibición para controlar sus idiomas.

Así, Ibáñez, Macizo y Bajo (2010) pidieron a un grupo de bilingües y traductores profesionales con nivel similar de idiomas que leyeran frases, palabra por palabra, a su propio ritmo. En todos los ensayos se pedía a los participantes que leyeran y comprendieran las frases y que las repitieran en el mismo idioma de presentación. Se manipuló el idioma de presentación de las frases (español-L1 e inglés-L2), que variaba entre ensayos de forma impredecible. Además, se introdujeron palabras cognadas

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[*] En este apartado, cuando hablamos de “bilingües” lo hacemos refiriéndonos a bilingües sin experiencia profesional en interpretación o traducción.

(palabras que comparten forma y significado similares en los dos idiomas) en algunas frases. La primera manipulación permite obtener un índice de inhibición entre idiomas, observado mediante el patrón asimétrico de coste de cambio (mayor coste al cambiar de L2 a L1) cuando los ensayos adyacentes implican dos idiomas diferentes (Meuter y Allport, 1999). Por otra parte, el efecto de cognados (menores tiempos de respuesta en palabras cognadas que en no cognadas) se considera un índice de la activación del idioma no requerido (Dijkstra et al., 1999; Kroll y Stewart, 1994; Macizo y Bajo, 2006). Los resultados de este experimento mostraron que la experiencia profesional en traducción influye en el procesamiento léxico. Los traductores profesionales eran más rápidos procesando las palabras cognadas en comparación con las palabras control, indicando que mantenían activos los dos idiomas durante la lectura. Además, no se observaron costes asimétricos en los traductores, indicando ausencia de inhibición del idioma irrelevante. Por el contrario, los bilingües sin experiencia en traducción presentaban mayores costes al cambiar a su L1 que a su L2 (patrón asimétrico de coste de cambio). Este resultado permite pensar que inhibían su primera lengua cuando comprendían las frases en su idioma alternativo. Asimismo, los bilingües procesaban las palabras cognadas igual de rápido que las palabras control, lo que sugiere que sólo mantenían activo el idioma en que se presentaban las frases en cada ensayo.

En conjunto, los resultados sugieren que los bilingües y los intérpretes emplean diferentes estrategias para controlar sus idiomas. Es decir, cada contexto de uso de idiomas (p. ej., contexto dual de idiomas e interpretación simultánea) requiere controlar cada idioma de forma diferente (p. ej., reducir la activación del idioma irrelevante vs. mantener ambos idiomas activos), lo que implicaría la intervención de diferentes mecanismos de control cognitivo. De acuerdo con la hipótesis de control adaptativo, el uso recurrente de distintos procesos de control conllevaría diferentes modulaciones de los mismos dependiendo del contexto de uso de idiomas. Por tanto, sería posible comprender cuáles son los mecanismos de control que son inherentes a la interpretación simultánea mediante la evaluación de las diferencias entre bilingües e intérpretes en tareas de control cognitivo. Aunque la investigación al respecto es escasa, a continuación revisamos los principales mecanismos de control asociados a la interpretación que se han propuesto de acuerdo con los resultados obtenidos.

Procesos cognitivos implicados en la interpretación simultánea

La intervención de procesos de control ejecutivo queda manifiesta en todas las etapas de la interpretación. Durante la comprensión, es necesario monitorizar posibles errores sintácticos y semánticos, además de emplear mecanismos de supresión de interferencia en información verbal (Gernsbacher y Shlesinger, 1997; Yudes, Macizo y Bajo, 2012), como los significados inapropiados de homónimos, formas sintácticas o interpretaciones literales de las metáforas. En la producción, los intérpretes deben monitorizar sus propios errores (Yudes, Macizo, Morales y Bajo, 2013). En cuanto a la reformulación, el intérprete debe replantear el mensaje original con coherencia y cohesión, utilizando estrategias de planificación del mensaje. Además, la inmediatez con la que los intérpretes deben reclutar los diferentes procesos implicados en la compresión, reformulación y producción del mensaje, y la necesidad de coordinar procesos de producción y compresión, pueden fomentar el desarrollo de estrategias específicas que faciliten la monitorización de sus recursos cognitivos.

Los intérpretes deben superar las limitaciones de procesamiento que supone atender a dos canales simultáneamente. Para conseguirlo, Cowan (2000) propone que podrían afrontar esta situación de dos maneras. Por un lado, pueden cambiar la atención rápida y eficazmente entre lo que están escuchando o diciendo, lo que permite al intérprete mantener el máximo de información en el foco atencional. Por otro lado, debido a la extensa práctica en las tareas de comprensión y producción, éstas pueden resolverse de forma más automática o menos demandante de recursos atencionales, lo que explicaría la facilidad con que las realizan simultáneamente. En cualquier caso, y como hemos comentado en el subapartado anterior, los mecanismos reguladores de compresión y producción deben ser distintos de los de naturaleza inhibitoria. La necesidad de mantener dos idiomas activos hace que no sea adaptativo inhibir información que se requiere para realizar la tarea, como confirman Ibáñez y colaboradores (2010).

Esta idea se confirma con los resultados obtenidos por Yudes, Macizo y Bajo (2011), que encontraron superioridad de los intérpretes en procesos de cambio atencional y flexibilidad cognitiva, pero no en procesos de control inhibitorio. En sus experimentos evaluaron a intérpretes profesionales, bilingües sin experiencia en interpretación y monolingües. En el Experimento 1 observaron la capacidad de flexibilidad cognitiva de los participantes mediante el Test de Clasificación de Tarjetas de Wisconsin (*Wisconsin Card Sorting Test*; WCST), que requiere la categorización de estímulos. En esta tarea, los participantes deben inferir una regla de categorización para organizar una serie de tarjetas. Las reglas se modifican a lo largo de la tarea, de modo que los participantes deben inferir las reglas continuamente, siguiendo la información de respuestas correctas o incorrectas. Los intérpretes necesitaron menos ensayos que los otros grupos para inferir la secuencia de reglas y, además, cometieron menos errores. En el Experimento 2 compararon a los grupos en una tarea Simon. Todos los grupos mostraron similares costes de interferencia (tiempos más lentos y más errores en los ensayos incongruentes que en los congruentes), indicando que la capacidad de control inhibitorio era similar en todos los grupos.

La superioridad de los intérpretes en el WCST sugiere que la monitorización es uno de los procesos de control necesarios en la interpretación simultánea. Mientras se interpreta, los procesos de comprensión, reformulación y producción del discurso en dos códigos diferentes deben alternarse continuamente. Por tanto, el intérprete debe regular (monitorizar) adecuadamente cada uno de estos procesos para no perder información y que no se produzca interferencia entre la lengua fuente y la lengua meta

(Christoffels y de Groot, 2005; Gerver, 1976). Por otra parte, también es necesario almacenar y manipular mentalmente grandes cantidades de información entrante para comprender, traducir y producir el mensaje y por ello se entiende que los procesos de memoria deben también estar implicados en la interpretación. Además, la monitorización y los procesos de memoria deben interactuar entre sí, porque el intérprete necesita auto-regular su propia producción, manteniendo la representación del mensaje en la lengua fuente hasta que se termina de producir en la lengua meta.

En cuanto a los procesos de memoria, la investigación ha encontrado que los intérpretes utilizan unidades mayores de información, a un nivel semántico más profundo que los no intérpretes (Jones, 1998; Meuleman y Van Besien, 2009) y muestran mayor facilidad de reconocimiento y recuperación de la información (Dimitrova, 2005). Es decir, la memoria parece jugar un papel fundamental en la interpretación, que no es tan importante en la comunicación cotidiana del bilingüe. Específicamente, se ha propuesto que la memoria de trabajo (MT) es un proceso de especial relevancia (Christoffels, De Groot y Kroll, 2006; Gile, 1997; Liu, Schallert y Carroll, 2004). El concepto "memoria de trabajo" se refiere al proceso encargado de almacenar y manipular temporalmente la información (p. ej., Baddeley, 1986, 2000). Aunque son muchos los modelos de MT propuestos, la mayoría concuerdan en que está compuesta por un sistema que se encarga de almacenar la información y otro, un ejecutivo central, responsable de controlar y coordinar la información almacenada (Baddeley, 1986, 1996, 2000; Kane, Bleckley, Conway y Engle, 2001; Kane, Conway, Hambrick y Engle, 2007).

La capacidad de MT generalmente se evalúa mediante tareas complejas de amplitud de MT. Estas tareas implican tanto a los componentes de almacenamiento como a los ejecutivos. En las tareas complejas de MT normalmente se pide a los participantes que memoricen una serie de estímulos (p. ej., palabras o dígitos) mientras procesan otra información como, por ejemplo, al resolver ecuaciones en la tarea de amplitud de operaciones (Turner y Engle, 1989) o al leer frases en la tarea de amplitud de lectura (Daneman y Carpenter, 1980). Por tanto, aunque la tarea principal consiste en almacenar una serie de estímulos en la memoria a corto plazo, la tarea secundaria requiere controlar y actualizar la información simultáneamente. Dado que la interpretación requiere almacenar grandes cantidades de información en la memoria a corto plazo mientras que se traduce y se reproduce en la lengua meta, una mayor capacidad de MT permitiría mayor eficiencia en la interpretación (De Groot y Christoffels, 2006).

Varios estudios relacionan la eficiencia en interpretación con alta capacidad de MT. Por ejemplo, la calidad de la interpretación correlaciona significativamente con tareas de amplitud de dígitos y amplitud de lectura (Christoffels, De Groot y Waldorp, 2003). Además, la capacidad de MT de los intérpretes profesionales es mayor que la de los bilingües sin experiencia en interpretación (Christoffels et al., 2003; Darò y Fabbro, 1994; Liu et al., 2004; Padilla et al., 1995; Tzou, Eslami, Chen y Vaid, 2012; pero véase

Chincotta y Underwood, 1998; Köpke y Nespoulous, 2006). Estos resultados sugieren que la MT es uno de los procesos que intervienen en la interpretación simultánea. Sin embargo, aún no está definido cuál es el papel que juega la MT al interpretar. Una posibilidad es que se encarga de mantener la información entrante durante la producción del discurso, facilitando así la coordinación entre comprensión y producción. Así, una MT eficiente conseguiría almacenar información a corto plazo mientras se reproduce el mensaje en la lengua meta.

La relación entre MT y coordinación entre procesos de producción y comprensión se ha estudiado mediante experimentos de supresión articulatoria. La supresión articulatoria es una técnica en la que los participantes deben memorizar listas de palabras mientras articulan sílabas irrelevantes (p. ej., "bla, bla, bla"). La articulación de sílabas impide a la MT el repaso subvocal de la información que se intenta memorizar (p. ej., Baddeley, Lewis y Vallar, 1984). En consecuencia, se produce una disminución del recuerdo a corto plazo del material en comparación con situaciones de estudio sin supresión articulatoria.

La interpretación simultánea podría considerarse una forma extrema de supresión articulatoria, ya que es necesario producir el mensaje en la lengua meta mientras almacenan la información que reciben en su lengua fuente. Por tanto, los intérpretes consiguen almacenar la información entrante mientras verbalizan la traducción de la información que ha entrado previamente. De hecho, la capacidad de retención de información bajo condiciones de supresión articulatoria está asociada con la calidad de la interpretación en bilingües sin experiencia previa en interpretación simultánea (Christoffels et al., 2003). Por otra parte, los intérpretes profesionales no suelen mostrar efecto de supresión articulatoria (menor recuerdo del material estudiado mientras se articulan sílabas que en silencio). Por ejemplo, Padilla y colaboradores (1995) compararon el recuerdo de palabras con y sin supresión articulatoria durante la fase de aprendizaje en un grupo de intérpretes, bilingües y monolingües. En la condición de supresión articulatoria se obtuvieron diferencias significativas entre los grupos, ya que se observó un decremento en el recuerdo de todos los grupos, excepto del grupo de intérpretes experimentados que, aparentemente, eran resistentes al efecto de supresión articulatoria. Además, se evaluó la capacidad de MT mediante las tareas de amplitud de dígitos y amplitud de lectura (Daneman y Carpenter, 1980). El hecho de que los intérpretes fueran también superiores en estas tareas, unido a los resultados de supresión articulatoria, parece indicar que la MT interviene en la habilidad para coordinar producción y compresión.

No obstante, los resultados de Padilla, Bajo y Macizo (2005) sugieren que la ausencia de efecto de supresión articulatoria en intérpretes no se debe a mayor capacidad de realizar dos tareas concurrentes. En su estudio compararon a un grupo de intérpretes, un grupo de monolingües seleccionados por su alta capacidad de MT (similar a la de los intérpretes) y otro grupo control formado por monolingües con MT normal. En un primer experimento, los participantes memorizaron palabras con y sin supresión articulatoria. Como en los estudios anteriores, los intérpretes no mostraron el efecto de coste supresión articulatoria. Por otra parte, tanto el grupo de alta MT como el control mostraron el efecto de coste, lo que parece indicar que la capacidad de almacenar información mientras se articulan sílabas es independiente de la capacidad de MT. En un segundo experimento, se pidió a los participantes que memorizaran palabras mientras realizaban una tarea de MT visuoespacial. En este caso, los resultados arrojaron que todos los grupos reducían su recuerdo de palabras cuando tenían que memorizarlas mientras. Es decir, aunque los participantes debían realizar dos tareas concurrentes (como en la supresión articulatoria), en este caso la ejecución de los intérpretes fue similar a la de los otros grupos, independientemente de su capacidad de MT. Estos hallazgos sugieren que la capacidad de simultanear verbalización y comprensión en la interpretación simultánea no refleja una habilidad general del control ejecutivo para coordinar múltiples tareas y procesos. Por el contrario, parecen indicar que implica una capacidad específica para coordinar procesos verbales.

En línea con este último resultado, Yudes, Macizo y Bajo (2012), sugieren que algunos procesos ligados a la recuperación de información léxico-semántica pueden ser los responsables de la ausencia de efecto de supresión articulatoria en los intérpretes y, por ende, de su capacidad de coordinar producción y comprensión. En su estudio, compararon a intérpretes y monolingües en tareas de recuerdo libre bajo condiciones de supresión articulatoria. Además, manipularon la naturaleza del material a recordar (palabras y pseudo-palabras), la complejidad de las articulaciones (palabras reales, discurso irrelevante) y la tasa de articulación. Como era de esperar, los monolingües mostraron el efecto de supresión articulatoria en todas las condiciones. Pero lo más interesante es que los intérpretes sólo mostraron el efecto de coste de supresión articulatoria en las condiciones más demandantes (recuerdo de pseudo-palabras mientras se articulan palabras reales). Este último resultado parece indicar que la familiaridad del material de estudio y, por tanto, los mecanismos de acceso léxico-semántico al mismo modulan el efecto de supresión articulatoria. Además, aunque los intérpretes tenían mayor capacidad de MT, tras introducirla como covariada en los análisis ésta no explicaba los resultados en supresión articulatoria.

Los resultados de los experimentos que acabamos de describir indican, por un lado, que los intérpretes son capaces de recordar mayor cantidad de información en tareas de MT. Por otra parte, los intérpretes muestran menores costes de supresión articulatoria que las personas sin experiencia interpretación, lo que indica que son más eficientes al coordinar producción y comprensión verbal. Los primeros estudios relacionaban la ausencia de supresión articulatoria en los intérpretes con su alta capacidad de MT (Padilla et al., 1995). Sin embargo, los hallazgos posteriores indican que la capacidad de coordinar producción y comprensión verbal parece estar más relacionada con procesos de acceso léxico y con el conocimiento lingüístico (Padilla et al., 2005; Yudes, Macizo y Bajo, 2012).

En un nuevo estudio, Yudes y colaboradores (2013) comprobaron que, junto a los cambios en la funcionalidad de la MT, una mayor capacidad para regular los distintos componentes de la interpretación (compresión, producción y reformulación) es otra de las características de la experiencia en interpretación. Para estudiar esto compararon las habilidades de comprensión de intérpretes y no intérpretes en una tarea de compresión de textos. Los participantes realizaron una tarea en la que debían detectar errores léxicos, sintácticos o semánticos. Tras la lectura de los textos, se evaluó su comprensión de los mismos mediante una tarea de verificación de frases y un cuestionario de preguntas abiertas. Los intérpretes detectaron más errores sintácticos y semánticos que los otros participantes y, además, mostraron mejor comprensión general que el resto de los grupos. Cabe resaltar que, aunque los intérpretes tenían mayor capacidad de MT que los otros grupos y la MT normalmente se asocia a procesos lingüísticos (véase Gathercole y Baddeley, 1993), esta superioridad no era la responsable de su comprensión lectora. Cuando se comparó a los intérpretes con participantes de alta capacidad de MT, los intérpretes volvían a ser superiores, tanto en compresión como en detección de errores. El hecho de que la detección de errores de los intérpretes sea mayor en aspectos semánticos y sintácticos (que requieren un procesamiento más profundo que los aspectos léxicos), sugiere que los intérpretes emplean estrategias de compresión más profunda que los no intérpretes, con menor focalización en los aspectos superficiales.

En conjunto, los resultados indican que los intérpretes son superiores solamente en aquellas capacidades relacionadas con la interpretación (capacidad de MT, coordinación entre procesos de comprensión y producción y flexibilidad cognitiva, pero no en control inhibitorio). Los experimentos de supresión articulatoria (Padilla et al., 2005; Yudes, Macizo y Bajo, 2012) demuestran que los intérpretes profesionales desarrollan mecanismos específicos de control (monitorización) que les permiten comprender y producir simultáneamente sin perjuicio de la calidad de la interpretación. Padilla y colaboradores (2005) concluyen que la coordinación entre procesos es posible cuando los intérpretes pueden beneficiarse de determinados aspectos de la información con la que trabajan, como por ejemplo el acceso a la información léxico-semántica almacenada en la memoria a largo plazo. Así, la ausencia del efecto de supresión articulatoria en intérpretes se debería tanto al acceso más eficaz de la información en memoria a largo plazo como a la capacidad de coordinar los procesos de producción y comprensión de la información. Resumiendo, los hallazgos de una ejecución superior o cualitativamente diferente en varias tareas de MT en los intérpretes profesionales, en comparación con otros grupos, sugiere la importancia de contar con una MT eficiente para la interpretación simultánea.

Sin embargo, los estudios de supresión articulatoria indican que la coordinación entre producción y comprensión no depende tanto de la capacidad de almacenamiento de información como de procesos de monitorización y de conocimiento lingüístico. Estos resultados encajarían con las perspectivas de control atencional (Engle, 2002; Kane et al., 2007), que proponen que las diferencias individuales en MT están relacionadas, más que con procesos de almacenamiento o memoria, con la capacidad de atención sostenida y controlada. Así, la capacidad de MT estaría reflejando la eficiencia de los procesos atencionales encargados de mantener o suprimir la información dependiendo de su relevancia para la tarea. Por tanto, la alta capacidad de MT de los intérpretes podría estar reflejando una alta capacidad de monitorización de información. No obstante, que la ventaja de recuerdo de los intérpretes desaparezca cuando estudian el material mientras realizan una tarea concurrente no verbal parece indicar que los mecanismos encargados de la monitorización están ligados específicamente al manejo de información verbal. Por otra parte, la relación entre la capacidad de MT y competencia verbal (Gathercole, 1995; Gathercole, Pickering, Hall y Peaker, 2001; Thorn y Gathercole, 2001) podría explicar también que los intérpretes, con altas habilidades verbales, puntúen alto en tareas de MT verbal. De hecho, es importante remarcar que, hasta donde alcanza nuestro conocimiento, todos los estudios previos se han centrado en tareas verbales de MT. Además, a pesar de que los procesos de monitorización parecen jugar un papel fundamental en la interpretación, las investigaciones se han centrado en evaluar el componente de almacenamiento de la MT mediante medidas complejas de amplitud de memoria. Por consiguiente, los datos que arrojan estas tareas no permiten evaluar el papel específico de los componentes de control atencional de la MT.

En nuestro trabajo queremos evaluar la relación entre interpretación simultánea y capacidad de monitorización en MT. A este fin, en la tercera serie experimental compararemos a intérpretes profesionales con bilingües de similares características demográficas y lingüísticas, pero sin experiencia en interpretación. En el Experimento 4 evaluaremos la capacidad de actualización de la información, controlando las demandas de almacenamiento, actualización y monitorización. Dado que los intérpretes necesitan mantener dos idiomas activos y coordinar comprensión y producción, esperamos que los intérpretes superen a los no intérpretes especialmente cuando se requiere actualizar y monitorizar información presentada simultáneamente por dos canales diferentes (p. ej. auditivo y visual).

Una vez evaluada la capacidad de actualización de los intérpretes con respecto a los bilingües, trataremos de dilucidar si la superioridad de los intérpretes en MT se relaciona con capacidades de control atencional. De acuerdo con la propuesta de control atencional de la memoria de trabajo de Engle y colaboradores (Engle, 2002; Kane et al., 2001, 2007; Kane y Engle, 2002; Shamosh et al., 2008) las variaciones en capacidad de MT se deben principalmente a diferencias individuales en el capacidad de controlar y dirigir la atención. Específicamente, sus estudios encuentran que las diferencias en capacidad de MT se asocian, fundamentalmente, con diferencias en la capacidad de mantener los objetivos de la tarea (Redick y Engle, 2006; Unsworth, Redick, Spillers y Brewer, 2012; Unsworth y Spillers, 2010). Ya que la actualización se considera uno de los componentes del sistema ejecutivo (Miyake y Friedman, 2012; Miyake et al., 2000), la interpretación podría influir, no solamente en los componentes específicos a la actualización, sino sobre toda una red más amplia de control atencional.

Para evaluar la relación entre control atencional e interpretación, en el Experimento 5 compararemos el funcionamiento de las redes atencionales de intérpretes y bilingües. De acuerdo con Posner y colaboradores (Posner y Petersen, 1990; Posner, 1994), la atención se compone por tres redes independientes pero coordinadas: alerta, orientación y control ejecutivo. La red de alerta se encarga de mantener la preparación para responder ante los estímulos entrantes. Esta red puede subdividirse en alerta fásica alerta tónica. Por alerta fásica entendemos el aumento de preparación de respuesta durante el corto periodo de tiempo que sigue a la presentación de una señal de aviso externa. Por su parte, la alerta tónica (o vigilancia) indica la preparación sostenida durante un largo periodo de tiempo (p. ej., Roca, Castro, López-Ramón y Lupiáñez, 2011). La red de orientación se relaciona con la selección de la relevante información que debe atenderse. Por último, la red de control ejecutivo es la encargada de monitorizar y resolver el conflicto producido por información interferente. La tarea de redes atencionales (*Attention Network Test*; ANT; Fan et al., 2002) y sus variantes, se han utilizado ampliamente para evaluar el funcionamiento y la interacción entre las distintas redes. En nuestro Experimento 5 emplearemos una versión de la ANT, la ANTI-V (Roca et al., 2011), que permite evaluar la interacción entre las distintas redes atencionales. Si la interpretación influye sobre el desarrollo del control atencional en general, deberíamos observar que los intérpretes tienen menos costes que los bilingües en todas las medidas. Por otra parte, si solo algunos procesos de control atencional están directamente relacionados con la experiencia de la interpretación, los resultados mostrarían que los grupos se diferencian en algunos índices específicos, pero no en otros. Por ejemplo, ya que los intérpretes deben mantener sus dos idiomas activos (de modo que no compiten entre sí) podríamos esperar que la interpretación no afecte a la resolución de conflicto. Por el contrario, las redes de alerta y orientación podrían mejorar con la experiencia en interpretación, ya que interpretar requiere mantener altos niveles de alerta y sensibilidad a las claves del contexto. Por tanto, los efectos específicos sobre los distintos procesos indicarían las habilidades específicas de control moduladas por la interpretación. Los resultados encontrados pueden guiarnos para comprender los mecanismos subyacentes a la coordinación de comprensión y producción verbal, así como al mantenimiento activo de dos sistemas lingüísticos.

1.5. ORGANIZACIÓN Y OBJETIVOS DE LA SERIE EXPERIMENTAL

El objeto principal de la presente tesis es profundizar en el papel modulador de la experiencia en la dinámica, transferencia y desarrollo de los procesos de control ejecutivo. En concreto, nos centramos en la experiencia bilingüe mediante el estudio de personas que necesitan controlar varios idiomas de forma cotidiana, a las que evaluaremos en tareas no verbales que requieren la participación coordinada de distintos procesos ejecutivos.

En la primera serie experimental (Experimentos 1 y 2) nos centraremos en conocer la influencia del bilingüismo sobre la dinámica de los distintos mecanismos de control cognitivo. Adoptando la idea de que el control ejecutivo tiene una naturaleza dual (Braver et al., 2007; Braver, 2012), exploraremos cómo el bilingüismo afecta a la interacción entre control proactivo y reactivo a nivel conductual (Experimento 1) y electrofisiológico (Experimento 2). A este fin, compararemos la ejecución de bilingües y monolingües en la tarea AX-CPT. Para resolver con éxito esta tarea es necesario ajustar de forma eficiente los procesos de monitorización e inhibición. Observar la ejecución de bilingües y monolingües a través de las condiciones de la tarea nos permitirá disociar si la experiencia bilingüe influye sobre procesos aislados o actúa modulando la coordinación entre los mismos. Además, estudiar los correlatos electrofisiológicos asociados a cada condición y, más concretamente, el análisis de los ERPs, permitirá observar el tipo de proceso que los participantes emplean para resolver la tarea.

Siguiendo la misma línea, la segunda serie experimental aborda el papel que el bilingüismo juega en el desarrollo de la coordinación de las funciones ejecutivas durante la infancia. Partiendo de la idea de que las funciones ejecutivas tienen una naturaleza unitaria y diversa, evaluaremos las habilidades ejecutivas de niños edades críticas en el desarrollo de procesos de control cognitivo (de 5-7 años). En el primer experimento de esta serie (Experimento 3) analizaremos la ejecución de niños bilingües y monolingües en una tarea Simon con distintas demandas de memoria de trabajo. En el Experimento 4 evaluaremos su desempeño en una tarea de memoria de trabajo con distintas demandas de control cognitivo. Las manipulaciones sobre la complejidad de procesos de control en cada tarea nos permitirán evaluar cada componente de forma relativamente aislada y combinados entre sí, de forma que podemos dilucidar cómo afecta el bilingüismo al desarrollo de las funciones ejecutivas. Si la experiencia bilingüe modifica el desarrollo de los componentes de control ejecutivo de forma aislada, deberíamos observar efectos diferenciales sobre cada componente. Alternativamente, si la modulación se produce sobre la parte unitaria de la función ejecutiva, no tendríamos por qué observar ventajas bilingües cuando analizamos cada componente por separado, pero sí cuando es necesario que interactúen entre sí.

Por último nos centraremos en analizar cómo modulan el procesamiento cognitivo distintos tipos de contextos bilingües que demandan diferentes tipos de control de idiomas. Para ello compararemos a intérpretes simultáneos profesionales y bilingües balanceados sin experiencia en interpretación. Mientras que los intérpretes simultáneos deben mantener dos idiomas activos a la vez, la experiencia de los otros bilingües implica activar sólo uno de sus idiomas. Por ello, analizaremos la ejecución de intérpretes y bilingües en tareas que requieren coordinación entre procesos de actualización de información en memoria de trabajo (Experimento 5) y diferentes redes atencionales (Experimento 6). Las diferencias encontradas entre los distintos tipos de bilingüismo pueden guiarnos para comprender distintas estrategias de control de idiomas. Además, nos indicarán cómo distintos contextos bilingües pueden influir sobre diferentes mecanismos de control. Si este es el caso, se apoyará la relevancia de atender a los requerimientos de control cognitivo específicos a cada entorno bilingüe a la hora de estudiar los mecanismos implicados en el control de idiomas y su transferencia a procesos ejecutivos generales.

En conjunto, nuestros experimentos van dirigidos a comprender estructura y dinámica de las redes neurales encargadas del control cognitivo. Por un lado, pretendemos profundizar en el papel modulador de la experiencia sobre la función ejecutiva. Por otra parte, nuestros resultados pueden contribuir a comprender la naturaleza de los procesos implicados en la selección y el control de idiomas.

1.6. REFERENCIAS

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Chapter II. SUMMARY INTRODUCTION AND AIMS

Over half of the world's population is bilingual, that is, uses two languages regularly. Consequently, the term "bilingualism" comprises a wide range of experiences, attending to variables such as language use or proficiency (Grosjean, 2013). In spite of this variability, all bilinguals share a common feature: they own a single brain to coordinate their languages. Research on bilingual language processing demonstrates that bilinguals co-activate both languages, even when there is only one language in use (for reviews see Dijkstra, 2005; Kroll, Dussias, Bogulski, & Valdés, 2012). As a consequence, they need to engage control mechanisms responsible for selecting the language that is appropriate to the situation, avoiding intrusions and interference from the alternative language.

A widely held opinion is that language control and selection are not achieved by a language-domain specific mechanism, but by domain-free processes that are in charge of selecting and controlling the flow of information in the bilingual minds. As a consequence, the recurrent necessity to solve cross-language activation would result in an over-trained cognitive control system, which would transfer to related non-verbal activities requiring similar control mechanisms. Indeed, a vast number of research suggests that bilingualism leads to benefits in tasks that involve conflict resolution or coping with competing stimuli. These results have been found in children (e.g., Adi-Japha, Berberich-Artzi, & Libnawi, 2010; Bialystok & Martin, 2004; Bialystok & Senman, 2004; Bialystok, 1999, 2010; Carlson & Meltzoff, 2008), adults (e.g., Colzato et al., 2008; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa, Hernández, & Sebastián-Gallés, 2008) and the elderly (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004).

However, the existing findings have sometimes been controversial, since they do not easily replicate (see, for instance, recent reviews by Hilchey & Klein, 2011; Kroll & Bialystok, 2013; Paap & Greenberg, 2013). These inconsistencies can be attributed to failures in the identification of the control mechanisms proposed for language control and selection (Costa et al., 2009), variability of bilingual experiences between studies (Green & Abutalebi, 2013) or even demographic characteristics associated with bilingualism but not directly related to language control (Paap & Greenberg, 2013).

The present work focuses on investigating the nature and dynamics of the cognitive mechanisms modulated by bilingualism. Armed with the assumption that cognitive control can be viewed as a wide network composed of different processes, we will mainly investigate the dynamics between the different cognitive mechanisms, across a range of bilingual experiences and at different developmental stages. Identifying these processes may serve two main purposes. First, it will help us to contrast the existing models of bilingual language selection and control. If bilinguals show benefits relative to monolinguals in certain cognitive processes, this may imply that these processes may be involved in cross-language negotiation. Second, it may serve to further advance our understanding of the mechanisms of brain plasticity and the capacity to transfer skills and processes trained in a certain domain (e.g., language) to other domains requiring related skills (e.g., action control).

To identify the potential mechanisms that benefit from bilingualism, we first need to understand the control processes involved in language selection. Hence, in the first section of the introduction we will review the main models of language selection and control in bilinguals. We will focus on inhibitory models (e.g., Green, 1998), due to their influence on subsequent cognitive control studies. Next, we will briefly summarize the main research that has evaluated the consequences of bilingualism on cognitive control mechanisms. The third and fourth sections will analyze two factors that may bias the outcomes and interpretations of existing research findings. Section three will highlight the need to adopt a multivariate approach instead of studying isolated executive function components. We will explain the dynamics of cognitive control processes and how bilingualism may affect them in both adulthood and childhood. The fourth section will focus on the varying effects that different bilingual contexts may exert on the results of cognitive control. In particular, we will focus on the case of simultaneous interpretation. Interpretation is a particular form of bilingualism, as it implies the need to keep active two languages at a time and, therefore, its control demands may differ substantially from other bilingual situations. The goal of the set of studies that constitute our experimental series will be to answer the questions that will arise from the different sections of the introduction. And in the final section in the introduction we will describe in some detail the structure and aims of these experiments.

2.1. LANGUAGE SELECTION AND CONTROL IN BILINGUALISM

Evidence related to the need to exert cognitive control when managing two or more languages comes from studies on language comprehension and production. Although our work will focus on domain-general cognitive control processes (not restricted to the verbal-domain), we first need to understand how language control and selection occur in bilingual situations. Below, we describe the main approaches that have addressed this issue.

Psycholinguistic models propose that, to express an idea or to name an object it is necessary, in the first place, to select the conceptual representation associated with that object or idea, and then access the syntactic and grammatical properties of the word, with the final step involving selecting the appropriate phonology in order to articulate it (Caramazza, 1997; Levelt, Roelofs, & Meyer, 1999). In the bilingual case, most models agree that both languages share a single semantic system (Costa, Miozzo, & Caramazza, 1999; De Bot, 1992; Kroll & Stewart, 1994; Poulisse & Bongaerts, 1994), which activates each language. As a consequence, the access to lexical representations becomes more costly in bilinguals relative to monolinguals, since selecting a concept activates two different lexical entries, one for each language.

The idea that both languages are active and compete for selection even when only one of them is needed has been widely demonstrated through tasks employing words that share certain properties (lexical, orthographical, or grammatical) in both languages. For instance, this effect appears in inter-lingual homographs (Beauvillain & Grainger, 1987; De Groot, Delmaar, & Lupker, 2000; Dijkstra, Grainger, & Heuven, 1999; Dijkstra, van Jaarsveld, & Brinke, 1998; Macizo, Bajo, & Martín, 2010 cognates (Costa, Caramazza, & Sebastián-Gallés, 2000; Dijkstra et al., 1999; Gollan, Forster, & Frost, 1997; Lemhöfer & Dijkstra, 2004; but see De Groot & Nas, 1991), or research using grammatical gender (Morales, Paolieri, & Bajo, 2011). Other sources of evidence come from Stroop-like tasks (Stroop, 1935). This paradigm, widely employed to evaluate interference solving processes (see Macleod, 1991), requires participants to suppress a prepotent response. In the bilingual version of the task, participants are presented with a word in a certain language and they need to name the color of the ink in their alternative language (i.e., the English word "green" appears written in blue, and the participant must say "*azul*"-in Spanish). The fact that bilinguals show the Stroop effect between languages (Chen & Ho, 1986; Zied et al., 2004) indicates that the two languages compete for selection, even when only one is necessary to perform the task.

This non-selective activation of languages would produce competition when selecting the lexical entries corresponding to the required language (Dijkstra, 2005; Hoshino & Thierry, 2011; Kroll & Stewart, 1994; Kroll, Sumutka, & Schwartz, 2005; Macizo et al., 2010; Marian & Spivey, 2003a, 2003b). Between languages interference makes speech production more complex, however, bilinguals are able to produce language fluently, without intrusions from the alternative languages. The main models for language control and selection propose that bilinguals employ some kind of control that drives attention toward the required language, reducing interference from the unwanted language. However, there are two main approaches that differ on whether they propose or not that language selection is achieved through some kind of inhibitory control.

Non-inhibitory views posit that, in spite of existing language co-activation, selection is dependent on the level of activation of the lexical candidates (Costa & Caramazza, 1999; Costa et al., 1999; Costa, 2005; Poulisse & Bongaerts, 1994). For instance, Costa (Costa & Caramazza, 1999; Costa et al., 1999; Costa, 2005) proposes that only the entries belonging to the target language are considered for selection and, therefore, there is no competition. For example, if a Spanish-English bilingual aims to speak Spanish, only lemmas in Spanish will compete. A second proposal understands selection in terms of activation (Poulisse & Bongaerts, 1994). The authors propose that the lexical entries in both languages are considered during selection, but this is achieved through different activation levels. According to this approach, the lexical system of the language in use receives higher activation than the alternative language. As a consequence, the required lexical entry is selected by increasing the activation levels of the target language in comparison to the alternative language. From non-inhibitory perspectives, bilinguals are sensitive to contextual cues, which are important in indicating the appropriate language. Language cues are represented at the same level as conceptual features, and these cues will therefore drive the activation of lexical or lemma representations only in the required language. Thus, language selection occurs at an early locus, as contextual cues allow a reduction of the activation of the candidates in the alternative language before entering into competition.

Alternatively, the most influential approaches for cognitive control mechanisms in bilingual language processing allow inhibitory control to play a key role in language selection. According to these proposals, an inhibitory mechanism reduces accessibility to the unwanted language. Thus, lemmas associated with the target language are selected through suppression of the lexical entries from the irrelevant language, avoiding intrusions (Abutalebi & Green, 2008; Green, 1998; Levy, Mcveigh, Marful, & Anderson, 2007; Macizo et al., 2010; Meuter & Allport, 1999). There are two main models based on these types of processes: the Bilingual Interactive Activation Model (BIA; Dijkstra & van Heuven, 1998; van Heuven, Dijkstra, & Grainger, 1998) and the Inhibitory Control model (IC; Green, 1998), which we describe below.

First, the BIA model assumes that a single lexical system integrates both languages. It is composed of four representational levels: features (graphical), letters, words, and language nodes. The first two levels activate lexical candidates in both languages, which, in turn, activate the language nodes in the corresponding language to the context. Language selection occurs through an interactive process of activation and inhibition (see Figure 6). Representations compete both inter- and intra-languages, and this competition is solved through a mechanism of lateral inhibition. To be more specific, the more active representations inhibit the lexical entries of the same language, so that the selection of a certain candidate reduces the likelihood of selecting neighboring candidates. Concurrently, language nodes activated through language context will inhibit the lexical entries in the alternative language.

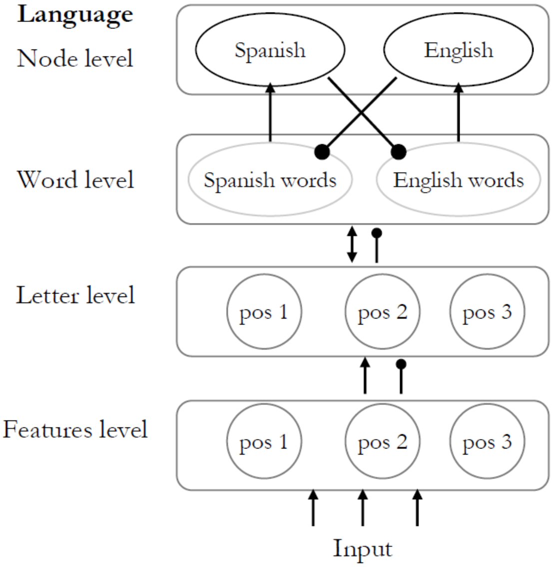

Figure 6. *Bilingual Interaction Active model (BIA). Excitatory connections are indicated through arrows (the arrows' tips signal the direction of the activation); inhibitory connections are represented in lines ending in circles.*

Among the inhibitory accounts, the Inhibitory Control model by Green (1998) (see Figure 7) is the most influential. This model explicitly proposes that language control is mediated by domain-general executive control mechanisms, based on the intervention of a supervisory attentional system (SAS; Norman & Shallice, 1986; Shallice & Burgess, 1996). The SAS is thought to be a unitary system, mainly dependent on the prefrontal cortex, which monitors and interacts with different cognitive processes. Green's approach suggests that this system would also be responsible for monitoring the activation of language competing schemas. Bilinguals need to exert inhibitory control over the non-required language, allowing the required language system to drive performance. In this manner, the mechanism that reduces the attention to the unwanted language will be the same as that which coordinates other cognitive domains. Given that the main inhibitory mechanism is thought to be a domain independent central process, Green's model (1998) assumes that bilingualism will have consequences for general cognitive processing.

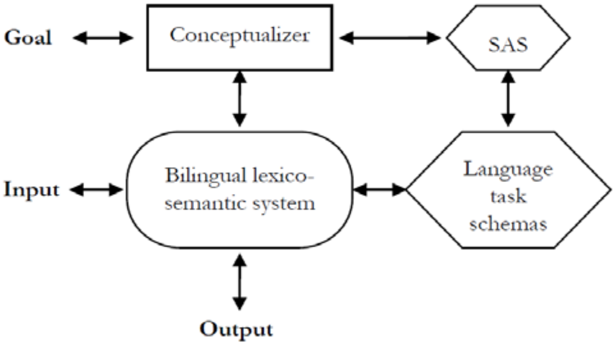

Figure 7. *Schematic representation of the Inhibitory model (extracted and adapted from Green, 1998).*

Thus, according to this perspective, when performing a task that requires the use of a certain language, the irrelevant language (which could be regarded as a distractor stimulus or noise) is suppressed in favor of the relevant language. In this manner, bilinguals solve between-languages competition through an active inhibitory mechanism that affects all the representations of the non-selected language. From the perspective of inhibitory models, language cues can contribute towards identifying the candidates in the target language instead of the irrelevant language, but they are not sufficient to eliminate competition for selection.

To summarize, this section reviews the main models that explain how bilinguals select the more appropriate language according to the situation. Although language co-activation is widely accepted, the debate focuses on distinguishing whether or not there is between-languages competition (see Kroll & Gollan, in press, for a review). In particular, non-inhibitory perspectives (e.g., Costa et al., 1999) support the notion that there is no competition; given that selection is language specific, the candidates in the irrelevant language are not considered for selection. In contrast, inhibitory theories (e.g., Green, 1998), argue that candidates in both languages compete for selection and, consequently, it is necessary to suppress the unwanted language. Both perspectives assume the constant intervention of language selection mechanisms to maintain the activation of the relevant language and avoid interference from the other, but what differs between them is the precise nature of the mechanisms thought to be responsible.

Consequently, inhibitory and non-inhibitory models make different predictions concerning the influence of a lexical selection mechanism over domain-general cognitive processes (Kroll & Bialystok, 2013). According to inhibitory models, selection occurs at a late locus, once lexical candidates are active in both languages, and it depends on the competition level (higher activation of the irrelevant language competitors will lead to higher inhibition). From this perspective, bilinguals will succeed in tasks involving coping with the conflict elicited by competing alternatives (once the alternatives are available). Alternatively, non-inhibitory models argue that selection occurs early, involving proactive attentional mechanisms in charge of directing the goal to select the appropriate language (before the competition occurs).

The present work parts from the idea that experience in a given process, albeit within a specific domain, can transfer to other domains that require similar processes. Thus, the study of cognitive control processes in bilinguals can serve to compare the inhibitory and non-inhibitory approaches of bilingual language control. In addition, identifying the influence of bilingual experience on cognitive control may contribute to existing knowledge about the nature, dynamics, and plasticity of the executive function. Guided by the influence of inhibitory theories, several studies have focused on evaluating the capacity of bilinguals to perform non-verbal tasks that involve conflict resolution (Bialystok et al., 2005; Colzato et al., 2008; Costa et al., 2009, 2008; Lee Salvatierra & Rosselli, 2010). In spite of the large body of existing research, the exact mechanisms involved in language control, along with the cognitive implications of bilingualism remain hitherto unclear. In the following section we review the main findings related to the influence of bilingualism on cognitive control and, more specifically, on inhibitory control.

2.2. BILINGUALISM AND INHIBITORY CONTROL

Inhibition and executive function

According to inhibitory models of language control, global inhibitory mechanisms could be directly related to bilingual language selection. The term inhibitory control refers to the capacity to suppress information or responses that are dominant, automatic or irrelevant for the task (Miyake & Friedman, 2012; Miyake et al., 2000). The main theories posit that inhibition is one of the core components of executive function, which is in charge of generating, maintaining, and adjusting the set of strategies responsible for processing and achieving the goals of a given task (for recent reviews, see Banich, 2009; Barkley, 2012; Jurado & Rosselli, 2007). Apart from inhibition, executive function* is thought to comprise a set of processes, such as the capacity to update information or cognitive flexibility (or attentional set shifting) (Miyake et al., 2000). Thus, different executive components are responsible for inhibiting distractive

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* In this work we will interchangeably use the terms "executive control", "executive function"; attentional control", or "cognitive control".

information, suppressing an unwanted response, updating information in mind, or shifting between different attentional sets. However, there is little agreement concerning the specific components of executive control, how they operate, and their underlying brain mechanism (see, for example, Braver, Paxton, Locke, & Barch, 2009; Koechlin & Summerfield, 2007). According to the influential theory developed by Miyake (2000), executive function has a unitary and diverse nature; that is, its multiple components are related, but they are also relatively independent.

Inhibitory models of language control have put forward the notion that bilingual language control and selection could be directly linked to the general capacity of inhibitory control. Following this idea, the first studies of the influence of bilingualism on general cognitive processes focused on investigating inhibitory control. But it is also the case that, bilinguals often need to switch between languages, depending on their interlocutors or the situation. Thus, in recent years some studies have also investigated the influence of bilingualism, not only on inhibition, but also on other functions (e.g., redirecting attention and modifying task goals).

To evaluate the influence of bilingual experience on inhibitory control, many studies have used attentional paradigms traditionally employed to explore individual differences in inhibitory control. These tasks contain competitive information that must be ignored in order to achieve successful performance (such as the Simon or the flanker tasks, see Figure 8).

Interference tasks are comprised of stimuli associated with a certain response, presented on congruent and incongruent trials. Whereas on congruent trials all the stimulus information is compatible with the correct answer, incongruent trials include competitive information, although irrelevant for solving the task.

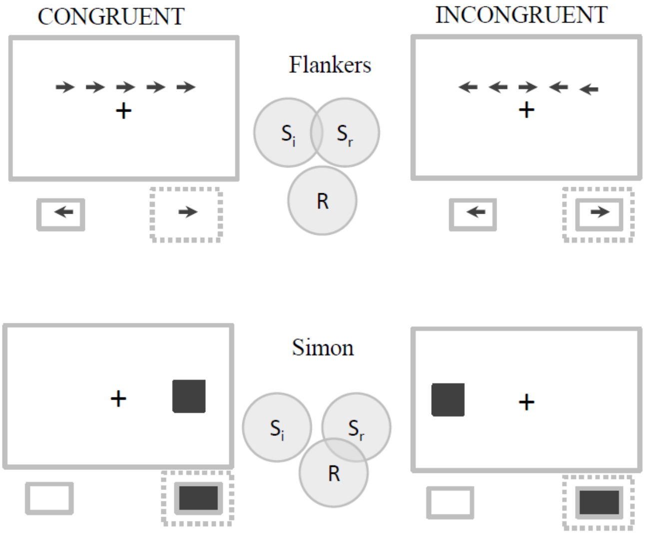

Figure 8. *Schematic representation of the flanker and Simon tasks. In the flanker task (above), when the direction of the flankers or task irrelevant stimuli (S_i) is congruent with the target arrorw (S_r), there is S_i – S_r compatibility. When the flanker's direction is incongruent with the target arrow, there is S_i – S_r incompatibility. In the Simon task (below), when the irrelevant feature of the task irrelevant stimuli (S_i -location-) agrees with the response location (R) associated with the task relevant stimulus dimension (S_r -color-) there is stimulus-response congruency (S_i – R). When there is no correspondence, there is S_i – R incongruence.*

For instance, the flanker task (Eriksen & Eriksen, 1974; Figure 8, up) requires participants to respond to the direction of a target arrow (left/right), surrounded by other arrows (flankers), which could point in either the same direction (congruent trials) or the contrary (incongruent trials). In the Simon task (Figure 8, below) participants are asked to associate a response with a certain stimulus (e.g., “press right to the red stimulus”; “press left to the green stimulus”). Given that stimuli can appear either at the left or right side of the display, on incongruent trials the stimulus associated with the response competes for the motor tendency to respond to the location where the stimulus appears.

These paradigms provide an index of interference, from the difference in response times or accuracy between congruent and incongruent trials. Smaller differences relate to smaller interference from competing information, which is usually interpreted as better inhibitory control (although we will discuss alternative interpretations in the next section). The effect of interference in these tasks, therefore, serves to evaluate individual differences in non-verbal dependent inhibitory control. Indeed, multiple studies employ these and related tasks to evaluate the modulations in cognitive control capacities derived from bilingualism.

The executive control advantage in bilinguals

Several studies report that bilinguals experience less interference than monolinguals in conflict tasks such as the Simon (Bialystok et al., 2005, 2004) and the flanker tasks –often inserted within the Attentional Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002) (Costa et al., 2009, 2008; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011). Furthermore, this bilingual advantage is reported throughout the lifespan in children (e.g., Adi-Japha et al., 2010; Bialystok & Martin, 2004; Bialystok & Senman, 2004; Bialystok, 1999, 2010b; Carlson & Meltzoff, 2008), young adults (e.g., Colzato et al., 2008; Costa et al., 2009, 2008) and the elderly (e.g., Bialystok et al., 2004).

Given that bilinguals often need to switch between languages, other studies also report bilingual benefits in switching tasks, which engage control processes related to shifting the task goals, inhibiting the previous target and redirecting the attention to a new one. This set shifting component is usually evaluated through the task switching procedure. The standard paradigm includes "pure" blocks, in which participants respond by attending to only one feature of the stimuli (e.g., color or shape) for all the trails composing the block. In contrast, in "mix" blocks, participants respond to one feature or another in a trial by trial base, following the particular instructions for the trial. These mixed blocks generate two types of trials: repetition trials, in which the task is the same on consecutive trials (e.g.: color-color), and switching trials, in which the task changes from one trial to another (e.g.: color-shape). The differences (in accuracy or response times) between repetition trials and switching trials in the mixed blocks produces a "switching cost" index, whilst the differences between mixed blocks and pure blocks results in the "mixing cost" index. The first index (switching cost) evaluates cognitive flexibility, or the capacity to cope with the proactive interference produced by the previous trial (Philipp, Kalinich, Koch, & Schubotz, 2008). It reflects the ability to reduce the attention paid to features signaled by the previous task (e.g.: color), and to drive the attention to a new feature (e.g., shape). The second index (mixing cost) measures the ability to maintain attentional control in a context that requires the subject to keep multiple tasks active. It reflects the capacity to continuously shift the task goals against maintaining a single task goal. The studies employing these tasks report bilingual advantages in switching cost but not in the mixing cost (Prior & Gollan, 2011; Prior & Macwhinney, 2009; Soveri, Rodriguez-Fornells, & Laine, 2011). Therefore, bilingualism appears to affect the capacity to drive attention to new task goals, which, in turn, involves inhibiting the previous target and redirecting the attention to a new one.

Taken together, the studies of inhibitory control support the notion that language selection and control are mediated by global executive control processes, as reflected by smaller interference effect in non-verbal conflict task and by smaller switching costs in non-verbal switching tasks. However, two main factors question the bilingual influence on inhibitory processes. First, the bilingual superiority does not appear systematically. Recent reviews have pointed to many studies failing to find bilingual advantages in tasks that involve conflict resolution or cognitive flexibility (Blumenfeld & Marian, 2013; Hernández, Martin, Barceló, & Costa, 2013; Hilchey & Klein, 2011; Paap & Greenberg, 2013; Tao et al., 2011). Second, bilinguals and monolinguals differ not only on performance in tasks that involve inhibitory control and/or switching. For example, bilinguals appear to outperform monolinguals in working memory tasks (Bialystok et al., 2004; Luo, Craik, Moreno, &

Bialystok, 2013), creativity (Hommel, Colzato, Fischer, & Christoffels, 2011; Kharkhurin, 2010; Ricciardelli, 1992), problem resolution and cognitive flexibility (e.g., dimensional card-sorting task, Bialystok, Craik, & Ruocco, 2006; Bialystok & Martin, 2004; Marzecová et al., 2013) along with episodic memory (Ljungberg, Hansson, Andrés, Josefsson, & Nilsson, 2013), suggesting that bilingualism may affect other cognitive processes.

To summarize, although a group of studies support inhibitory models (since bilinguals surpass monolinguals in tasks involving inhibitory control), other studies fail to replicate these findings. In addition, differences between bilinguals and monolinguals in non-inhibitory tasks suggest that bilingualism may affect other cognitive processes beyond inhibition. These factors bring into question the notion that inhibition is the only mechanism responsible for language control and selection (or, at least, that their use transfers to other cognitive domains) and thus prompt us to consider the possible involvement of alternative processes in bilingualism.

Nevertheless, the elusiveness of the bilingual inhibitory advantage could simply reflect that different tasks tap into different aspects of inhibitory control. The term “inhibition” often refers to different functions and processes (Friedman & Miyake, 2004). For example, we need to bear in mind that, even when the tasks require participants to solve the conflict elicited by competing responses (such as language control and selection according to inhibitory proposals) the nature of the conflict they produce might not be identical (see Figure 8). Some tasks, such as the flanker task, require a reduction of the conflict produced by stimulus information (interference suppression), while others – such as the Simon task– demand suppression from a prepotent response to the stimulus (response inhibition).

The language control mechanisms modulated by bilingualism would be those more closely related to the type of conflict elicited by language co-activation. Consequently, bilingual advantages should appear specifically in tasks that require similar mechanisms of conflict resolution. This idea is compatible with attentional control theories that favor the notion of plasticity and independence of different conflict control processes (Egner, Delano, & Hirsch, 2007; Garavan, Hester, Murphy, Fassbender, & Kelly, 2006). In other words, it is expected that training in interference suppression would not affect response inhibition and vice versa. Indeed, the studies that have tried to dissociate these two inhibitory processes show that the bilingual advantages seem to relate more to tasks involving the need to ignore competing information than response inhibition (Bialystok & Martin, 2004; Bialystok & Viswanathan, 2009; Blumenfeld & Marian, 2013; Colzato et al., 2008; Esposito, Baker-Ward, & Mueller, 2013; Luk, Anderson, Craik, Grady, & Bialystok, 2010; Martin-Rhee & Bialystok, 2008).

However, although the bilingual advantage seems to be more robust in tasks involving cognitive control similar to that required in language selection, the observed results are far from consistent. Thus, some studies have failed to replicate the bilingual advantage in interference suppression tasks (e.g. the flanker task, see Hilchey & Klein, 2011 for a review). However, studies employing neurophysiological measures show more consistency so that, even in the absence of behavioral differences, bilinguals and monolinguals seem to employ different brain areas to solve tasks involving interference suppression (Abutalebi et al., 2012; Bialystok et al., 2005; Garbin et al., 2010; Kousaie & Phillips, 2012; Luk et al., 2010). Therefore, although the bilingual influence may not always be evident when looking at performance in the tasks, bilinguals seem to engage the neural networks in charge of efficient conflict resolution.

In addition, it is especially relevant that neuroimaging studies of language processing in bilinguals reveal that some of the regions engaged in avoiding interference between languages are similar to the ones associated with non-verbal control mechanisms (for reviews, see Hervais-Adelman, Moser-Mercer, & Golestani, 2011; Moreno, Rodriguez-Fornells, & Laine, 2008; Rodriguez-Fornells, De Diego Balaguer, & Münte, 2006). Furthermore, some studies report that bilingual performance in language switching and non-verbal task switching recruit similar brain regions (Garbin et al., 2010; Luk, Green, Abutalebi, & Grady, 2012). Taken together, neurophysiological studies support the idea that bilinguals employ common brain networks for language control and domain-general conflict resolution. Moreover, the bilingual advantage relates to a more efficient recruitment of brain areas involved in inhibitory control in the presence of competition. These results support the inhibitory hypotheses and may explain why a bilingual advantage is not always evident in inhibitory tasks.

However, inhibitory models do not provide an explanation for bilingual advantages in other (non-inhibitory) tasks. For example, apart from reduced interference effects (e.g., lower number of errors or response times on incongruent trials), some experiments using conflict tasks have shown that bilinguals are overall faster on both congruent and incongruent trials (e.g., Bialystok, 2006; Costa et al., 2008; Martin-Rhee & Bialystok, 2008; see also Hilchey & Klein, for a review). This last effect seems to emerge under conditions that demand high monitoring, indicating that inhibitory control might not be the only mechanism responsible for the observed bilingual advantages.

An important finding in this line comes from a series of studies by Costa and colleagues (2009), which compared bilinguals and monolinguals on a flanker task. The authors found that language group differences arose only under high monitoring conditions (with a similar proportion of congruent and incongruent trials; Experiment 2), but not under low monitoring conditions (when the proportion of congruent trials were very high -92%- or very low -8%-; Experiment 1). Furthermore, only under high monitoring conditions were bilinguals faster overall than monolinguals. These results indicate that differences due to bilingualism are not restricted to conflict conditions (incongruent trials), but to the task in general. They interpreted this finding as indicating that monitoring processes might be involved in bilingual language selection. However, Prior (2012) contrasted monitoring and inhibitory capacities as alternative processes underlying the bilingual advantage through a 2-lag non-verbal switching task, which permits the dissociation of monitoring and inhibitory control abilities. The results indicated that bilinguals exerted higher inhibitory control than monolinguals, but did not imply any specific bilingual advantage in monitoring. Other studies measuring different aspects of inhibitory control (such as active and reactive inhibition), however, emphasize that alternative processes, such as efficient maintenance of the task goal, may underlie bilingual advantages (Colzato et al., 2008).

Conclusions

To summarize, different studies show that bilinguals outperform monolinguals on tasks that involve conflict resolution. Furthermore, even when bilinguals and monolinguals do not differ in their performance on interference tasks, neurophysiological data suggest that they differ in terms of their engagement of brain functions. These results suggest that bilingualism modifies the neural networks involved in task resolution, which would also be related to the ones that play a role in language control. Nevertheless, some studies provide evidence that precludes explanations in terms of inhibitory theories. For instance, there are different findings from studies involving tasks that tap into different inhibitory control demands (e.g., interference suppression or response inhibition), along with difficulties in replicating the bilingual inhibitory advantage, and the existence of data showing non-inhibitory bilingual advantages (e.g., faster overall response times). These data have recently generated alternative proposals, which suggest that the ability to manage and to cope with competing information may not be the main factor underlying the bilingual advantage. From this perspective, mechanisms related to monitoring or the maintenance of task goals might better endorse the bilingual superiority on attentional tasks (e.g., Colzato et al., 2008; Costa et al., 2009).

In the next section we will examine some of the factors that may account for the inconsistences among previous findings and that may be useful to provide a coherent account of these data. In particular, our starting point will be to emphasize that bilingualism should be considered an experience that dynamically modifies the mechanisms responsible for language and cognitive processing. The rationale for this approach comes from the fact that most of the previous studies have focused on exploring specific and isolated executive components (mainly in inhibitory control). And whilst this strategy has been useful for identifying the specific role of each control mechanism, it does not allow the detection of the possible modulatory roles and interactions between multiple mechanisms. Next, we will emphasize the importance of considering bilingualism as a categorical variable. As discussed at the beginning of this chapter, bilinguals differ not only in socioeconomic, cultural, and educational factors but more importantly, in linguistic aspects such as proficiency, dominance, or the context of use of their languages, to name but a few. Differences in these and other aspects may imply the existence of different strategies to solve language co-activation that could therefore place different demands on cognitive resources. We will examine these factors below.

2.3. THE DYNAMIC NATURE OF COGNITIVE CONTROL PROCESSES

Most previous research has evaluated the role of each executive control component independently, giving the impression that bilingualism affects isolated components. This fragmented approach prevents us from observing a key feature of bilingualism – that is, managing several languages modulates and reshapes a wide neural network responsible for language processing. Consequently, focusing on single components to understand the cognitive changes derived from bilingualism seems to be a biased strategy. Alternatively, recent proposals suggest that the bilingual advantage might result from modulations on the dynamics between several cognitive control mechanisms (Bialystok, Craik, & Luk, 2012; Costa et al., 2009; Green & Abutalebi, 2013; Kroll & Bialystok, 2013). Thus, more global approaches propose that bilingual advantages rely on differential "monitoring" (Costa et al., 2009), "coordination" (Bialystok, 2011) or "adaptation" (Green & Abutalebi, 2013) between control processes.

Therefore, it seems essential to investigate the influence of bilingualism on cognitive control from a more holistic perspective, which is also the approach of some recent cognitive control models. For instance, Miyake and Friedman (2012) propose, in a recent review of their model, that executive function must be understood from a "unity and diversity" framework (see Figure 9). From this perspective, each executive skill (inhibitory control, shifting, and updating) is composed of a common executive mechanism (unity) and of specific components (diversity). The common function relates to the capacity to actively maintain the task goals, which serve to effectively direct lower level processes. Therefore, modulations in this common factor might underlie some of the bilingual advantages found in conflict solving. Additionally, changes in this unitary factor will also affect the functioning of the multiple executive components (including the non-inhibitory ones), which could account for the non-inhibitory bilingual advantages.

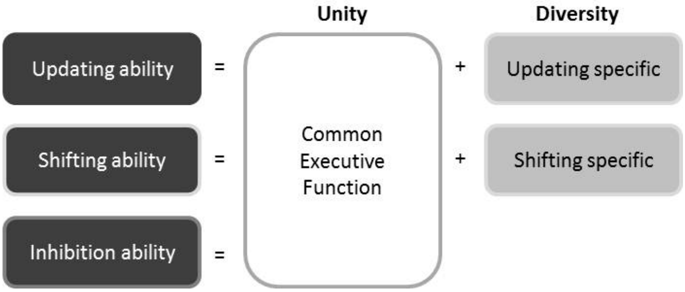

Figure 9. *(Adapted from Miyake & Friedman, 2012). Schematic representation of unity and diversity of the three executive functions.*

Alternatively, we also need to consider the possibility that other control mechanisms (apart from inhibition) could cooperate to achieve efficient language selection. For instance, processing contextual cues might intervene in selecting the appropriate language (i.e., "who am I talking to?"; "am I at home or at work?"). From this view, bilinguals would be constantly monitoring intra- and extra-linguistic cues to successfully select the appropriate language for comprehension and production. Additionally, bilinguals need to keep active the planned language while processing new cues that may induce a language switch (Costa, La Heij, & Navarrete, 2006; Costa, Santesteban, & Ivanova, 2006; Finkbeiner, Almeida, Janssen, & Caramazza, 2006; Finkbeiner, Gollan, & Caramazza, 2006; Kuipers & La Heij, 2008; Philipp, Gade, & Koch, 2007). This leads to the idea that a single process is not necessarily responsible for language control, but that language control might result from coordination between multiple processes (Bialystok, Craik, & Luk, 2012; Costa et al., 2009; Costa, Santesteban, & Ivanova, 2006; Prior, 2012), which adapts according to the demands of the situation (Costa et al., 2006; De Groot & Christoffels, 2006; Festman & Münte, 2012; Green & Abutalebi, 2013; Kroll & Bialystok, 2013). Hence, cognitive processes must cooperate to achieve successful communication, and the common executive function might be responsible for coordinating the implied mechanisms. This perspective could explain the evidence for bilingual advantages in both inhibitory and monitoring processes described in section 2.2. (Colzato et al., 2008; Costa et al., 2009; Garbin et al., 2010; Hernández, Costa, & Humphreys, 2011; Hernández et al., 2013; Prior & Gollan, 2011; Prior & Macwhinney, 2009; Prior, 2012).

The role of coordination between proactive and reactive control processes in language control is implicitly considered in Green's inhibitory control model (Green, 1998), and explicitly discussed in the adaptive control hypothesis recently proposed by Green y Abutalebi (2013). According to the adaptive control hypothesis, cognitive processes cooperate and adapt depending on the demands of the situation to achieve the highest efficiency, which leads to adaptive changes in the related neural circuitry.

Therefore, a situation requiring the management of two languages would lead to the adaptation of the cascade of processes involved in language selection. Consequently, inhibitory and non-inhibitory perspectives are not necessarily exclusive, as their associated mechanisms may interact to achieve language control.

This proposal can be framed in terms of some attentional theories, which suggest that the interaction between different cognitive processes is responsible for cognitive control. Thus, Braver's dual mechanism of control framework (e.g., Braver, Gray, & Burgess, 2007; Braver, 2012) proposes the involvement of reactive and proactive control processes, which are relatively independent, but mutually complementary. Proactive control is an early attentional mechanism, which selects and maintains the tasks goals. It anticipates incoming events and protects against interference, selecting the appropriate alternative prior to competition. In the case of bilingualism, it would serve, for example, to process contextual cues for an early selection of the appropriate language. Reactive control, in turn, is responsible for detecting and solving interference from a conflict situation. This mechanism would select the appropriate lexical entry once the cross-language alternatives enter into competition. The adequate adjustment between these two mechanisms would allow for efficient performance on tasks in which there is a need to choose between multiple alternatives.

Some studies have set out to dissociate the influence of bilingualism on different aspects of inhibitory control, such as conflict monitoring and inhibition (Costa et al., 2009; Prior, 2012), interference suppression and response inhibition (Bialystok & Martin, 2004; Bialystok & Viswanathan, 2009; Blumenfeld & Marian, 2013; Luk et al., 2010; Martin-Rhee & Bialystok, 2008) or active and reactive inhibition (Colzato et al., 2008). However, none have directly addressed whether bilingual experience modulates the coordination between them. One of the main aims of our work is to understand precisely the influence of bilingualism on the cascade of processes required for solving conflict situations. To this end, the first experimental series will address the idea that the dynamic combinations between monitoring and inhibition processes achieve conflict resolution under conditions in which there is distracting or competing information. In Experiment 1 we will compare bilinguals and monolinguals in an AX version of the continuous performance task (AX-CPT), which requires adjusting proactive (monitoring) and reactive (inhibition) control processes to achieve successful performance. In Experiment 2 we will further explore these mechanisms by evaluating the adjustment between both mechanisms through analysis of the cortical potentials (ERPs) associated with proactive and reactive control.

Thus, in our first experimental series we will evaluate young adults, whose control processes are at the peak of their capacities. However, we may also speculate about how these mechanisms develop in the bilingual mind. During childhood, bilingualism may affect the development of specific executive components or, alternatively, it could affect the common executive component. Below we describe the existing data related to the influence of bilingualism during the development of executive function in childhood.

Bilingualism and development of executive function

Research has shown that bilingualism leads to an earlier maturation of cognitive control capacities during childhood (Adi-Japha et al., 2010; Bialystok, Barac, Blaye, & Poulin-Dubois, 2010; Bialystok, 2010; Carlson & Meltzoff, 2008; Yang, Yang, & Lust, 2011). As in adults, most studies have mainly evaluated single components, such as interference control (Engel de Abreu, Cruz-Santos, Tourinho, Martin, & Bialystok, 2012; Martin-Rhee & Bialystok, 2008; Yang et al., 2011) or cognitive flexibility (Bialystok & Martin, 2004; Bialystok & Viswanathan, 2009; Bialystok, 1999). The few studies tapping into updating (or working memory) capacity, do not report bilingual advantages in this component (Bialystok & Feng, 2009; Bonifacci, Giombini, Bellocchi, & Contento, 2010; Engel de Abreu, 2011; but see Soliman, 2014). These similarities with the findings from research with adults also extends to some inconsistences: some studies fail to find bilingual advantages in children (Duñabeitia et al., 2013; Gathercole et al., 2014; Morton & Harper, 2007) and others describe that bilingual children are overall faster than their monolingual peers in conflict tasks (Martin-Rhee & Bialystok, 2008; Yang et al., 2011). The similar pattern of results between children and adults implicitly suggests that bilingualism could modulate the coordination between cognitive control processes during early development. In a recent study, Bialystok (2011) evaluated this idea explicitly, reporting that bilingual children were more efficient than monolinguals only when they needed to coordinate different executive control components.

This idea could be further explored by studying children's working memory development. From the unity-diversity perspective of executive function (Miyake & Friedman, 2012; Miyake et al., 2000), bilingual children should excel in working memory tasks, particularly under conditions requiring other executive components. There are two main predictions that emerge from this hypothesis. First, if the common executive aspect (unity) is responsible for the bilingual advantages in conflict situations, this should affect other components, including working memory. Second, managing language coactivation requires not only inhibition and language selection. As previously mentioned, it may demand other processes, such as maintaining and updating contextual representations, or language cues, which involves working memory. Additionally, the adaptive control hypothesis also predicts that the updating skill should readjust along with the other two components, which would be reflected in interactions between executive components. In conclusion, if bilingualism modulates the specific component of working memory (diversity) during its early development, we should find a main working memory effect when manipulating other executive components. If working memory is integrated within the other two components (unity), the effect of working memory will be modulated in accord with the demands of the other components.

Our second experimental series will evaluate the influence of bilingual experience on the development of executive control during childhood. To do so, we will evaluate children (in critical stages of the development of executive functioning) in tasks that, in order to be solved, require an efficient combination of different aspects of executive control (specifically, inhibitory control and working memory). From a unitary view of executive function development, bilingual experience should affect differentially each component. A more global and interactive view could explain the absence of advantages in each separate component, but those differences will appear when they need to interact with each other.

2.4. DIFFERENT BILINGUAL EXPERIENCES ENGAGE DIFFERENT COGNITIVE RESOURCES

The fact that the term "bilingualism" can be used to refer to a wide set of individuals could also be responsible for the inconsistencies found in the study of bilingual cognitive advantages. Most of the studies we report here focused on highly proficient bilinguals who acquired their second language at an early age (e.g., before 6 years old) and practice both languages frequently (e.g., daily use of both languages). However, the subjects of these studies often differ in other aspects of bilingualism (e.g., the language combinations, socioeconomic factors that led to bilingualism or the context of use of each language) and they could partially account for variations in the results. For example, some studies have reported that bilinguals who are accustomed to switching between their languages are more efficient in non-verbal switching tasks than the bilinguals who do not switch (Prior & Gollan, 2011), while others show a link between individual differences in cognitive control and the capacity to control two languages (Festman & Münte, 2012; Festman, Rodriguez-Fornells, & Münte, 2010)

Taking these facts into account, Green (Green & Abutalebi, 2013; Green, 2011) emphasizes that the need for language control is crucial for the adaptation of cognitive control processes. In the adaptive control hypothesis (Green & Abutalebi, 2013) the authors propose that language control processes adapt according to the recurrent demands of the language context. Therefore, it stresses the importance of identifying, the control processes demanded by different bilingual contexts whilst showing how each context modulates the properties and coordination of the required control processes. Thus, according to the conversational pattern between the interlocutors, there will be different types of bilingual contexts (e.g., single language, dual language or dense code-switching contexts). Each of these contexts may require different involvement of the control mechanisms that, in turn, will result in differential modulations on cognitive control dynamics (see Figure 10).

	Interactional contexts		
Control processes	**Single language**	**Dual language**	**Dense code-switching**
Goal maintenance	+	++	=
Interference control: conflicto monitoring and interference suppression	+	++	=
Salient cue detection	=	+	=
Selective response inhibition	=	+	=
Task disengagement	=	+	=
Task engagement	=	+	=
Opportunistic planning	=	=	=

+ indicates the context increases the demand on that control process (++ higher demands); = indicates that the context has neutral effects.

Figure 10. *Cognitive control mechanisms proposed by the adaptive control hypothesis and their relation with different interactive contexts (extract from Green & Abutalebi, 2013).*

According to this view, to understand the control mechanisms involved in language coordination it is crucial to identify the cognitive demands for each bilingual context. After exploring the influence of bilingualism on the dynamics between some of the cognitive control processes, our next goal is to investigate the effect of different bilingual experiences on the cognitive control networks. To do so, we evaluated which control processes mediate in bilingual contexts that require the maintenance of two languages at a time, such as simultaneous interpretation. Although it is not a frequent form of bilingualism, simultaneous interpretation is an extremely demanding instance of language control. Due to its complexity, the mechanisms involved in this activity may differ from those required in other bilingual contexts. Identifying the cascade of processes involved in this situation can allow us to better understand the dynamics of language control as well as the adaptation of domain-free cognitive processes. In the next section we will describe some of the mechanisms thought to intervene in simultaneous interpretation as well as the main findings concerning its influence on cognitive control processing.

Executive function and simultaneous interpreting

As described in section 2.1, theories on bilingualism explain language control and selection in terms of language inhibition or activation. Language control is also crucial in simultaneous interpreting as professionals need to produce the information in the target language whilst avoiding interference from the source language. For instance, positron emission tomographic (PET) research shows that translating words relates to an increase of activation on brain regions related to control mechanisms (such as the anterior cingulate cortex; henceforth denoted as ACC), thus supporting the suggestion of the involvement of control mechanisms during interpreting (Price, Green, & von Studnitz, 1999). Nevertheless, it is hard to relate the control mechanisms involved in interpreting to the inhibitory mechanisms proposed by language control approaches since interpreting requires that both languages are kept active. Therefore, while the challenge for bilinguals[*] is to reduce the activation of the non-required language, the challenge for interpreters is to keep their two languages active at a given time. This fact could presumably lead to the engagement of different control processes in each bilingual context. Empirical data support this idea, showing that interpreters do not employ inhibition to control their languages as bilinguals do (Ibáñez, Macizo, & Bajo, 2010).

According to the adaptive control hypothesis, if bilinguals and interpreters recurrently employ different language control processes, this would lead to differential modulations on the control system. Hence, it would be possible to distinguish the control mechanisms inherent in interpreting by looking at differential patterns of cognitive control between bilinguals and interpreters. Although the research in this field is scarce, we will review the main control mechanisms proposed to mediate simultaneous interpreting.

Executive control processes need to intervene in all of the interpreting phases. First, during comprehension, interpreters need to monitor possible syntactic or semantic errors as well as suppress the interference from homonyms or metaphors (Gernsbacher & Shlesinger, 1997; Yudes, Macizo, & Bajo, 2012). Second, during production, they need to monitor their own errors (Yudes, Macizo, Morales, & Bajo, 2013) and, finally, during the reformulation of the message, interpreters must

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[*] In this section, when we use the term "bilinguals" we refer to bilinguals with no professional experience in interpreting or translation.

employ planning strategies. Furthermore, the need to coordinate comprehension and production requires strategies to monitor their cognitive resources. To overcome the processing limitations derived from attending to two channels simultaneously, Cowan (2000) proposes two alternatives. One possibility is that interpreters could rapidly switch their attention between comprehension and production, which would allow them to maintain the maximum amount of information in attentional focus. Alternatively, because extended experience in a certain task often derives on an automatization of that task (thus decreasing the demands of attentional resources), interpreters might have automatized many language processing components so that they might be able to comprehend and produce speech in a relatively automatic manner. Therefore, interpreters could perform both tasks without exceeding their processing limitations. In any case, none of these alternatives would require the intervention of inhibitory mechanisms in regulating comprehension and production, because the need to hold two languages active is incompatible with inhibiting the information required to solve the task.

Actually, Ibáñez and colleagues (Ibáñez, Macizo, & Bajo, 2010) reported that interpreters and bilinguals engage different language control strategies. In a language switching task in a sentence reading context with embedded cognate words, interpreters, relative to bilinguals, showed smaller asymmetric language switching costs (longer reaction times when shifting from L2 to L1 than from L1 to L2 – which is considered a language inhibition index) and faster response times in cognate relative to non-cognate words (which is thought to reflect the alternative language activation). This idea has been further corroborated by Yudes, Macizo, and Bajo (2011) who found that interpreters outperformed bilinguals and monolinguals in shifting and cognitive flexibility, but not in inhibitory control, as measured by the Wisconsin Card Sorting Test (WCST) and a Simon task respectively. Thus, all participants showed similar interference costs in the Simon task (slower response times and more errors on incongruent trials relative to congruent trials). However, interpreters needed fewer trials to solve the WCST and committed fewer perseverative errors than the other groups. These results suggest that monitoring might be one of the control processes required in simultaneous interpreting.

During interpreting it is necessary to alternate and regulate (monitor) comprehension, reformulation and production without losing information and avoiding interference between the source and the target languages (Christoffels & de Groot, 2005; Gerver, 1976). Furthermore, it is also necessary to store and operate with high quantities of information in mind, which may imply a role for memory processes. In addition, monitoring and memory processes must interact, as interpreters need to auto-regulate their own production, maintaining the message in the source language until its reproduction in the target language.

With respect to memory processes, studies report that interpreters outperform non- interpreters on tasks that require memory processes. For instance, they can maintain bigger information units, and at a deeper semantic level, and retrieve the information easily (Dimitrova, 2005; Jones, 1998; Meuleman & Van Besien, 2009). These outcomes suggest that memory plays a crucial role in interpreting, which may not be that important in other bilinguals contexts. In particular, working memory (WM) seems to be of special relevance in interpreting (Christoffels, De Groot, & Kroll, 2006; Gile, 1997; Liu, Schallert, & Carroll, 2004). The term "working memory" refers to the process responsible for temporarily storing and manipulating information in mind (e.g., Baddeley, 1986, 2000). Although there are different WM models, most agree that it is composed of a storing system and a central executive, which controls and coordinates the stored information (Baddeley, 1986, 1996, 2000; Kane, Bleckley, Conway, & Engle, 2001; Kane, Conway, Hambrick, & Engle, 2007). Given that interpreting requires the storage of high quantities of information in short term memory while reformulating and producing the message in the source language, a higher WM capacity would lead to higher efficiency in interpreting (De Groot & Christoffels, 2006).

Several studies link interpreting with high WM capacity (Chincotta & Underwood, 1998; Christoffels, De Groot, & Waldorp, 2003; Darò & Fabbro, 1994; Köpke & Nespoulous, 2006; Liu et al., 2004; Padilla, Bajo, Cañas, & Padilla, 1995; Tzou, Eslami, Chen, & Vaid, 2012), thus suggesting that WM mediates simultaneous interpreting. Nevertheless, the specific role of WM in interpreting remains unclear. One possibility is that WM maintains the information during speech production, favoring the coordination between comprehension and production. The relation between WM and comprehension and production coordination has been studied through articulatory suppression studies. In articulatory suppression experiments, participants must recall lists of words while articulating irrelevant syllables (e.g., “bla, bla, bla”). The syllables articulation prevents WM from subvocal rehearsal of the to-be-remembered information (e.g., Baddeley, Lewis, & Vallar, 1984) and as a consequence, it produces a decrement in information recall.

Simultaneous interpreting could be considered to be an extreme form of articulatory suppression, as it requires producing the speech in the target language while storing information from the source language. Therefore, interpreters are capable of storing the input information while verbalizing the reformulated output. Indeed, the capacity of remembering information under articulatory suppression conditions is associated with the quality of the interpretations in bilinguals with no previous experience in interpreting (Christoffels et al., 2003). Furthermore, interpreters show a reduced articulatory suppression effect (lower recall of material studied while articulating syllables than in silence) and are thus apparently resistant to this effect (Padilla, Bajo, & Macizo, 2005; Padilla et al., 1995; Yudes, Macizo, & Bajo, 2012).

In summary, interpreters seem to have higher WM capacity than non-interpreters, whilst the smaller articulatory suppression effects indicate that they are more efficient at coordinating verbal comprehension and production. Some studies have suggested a link between the absence of articulatory suppression and high WM capacity (Padilla et al., 1995). However, other experiments indicate that the capacity to coordinate verbal comprehension and production seems to be more strongly related to verbal skills such as lexical access and linguistic knowledge (Padilla et al., 2005; Yudes, Macizo, & Bajo, 2012; Yudes, et al., 2013). The results of articulatory suppression, together with the WM capacity scores, indicate that, more than storing skills, monitoring processes and linguistic knowledge are responsible for the efficient coordination of comprehension and production in interpreters.

This idea is compatible with attentional control perspectives (Engle, 2002; Kane et al., 2007), which propose that individual differences in WM are more related to the capacity of sustained and controlled attention than to storage or memory processes. Thus, WM capacity will be reflecting the efficiency of attentional processes responsible for maintaining or suppressing information, depending on its relevance to the task. Hence, the high WM capacity of interpreters might be reflecting efficient attentional control. Nevertheless, the relation between WM capacity and verbal proficiency (Gathercole, Pickering, Hall, & Peaker, 2001; Gathercole, 1995; Thorn & Gathercole, 2001) could also explain why interpreters (who develop high verbal skills) score highly in verbal WM tasks. It is therefore worth noting that, as far as we know, all previous studies have focused on verbal WM tasks. Further, despite the crucial role that monitoring processes seem to play in interpreting, research has focused on investigating the storing component of WM through complex span tasks. Consequently, the results from these tasks do not allow for the evaluation of the specific role of the attentional components of WM.

In the current work we aim to evaluate the relationship between simultaneous interpreting and WM monitoring/updating capacity. To do so, in our third experimental series we will compare professional interpreters with bilinguals. In Experiment 5 we will evaluate the updating capacity, controlling for storing, updating and monitoring demands. Given that interpreters need to maintain two languages active and coordinate comprehension and production, we expect interpreters to surpass bilinguals, especially under conditions that require the updating and monitoring of information presented through two different channels (e.g., auditory and visual) concurrently.

Having evaluated the updating capacity of interpreters compared with bilinguals, we will try to ascertain whether the interpreters' superiority in WM relates to general attentional control skills. According to the attentional control proposal of WM by Engle and colleagues (Engle, 2002; Kane et al., 2001, 2007; Kane & Engle, 2002; Shamosh et al., 2008) variations in WM are mainly due to individual differences in the capacity to control and direct attention, and more specifically, to the capacity for maintaining the task goals (Redick & Engle, 2006; Unsworth, Redick, Spillers, & Brewer, 2012; Unsworth & Spillers, 2010). Given that updating is considered to be one of the core components of the executive system (Miyake & Friedman, 2012; Miyake et al., 2000), interpreting could influence not only the specific component of updating, but a wider attentional control network.

To evaluate the relationship between attentional functions and interpreting, in Experiment 5 we will compare the functioning of the attentional networks of interpreters with that of bilinguals. According to Posner and colleagues (Posner & Petersen, 1990; Posner, 1994), attention is composed of three independent but coordinated networks: alertness, orientation, and executive function. In Experiment 5 we will employ a version of the Attention Network Test (ANT; Fan et al., 2002), the ANTI-V (Roca, Castro, López-Ramón, & Lupiáñez, 2011), which permits the evaluation of the interaction between the different attentional networks. If interpreting influences attentional control in general, we should observe that interpreters have fewer costs than bilinguals in all of the measures. On the other hand, if only some specific attentional control processes are directly related to experience in interpretation, results would show group differences for some specific attentional indices but not for others. For example, because interpreters keep their two languages active in mind so that they are not placed in competition, we might expect that interpreting may not affect conflict resolution. In contrast, alertness and orienting can be enhanced by interpreting experience since interpreting requires high levels of alert and high responsiveness to contextual cues during task performance. The obtained results could allow us to understand the underlying mechanisms of coordinating comprehension and production, as well as the active maintenance of two language systems.

2.5. ORGANIZATION AND GOALS OF THE EXPERIMENTAL SERIES

The main goal of the experiments reported in this thesis is to evaluate the modulatory role of bilingualism in the dynamics, transfer, and development of the executive control processes. In particular, we will assess bilinguals on nonverbal tasks that require a coordinated involvement of different executive processes.

In the first experimental series (Experiments 1 & 2) we will focus on the influence of bilingualism on the dynamics between different mechanisms of cognitive control. Adopting the idea that executive control has a dual nature (Braver et al., 2007; Braver, 2012), we will explore the effect of bilingualism on the interactions between proactive and reactive control, at both behavioral (Experiment 1) and electrophysiological (Experiment 2) levels. To do so, we will compare the performance of bilinguals and monolinguals on the AX-CPT. The observation of performance through the conditions of this task will allow us to ascertain whether bilingual experience affects isolated processes or the co-ordination between them. Furthermore, we will study the electrophysiological correlates associated with each condition and, more specifically, ERPs analyses, which will allow for the observation of the processes that each language group engages for solving the task.

Along the same line of enquiry, the second experimental series will address the role that bilingualism plays during the development of the dynamics between executive functions during childhood. Based on the view that executive function is both unitary and diverse, we will evaluate the executive skills of children at critical ages (5-7 years) for the development of cognitive control processes. In the first experiment of this series (Experiment 3), we will analyze the performance of bilingual and monolingual children on a Simon task with different working memory demands. In Experiment 4 we will evaluate their performance on a working memory task with different cognitive control demands. Manipulations of the complexity of control processes in each task will allow for the evaluation of each component in relative isolation and in combination with others. If bilingualism modifies the development of isolated executive control components, we should observe differential effects on each component. Alternatively, if modulations occur on the unitary aspect of executive function, we should not necessarily observe bilingual advantages when analyzing each component separately, but they will emerge under conditions in which there is the need to interact between them.

Finally, we will focus on analyzing the modulatory role of different bilingual contexts on cognitive processes. To this end, we will compare professional simultaneous interpreters with bilinguals who have no professional experience in interpreting. Whereas simultaneous interpreters need to hold two languages active at the same time, other bilinguals need to select only one language. Therefore, we will analyze the performance of interpreters and non-interpreters in tasks that require coordination between updating processes in working memory (Experiment 5) and different attentional networks (Experiment

6). Differences between the distinct types of bilingualism may guide us to understand different language control strategies. Furthermore, they will indicate whether different bilingual contexts may affect different control mechanisms. If this is the case, our results will serve to emphasize the relevance of considering the specific cognitive control requirements of each bilingual situation when investigating the language control related mechanisms and their transfer to domain-general executive processes.

Taken together, our experiments aim to understand the structure and dynamics of the neural networks responsible for cognitive control. One main objective is to better identify the modulatory role of experience on the executive function, whilst the other is to consider how our results may contribute to an understanding of the nature of the processes involved in language selection and control.

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Chapter III. EXPERIMENTAL SECTION

Experimental Series I. DUAL MECHANISMS OF INHIBITORY CONTROL IN BILINGUALS AND MONOLINGUALS (Experiments 1 & 2)

Experiment 1. Dual Mechanisms of Inhibitory Control in Bilinguals and Monolinguals[*]

Growing evidence shows that executive functioning benefits from bilingual experience. However, the nature of the mechanisms underlying this advantage remains to be clarified. Whereas some have put forward single process accounts to explain the superior performance of bilinguals relative to monolinguals in executive control tasks, recent findings have been interpreted by considering the dynamic combination of monitoring and inhibitory processes to overcome interference from distractor information. In the present study we explored this idea by comparing monolinguals and highly proficient bilinguals in the AX-CPT. This task requires individuals to adjust proactive (monitoring) and reactive (inhibition) control to achieve efficient performance. We also examined the extent to which a well-known index of inhibitory capacity, the stop-signal reaction time, predicts accuracy in the AX-CPT. Results showed that bilinguals outperformed monolinguals in the experimental condition where higher requirement of proactive-reactive control adjustment was required. Interestingly, the inhibition index predicted errors in this condition only in the sample of bilinguals. These findings suggest that a better understanding of the cognitive benefits of bilingualism may require consideration of how bilinguals adjust different executive control mechanisms to cope with interference.

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[*] The studies included in this section correspond to the content of the paper published as Morales, J., Gómez-Ariza, C. J., & Bajo, M. T. (2013). Dual mechanisms of cognitive control in bilinguals and monolinguals. *Journal of Cognitive Psychology*, *25*, 531-546.

The role that cognitive control plays when selecting and switching between languages has been the object of increasing research within the last past decades since the work by Peal and Lambert (1962). In this seminal study, they showed that bilingual children outperformed their monolingual peers in nonverbal intelligence. Their results suggested that there are nonlinguistic advantages associated with using 2 or more different languages. Since then, many studies have repeatedly shown bilingual advantages in tasks involving cognitive control in children (Adi-Japha, Berberich-Artzi, & Libnawi, 2010; Bialystok, 1999, 2010; Bialystok & Martin, 2004; Bialystok & Senman, 2004; Carlson & Meltzoff, 2008), young adults (Bialystok, Craik, & Ryan, 2006; Colzato et al., 2008; Costa, Hernández, & Sebastián-Gallés, 2008; Prior & MacWhinney, 2010), and older adults (Bialystok, Craik, Klein, & Viswanathan, 2004). This advantage has been found in a wide variety of experimental procedures involving conflict resolution such as the Stroop task (Bialystok, Craik & Luk, 2008; Blumenfeld & Marian, this issue 2013), the Simon task (Bialystok, 2006; Bialystok et al., 2008), the flanker task (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa et al., 2009; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011), task-switching (Prior & Gollan, 2011; Prior & MacWhinney, 2010; Soveri, Rodriguez-Fornells, & Laine, 2011), or the antisaccades task (Bialystok, Craik, & Ryan, 2006). Besides, the bilinguals superiority has been also extended to working memory (Bialystok et al., 2004) and tasks measuring creativity (Hommel, Colzato, Fischer, & Christoffels, 2011; Kharkhurin, 2010; Ricciardelli, 1992), problem solving and cognitive flexibility (p. ej., dimensional card-sorting task, Bialystok, Craik, & Ruocco, 2006; Bialystok & Martin, 2004; Marzecová et al., 2013).

This superior performance of the bilinguals in cognitive control tasks has been attributed to their constant need to control and negotiate their 2 languages. Many studies have shown that bilinguals activate their 2 languages even in situations where they are required to use only 1 (Blumenfeld & Marian, 2007; Colomé, 2001; Dijkstra, 2005; Hoshino & Thierry, 2011; Ju & Luce, 2004; Kroll & Stewart, 1994; Macizo, Bajo, & Martín, 2010; Spivey & Marian, 1999). The consequence of this is that the bilinguals need to constantly use language selection mechanisms to maintain activation of 1 language and avoid interference from the other. The idea, then, is that the executive control mechanisms in charge of resolving competition in linguistic settings are similar to the control mechanism acting in the domains of perception, attention, or action (Abutalebi & Green, 2007; Bialystok, 2001; Kan & Thompson-Schill, 2004). Thus, the constant need for language control increases the ability of the bilinguals to ignore irrelevant information and develop efficient executive control across all domains of perceptual and cognitive processing.

One of the language selection mechanisms proposed by some bilingual models is that of inhibition (e.g., Abutalebi & Green, 2007; Dijkstra & Van Heuven, 2002; Green, 1998; Van Heuven, Scheriefers, Dijkstra, & Hagoort, 2008). According to these inhibitory models, language selection in bilinguals is achieved by means of the activation of the target language and the suppression of the irrelevant-competing nontarget language representations. At the lexical level, each lemma has an associated language tag (e.g., L1 or L2) specifying the language of each unit. Although initially lemmas from the 2 languages would be active, the language tags would exert inhibitory control over lemmas belonging to the non-intended language. Inhibition can be targeted globally to the language when the context clearly signals the language to be spoken or comprehended or it can be applied to specific lexical/ semantic representations when they get activated in mixed contexts (De Groot & Christoffels, 2006; Guo, Liu, Misra, & Kroll, 2011). According to the inhibitory control model (IC model; Green, 1998), inhibition is reactive in the sense that it is triggered when the alternative language is activated and it is proportional to the degree of between-language competition. Hence, the stronger the level of activation of the non-intended language, the stronger the inhibition applied. From this perspective, the bilingual advantage is related to the use of reactive inhibitory processes for conflict resolution (see Braver, Gray, & Burgess, 2007, and Braver, 2012, for a theoretical framework that distinguishes between proactive and reactive modes of cognitive control) so that their attentional system reacts in a more efficient manner to the presence of competition. This proposal offers a clear interpretation to the smaller interference effects found in Stroop (Bialystok et al., 2008; Blumenfeld & Marian, 2010; Tse & Altarriba, 2012; Zied et al., 2004), flanker (Costa et al., 2008, 2009), or Simon tasks (Bialystok, 2006; Bialystok et al., 2004), and to the lower switching cost for bilinguals in verbal and nonverbal switching procedures (Garbin et al., 2010; Prior & Gollan, 2011; Prior & MacWhinney, 2009).

However, there are some recent suggestions that the ability to react to competition and suppress irrelevant competing information might not be the underlying cause of the bilinguals' advantage. Instead, it has been suggested that mechanisms related to monitoring and goal maintenance might underpin the bilinguals' superior performance in attentional tasks (Colzato et al., 2008; Costa et al., 2009). The idea is that proactive control processes (Braver, 2012) help bilinguals to reduce interference before it occurs. Proactive control means that goal representations are triggered in preparation for the task and maintained during periods in which they are required. For example, in the bilingual case, one could argue that selection of the proper language for communication requires monitoring of the context in which communication is going to occur (Who I am speaking to?, What language does the receiver speak?, Am I at home or at work?, etc.).

From this perspective, bilinguals are continuously monitoring intra- and extra-language cues to select the appropriate language for comprehension and production (Costa, La Heij, & Navarrete, 2006; Costa, Santesteban, & Ivanova, 2006; Finkbeiner, Almeida, Janssen, & Caramazza, 2006; Finkbeiner, Gollan, & Caramazza, 2006; Kuipers & La Heij, 2008; Philipp, Gade, & Koch, 2007) with the goal to maintain the appropriate language active while seeking for new cues that may induce a language switch. Hence, the bilingual advantage in executive control tasks may come from this proactive attentional control of their languages that may extend to nonlinguistic domains.

Support for this later proposal comes from several lines of research. First, a number of studies suggest that bilinguals show not only smaller interference effects (lower cost for incongruent trials in flanker, Simon, or Stroop tasks) but also overall faster reaction times in both congruent and incongruent trials (e.g., Bialystok, 2006; Costa et al., 2008; Martin-Rhee & Bialystok, 2008). These faster overall reaction times appear only in high monitoring conditions. For example, Costa et al. (2009) had bilinguals and monolinguals perform flanker tasks under low (Experiment 1) or high (Experiment 2) monitoring conditions. They manipulated monitoring demands by varying the proportion of congruent and incongruent trials. The rationale behind this was that similar proportions of congruent or incongruent trials would require constant switching from conflict to non-conflict situations, thus forcing participants to continuously monitor the requirement of each trial to select the appropriate response. In contrast, when the proportion of congruent and incongruent trials is unbalanced monitoring processes would be much less involved since there would be little variation in responses throughout the trials. Results indicated that the effect of bilingualism on overall reaction times was only present when the task involved similar proportion of congruent and incongruent trials (high monitoring conditions), suggesting that monitoring processes may be involved in language selection. Although it could be argued that similar proportion of congruent and incongruent trials reduces cue validity and that the bilingual overall advantage may be due to their better ability to suppress attention to the cues (reducing, thus, the conflict), it is hard for this argument to accommodate the fact that congruent trials produced similar facilitation in the 2 proportion conditions. The overall pattern, therefore, suggests that the cues were equally attended in the 2 proportion conditions and that monitoring demands rather than cue suppression may explain differential effects.

Second, neurophysiological measures have also provided evidence for higher efficiency of monitoring processes in bilinguals, with studies that have examined the brain activation of bilinguals while performing nonverbal tasks that involve executive control. Research in this field has found qualitative differences in brain activation during executive tasks that require coping with conflict. The anterior cingulate cortex (ACC) is a core structure in the neural network involved in monitoring conflicting information (Botvinick, Cohen, & Carter, 2004; Carter, Botvinick, & Cohen, 1999). Lower activation of the ACC has being reported for bilinguals relative to monolinguals in nonverbal tasks that involve conflict resolution such as the flanker tasks (Abutalebi et al., 2011). Similarly, Garbin et al. (2010) reported that monolinguals and bilinguals recruited different brain areas when performing a nonverbal task-switching paradigm. Bilinguals employed brain areas normally engaged during language control (left inferior gyrus), and activated ACC in a lower magnitude than monolinguals, whose brain activation recruited mainly the ACC. These results suggest that the bilinguals' experience modulates the neural networks involved in conflict monitoring. Bilinguals seem to more efficiently use the ACC getting equal or better results than their monolingual counterparts with lower levels of activation of the ACC. Interestingly, this low activity of ACC in the presence of conflict have also been found in bilinguals performing verbal tasks that entail cognitive control in language switching (see Luk, Green, Abutalebi, & Grady, 2012, for a meta-analysis).

Third, some studies have compared bilingual and monolingual performance in tasks that require different components of executive control. For example, Colzato and colleagues (2008) tested the inhibitory hypothesis using a set of attentional tasks involving different features of inhibition. In 3 different studies, they tested the role of inhibition in a group of young bilinguals and a group of comparable monolinguals. Their results showed no between-group differences in stop-signal reaction time, but larger inhibition of return (IOR), and attentional blink (AB) for bilinguals relative to monolinguals. They argued that the bilingual advantage mainly lies in their higher goal maintenance capacity since they did not differ from the monolinguals in response suppression capacity as indexed by the stop-signal task, and both the larger IOR and AB effects can be interpreted as a higher capacity for goal maintenance.

In summary then, the smaller congruent-incongruent differences of the bilinguals relative to the monolinguals in conflict tasks suggest that the bilingual advantage is related to their ability to ignore or suppress irrelevant information (reactive control through inhibition). Alternatively, the greater ability of the bilinguals to adjust to mixed contexts of congruent-incongruent trials in conflict tasks together with their differential performance in tasks such as attentional blink, Stroop, task switching, ANT, or visual search (Hernández, Costa, & Humphreys, 2012) that require goal maintenance suggests that monitoring and goal maintenance (proactive control) may be the underlying cause of the bilingual advantage.

Reactive and proactive controls have sometimes been discussed as alternative explanations of the bilingual advantage and of language control. For example, in a recent study, Prior (2012) contrasted monitoring and inhibition in bilinguals as alternative processes underlying the bilingual advantage. In her study, participants performed a 2-lag nonverbal switching task. Inhibition was assessed by comparing performance in the last trial of an ABA sequence of trials with the last trial of a CBA sequence. In addition, monitoring was assessed by measuring the fade-out effects produced by introducing an unexpected single task block right after the mixed blocks. Performance in the last (fade-out block) was used to indicate how fast monolingual and bilingual participants adjusted their RT to the decrease in monitoring demands in this single block. Efficient monitoring would manifest in faster adjustment of RTs to the level of single task performance. Results exhibited larger lag-2 repetition costs for bilinguals than for monolinguals suggesting stronger inhibition to the A task by the bilingual participants relative to the monolinguals. In contrast, bilinguals and monolinguals did not differ in how fast they adjusted their performance in the fade-out block, suggesting that the bilinguals were not superior to the monolinguals adjusting their monitoring system.

Importantly, recent proposals (Bialystok, Craik, & Luk, 2012; Costa et al., 2009) suggest that the bilingual advantage may not be explained by a single process but by the dynamic combination of these 2 types of executive control mechanisms (proactive/monitoring and reactive/inhibition). These proposals are consistent with theoretical frameworks within the attention and executive control fields that suggest that proactive and reactive cognitive control are relatively independent and complementary so that successful cognition may depend upon some mixture of the 2 processes (Braver, 2012; Burgess & Braver, 2010). According to these proposals, proactive control has the advantage that behavior can be adapted to the context in advance to achieve the goal, but it has the disadvantage that it is very demanding of working memory resources to keep the goal continuously active while performing the task. In contrast, reactive control has the advantage that working memory is kept free to perform other task components, with the disadvantages that the goal has to be reactivated when necessary and that conflict detection mechanisms are required to signal when inhibitory control is needed. Within this framework, individual differences in cognitive control may be better understood by examining differences in the dynamics relating proactive and reactive control modes rather than by making simpler hypotheses about each of these modes of control. The joint role of proactive and reactive processes in language control was also recognized in the IC model (Green, 1998) where task schemas are assumed to be activated proactively to direct processing. The purpose of the study reported here is to study differences between monolinguals and highly proficient bilinguals in proactive and reactive control by using an AX version of the Continuous Performance Test (CPT; Rosvold et al., 1956).

The AX-CPT has been extensively used to explore changes in proactive and reactive control in different populations (e.g., Lee & Park, 2006; Locke & Braver, 2008; Ophir, Nass, & Wagner, 2009; Paxton, Barck, Racine, & Braver, 2008). In the particular version of the task that we used in our study (Ophir et al., 2009), participants were presented with cue-probe pairs and were instructed to respond "yes" to a target X-probe when preceded by an A-cue and to respond "no" to any other cue-target combinations. Target trials (AX) occurred through the experiment with very high frequency (70%). In 10% of the trials, a noncue letter preceded the target (e.g., BX); in another 10% of the trials, the cue was followed by a distractor (e.g., AY); and in the remaining 10% of the trials the noncue letter preceded a distractor (e.g., BY). Demands for goal maintenance were introduced by presenting 3 distractor letters between every cue and the probe (see Figure 11 for a graphical description of the task). The distractors could be any letter except "A", "X", or "Y", and were printed in white; the cues and the probes were printed in red. Participants were instructed to respond with a "no" button press to the distractors.

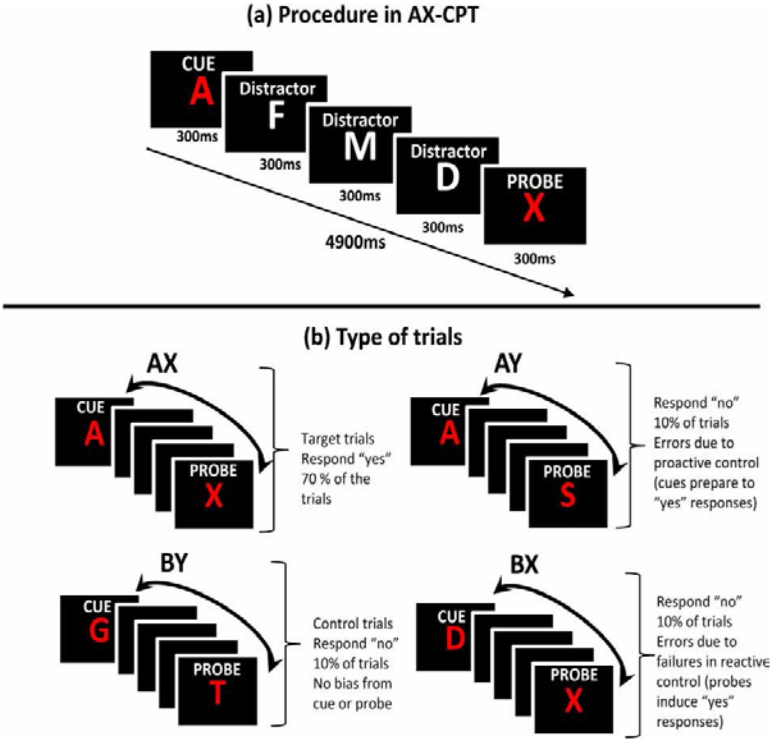

Figure 11. *Procedure for the AX-CPT. (a) The series of events in a typical target trial. (b) The 4 different types of trial, the correct response for each of them, and the proportion of a given trial during the task. AX are target trials ("yes" response, 70% of the trials). BY are control trials in which both cue and probe differ from the target trials ("no" response, 10% of the trials). AY trials (10%) share the cue with target trials and erroneously bias participants to expect the target probe. Errors in these trials signal high reliance on proactive control and failure to reactively suppress the incorrect "yes" response. Finally, BX trials (10%) share the probe with the target trials, but the cues signals "no" responses. Errors in these trials reflect failures in reactive control, that is, failures to suppress a "yes" response to the X-probe.*

Proactive (monitoring/goal maintenance) and reactive control (response suppression) can be assessed by comparing different types of trial (see Figure 11). For example, BX trials trigger dominant but inappropriate response (“yes” to the “X”) that would need reactive inhibitory control to withdraw the “yes” response. Failures in inhibitory control would produce higher number of errors in this condition than in the baseline BY control condition where the probe does not trigger the “yes” response. Similarly, high reliance in cue monitoring and maintenance processes would produce high target expectancies when the A-cue is presented (A-cues signal X probes for 70% of the trials) so that AY trials may induce more errors than the control BY condition where the cue does not signal the highly probable X-target. That is, proactive control might be beneficial for BX probes but it might be detrimental to performance on AY trials. Thus, the relative reliance in proactive and reactive control can be assessed by the relative proportion of errors in AY and BX conditions relative to the BY control condition. Monitoring and maintenance of contextual cues would facilitate responding “no” to an X-probe when preceded by the non-A-cue (“BX” trials), whereas it would impair correct responding to AY trials, since presentation of the A-cue would bias “yes” responding to non-X-probe (“AY” trials). Hence, monitoring and contextual processing would be indexed by larger rates of AY errors relative to BX and BY with little differences between the last 2 conditions. In contrast, reliance on reactive inhibitory processes would be signaled by similar error rates and response times to AY and BY trials with performance in the BX trials depending upon the success of the inhibitory process. Therefore, different proportion of errors and different response times to these conditions may reflect variation in proactive and reactive inhibition. Optimum performance in the task would require both monitoring and inhibition to keep the number of errors to a minimum. Thus, our proposal is that because bilinguals need both to monitor for intra- and extra-language cues and to suppress the irrelevant language when not needed in their normal lives, they would show an advantage at negotiating the relative use of proactive and reactive control to achieve better performance so that they will adjust monitoring and inhibition to achieve the smaller number of errors in the task.

To explore the relative involvement of proactive control and reactive inhibitory control in performing the AX-CPT, we also asked participants to perform a stop-signal task. The stop-signal task (Logan & Cowan, 1984) has been widely used to study response inhibition (e.g., Eagle, Baunez, Hutcheson, Lehmann, & Robbins, 2008; Kindlon, Mezzacappa, & Earls, 1995; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Logan, Shachar, & Tannock, 1997; Ridderinkhof, Band, & Logan, 1999; Yamaguchi, Logan, & Bissett, 2012). In this task, participants are instructed to respond to stimuli, but whenever they are presented with a stop signal they must suppress their response to the current trial. The stop-signal reaction time (SSRT) is computed as a measure of inhibitory efficiency (Verbruggen & Logan, 2008). Although previous studies with this task have not shown differences between monolinguals and bilingual participants (Colzato et al., 2008), our intention in using this task was to correlate it with performance in the AX-CPT to assess the relative involvement of inhibitory control in responding to AY and BX trials. In summary, in the present study highly proficient bilinguals and monolingual participants matched in intelligence and age performed the AX-CPT to explore whether bilinguals outperform the monolinguals in a situation that requires adjusting proactive and reactive control for efficient performance. To assess the relative involvement of inhibitory processes, AY and AX errors will be correlated with the scores in the stop-signal task (reactive inhibition).

METHOD

Participants

Forty-four young adults participated in the study. Our sample included 23 Spanish monolinguals (15 females) with a mean age of 21.4 years (*SD* =2.7) and 21 bilingual participants (15 females), mean age 22.4 years (*SD* =5.8), *t*(30.23) < 1. Both groups were matched in IQ as measured by the Raven's Standard Progressive Matrix task (SPM; Raven, Court, & Raven, 1988). They all completed the 60 matrixes comprising the test so that the maximum score was 60. The mean score for bilinguals was *M* =47.2 (*SD* =4.8) and for monolinguals was *M* =49.8 (*SD* =6.3), *t*(41) =- 1.67, *p* =.10. Bilinguals and monolinguals filled out a language history questionnaire in which they completed their self-perception of proficiency in 2 languages (see Macizo & Bajo, 2006). We used the language history questionnaire to measure language proficiency, since recent reports have shown high correlations between self-reported proficiency and objective measures of proficiency (Marian, Blumenfeld, & Kaushanskaya, 2007; see also Colzato et al., 2008, and Costa, Kovacic, Franck, & Caramazza, 2003, for studies that also used self-reported measures of language proficiency). We selected bilinguals who had acquired their second language before 6 years of age and were exposed to their 2 languages daily. Nineteen of them were simultaneous bilinguals and the other 2 bilinguals acquired their L2 somewhat later (but before age 6), but they felt more proficient in L2 (their language of formal education). All the bilinguals spoke Spanish (14 selected Spanish as their L1) and a different language, namely Arabic (1), Catalan (1), English (7), French (2), German (7), Italian (2), and Russian (1). Monolingual and bilingual participants were university students at the moment of participation or had finished their university studies a couple of years before participation. Monolinguals had basic knowledge of a second language (English -20-, or French -3-) as it was acquired in school. In the questionnaire, participants were asked to rate their L1 and L2 proficiency in 4 language skills (speaking, speech comprehension, writing, and reading) in a 10-point scale (maximum score =10). Analyses of language proficiency questionnaire revealed that both groups were equivalent in their L1, but they differed in L2 (see Table 1 for participants' characteristics). Bilinguals were highly proficient in all L2 skills (all scores ≥9), whereas monolinguals had poor self-rating scores in L2 and differed significantly from bilinguals in all the measures (all *t*s[42] <.001). Participants were recruited by advertising the experiment in different schools and faculties at the University of Granada.

Table 1. *Mean (and standard deviation) background measures and self-rated language proficiency by language group*

			Monolinguals	Bilinguals
N			23	21
Age			21 (0.8)	22 (0.8)
SPM			47 (5.0)	49 (6.5)
Language proficiency	L1	Speaking	9.1 (1.0)	9.6 (0.7)
		Speech comprehension	9.4 (1.0)	9.6 (0.7)
		Writing	9.0 (1.2)	9.4 (1.0)
		Reading	9.2 (0.8)	9.7 (0.7)
	L2	Speaking	4.8 (2.0)	9.1 (1.2)
		Speech comprehension	5.7 (2.1)	9.0 (1.2)
		Writing	4.7 (2.1)	9.3 (1.2)
		Reading	6.2 (2.0)	9.1 (1.5)

Materials and procedure

All participants completed the language history questionnaire and signed consent forms prior to testing. They were tested individually in a quiet room on 2 experimental tasks: the AX-CPT for proactive and reactive executive control, and the stop-signal task for inhibitory control of motor responses. Participants also completed the Raven's SPM to control IQ. The order of tasks was counterbalanced across participants. Each session lasted approximately 60 minutes and participants received 10 euro for their participation. Testing was conducted in Spanish. We describe the 2 experimental tasks next.

AX-CPT. This task is a version of the Continuous Performance Task employed by Ophir et al. (2009). Specifically, we used the condition that included distractors as they showed it to be more sensitive to individual differences in young healthy adults than other versions of the task (see Figure 11a). In this procedure, participants were presented with a sequence of letters for 300 ms each in the centre of a black screen. The letters were displayed on a cue-probe basis so that 4900 ms elapsed between presentation of cue and probe. The intertrial interval was 1000 ms. Participants were instructed to maintain the cue in memory (which could be either the letter “A” or some other letter but not “X”, “K”, or “Y”, due to their perceptual similarity with “X”) until they saw the probe (which could be either the letter “X” or some other letter, but not “A”, “K”, or “Y”). Whenever they saw the cue “A” followed by the probe “X”, they were to respond by pressing the “yes” button. In any other possible cue-probe combination participants were told to press the “no” button, as they were to respond to all probe letters. In the interval between each cue and probe, presented in red, participants saw 3 distractor letters (which could be any letter except “A”, “X”, “K”, or “Y”) presented in white. Distractors were presented each for 300 ms with a 1000 ms interval between letters. Participants were instructed to respond “no” to each distractor.

The task consisted of 1 practice block composed by 10 practice trials including all 4 possible experimental conditions (see Figure 11b): AX (a cue “A” followed by a probe “X”), BX (a probe “X” preceded by a non-A-cue), AY (any probe but “X” preceded by a letter “A”), and BY (any cue but “A” and any probe but “X”). Participants were provided with feedback on accuracy and RT after each practice trial. Completion of the practice block was followed by the experimental block composed of 100 trials. In both practice and experimental phases AX trials occurred for 70% of the trials and each of the remaining experimental conditions appeared for 10% of the trials.

Stop-signal task. We used the STOP-IT software (Verbruggen, Logan, & Stevens, 2008) following their standard parameters. Participants were instructed to respond as quickly as possible to visual stimuli (circles and squares) by pressing a given key on the keyboard. In some trials an auditory stop signal was presented shortly after the visual stimulus onset and the participants were to withdraw their response in these cases.

The task consisted of a practice phase of 32 trials and an experimental phase of 3 blocks of 64 trials. In both phases, each trial started with the presentation of a fixation sign (+) for 250 ms after which the corresponding visual stimulus appeared for 1250 ms. Response keys were “z” (for squares) and “m” (for circles). The interstimulus interval was 2000 ms and was independent of RT. The fixation sign and stimuli were presented in the centre of the screen, in white, on a black background. On 25% of the trials an auditory stop signal (750 Hz, 75 ms) was presented after a variable stop-signal delay (SSD). The SSD was initially set at 250 ms and continuously adjusted depending on performance, according to a tracking procedure to obtain a probability of stopping of .50. Thus, when inhibition was successful SSD increased by 50 ms and when inhibition was unsuccessful, it decreased by 50 ms. Response registration continued during stop-signal presentation.

There was a 10 s delay between blocks wherein participants received information about their performance in the last block (number of incorrect responses on no-signal trials, number of missed responses on no-signal trials, mean RT on no-signal trials, and percentage of correctly suppressed responses).

RESULTS AND DISCUSSION

AX-CPT. The dependent measures on this task were proportion of errors and response times (RTs; see Table 2). Responses under 100 ms and over 1000 ms (2.5% of the trials) were removed from the analyses. In addition, data from 2 monolingual participants were excluded because their rate of invalid trials in the control (BY) condition was over 50%. Both groups exhibited high rates of "yes" responses to AX trials, with low proportion of errors, though bilinguals marginally outperformed monolinguals, $F(1, 40) = 3.54$, MSE =.002, $p = .07$, $\eta^2_p = .081$. No differences between them were evident from RTs, $F(1, 40) = 1.87$, $MSE = 7120$, $p = .18$, $\eta^2_p = .045$ (see Table 2 for descriptive measures).

Table 2. *Mean proportion of errors and RTs (with standard deviations in parentheses) by condition and language group in the AX continuous performance task.*

Condition	Monolinguals		Bilinguals	
	Errors	RT (ms)	Errors	RT (ms)
AX	0.07 (.06)	360 (48)	0.04 (.03)	396 (109)
AY	0.26 (.20)	492 (81)	0.15 (.20)	546 (127)
BX	0.04 (.08)	273 (58)	0.07 (.18)	336 (116)
BY	0.02 (.04)	294 (71)	0.02 (.04)	344 (109)

To test our hypotheses, we performed a mixed model ANOVA on errors rates, with language group (monolingual vs. bilingual) as a between-subject variable and trial type (AY, BX, BY) as a within-participant factor. The analysis revealed that the main effect of type of trial was significant, $F(2, 80) = 22.88$, MSE $= .018$, $p < .0001$, $\eta^2_p = .364$. Pairwise comparisons demonstrated that participants committed significantly more errors in AY trials than in BX ($p < .001$) and BY trials ($p < .001$) (proportion of errors =.21 [*SD* =.21], .05 [*SD* =.14], and .02 [*SD* =.04], respectively), whereas differences between BX and BY trials were not significant ($p = .09$). The main effect of group was not significant (*M* =.11, *SD* =.20, for monolinguals, and *M* =.08, *SD* =.20, for bilinguals), $F(1, 40) = 1.15$, MSE $= .025$, $p = .30$, $\eta^2_p = .028$, but the language group by trial type interaction reached significance, $F(2, 80) = 3.26$, $MSE = .018$, $p = .04$, $\eta^2_p = .075$[*] (see Table 2). Further analyses confirmed that monolinguals and bilinguals showed comparable performance in BX and BY conditions. However, monolinguals produced significantly more "yes" (incorrect) responses to AY trials than the bilinguals, $F(1, 40) = 4.18$, MSE =.04, $p = .047$, $\eta^2_p = .095$. In summary, although both groups tended to commit more errors in AY than in BY trials, this effect was significantly more pronounced in monolinguals than in bilinguals. Since the difference between AY and BY trials is often interpreted as an index of reliance on context monitoring, the larger difference between AY and BY in monolinguals relative to the bilingual participants suggests that, although both were processing and using the context to predict the target and adjust their performance in the task, the monolinguals were relying on the context to a larger extent than the bilinguals.

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[*] We also performed analyses in which we only included the 19 simultaneous bilinguals, and we obtained similar patterns of results. Thus, the ANOVA on accuracy showed that the interaction of Group x Type of trial was significant, $F(2, 76) = 3.29$, MSE =.19, $p = .043$, $\eta^2_p = .08$, with the monolinguals producing significantly more "yes" (incorrect) responses to AY trials than the bilinguals, $F(1, 38) = 3.31$, MSE =.042, $p = .077$, $\eta^2_p = .08$. Similarly, the ANOVA on RT showed significant main effects of group, $F(1, 38) = 3.91$, MSE =23910, $p = .05$, $\eta^2_p = .093$ (monolinguals were faster than the bilinguals), and type of trial, F(2, 76) =248.15, MSE =2391, $p < .001$, $\eta^2_p = .87$, with AY trials producing slower responses that AX or BY trials. Finally, the comparisons between monolinguals and bilinguals on [p(respond/signal)] and SSRT were no significant, $Fs(1, 38) < 1$, and the correlation between SSRT and AY errors in the bilinguals was $r = .49$, $p = .04$.

For RTs we conducted a similar ANOVA with group and trial type as independent variables. Although the interaction did not reach significance ($F < 1$), both main effects did. Thus, the monolinguals (M =353, SD =81) tended to respond faster than the bilinguals (M =409, SD =127), $F(1, 40)$ =4.19, MSE =98147, p =.047, η^2_p=.095. In addition, response times depended upon the type of trial, $F(2, 80)$ =249.87, MSE =603490, $p < .001$, η^2_p=.86. Pairwise comparisons showed that participants were slower responding to AY trials (M =519, SD =109) than to BX (M =304, SD =96, $p < .001$) and BY trials (M =319, SD =95, $p < .001$), with the latter 2 conditions marginally differing from one another (p =.06). The fact that the bilinguals were slower than the monolinguals when responding to “no” trials was surprising since most experiments comparing bilinguals and monolinguals in attentional tasks have reported an overall bilingual advantage in response times (Bialystok, 2006; Bialystok et al., 2004; Costa et al., 2008, 2009; Martin-Rhee & Bialystok, 2008; but see Prior, 2012, for longer RTs in a lag-2 switching task). Hence, we decided to examine RT distributions to AY trials relative to BY ones. We focused in these conditions since the effect of interest was the relative smaller number of errors of bilinguals in the AY condition that would lead them to have a smaller context monitoring effect (AY vs. BY effect). Because our hypothesis was that the bilinguals adjusted their monitoring (proactive) and inhibition (reactive) control processes to achieve better performance in the task, we wanted to assess if their longer reaction times reflected their greater reliance on reactive control relative to monolinguals. Previous studies indicate that benefits in certain processes might result in poorer performance. For example, younger adults usually show larger error rates in AY trials than older adults, reflecting stronger proactive control (Braver et al., 2001). Also, the bilinguals in the Prior (2012) study exhibited longer RTs in a lag-2 repetition trials of task switching paradigm, suggesting stronger inhibitory control. Note that, in the present study, context monitoring would necessarily lead to faster responses than inhibition since it depends on processing of the cue, whereas inhibitory processes cannot be engaged until the target has been presented. Hence, high reliance on proactive control would lead to faster, but less accurate responses to AY, whereas reliance on inhibitory control would lead to slower, but more accurate responses to AY. To explore whether the slower RTs in the bilinguals were caused by their greater reliance on inhibitory control, we performed delta plots analyses.

Delta plots have been used to explore individual differences in the relative engagement of response inhibition (e.g., De Jong, Liang, & Lauber, 1994; Ridderinkhof, Van den Wildenberg, Wijnen, & Burle, 2004). Although we did not have a large number of data points to perform full analyses, we decided to use them to explore the relative contribution of inhibition to AY responses. The rationale behind this is that monolinguals and bilinguals might differ in how they cope with conflict in a situation (AY) wherein appropriate monitoring would prompt one to respond "yes" but the correct response is "no". Correct responding may be achieved by paying less attention to the context cue (less proactive control) or by paying attention to it but inhibiting response when the Y appears (more reactive control). Hence, the lower number of errors of the bilinguals relative to the monolinguals may be achieved by either investing less attention to the cue (low monitoring) or by more efficient inhibition. Delta plots can be used to disentangle inhibitory effects from RTs. Delta plots are constructed by plotting the conflict effect (AY-BY in our case) as a function of response speed. Conflict effects usually show positive slopes since experimental effects tend to increase for longer response times (Luce, 1986; Ridderinkhof et al., 2004; see Roelofs, Piai, & Garrido-Rodriguez, 2011, for delta plots applied to bilingual performance). Inhibition is assumed to decrease interference, but inhibition needs time to act since it is reactive to conflict from the target. As a consequence, the effect of inhibition would also be stronger at longer RTs and its effects should be largest towards the tail of the RT distribution. Hence, although conflict effects are larger at slower RT, if inhibition is applied interference is reduced and the positive slope between conflict and RT would decrease.

To calculate delta plots the RTs for each participant and condition (AY and BY), were ordered and divided into 5 quintiles, and we obtained the mean RT for each quintile and condition. The obtained cumulative distribution curves of RTs for both groups can be seen in Figure 12a and Figure 12b. Next, the RT difference between AY and BY was calculated for each quintile in each language group. As mentioned, the main assumption is that response inhibition takes some time to develop (De Jong et al., 1994; Ridderinkhof et al., 2004). Thus, if conditions differ in the amount of inhibition that is applied, RT differences between interference conditions should not increase linearly as a function of RT but instead level off and become reduced for slow responses. Hence, reduced interference effects should be expected in slow responses in conditions that involve more inhibition. As to our experimental conditions, if monolinguals and bilinguals differ in how they manage to adjust monitoring and response inhibition, one could expect a different pattern of delta plots in both language groups. Specifically, bilinguals should show steeper slope for slow responses relative to monolinguals in AY trials. Visual inspection of Figure 12a and Figure 12b shows that the difference between AY and BY trials at longer RTs is smaller for the bilinguals than for the monolinguals. Figure 12c shows delta plots for both groups. Although the interaction between quintile and group did not reach significance, $F(4, 136) = 1.28$, MSE =21740, $p = .28$, $\eta^{2}_{p}{}^{=}.036$, since we had specific hypotheses we performed 1-tailed t-tests contrasting the first versus the fifth quintile in each group. These analyses revealed that although the difference was not significant in the monolinguals, $t(17) < 1$, $\eta^{2=}.05$, it was significant in the bilinguals, $t(17) = 1.74$ $p = .05$, $\eta^{2=}.15$.

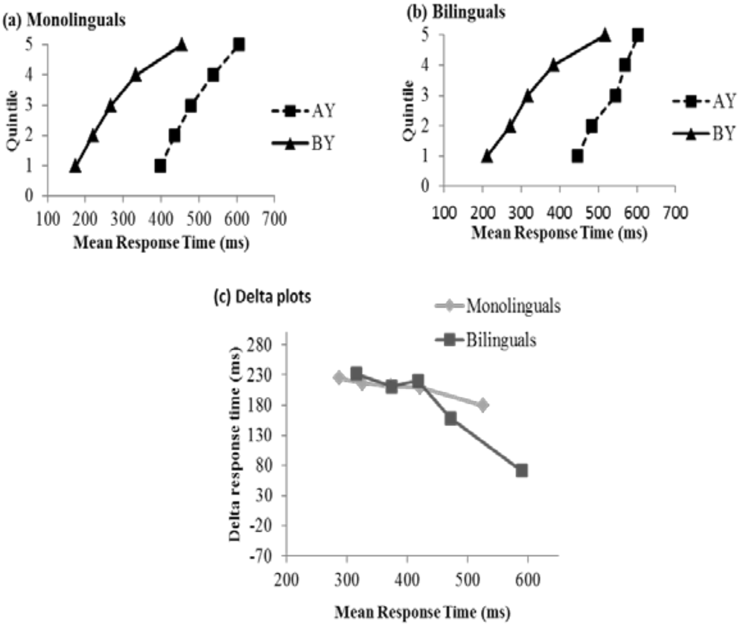

Figure 12. *Cumulative distribution curves for response times in AY and BY trials of AX-CPT for (a) monolinguals and (b) bilinguals. (c) Delta plots showing the condition difference (deltas) as a function of quintile (1-5) by language group.*

Stop signal. The stop-signal task was used as a pure index of response inhibition, and with the main purpose of correlating the performance of the bilingual and monolingual participants with their performance in the AY condition of the AX-CPT. The rationale again was that if correct performance in the AY condition depended on the efficiency of reactive control, stop-signal performance should be able to predict AY errors. We used ANALYZE-IT, the program provided by Verbruggen et al. (2008)

to calculate SSRT (stop-signal reaction time). In this program, SSRT is calculated by subtracting mean SSD (stop-signal delay) from the untrimmed mean RT. The overall probability of responding on stop trials [p(respond/signal)] for all participants was around .50 (see Table 3) except for 3 participants (1 bilingual and 2 monolinguals) who were removed from analysis following the indications by Verbruggen et al. regarding the unsuitability of the subtraction method for participants with stop responses significantly above or below 50%. We performed 1-way ANOVAs on [p(respond/signal)], hits in go-signal trials, go-signal response times (RTs), and SSRT. Comparison between monolinguals and bilinguals in [p(respond/signal)] was not significant, $t(39) < 1$. Importantly, both groups showed a comparable good percentage of hits in go-signal trials, $t(39) < 1$ (see Table 3). To determine the effect of bilingualism on the ability to inhibit prepotent responses, we performed 1-way ANOVAs on go-signal response times (RTs) and stop-signal response times (SSRTs), respectively. As evident from the data in Table 3, responding to go-signal trials took monolinguals and bilinguals about the same amount of time, $F(1, 40) < 1$. More relevant, and replicating the finding by Colzato et al. (2008), the analysis on SSRT did not reveal significant differences between the language groups, $F(1, 40) < 1$.

Table 3. *Mean scores on the stop-signal task (with standard deviations in parentheses) by language group*

	Monolinguals	Bilinguals
P (respond/signal)	.46 (.04)	.46 (.05)
Hits go trials	.94 (.13)	.96 (.07)
RT go trials	659 (187)	651 (170)
SSRT	252 (73)	252 (60)

As mentioned, our aim was to examine the relative contribution of reactive (inhibitory) and proactive (monitoring/contextual processing) control in the AX-CPT. Hence, we correlated SSRT, a well-established measure of inhibitory efficiency, and errors in AX, AY, BX, and BY trials for each language group. Inspection of Table 4 shows that the bilinguals' SSRT scores significantly correlated with AY errors, r =.52, p =.02, but they did not predict this type of errors in monolinguals, r =.27, p =.27 (see Figure 13 for scatterplots of these correlations). The significant correlation shows that bilinguals with shorter SSRTs also have fewer errors, indicating that their better performance (fewer errors in the AY condition) was related to their ability to stop prepotent responses.

Table 4. *Correlations between proportion of errors in the different conditions of the AX-CPT and stop-signal reaction time (SSRT) for each language group.*

	Monolinguals					Bilinguals				
	AX	AY	BX	BY	SSRT	AX	AY	BX	BY	SSRT
AX	-					-				
AY	.41*	-				.69**	-			
BX	-.01	.35	-			-.04	.02	-		
BY	.06	.40	.11	-		.00	.03	.44*	-	
SSRT	.19	.27	-.04	.05	-	.29	.52*	.14	.42	-

** $p < .01$

* $p < .05$

Interestingly, bilinguals also showed that errors in BY correlated with errors in BX and errors in AY correlated with errors in AX (see Table 4), indicating that they also used proactive control so that conditions with similar contexts correlated with each other. Monolinguals also showed significant correlation between AY and AX conditions, although the correlation between, BY and BX did not reach significance. Overall, the pattern of correlations seems to suggest that both monolinguals and bilinguals used the context to adjust their responses (correlation between AX and AY and BX and BY). However, the correlation between SSRT scores and errors in the AY condition also suggests that the bilinguals relied more on inhibition to produce fewer errors in this condition. RTs did not correlate significantly with SSRT in any condition.

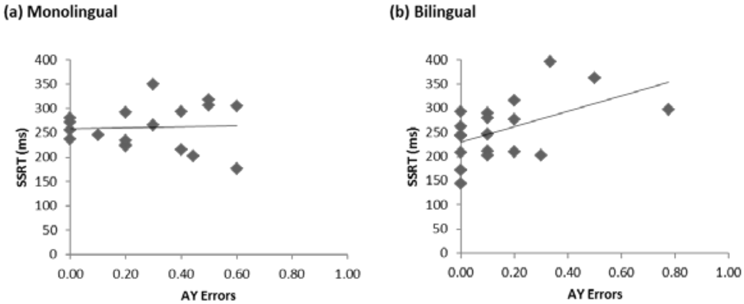

Figure 13. *Scatterplots for the correlation between SSRT and accuracy in the (a) monolingual and (b) bilingual group*

GENERAL DISCUSSION

The main goal of the present study was to examine the dynamics of proactive and reactive control in highly proficient bilinguals. This issue is important because the debate on the mechanisms underlying the bilingual advantage in executive control tasks has traditionally focused on single-process accounts. Thus, much of the data have been interpreted as supporting either that the bilingual advantage is related to inhibitory control (Abutalebi & Green, 2007; Prior, 2012; Van Heuven et al., 2008) or that it is due to more efficient monitoring/goal maintenance processes (Colzato et al., 2008; Costa et al., 2009).

Recently, however, it has been suggested that the superior performance of bilinguals in executive control tasks may be better explained by considering the dynamic combination of the 2 types of executive control mechanisms (proactive/ monitoring and reactive/inhibition) (Bialystok et al., 2012; Costa et al., 2009). Thus, to accomplish our goal we examined the relative engagement of each of these mechanisms by using a highly demanding version of the AX-CPT thought to require different participation of the 2 processes in different conditions (Ophir et al., 2009). We expected bilinguals to be more efficient than their monolingual counterparts in regulating/adjusting proactive and reactive control due to their need to negotiate the activation of their 2 languages by monitoring internal and external cues and by reacting to the interference produced by the unintended language when needed (Costa, La Heij, & Navarrete, 2006; Costa, Santesteban, & Ivanova, 2006; Finkbeiner, Almeida, et al., 2006; Finkbeiner, Gollan, & Caramazza, 2006; Kuipers & La Heij, 2008; Philipp et al., 2007). Different findings from the present study support this hypothesis.

First, both language groups showed comparable performance in AX trials, a condition where the context cue correctly predicts the target and proficient monitoring would prompt a correct response. Similarly, both groups showed comparable performance in responding to BX trials, where proper monitoring would also facilitate responding “no” to an X probe as preceded by a non-A-cue. The fact that both groups showed more errors in the AY condition relative to the BY condition and that BX errors were relatively small and similar to the BY condition suggests that the monolinguals and the bilinguals were using monitoring processes to help their performance. However, bilinguals significantly outperformed monolinguals in the AY condition where higher requirement of proactive-reactive control adjustment was required for correct performance. Since high reliance on context monitoring would produce great target expectancies after an A-cue presentation, only an efficient adjustment of proactive and reactive control would lead to the suppression of the incorrect “yes” responses to Y targets in comparison with the BY control condition (where the cue does not signal the highly probable X target). This pattern, together with the similar stop-signal performance for the bilinguals and monolingual groups, suggests that it may be the dynamic combination of proactive and reactive control that makes bilinguals less prone to errors. The idea is that, although bilinguals monitored and paid attention to the context cue, they were also able to use inhibitory control when the context provided incongruent information. Support for the superior capacity of bilinguals to adjust inhibitory control with monitoring comes from the examination of RT distributions of the AY-BY effect. Since it is assumed that inhibition takes time to react, a reduced amount of interference for slow responses relative to fast responses may be interpreted as an index of inhibition. Delta plot analyses indicated that both language groups performed differently with the bilinguals showing a reduced effect of cue-target incompatibility (AY-BY) for slow responses relative to the monolinguals. This allows us to suggest that bilinguals engaged more than monolinguals in reactive control to overcome cue-target incongruities. However, more efficient inhibitory control by itself cannot explain the superior performance of the bilinguals in the AY condition since they showed similar SSRT responses (an index of inhibition) as the monolinguals. Hence, taking together the pattern shown in the AX-CPT and the stop-signal tasks suggests that it is the dynamic combination of proactive and reactive control that makes bilinguals reduce the number of errors in the highly demanding AY condition. Interestingly, this interpretation could account for the unexpected slower responses of bilinguals. Better regulation of context processing and suppression of inappropriate responses, as measured by accuracy, may come at the expense of longer response times.

A finding of special relevance to support our interpretation of the differences between monolinguals and bilingual in the AX-CPT has to do with the correlations observed between the proportion of errors to AY trials and the stop-signal reaction time, an index of inhibitory efficiency. Although no differences in SSRT were found between both groups (which replicate previous results), this index was able to explain the 27% of variance of AY errors in the bilingual group (whereas it did not predict performance in any other condition for any of the 2 groups). Overall, these findings suggest that a key difference between monolinguals and bilinguals relies on their ability to inhibit dominant responses in tasks where monitoring is also required, but it may produce benefits in some conditions and impairments in others. This overall pattern may be interpreted within the general attentional framework proposed by Braver (2012; Braver et al., 2007). According to this framework, 2 different control mechanisms must be distinguished: On the one hand, proactive control involves sustained and anticipatory maintenance of goal-relevant information; on the other hand, reactive control reflects stimulus-driven activation, based on interference demands. By using the AX-CPT paradigm, Braver and others have examined individual differences in the use of proactive and reactive control in a variety of groups such as older adults, children, and patients with schizophrenia (Barch et al., 2001; Braver et al., 2001; Chatham, Frank, & Munakata, 2009). Our findings indicate that the AX-CPT paradigm may also be useful to study executive control capacities in individuals with different bilingual experience.

Altogether, our results fit well with theories that highlight the key role of inhibitory control in language selection (Abutalebi & Green, 2007; Dijkstra & Van Heuven, 2002; Green, 1998; Van Heuven et al., 2008). A number of studies have shown that bilingual experience provides people with enhanced inhibitory abilities, although these benefits seem to be limited to children and older adults (e.g., Bialystok, Martin, & Viswanathan, 2005). Indeed, this type of single-process account has difficulty explaining the differential performance of bilingual and monolingual young adults in executive control tasks in terms of inhibitory control (see Hilchey & Klein, 2011, for a review, and our own results considering the stop-signal task). Maybe the reliance on inhibitory capacities becomes more evident in the developmental periods that have shown to be more sensitive to changes in executive control (Bialystok et al., 2012). Our findings, however, join others to suggest that a better understanding of the benefits of being bilingual may be derived from considering how bilinguals adjust different executive control mechanisms (Bialystok et al., 2012; Costa et al., 2009).

This idea also agrees with neurophysiological data demonstrating that bilinguals and monolinguals engage differential neural networks in tasks involving conflict monitoring (i.e., ACC), and that these differences appear to be modulated by the linguistic control derived from bilingual experience (Abutalebi et al., 2011; Luk et al., 2011). The involvement of distinct brain areas in bilinguals relative to monolinguals when performing similar tasks might reflect differential implication of executive processes, which efficiently interact to produce the bilingual advantage. More specifically, in the light of our results, the differential pattern of brain activity for bilinguals and monolinguals might reflect differences in how proactive and reactive control (or any other executive) mechanisms are adjusted to achieve better performance. Future studies should examine this issue.

In conclusion, our data provide evidence for a multicomponent perspective in the explanation of the bilinguals' advantage in cognitive control. The use of both the AX-CPT and the stop-signal task with the same set of bilingual and monolinguals allowed us to disentangle the relative contribution of reactive and proactive control in the bilingual participants. From the dual mechanism view considered here, proactive and reactive control would interact and adjust to one another according to the task demands in order to successfully monitor and overcome the conflict.

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Experiment 2. Bilingualism modulates dual mechanisms of cognitive control: Evidence from ERPs*

Recent behavioral findings with the AX-CPT (Morales, Gómez-Ariza & Bajo, 2013) show that bilinguals only outperform monolinguals under conditions that require the highest adjustment between monitoring (proactive) and inhibitory (reactive) control, which supports the idea that bilingualism modulates the coordination of different control mechanisms. In an ERP experiment we aimed to further investigate the role that bilingualism plays in the dynamic combination of proactive and reactive control in the AX-CPT. Our results strongly indicate that bilingualism facilitates an effective adjustment between both components of cognitive control. First, we replicated previous behavioral results. Second, ERP components indicated that bilingualism influences the conflict monitoring, response inhibition and error monitoring components of control (as indexed by the N2 and P3a elicited by the probe and the error-related negativity following incorrect responses respectively). Thus, bilinguals exerted higher reactive control than monolinguals but only when they needed to overcome the competing cue-information. These findings join others in suggesting that a better understanding of the cognitive benefits of bilingualism may require consideration of a multi-component perspective.

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Extensive training in one specific domain can transfer to other domains that share related cognitive functions (e.g., Bialystok & Depape, 2009; Schellenberg & Moreno, 2004) and can even modulate their supporting neural networks (for a review, Habib & Besson, 2009). A vast number of studies have demonstrated that bilingualism influences cognitive control, as bilingual speakers surpass monolinguals in a variety of non-verbal tasks that involve conflict resolution (Bialystok et al., 2005; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa, Hernández, & Sebastián-Gallés, 2008), inhibitory control (Colzato et al., 2008; Lee Salvatierra & Rosselli, 2010), or task switching (Prior & Gollan, 2011; Prior & Macwhinney, 2009), and they also engage differently the same neural circuits to solve these tasks (Abutalebi et al., 2012; Luk, Green, Abutalebi, & Grady, 2012). However, the question of how bilingualism modulates the cognitive mechanisms underlying this advantage is still one of intense debate (for a review, Kroll & Bialystok, 2013). By using both behavioral and electrophysiological (event-related potentials – henceforth ERPs) measures, the present study aims to better understand how bilingual experience influences the dynamics and coordination of different control mechanisms.

The rationale for expecting cognitive advantages in bilinguals comes from the bilinguals' need to coordinate two languages in their minds. Present evidence suggests that bilinguals co-activate their two languages even when only one is in use (for reviews, see Bialystok, Craik, Green, & Gollan, 2009; Kroll, Bobb, & Wodniecka, 2006). Consequently, they need to continuously employ language selection mechanisms to avoid intrusions and to reduce interference from the unwanted language. These language control mechanisms are thought to be similar to the ones engaged in conflict resolution in non-linguistic domains (Abutalebi & Green, 2007; Bialystok, 2001; Kan & Thompson-Schill, 2004). Thus, bilinguals would more efficiently recruit cognitive control resources, relative to monolinguals, becoming more competent in tasks that tap into similar control processes (i.e., ignoring irrelevant information).

According to influential inhibitory models (Abutalebi & Green, 2007; Dijkstra & van Heuven, 1998, 2002; Green, 1998; van Heuven, Schriefers, Dijkstra, & Hagoort, 2008), language selection occurs once lexical candidates are activated in both languages by means of inhibitory mechanisms that reduce the level of activation of the unintended language. Inhibition is proportional to the level of competition, so that the stronger the activation of competitors in the unintended language, the stronger the inhibition. Inhibition can be targeted globally to the language when the context clearly signals the language in use or it can be applied to specific lexical/semantic representations when they get activated in mixed contexts (De Groot & Christoffels, 2006; Guo, Liu, Misra, & Kroll, 2011). From this perspective, language selection is produced by reactive control, a just-in-time manner of resolving interference after detection of competing information. Hence, bilinguals, relative to monolinguals, would excel in tasks that involve conflict resolution produced by competing alternatives, which is compatible with the smaller interference effects found in bilinguals in interference tasks such as the Stroop (Blumenfeld & Marian, 2011; Martin-Rhee &

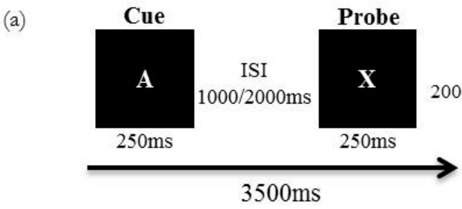
Bialystok, 2008; Tse & Altarriba, 2012; Zied et al., 2004), flanker (Costa et al., 2009, 2008; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011) or Simon tasks (Bialystok et al., 2005; Bialystok, Craik, Klein, & Viswanathan, 2004) and to the lower switching cost for bilinguals in verbal and non-verbal switching procedures (Garbin et al., 2010; Prior & Gollan, 2011; Unsworth & Spillers, 2010).

However, recent proposals suggest that monitoring and goal maintenance might also underlie the superiority of bilinguals in attentional tasks (Colzato et al., 2008; Costa et al., 2009). According to this view, proactive control processes (Braver, Gray, & Burgess, 2007; Braver, 2012) would help bilinguals to cope with interference before it occurs. The selection of the intended language would involve context monitoring for cues to successfully select the proper language for comprehension, production, and maintenance of the intended language until new cues induce a language switch (Costa, La Heij, & Navarrete, 2006; Costa, Santesteban, & Ivanova, 2006; Finkbeiner, Almeida, Janssen, & Caramazza, 2006; Finkbeiner, Gollan, & Caramazza, 2006; Philipp, Gade, & Koch, 2007).

A more integrative view proposes that control might be exerted by a dynamic combination of proactive and reactive executive mechanisms rather than by a single process that would be modulated by demands of the situation (Costa, Santesteban, et al., 2006; De Groot & Christoffels, 2006; Festman & Münte, 2012; Green & Abutalebi, 2013; Kroll & Bialystok, 2013; Morales, Gómez-Ariza, & Bajo, 2013). As recently argued by the adaptive control hypothesis (Green & Abutalebi, 2013), interactive bilingual contexts require that different cognitive control processes act collaboratively to achieve successful communication. Within this framework, individual differences in cognitive control may be better understood by examining the interplay between proactive and reactive control, rather than by proposing simpler hypotheses concerning each of these modes of control.

Accordingly, Morales and colleagues (Morales et al., 2013) recently found differential dynamics between proactive and reactive control in early bilinguals and monolinguals, revealed from a modified version of the Continuous Performance Task (CPT, Rosvold, Mirsky, Sarason, Bransome, Jr., & Beck, 1956), the AX-CPT (see Figure 14a). This task requires participants to respond YES to every *X* probe preceded by an *A* cue, and to respond NO to any probe that breaks that rule (i.e.: BX, AY or BY trials). The AX combination occurs at a very high frequency (70% of the trials), so participants prepare to respond YES after seeing an *A* cue, motivated by proactive control mechanisms. The AX-CPT constitutes an excellent tool to investigate the interactions between proactive and reactive control because, to keep errors at a minimum, it is crucial to adjust both processes according to the task demands by detecting and solving the conflict produced by the unexpected stimulus (Y) that invalidates the previous contextual information (A). Morales and colleagues found that both groups exhibited the normal pattern of higher error rates in AY trials relative to other types of trials, indicating similar proactive control. However, bilinguals committed fewer errors than monolinguals in the critical AY condition, while showing equivalent performance in the other conditions. In addition, although both groups were comparable in terms of reactive inhibition (as measured by the stop-signal task; Logan & Cowan, 1984), the stop-signal reaction time (SSRT) only predicted AY errors in the bilingual group, thus suggesting that the lower number of errors in the AY condition might have been due to differential recruitment of reactive control.

In the current study, we aimed to disentangle the precise processes that allow bilinguals to be more efficient in performing the AX-CPT by analyzing electroencephalographic (EEG) recordings. Due to its high temporal resolution, ERP recordings permit online observation of the cortical responses associated with the task, allowing us to monitor the ongoing neural processes and to evaluate the interplay of proactive and reactive mechanisms.



CUE	PROBE	%	RESPONSE	CONDITION
A	**X**	70%	Yes	Target trials
A	**Y**	10%	No	Errors due to **Proactive Control** (cue prepares to «yes» responses)
B	**X**	10%	No	Errors due to failures in **Reactive Control** (probe induces «yes» responses)
B	**Y**	10%	No	Control trials (no bias from cue or probe)

(b)

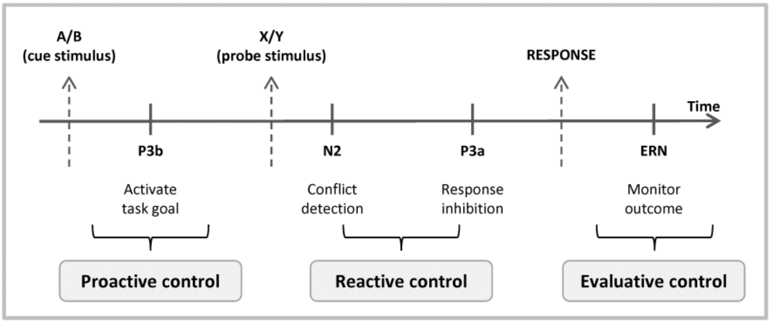


Figure 14. *(a) Schematic representation of the AX-CPT procedure and the four types of trials that conform the task. (b) Schematic overview of the control processes involved in the AX-CPT and their associated ERP components.*

Previous ERP and neuroimaging studies have clearly identified the brain regions and ERP components that reflect the cognitive processes associated with the AX-CPT (e.g., Dias, Foxe, & Javitt, 2003; Hämmerer, Li, Müller, & Lindenberger, 2010; Lenartowicz, Escobedo-Quiroz, & Cohen, 2010; see Figure 14b, for a schematic representation of the associated task components; Smid, de Witte, Homminga, & van den Bosch, 2006). Proactive control is observed by neural responses during the cue-probe interval (cue-P3b). Cue-P3b (reaching its maximum at 300-600 ms after stimulus presentation at electrode site Pz; Polich, 2003) is thought to reflect target categorization, context updating, and memory of task-relevant information (Polich, 2007). Its amplitude increases with the salience of the stimuli and when current information needs to be substituted with relevant novel information. Higher cue-P3b amplitudes for B cues characterize well-functioning proactive control, as they are more salient stimuli due to their low frequency compared to *A*-cues (Gratton et al., 1990; Ruchkin, Canoune, Johnson, & Ritter, 1995; Wright, Geffen, & Geffen, 1993). Therefore, any language group differences in the amplitudes of the cue-processing component should reflect distinct engagement of proactive control, as reflected by context processing and task goal activation (cue-P3b).

The influence of bilingualism in reactive control processes should be reflected at the probe-processing level. N2 and P3a, measured after probe presentation, seem to reflect different sub-processes of reactive control, namely conflict detection and response inhibition, respectively (e.g., Band & van Boxtel, 1999;

Beste, Saft, Andrich, Gold, & Falkenstein, 2008; Beste, Willemssen, Saft, & Falkenstein, 2010; Huster, Westerhausen, Pantev, & Konrad, 2010; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003; Roche, Garavan, Foxe, & O'Mara, 2005; Schmajuk, Liotti, Busse, & Woldorff, 2006). Conflict detection relates to probe-N2, a frontocentral component that peaks 200-350 ms after stimulus presentation (Folstein & van Petten, 2008). It is associated with stimulus categorization processes and conflict monitoring (van Veen & Carter, 2002a, 2002b; Yeung, Botvinick, & Cohen, 2004), it is larger for less frequent or less prepotent responses (Donkers & van Boxtel, 2004; Nieuwenhuis et al., 2003), and it correlates with activity in the anterior cingulate cortex (ACC), a critical structure for conflict detection (Falkenstein, 2006; Mathalon et al., 2003). Probe-N2 is thought to reflect the need to inhibit an incorrect response tendency (Eimer, 1993; Jodo & Kayama, 1992) and response conflict elicited by irrelevant stimulus information (Nieuwenhuis et al., 2003; Yeung & Cohen, 2006). AY trials elicit larger N2 amplitudes relative to AX, BX and BY trials in healthy young adults (Beste, Domschke, Radenz, Falkenstein, & Konrad, 2011; Hämmerer et al., 2010), given that participants are prompted to prepare a YES response after an A-cue and the probability for a Y-probe to appear is only 10%. Interestingly, the N2 component is also related to bilingual language selection, since it arises when bilinguals need to suppress interference from the unwanted language (Moreno, Rodriguez-Fornells, & Laine, 2008; Rodriguez-Fornells, De Diego Balaguer, & Münte, 2006). Bilinguals also show larger N2 amplitudes compared to monolinguals in non-verbal tasks that involve conflict monitoring, such as response inhibition (Go-NoGo task; Fernandez, Tartar, Padron, & Acosta, 2013). In turn, the late anterior component probe-P3a (peaking at 300-600 ms) is thought to reflect response suppression (Bekker, Kenemans, & Verbaten, 2004; Bruin & Wijers, 2002; Jonkman, 2006; Schupp, Lutzenberger, Rau, & Birbaumer, 1994; Smith, Johnstone, & Barry, 2008). It shows a positive activation on AY trials compared to the other AX-CPT conditions due to the necessity to monitor the inhibitory processes required to overcome the prepared YES response elicited by the *A* cue (Beste et al., 2011; Kam, Dominelli, & Carlson, 2012).

Evaluative control can be investigated through the amplitude of the error-related negativity (ERN), a medial-frontal negative deflection that peaks 50-100 ms after an incorrect response. It is thought to reflect error-detection (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993) or a response conflict monitoring mechanism reflecting the degree of conflict between simultaneously activated response tendencies with reduced ERN amplitudes corresponding to lower conflict conditions (Botvinick, Cohen, & Carter, 2004; Yeung et al., 2004). Accordingly, if bilingualism influences the error monitoring system, it should be reflected in reduced ERN of bilinguals relative to monolinguals.

Hence, in the present study we used the AX-CPT and analyzed the ERPs components associated with cue and target presentations to further explore the interplay between proactive and reactive control in bilinguals. We employed a version of the task in which the cue-probe delay intervals were manipulated (Beste et al., 2011) since longer cue-probe delays require higher context maintenance, and individual differences in proactive control might be better observed in this more demanding condition (for reviews see Braver & Barch, 2002; Braver, Cohen, & Barch, 2002).

Individual differences in proactive control would be reflected in P3b amplitudes to *A* and *B* cues, with larger amplitudes associated with the more salient *B* cues. Behaviorally, reliance on proactive control would be reflected in similar responses to B probe-trials (BX and BY trials) with low error rates for the BX condition, despite the fact that X probes may be erroneously associated with Yes responses. On the other hand, efficient reactive control would be associated with larger amplitudes to N2 (stronger conflict detection) and P3a (response inhibition) associated with the probe. Behaviorally, more efficient inhibition would be related to smaller numbers of errors in the AY condition. Attention to the cue (proactive control) would make participants more likely to erroneously respond Yes to AY trials, unless they detect the new relevant information and inhibit the prepotent response (reactive control).

Given that behavioral evidence suggests that more efficient adjustment of control mechanisms leads to the bilingual advantages in the task (Morales et al., 2013), between group differences in the neural correlates associated with these control mechanisms will provide us with valuable information regarding the differential dynamics engaged to solve the task derived from language experience.

METHOD

Participants

Fifty-two young adults participated in this study (see Table 5 for participant's characteristics). The sample included 25 bilinguals (19 females) and 27 monolingual controls (25 females). All bilinguals spoke Spanish and a different language on a daily basis and acquired both languages before 6 years of age. The additional languages they spoke were Arabic (2), Catalan (6); Czech (1); English (6); French (1); Galician (1); German (5); Italian (1); Romanian (1) and Russian (1). Although the majority of the bilinguals acquired their two languages simultaneously, fifteen of them tagged Spanish as their first language in terms of dominance. Participants were recruited by advertising the experiment in different schools and faculties at the University of Granada. Participants received course credits or 15 euro for their participation.

Table 5. *Mean (and standard deviation) background measures, working memory scores, self-rated language proficiency and bilingual switching (BSW) by language group.*

			Monolinguals	Bilinguals
N			27	25
Age			22 (3.4)	26 (4.2)
SPM			51 (5.8)	51 (4.4)
OSpan		Span	4.4 (1.2)	4.3 (1.2)
		% Correct words	63 (28)	65 (30)
		% Correct operations	72 (14)	77 (10)
Language proficiency	L1	Speaking	6.4 (0.7)	6.6 (0.7)
		Speech comprehension	6.8 (0.4)	6.7 (0.6)
		Writing	6.5 (0.5)	6.2 (1.0)
		Reading	6.7 (0.5)	6.4 (0.9)
	L2	Speaking	3.3 (1.1)	6.7 (.06)
		Speech comprehension	3.4 (1.4)	6.7 (0.4)
		Writing	3.7 (1.1)	6.3 (1.1)
		Reading	4.2 (1.1)	6.5 (0.7)
		% Second language exposure (diary)	7 (9.1)	48.5 (29.7)
BSW*		Language switching (6-30 pts)	--	16.7 (2.9)
		Contextual switches (3-15 pts)	--	8.4 (2.5)
		Unintended switches (3-15 pts)	--	5.9 (2.9)

*Bilingual Switching Questionnaire

All participants completed a language history questionnaire to self-rate their language proficiency (Li, Sepanski, & Zhao, 2006; see Table 5). Monolinguals reported basic knowledge of a second language (English) acquired in school. In the questionnaire, participants were asked to rate their L1 and L2 proficiency in four language skills (speaking, speech comprehension, writing and reading) in a 7-points scale (ranging from 1 = very poor to 7 = excellent). Analyses of language history questionnaire (see Table 5 for participants' characteristics) revealed that both groups were equivalent in their L1 skills (all *ps* > .5), but differed in L2 (all *ps* < .001). Bilinguals scored equivalently their L1 and L2 capabilities (*p* > .5), whereas monolinguals had poor self-rating scores in L2 and differed significantly from bilinguals in all the measures (all *p*s < .001). Bilinguals also completed a self-assessment questionnaire to explore language switching from L1 to L2, L2 to L1, contextual switching, and unconscious switching (Rodriguez-Fornells et al. 2011).

T-test comparisons showed that both groups had equivalent fluid intelligence and working memory skills (see Table 5). Bilinguals and monolinguals reached similar scores in SPM, operational span, proportion of recalled words and proportion of equations correctly solved (all *ts*(50) < 1).

Materials and methods

All participants signed consent forms prior to testing. They were tested individually in a quiet room on three tasks: the AX-CPT for proactive and reactive executive control and two control tasks: the operational span task (OSpan; adapted from Turner & Engle, 1989) to control for working memory capacity and the Ravens's Standard Progressive Matrix test (SPM; Raven, Court, & Raven, 1988) to control IQ. The order of the tasks was pseudo-counterbalanced across participants. They completed the tasks in two sessions: first, participants engaged in the ERP recording session while performing the AX-CPT and the OSpan task. This session lasted approximately 90 minutes. In the second session, which lasted around 30 minutes, participants performed the Raven's task. Below, we describe the tasks' materials and procedure.

Raven's SPM test (Raven, Court, & Raven, 1988). Participants performed a computerized version of this task that required completing sixty matrixes as measure of non-verbal fluid intelligence. The maximum raw score was 60.

Operational Span (Ospan) task. In this working memory task (adapted from Turner & Engle, 1989), participants were asked to solve arithmetical operations while maintaining sets of Spanish words in memory. At the beginning of each trial, a fixation cross appeared in the middle of the screen for 1000 ms followed by a mathematical expression [e.g., (18 / 3) - 4 = 2] for 3750 ms. Participants were then required to respond whether the equation was correct or incorrect by pressing a button (*k* = correct; *d* = incorrect). After that, a Spanish word appeared on the screen during 1250 ms. Participants had to memorize the words until the end of the set, when the word "remember" appeared on the screen and they were to type all the words they could remember. The number of the to-be-recalled words increased from 2 to 6 operation-word pairs. There were three sets per size, making a total of fifteen sets. Before completing the experimental sets, participants performed two practice trials. They were instructed pay attention to both mathematical operations and word recalling so that their performance was equally good for both. We measured span as the maximum string of words correctly recalled (maximum span = 6). As an example, if a participant correctly recalled the 3 trials of string 4, but recalled less than 2 trials in string 5, she would score 4 for span. If she correctly recalled only 2 trials of string 4, the span score would be 3.5. We also calculated the proportion of words recalled correctly as well as the proportion of equations solved correctly.

AX-CPT. In this task we used a procedure similar to that described in Beste and colleagues (Beste et al., 2011; see Figure 14a). Participants were presented with pairs of letters and were instructed to press the "yes" button whenever they saw an *X*-probe preceded by an *A*-cue. In any other case they were to respond "no". They were required to respond to all of the probes. AX trials constituted 70% of the trials. Each of the other 3 conditions (AY, BY, BX) occurred on 10% of the trials. Each cue appeared for 250 ms followed by a blank interval that could be either short (1000 ms) or long (2000 ms). After the interval, the probe appeared for 250 ms followed by a variable inter-trial blank screen (ITI = 2000 ms for the short-delay condition and 1000 ms for the long one). Participants were told to respond within 800 ms after the probe appearance. If they failed to do so a beep sound indicated that no response had been given in time and the trial was marked as "no response". In total, the task included 720 trials divided into four blocks (2 blocks by interval condition). The order of interval condition and response buttons was counterbalanced across participants.

ERP data acquisition and analysis

During the AX-CPT, the continuous electroencephalogram (EEG) was recorded from 64 scalp electrodes mounted in an elastic cap (Quick-Cap, Neuroscan Inc.). The vertical and horizontal eye movements were also recorded from bipolar pairs of vertical (VEOG) and lateral (HEOG) electrodes to allow corrections of blink artifact. The electrical signal was amplified with Neuroscan Synamps at a sampling rate of 500 Hz and a 0-30 Hz bandwidth filter. Electrode impedances were kept below 10 kΩ. Digital tags were obtained for both cues and targets. Ocular artifacts were corrected by means of a regression analysis in combination with artifact averaging (Scan, 4.5). Results of the ocular correction procedure were visually inspected.

We based our ERP segmentation and analyses on previous ERP studies which used the AX-CPT (Beste et al., 2011; van Wouwe, Band, & Ridderinkhof, 2011). Thus, we averaged epochs individually for each participant, experimental condition and trial type. Only epochs for correct responses were extracted, except for ERN. We applied artifact rejection procedures on the resulting epochs in two ways; automatically with an amplitude threshold of ±50 μV, and visually by rejecting trials with artifacts. Before quantifying ERPs, data were re-referenced to linked mastoids. For cues, the epochs ranged from -200 prior cue presentation until 1250/2250 ms (short/long delays, respectively). The epoch segmentation of probes ranged between -200 ms prior probe appearance until 1000 ms. For ERN the epochs were response-locked from -200 ms until 1000 ms after responding.

The resulting epochs were grouped into grand mean averages across groups. Three participants (one bilingual and 2 monolinguals) were excluded from analyses due to poor data recording.

To obtain each of the components, EEGs were filtered off-line from 0.01 (high-pass filter) and 30 Hz (low-pass filter), slope 24 db/octave, at the corresponding electrode site of interest. In addition, given that the N2 component tends to be absorbed by the larger P3, which may obscure variation in its amplitude across the different conditions (Donkers, Nieuwenhuis, & van Boxtel, 2005), we filtered out the P3 by using 2 Hz (high-pass) and 12 Hz (slope 24 db/octave) bandpass filters.

Cue processing component

P3b was aligned to a baseline of -200 ms until cue presentation. The component was obtained at Fz, Cz, Pz, and Oz (Jonkman, 2006; Lenartowicz et al., 2010). The mean P3b amplitude was calculated at the time window from 350-650 ms, corresponding to the latencies between which the grand averages exceeded half of the peak amplitude of *B* cues (van Wouwe et al., 2011).

To control for possible differential topographic distributions due to language experience and to confirm that cue-P3b reached its maximum amplitude at Pz (Jonkman, Lansbergen, & Stauder, 2003; Lenartowicz et al., 2010; Polich, 2007; van Wouwe et al., 2011), we performed a mixed analysis of variance (ANOVA) with Location (Fz, Cz, Pz, and Oz, averaged over AX-CPT conditions) and language group (bilingual, monolingual) as factors, for each component. The analyses confirmed that Pz was the electrode of maximum amplitude for cue-P3b, and that there were neither group differences nor interactions. Thus, we conducted separate ANOVAs at Pz for cue (A, B), delay (short, long), and language group to evaluate modulations due to language experience in proactive control (cue-P3b).

Probe processing components

We set the baseline for the N2 and P3a probe-locked components from -200 ms until probe presentation, measured at frontocentral electrodes Fz, FCz, FC3 and FC4. The mean amplitude for N2 and P3a were measured at time windows of 250-350 ms and 350-500 ms, respectively, after probe presentation. Given the uneven number of AX trials relative to the other types of trials, we did not include AX in the analyses of probe processing components. Following the data analyses of previous research with this task (van Wouwe et al., 2011) and in order to confirm that probe processing components (N2, P3a and ERN) reached their maximum at FCz (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; van Veen & Carter, 2002a, 2002b; van Wouwe et al., 2011) whilst controlling for possible distributional effects of language group, we performed a mixed ANOVA with Location (FCz, Fz, FC3, and FC4, averaged over AX-CPT conditions) and language group (bilingual, monolingual) as factors, for each component. The analysis confirmed that FCz was the electrode of maximum amplitude and that there were no group differences. Thus, we conducted ANOVAs at FCz for condition (AY, BX, BY), delay (short, long), and language group to evaluate modulations of conflict monitoring and response inhibition effects due to language experience. Planned comparisons with Bonferroni corrections were conducted where appropriate.

Evaluative processes

ERN was response-locked, aligned to a baseline of -200-0 ms previous to a given response. We established the measurement window from 0 until 100 ms after a given response.

Given the general low proportion of errors, no single condition reached a sufficient number of valid cases to be analyzed separately. However, and because of the relevance of this measure for our research question, we decided to look at ERN in an exploratory manner. To do so, we collapsed the four conditions at the two delay conditions and obtained the ERN from the EEGs of correct and incorrect responses.

With respect to the probe processing components, we performed an ANOVA at FCz, the electrode of maximum amplitude, with Response (correct, incorrect), and Group as factors.

RESULTS

Behavioral Results

We analyzed RTs and proportion of errors on the AX-CPT. Due to the different proportion of trials across conditions, AX trials were analyzed separately from the remaining 3 types of trials

(Braver et al., 2001; Braver, Satpute, Rush, Racine, & Barch, 2005; Lorsbach & Reimer, 2010; Paxton, Barch, Racine, & Braver, 2008). Thus, we first conducted Group (bilingual, monolingual) x Delay (short, long) ANOVAs on performance on AX trials, and then three-way ANOVAs on RT and errors with Group, Delay and type of Trial (AY, BX, BY) as factors.

The analyses of AX trials failed to show a significant main effect of Delay for RTs, $F(1,50) = 1.04$, $MSE = 609.7$, $p = .31$, $\eta^2_p = .020$, and accuracy, $F(1,50) = 1.71$, $MSE = .000$, $p = .20$, $\eta^2_p = .033$. Similarly, Delay was not significant in the Trial type (AY, BX, and BY) x Delay (short and long) ANOVA on RT and accuracy (all Fs < 1), and there was not a significant interaction between Delay and any other variable in any of the analyses (all ps > 0.1). Thus, for the sake of simplicity, we collapsed the data across the two delay conditions (see Table 6).

Table 6. *Mean proportion of errors and RTs (and standard deviations) by trial and language group in the AX continuous performance task.*

Condition	Monolinguals		Bilinguals	
	Errors	RT (ms)	Errors	RT (ms)
AX	.023 (.023)	386 (59)	.007 (.009)	406 (55)
AY	.163 (.129)	514 (48)	.087 (.081)	527 (52)
BX	.057 (.057)	358 (84)	.017 (.025)	361 (67)
BY	.012 (.028)	363 (81)	.003 (.006)	361 (68)

The one-way ANOVA on RT with language group as factor revealed that both groups responded at similar speeds on AX trials, $F(1,50) = 1.60$, $MSE = 3296$, $p = .21$, $\eta^2_p = .031$. Similarly, the factorial analysis with language group and Trial Type (AY, BX, BY) showed that the two groups did not differ in their RTs to any of the three types of trial conditions, $F<1$ (interaction Group x Trial with $F < 1$). As expected, there was a statistically significant effect of type of Trial, $F(2,100) = 411$, $MSE = 1064$, $p < .01$, $\eta^2_p = .892$. Pairwise comparisons with Bonferroni corrections revealed that participants responded slower to AY trials ($M = 520$ ms; $SD = 50$) than to BX ($M = 360$ ms; $SD = 76$ ms) and BY trials ($M = 362$ ms; $SD = 75$ ms) (both *p*s < .01). Mean RTs to BX and BY trials did not differ significantly (*Fs* < 1).

Error analysis on AX trials showed that bilinguals committed less errors (0.8%) than monolinguals (2.6%), $F(1,50) = 13.61$, $MSE = .001$, $p < .01$, $\eta^2_p = .21$. The group x trial (AY, BX, BY) ANOVA also revealed that bilinguals committed significantly fewer errors than monolinguals (3.6% vs. 7.8%, respectively), $F(1,50) = 65.38$, $MSE = .015$, $p < .01$, $\eta^2_p = .15$. The main effect of Trial was statistically significant, $F(2,100) = 58.11$, $MSE = .007$, $p < .01$, $\eta^2_p = .53$. AY trials elicited more errors (12.5%) than BX trials (3.7%) and the latter more errors than BY trials (.8%) (all comparisons with $p < .01$, Bonferroni corrected). The interaction Trial x Group was also significant, $F(2,100) = 4.81$, $MSE = .007$, $p < .01$, $\eta^2_p = .088$. T-test comparisons indicated that whereas bilinguals committed less errors compared to monolinguals on both AY, $t(50) = 2.51$, $p < .05$, $d = 0.72$ (8.8% vs. 16.3%) and BX trials, $t(50) = 3.15$, $p < .01$, $d = 1.49$ (1.7% vs. 5.7%), both groups performed similarly on BY trials, $t(50) = 1.56$, $p = .12$, $d = 0.50$ (0.3% vs. 1.2%).

ERP results

The analyses for each of the AX-CPT processes as a function of language group are detailed below. First, we present the context maintenance effects by comparing language groups in each of the obtained ERP components by delay condition (short vs. long). Second, we report the component associated with cue processing (cue-P3b), followed by analyses of probe processing (N2 and probe-P3a). Finally, we describe the ERN component following a given response.

Context maintenance effect

Group differences in context maintenance should be reflected in differential effects of a delay across the different components. We performed ANOVAs on ERP amplitudes for each component of interest with Delay, Trial and Group as factors revealed significant effects of Delay only for cue-P3b and probe-P3a components. As for cue-P3b the analysis showed larger amplitudes for the shorter than for the longer interval ($M = 3.9$ μV vs. $M = 2.2$ μV), $F(1,49) = 19.77$, $MSE = 7.31$, $p < .01$, $\eta^2_p = .288$. Delay did not interact with Group $F(1,49) = 0.25$, $MSE = 7.31$, $p = .62$, $\eta^2_p = .005$, but it interacted with type of Cue, $F(1,49) = 4.06$, $MSE = 1.35$, $p < .05$, $\eta^2_p = .077$. Follow-up analyses showed that while activation was always larger for B than A cues, the largest effect was associated with short intervals, [short delay:

$F(1,50) = 69.26$, $MSE = 5.55$, $p < .01$, $\eta^2_p = .581$; long delay:, $F(1,50) = 46.51$, $MSE = 5.69$, $p < .01$, $\eta^2_p = .482$]. The interaction Delay x Cue x Group was non-significant ($F<1$).

For probe-P3a we did not find a main effect of Delay, $F<1$, but a significant interaction Trial by Delay, $F(2,96) = 4.17$, $MSE = 463.17$, $p < .05$, $\eta^2_p = .080$. Further analyses demonstrated that AY-BY effect $F(1,48) = 50$, $MSE = 4.54$, $p < .01$, $\eta^2_p = 0.187$, was larger for long (M= 7.4 µV; $CI_{.95}$ =5.4-8.7 µV) than for short delays (M= 5.7 µV; $CI_{.95}$ =4.4-7.0 µV). However, the interaction Delay by Trial in the BX-BY comparison was not significant, $F(1,48) = 1.75$, $MSE = 3.57$, $p = .19$, $\eta^2_p = 0.035$, with no delay differences in the BX-BY trials.

Cue processing component

P3b. Figure 15 shows the P3 amplitude elicited by *A* and *B* cues at Pz. The ANOVA Type of cue (*A*, *B*) x Group (monolingual, bilingual) showed that *B* cues elicited a larger positive deflection ($M = 4.79$ µV) than *A* cues ($M = 1.24$ µV), $F(1,49) = 66.92$, $MSE = 4.87$, $p < .01$, $\eta^2_p = .57$. No other source of variability reached statistical significance [Group: $F< 1$, Interaction: $F(1,49) = 1.0$, $MSE = 4.87$, $p = .32$, $\eta^2_p = .020$].

Probe processing components

N2. Figure 16 shows the N2 amplitude elicited by AY, BX, and BY trials at the most negative channel, FCz. To evaluate the modulation of conflict monitoring by the participants' language experience, we conducted an ANOVA on amplitudes at FCz with

Trial (AY, BX, and BY) and Group as factors. Although the main effect of Group was not significant ($F < 1$,), the interaction Trial by Group was, $F(2,98) = 3.73$, $MSE = 1.27$, $p < .05$, $\eta^2_p = .705$. Subsequent t-tests showed that whereas both groups showed equivalent levels of responding on BX and BY trials, ts $(50) < 1$, for AY trials bilinguals showed more negative mean amplitudes ($M = -3.14$ µV) than monolinguals ($M = -2.34$ µV), $t(50) = -1.93$, $p = .059$, $d = .055$.

P3a. Figure 17 shows the probe-locked P3 amplitude elicited by AY, BX, and BY trials at the most positive location, FCz. The ANOVA conducted on the amplitudes at FCz with Type of trial (AY, BX, BY) and Group as factors showed a main effect of Trial, $F(2, 98) = 115.9$, $MSE = 6.35$, $p < .01$, $\eta^2_p = .707$. Pairwise comparisons indicated that AY trials elicited more positive mean amplitudes ($M = 8.48$ µV) than BX ($M = 1.91$ µV) and BY trials ($M = 1.99$ µV), (both ps $< .0001$) with the latter two being equivalent ($t < 1$). The main effect of Group was not significant ($F < 1$), but there was a significant interaction between Trial and Group, $F(2, 98) = 4.48$, $MSE = 6.24$, $p < .05$, $\eta^2_p = .084$. Further analyses showed that the difference between AY and BY trials was larger in bilinguals ($M = 8.04$ µV, $CI_{.95} = 6.24$-9.84 µV) than in monolinguals ($M = 5.28$ µV, $CI_{.95} = 3.59$-6.97µV) (interaction with $F(2, 49) = 4.40$, $MSE = 7.798$, $p < .05$, $\eta^2_p = .082$). Both groups showed comparable mean amplitudes on BY and BX trials (all Fs < 1).

Error monitoring

ERN. Figure 18 shows mean ERN amplitudes. The ANOVA on amplitudes at site FCz with Response (correct, incorrect) x Group revealed a main effect of response, *F*(1, 46) = 7.20, *MSE* = 2.038, $p < .05$, $\eta^2_p = .135$, modulated by the significant interaction Response x Group, *F*(1, 46) = 4.99, *MSE* = 2.038, $p < .05$, $\eta^2_p = .098$. One-way ANOVAs for each group showed that whereas monolinguals showed a more negative activation for incorrect responses (*M* = -0.98 μV; *SD* = 1.41) compared to correct responses (*M* = 0.46 μV; *SD* = 1.87), *F*(1, 25) = 13.19, *MSE* = 2.03, $p < .01$, $\eta^2_p = .345$, bilinguals showed equivalent activation regardless of response type, $F < 1$ (for incorrect responses *M* = -0.21 μV; *SD* = 1.46; for correct responses *M* = -0.08 μV; *SD* = 2.27).

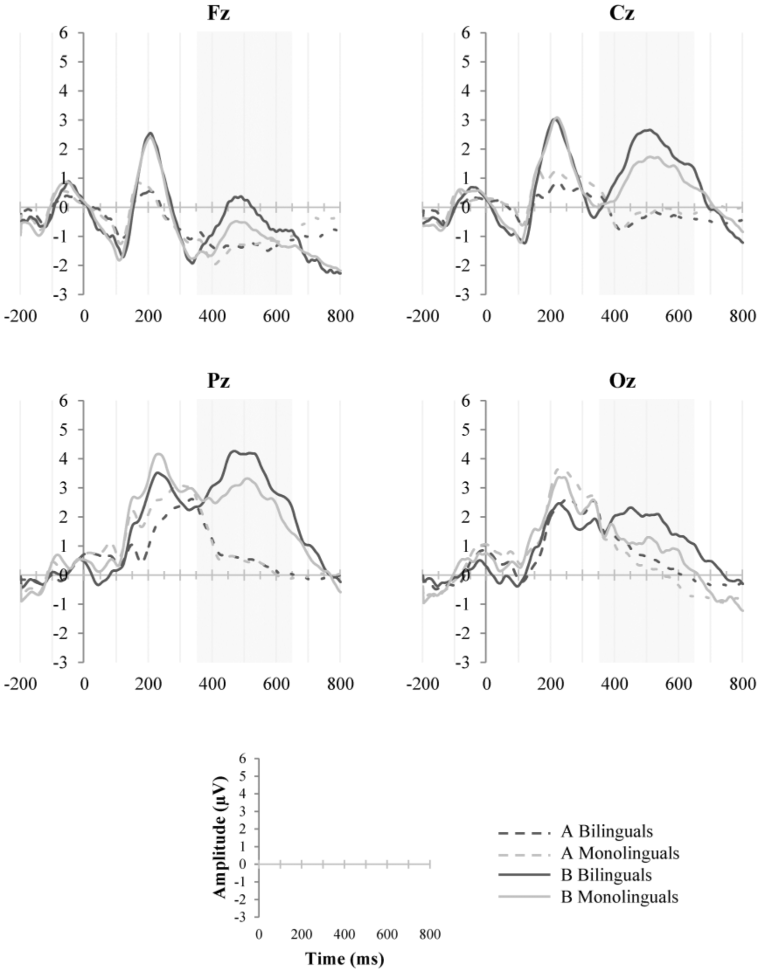


Figure 15. *Grand average ERPs (P3b) elicited by the A cue (dashed lines) and the B cue (solid lines) at Fz, Cz, Pz, and Oz, separately for bilinguals (dark lines) and monolinguals (light lines). Shaded area indicates window of analysis.*

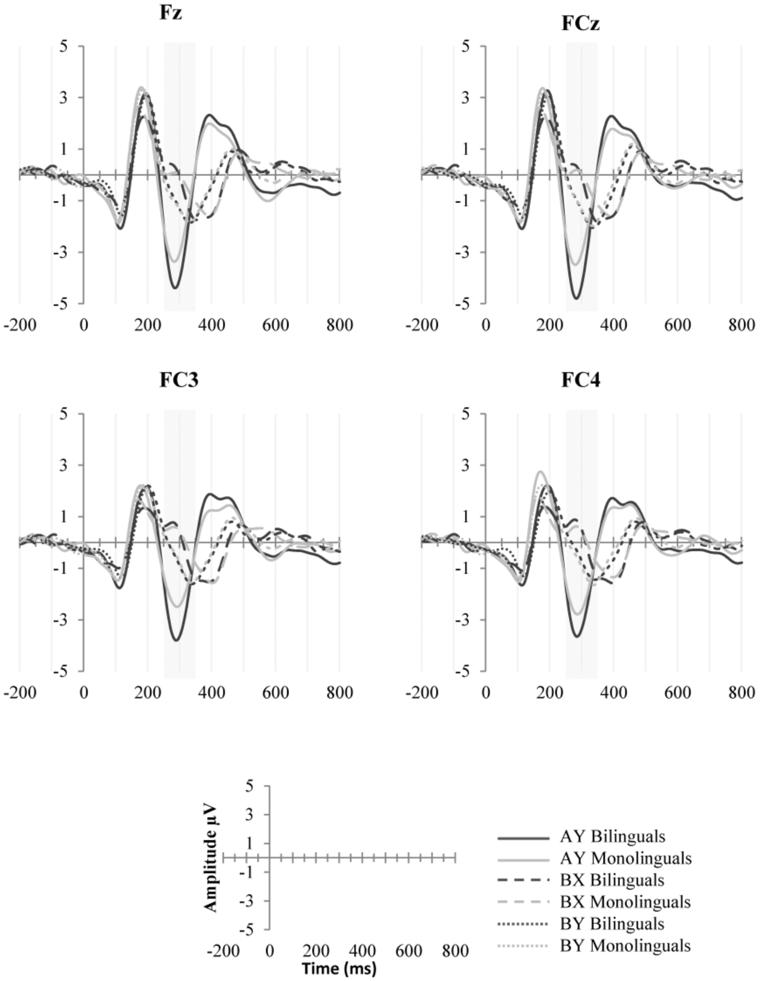


Figure 16. *Grand average ERPs (N2) elicited by AY (solid lines), BX (dashed lines) and BY (dotted lines) trials at Fz, FCz, FC3 and FC4, separately for bilinguals (dark lines) and monolinguals (light lines). Shaded area indicates window of analysis.*

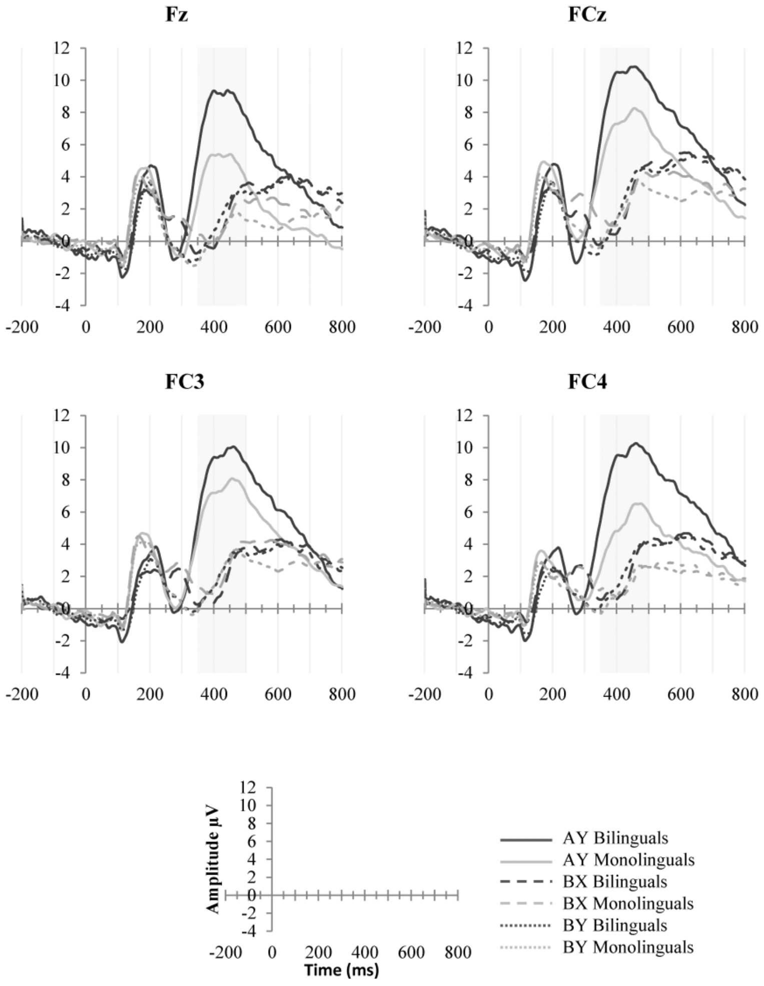


Figure 17. *Grand average ERPs (P3a) elicited by AY (solid lines), BX (dashed lines) and BY (dotted lines) trials at Fz, FCz, FC3 and FC4, separetely for bilinguals (dark lines) and monolinguals (light lines). Shaded area indicates window of analysis.*

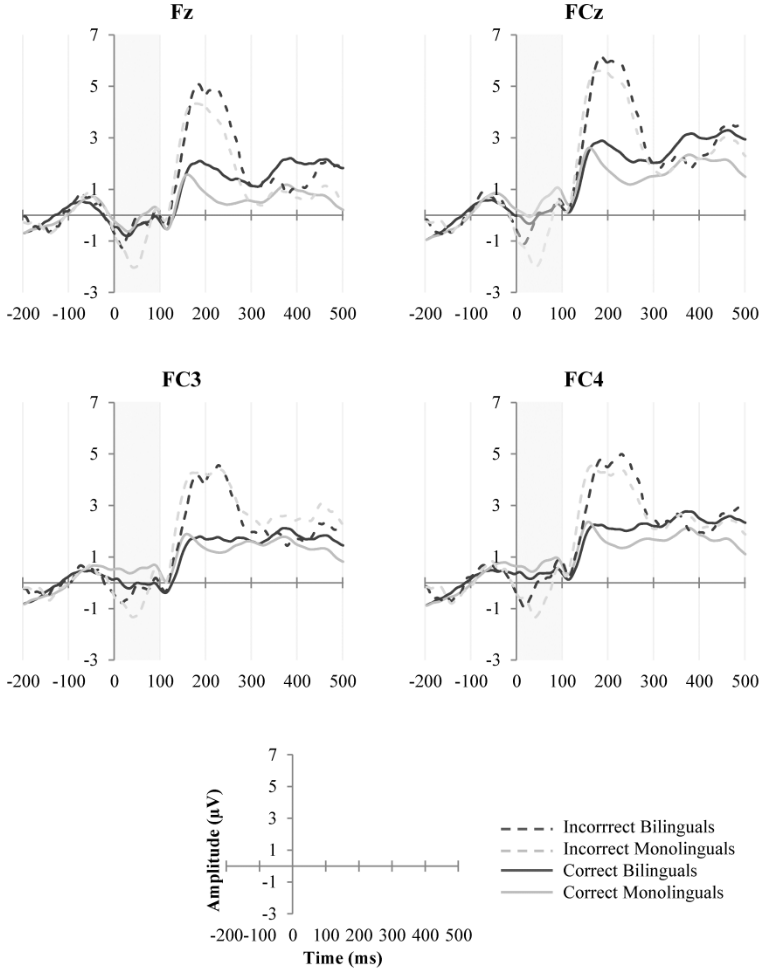


Figure 18. *Grand average ERPs (ERN) elicited by correct (dashed lines), and incorrect (solid lines) responses at Fz, FCz, FC3 and FC4, separately for bilinguals (dark lines) and monolinguals (light lines). Shaded area indicates window of analysis.*

DISCUSSION

The main goal of the present study was to evaluate the influence of bilingualism on the dynamics between proactive and reactive mechanisms of control by measuring the associated ERP components. Our results strongly suggest that bilingualism facilitates an effective adjustment between both components of control whereas it does not change goal activation or preparation mechanisms. This finding is of special relevance since recent research highlights the importance of approaching the bilinguals' executive control advantages in terms of coordination rather than in terms of isolated mechanisms. Whereas previous approaches have focused on either reactive/inhibitory control (Abutalebi & Green, 2007; Prior, 2012; van Heuven et al., 2008) or monitoring and goal maintenance/proactive control (Colzato et al., 2008; Costa et al., 2009), more recent proposals have put forward the notion that it is the dynamic combination of proactive and reactive control that better explains the influence of bilingualism on executive control (Bialystok, Craik, & Luk, 2012; Costa et al., 2009; Green & Abutalebi, 2013).

Results of a previous behavioral study with the AX-CPT support the idea that bilingualism entails better coordination of proactive and reactive control (Morales et al., 2013). In their study, bilinguals committed fewer errors than monolinguals on AY trials, where efficient adjustment of proactive and reactive control is required. Thus, in the present study we aimed to extend these findings by asking a group of early balanced bilinguals and a group of matched monolinguals to perform the

AX-CPT while recording their ERP activity. In this manner we would be able to observe online the relative involvement of different control mechanisms during the task, as well as to assess the possible source of the bilingual advantage in this task.

Importantly, our pattern of results fit perfectly with previous findings. As expected, the behavioral data showed that both groups responded at similar speeds but with slower responses and more errors on AY trials than on the other trials. This result indicates that both groups employed a proactive strategy to solve the task, since the cost on AY trials reflects inappropriate Yes responses prompted by *A* cues. More interestingly, we replicated the previous results by Morales and colleagues (Morales et al., 2013) showing that bilinguals made fewer AY errors than monolinguals whilst both groups did not differ in their performance in the other conditions. These findings support the idea that bilinguals benefit from a more efficient coordination of reactive and proactive control that would allow them to better overcome the cue bias by using probe information.

The ERP data fully endorse the behavioral findings of the AX-CPT. The component related to proactive control, cue-P3b was unaffected by language experience. However, bilinguals showed larger probe-related N2 and P3a amplitudes on AY trials relative to monolinguals, thus indicating stronger conflict monitoring and response inhibition, whereas activation remained equal for both language groups on BX and BY trials.

The probe-processing components indicated differential reactive control activation due to language experience. First, bilinguals exhibited more negative N2 amplitudes to AY trials than monolinguals, which is thought to reflect stronger conflict detection (Yeung & Cohen, 2006; Nieuwenhuis, Yeung, Van den Wildenberg, & Ridderinkhof, 2003). Second, bilinguals also showed better inhibition of prepotent responses compared to monolinguals, as expressed by larger positive mean probe-P3a amplitudes to AY trials. Thus, the data of both probe-ERP components support the possibility that bilinguals, relative to monolinguals, exert more reactive control to cope with the interference produced on AY trials, which results in fewer errors.

Differences in proactive control cannot account for the differential pattern of activation between groups. First, all participants, regardless of their language experience, showed a similar pattern of proactive activation in the cue-related component. Both groups showed comparable higher central-parietal cue-P3b mean amplitudes associated with the more salient *B* cues compared to *A* cues. This finding suggests no language experience-related differences in context activation and task goal activation. Second, both groups showed comparable probe-related mean amplitudes on BX and BY trials and the performance on these trials did not decrease in bilinguals. This pattern indicates that bilinguals do not rely on a reactive mode of control as a general strategy. Additionally, our data cannot be explained in terms of group differences in maintenance skills since we found no group differences (behavioral or neurophysiological) related to the length of the delay. This result, along with the similar scores in working memory, suggests that both groups had high context maintenance capacities. Hence, the better performance of the bilinguals in the AX-CPT seems to rely on factors others than maintenance capacity.

While behavioral and ERP data from the present study indicate that monolinguals and bilinguals engage similarly in proactive or monitoring control, our findings also show important differences between both groups. In particular, monolinguals seem to rely on proactive control to solve the task whereas bilinguals selectively adjust and engage proactive and reactive mechanisms according to the task demands, as reflected by the larger amplitudes in probe-N2 and -P3a components to AY trials. This idea of better self-regulation in bilinguals is further supported by the reduced ERN in bilinguals compared to monolinguals. This result is in accord with those from other studies that relate smaller ERN amplitudes to better control and a more efficient self-monitoring system (Festman & Münte, 2012; Kousaie & Phillips, 2012). Interestingly, in the field of bilingualism, reduced ERN has been related to better language control and less unconscious intrusions from an unwanted language. However, because of the low rate of errors observed in our study, our finding of reduced ERN needs to be interpreted with caution.

Overall, these results may be interpreted within the dual mechanism framework of cognitive control (Braver et al., 2007; Braver, 2012), which posits that the flexible dynamic between proactive and reactive control mechanisms can change according to individual features (Braver et al., 2007; Braver, Paxton, Locke, & Barch, 2009). Within this framework, the AX-CPT has served to examine differential behavioral and neurophysiological dynamics in a variety of groups such as children, young and older adults, and schizophrenia patients (Braver et al., 2001; Braver, Barch, & Cohen, 1999; Jonkman, 2006; Paxton et al., 2008). Moreover, the flexible nature of these control mechanisms also appears intra-individually, as the relative engagement of reactive and proactive control shifts depending on variations in mood, motivation and tasks demands (see Braver 2012 for a review).

Within the dual mechanisms of control framework, previous neuroimaging and ERP data have provided evidence for the neural circuits involved in the AX-CPT. Thus, it has consistently been demonstrated that the ACC and the dorsolateral prefrontal cortex (DLPFC), both associated with a network of fronto-parietal regions (Garavan et al., 2006; Watanabe et al., 2002), relate to conflict monitoring and response inhibition (Barch et al., 2001; Carter et al., 1998; Dias et al., 2003). Hence, the differential activation in conflict monitoring and response inhibition of the bilinguals and monolinguals in our study suggests that the bilinguals' cognitive advantages are linked to a modulation of this fronto-parietal network. Moreover, the fact that this differential activation is confined to the AY trials (where reactive control needs to interplay with proactive control), might be reflecting the higher flexibility of bilinguals in the same areas of the lateral prefrontal cortex (PFC), which fluctuates with shifts from proactive to reactive control and vice versa (Braver et al., 2009).

Interestingly, these regions have been shown to be modulated by bilingual experience in non-verbal tasks involving conflict monitoring (Garbin et al., 2010; Kousaie & Phillips, 2012; Luk, Anderson, Craik, Grady, & Bialystok, 2010) and to be involved in the linguistic control derived from bilingual experience (Abutalebi & Green, 2008; Luk et al., 2012). The present findings provide further support for a modulation of this fronto-parietal network by bilingualism, which would make it more flexible and capable of adapting its activation according to the task demands.

Our results can be framed within the adaptive control hypothesis (Green & Abutalebi, 2013), which posits that the recurrent need to control for languages may re-adapt the cascade of processes involved in cognitive control. The AX-CPT biases a proactive control strategy but, on AY trials, bilinguals were more capable than monolinguals to engage reactive control to overcome a biased YES response. An adaptive control system would also be capable of engaging more proactive control when needed in tasks that favor a reactive control mode. This could be a plausible explanation for the smaller ACC activation of bilinguals compared to monolinguals in tasks that involve coping with conflict (Abutalebi et al., 2012). This activation pattern may reflect the possibility that early attentional mechanisms prevent from interference, so bilinguals will not need to engage areas involved in conflict resolution. Future research should explicitly investigate whether bilingualism may also help to temper reactive control in favor of proactive control when this is the more efficient strategy to confront a certain task.

In sum, both bilinguals and monolinguals rely on context information to solve the task. However, the ERP activation associated with probe processing indicates that bilinguals are able to exert higher reactive control when needed. Bilinguals more efficiently detected the conflict stimuli and engaged more resources for response inhibition, but only under the AY condition, that requires the updating and substitution of the previously activated goal under the appearance of new conflict information. Our results join others in supporting a multi-component perspective of the effects of bilingualism on executive control.

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Experimental Series II. WORKING MEMORY DEVELOPMENT IN BILINGUAL AND MONOLINGUAL CHILDREN (Experiments 3 & 4) [*]

Two studies are reported comparing the performance of monolingual and bilingual children on tasks requiring different levels of working memory. In the first study, 56 5-year-olds performed a Simon-type task that manipulated working memory demands by comparing conditions based on two rules and four rules and manipulated conflict resolution demands by comparing conditions that included conflict with those that did not. Bilingual children responded faster than monolinguals on all conditions and bilinguals were more accurate than monolinguals in responding to incongruent trials, confirming an advantage in aspects of executive functioning. In the second study, 125 children 5- or 7-year-olds performed a visuospatial span task that manipulated other executive function components through simultaneous or sequential presentation of items. Bilinguals outperformed monolinguals overall, but again there were larger language group effects in conditions that included more demanding executive function requirements. Together, the studies show an advantage for bilingual children in working memory that is especially evident when the task contains additional executive function demands.

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[*] The studies included in this chapter correspond to the content of the paper published as Morales, J., Calvo, A., & Bialystok, E. (2013). Working memory development in bilingual and monolingual children. *Journal of Experimental Child Psychology*, *114*, 187–202.

It is now recognized that a variety of cognitively demanding experiences modulate brain development and, by extension, modify cognitive functioning (e.g., Green & Bavelier, 2003; Maguire et al., 2000; Polk & Farah, 1998; Salthouse & Mitchell, 1990). The modification to cognitive functioning typically follows from intensive practice in a particular process entailed by the experience. For example, video game players have superior spatial resolution of visual processing, presumably because of the practice obtained during gaming (Green & Bavelier, 2003). The exercise of speaking two or more languages on a daily basis is another experience that has been shown to produce changes in cognitive performance (see review in Bialystok, 2009). The mechanism by which bilingualism leads to this experience-induced cognitive change is likely based on the need to monitor attention to the target language in the context of joint activation of the other language. Substantial evidence from a variety of sources has supported the view that both languages are active in mind to some extent during both comprehension and production (Blumenfeld & Marian, 2007; Francis, 1999; Grainger, 1993; Kroll & de Groot, 1997; Marian & Spivey, 2003; Rodriguez-Fornells, Rotte, Heinze, Nosselt, & Munte, 2002; Thierry & Wu, 2007). The procedures for monitoring attention to the target language have been shown to be handled at least in part by the executive control system (see Luk, Green, Abutalebi, & Grady, in press, for a meta-analysis of functional magnetic resonance imaging evidence), and the recruitment of that system for language use improves its efficiency for a broad range of tasks. The process by which the executive control system interacts with language selection and the subsequent effect on specific aspects of that system, however, are not well understood. Such precision is necessary in order to understand the unique structure of bilingual minds and how experience can affect cognitive outcomes.

One area of uncertainty is the identification of the specific executive control function components that are involved in bilingual language processing and, subsequently, are boosted for bilinguals. A widely accepted interpretation of executive control proposed by Miyake and colleagues (2000) consists of three core components roughly corresponding to inhibition, shifting, and working memory. Early studies showing bilingual differences in performance focused primarily on inhibition (see Bialystok, 2001, for a review), tracing the bilingual advantage in executive control to the need to inhibit the irrelevant but jointly activated language (cf. Green, 1998). Subsequent research, however, has challenged that interpretation; bilingual advantages have been found in preverbal infants long before any inhibition could be relevant (Kovács & Mehler, 2009), some types of inhibition have been implicated in these effects and others have not (Colzato et al., 2008), and conditions that involved no inhibition appear to be equally affected (Hilchey & Klein, 2011). Therefore, the precise nature of how executive control is involved in bilingual performance is not clear.

Recently, Miyake and Friedman (2012) took a broader view and proposed that the executive function is characterized by "unity and diversity", that is, a set of correlated but separable abilities. This view captures a trend in recent research that emphasizes a reliance of executive function components on a common underlying mechanism (Best & Miller, 2010; Garon, Bryson, & Smith, 2008; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003). On this view, working memory is automatically affected by any experience that affects the executive function system more broadly. Evidence for bilingual advantages in aspects of two of the three components, inhibition and shifting, is already documented, so from the concept of "unity" it follows that bilinguals should demonstrate enhanced working memory.

Understanding both the status of working memory in the constellation of the executive function and the effect of bilingualism on its development is important because working memory is arguably the most important component of the executive function. Working memory is central to a wide variety of cognitive abilities, especially those that involve dealing with interference, conflict, or distraction (see Kane, Conway, Hambrick, & Engle, 2007, for a review) and predicts essential cognitive and academic outcomes in children. For example, reading comprehension requires holding the previous text in mind so it can be related to the current material, and mental arithmetic requires holding numbers in mind while the operation is applied to update the result. Not surprisingly, therefore, the early acquisition of literacy and numeracy skills (Adams & Gathercole, 1995; Blair & Razza, 2007; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Gathercole, Pickering, Knight, & Stegmann, 2004; Savage, Cornish, Manly, & Hollis, 2006) and later language and math achievement (Barrouillet & Lepine, 2005; Blair & Razza, 2007; Bull & Scerif, 2001; Espy et al., 2004;

Gathercole et al., 2004; Passolunghi, Vercelloni, & Schadee, 2007; Swanson & Kim, 2007) depend heavily on working memory.

Previous research investigating the effect of bilingualism on executive control has focused largely on the role of inhibition and shifting. Thus, the tasks typically require participants to switch between rules (Bialystok, 1999; Bialystok & Viswanathan, 2009; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Prior & MacWhinney, 2010) or to ignore interference from irrelevant stimuli, as in the Simon task (Bialystok, Craik, Klein, & Viswanathan, 2004; Martin-Rhee & Bialystok, 2008), flanker task (Carlson & Meltzoff, 2008; Costa, Hernández, & Sebastián-Gallés, 2008; Yang, Yang, & Lust, 2011), or Stroop task (Bialystok, Craik, & Luk, 2008). The typical finding is that bilingual participants perform faster on both congruent and incongruent trials in conflict tasks and switch between rules more efficiently, invoking both inhibition and switching into the account. For this reason, recent accounts of bilingual advantages in executive functioning have taken a more holistic view and attributed the advantage to broader processes such as conflict monitoring (Costa et al., 2009; Hilchey & Klein, 2011) and coordination (Bialystok, 2011). However, few studies have addressed the possibility that working memory is also involved in these tasks and is modified by bilingualism.

Some fragmentary evidence suggests that working memory might be affected by bilingualism in the same way as found for inhibition and shifting. Bialystok and colleagues (2004) presented younger and older adults who were monolingual or bilingual with a Simon task in which they were asked to indicate the color of a square by pressing the appropriate response key. In the experimental conditions, the squares were presented on either the left or right side of the display and either corresponded or not to the position of the relevant response key, creating congruent and incongruent trials. In a control condition, the stimuli were presented in the center of the display, so there was no interference from position. There was also a working memory manipulation consisting of 2-stimulus and 4-stimulus conditions in which the latter required holding more stimulus–response pairings in mind. The expectation was that the two language groups would perform equivalently in the control condition and that the increase in difficulty from the 2-stimulus presentation to the 4-stimulus presentation in the control condition would be equivalent for participants in the two language groups. As expected, there were no response time (RT) differences between language groups for the 2-stimulus condition, but the surprising result was that the additional time needed to hold in mind 4 stimulus pairings was significantly longer for the monolingual participants than for the bilinguals. This difference was larger for the older adults than for the younger adults, suggesting that bilingualism also slows the decline of these abilities with age. Thus, it appeared that even at this basic level of working memory, the bilingual participants were more efficient than the monolinguals. However, studies comparing simple working memory performance in monolingual and bilingual children have found no evidence of difference (Bialystok & Feng, 2010; Bonifacci, Giombini, Bellocchi, & Contento, 2011; Engel de

Abreu, 2011). Therefore, the few studies on this topic are inconclusive, so there is no clear evidence regarding whether working memory, like inhibition and shifting, is also enhanced for bilinguals.

The characterization of the executive function as consisting of unity and diversity makes it challenging to investigate the components individually, but it is nonetheless crucial to determine whether differences in working memory can be identified and how they might interact with the other components. Working memory is the missing piece in the explanation of cognitive effects of bilingualism and requires independent study not only to understand cognitive processing in bilinguals but also to understand the integrity of executive control in development.

The hypothesis in the current research is that working memory is enhanced in bilingual children, particularly in conditions for which the other core components of executive control are also required. There are two reasons for this hypothesis. First, from the perspective of unity, the established effect of bilingualism on some components of the executive function will necessarily involve all of the components, including working memory, through their common foundation. Second, from the perspective of diversity, the joint activation of both languages for bilinguals in language processing requires not only inhibition and selection but also maintenance of representations of context, interlocutors, and discourse—all functions of working memory. Therefore, as with the other two components, the relations should be observed through interactions with other executive function processes. Just as inhibition of irrelevant information in an incongruent trial is observed primarily in the context of shifting between congruent and incongruent trials, so too we expect that working memory effects will be observed in situations where working memory demands are integrated with demands for inhibition and shifting. On this view, the core components of the executive function system are all involved in bilingual processing and are all modified as a consequence. It is empirically difficult to isolate the core components of the executive function, an issue that is central to the study of executive function. Bilingualism provides a unique window to test unity and diversity account. To the extent that working memory is uniquely modified by bilingualism—the diversity view—there should be a main effect of working memory across manipulations in other components of the executive function. To the extent that working memory is integrated with the other components—the unity view—the strength of the working memory effect will be modulated by other task demand.

EXPERIMENT 3

Manipulation of the executive function demands in a Simon task paradigm was adapted from Bialystok and colleagues (2004) to create a task appropriate for children. Working memory demands were operationalized as the difference between performing the task while holding in mind either two response rules or four response rules in conditions that either had minimal additional executive control demands or included conflict and so required inhibition and shifting. Thus, manipulations in working memory could be examined across levels of executive control.

METHOD

Participants

Participants in the first study were 64 5-year olds (mean age =5 years 5 months, *SD* =5.4) who were attending kindergarten. All of the children lived in the same homogeneous middle-class community and attended the same neighborhood schools in a large city. Questions regarding parents' level of education revealed that all parents had at least college-level diplomas. Of this total sample, 7 children had mixed language experiences and could not be clearly classified as bilingual or monolingual and so were excluded from the analyses, and 1 monolingual child was excluded because his score on one task used to assess nonverbal intelligence was more than 2 standard deviations below the group mean. Thus, the final sample was composed of 56 children and included 29 monolinguals (17 boys and 12 girls) and 27 bilinguals (11 boys and 16 girls). All of the bilingual children spoke English at school and in the community and spoke a different language at home; they had been exposed to both languages since birth and used them daily. The non-English languages included Arabic (2), Bulgarian (1), Cantonese (2), Chinese (2, dialect unspecified), French (1), Hebrew (1), Igbo (1), Mandarin (4), Portuguese (1), Russian (7), Serbian (1), Spanish

(3), and Urdu (1). All parents completed a questionnaire about the language environment at home, the language used for specific activities, and the languages used for interactions between family members. The responses were indicated on a 5-point scale where 1 =entirely in English and 5 =entirely in the non-English language, with 3 indicating balanced usage. The score for monolinguals was consistently 1. For bilinguals, the language spoken by the children obtained an average score of 2.5 (*SD* =1.1), indicating a slight bias for English, and the language spoken by parents to children obtained an average score of 3.5 (*SD* =1.0), indicating a slight bias for the non-English language.

Materials and procedure

Children were tested individually on three tasks in a quiet room at their school. Two background measures were administered: the Peabody Picture Vocabulary Test (PPVT-III; Dunn & Dunn, 1997) to assess receptive vocabulary in English and the Matrices subtest of the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 2004) to evaluate the equivalency of both groups on fluid intelligence. The third task was the pictures task, which is a Simon-type task that included a manipulation of working memory demands. The order of the tasks was as follows: Part 1 of the pictures task, K-BIT, Part 2 of the pictures task, and PPVT-III. The session lasted approximately 40 min, and children were given stickers on completion to thank them for their participation.

The measures for English receptive vocabulary (PPVT-III) and fluid intelligence (K-BIT) were administered and scored according to standard procedures.

Pictures task. The pictures task was programmed in E-Prime software (Schneider, Eschman, & Zuccolotto, 2002) and presented on a Dell Latitude C840 laptop computer with a 15-inch monitor. All participants completed four conditions consisting of two blocks of 24 trials per condition, producing a total of 48 trials for each of the four conditions. The four conditions were created by combining two working memory levels (2 stimuli vs. 4 stimuli) with two conflict levels (central presentation vs. side presentation).

Center-2. An illustration of this task is presented in Figure 19. Two stimuli, a purple flower and a red heart, were presented one at a time in the center of the screen. Participants were instructed to press a designated key to indicate which stimulus was shown. The keys were located on the right and left sides of the keyboard, and each was marked with a sticker indicating the color of the designated figure. The assignment of the key to the left or right position was counterbalanced across participants.

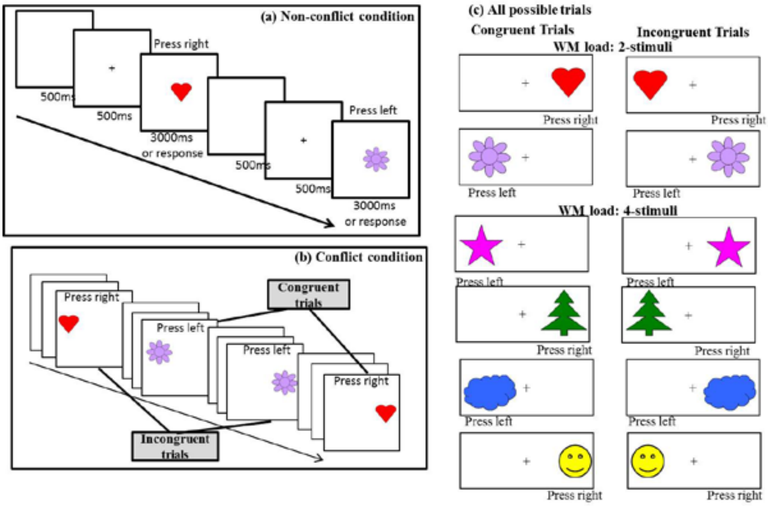


Figure 19. *Pictures task. (a) Procedure employed in the pictures task, center conditions. (b) Trial types in the conflict conditions. (c) Stimuli and trial types in the conflict conditions by memory load. WM = working memory.*

Each trial began with a 500-ms blank screen followed by a centered fixation cross for another 500 ms. After this, the stimulus appeared and children were asked to respond by pressing the correct key as quickly as possible without making mistakes. Timing began with the onset of the stimulus and terminated with the response. Children were not able to respond during the blank or fixation screens. The stimulus remained on the screen for a maximum of 3000 ms or until a response was made.

Conflict-2. The parameters were the same as in the previous condition, but the stimulus appeared on either the right or left side of the screen (see Figure 19). The relationship between the presentation position and the position of the correct response key created congruent trials (the two positions were the same) and incongruent trials (the two positions were different).

Center-4. This condition was similar to the center-2 condition except that there were 4 stimuli: a blue cloud, a green tree, a yellow smiley, and a pink star. Children were instructed to press one key for 2 of the stimuli (blue cloud and yellow smiley) and to press the other key for the other 2 stimuli (green tree and pink star). The instructions were presented as four individual rules, one per stimulus (e.g., "press the right key for the green tree", "press the right key for the pink star"). All stimuli appeared in the center of the screen.

Conflict-4. As in conflict-2, the stimuli were presented in the left or right position of the screen, creating congruent and incongruent trials.

All conditions began with instructions and a practice block consisting of 4 trials for the center blocks and 8 trials for the conflict blocks. The practice was repeated as needed until the child understood the instructions and could perform without error, but nearly all children learned the task after one practice block. The four conditions were presented in two sets beginning with the two conditions based on 2 stimuli and then, after a break to complete the K-BIT, the two conditions based on 4 stimuli.

The center conditions always preceded the conflict conditions. This fixed order was used to ensure that children understood the task and could perform it properly in the simpler condition before introducing the conflict condition. Trials within blocks were randomly presented and equally distributed.

The four conditions manipulate the involvement of working memory (2 stimuli vs. 4 stimuli) and other executive control demands (center presentation vs. side presentation). For the center conditions, participants needed to hold arbitrary rules in mind to execute the task, with greater demands on the 4-stimulus conditions than on the corresponding 2-stimulus conditions. Therefore, the difference between performances on the 2-center and 4-center conditions indicates the ability to maintain arbitrary rules. The conflict conditions introduce the requirements for inhibition to focus on the rule-defined target and resist the response key primed by the position of the stimulus and shifting to monitor congruent and incongruent trials and stimulus changes. Thus, working memory can be examined in conditions that vary in executive control demands.

RESULTS

Mean scores and standard deviations for the vocabulary and reasoning measures are reported in Table 7. Two-way analyses of variance (ANOVAs) for each background measure with gender and language group as between-participants factors showed no differences in age (*F*s < 1) or K-BIT scores (*F*s < 1). Regarding vocabulary skills in English, monolingual children obtained higher scores (*M* =111.6, *SD* =9.3) than bilinguals (*M* =102.1, *SD* =12.2) on the PPVT-III, *F*(1, 52) =10.44, *p* =.002, *d* =0.88, consistent with previous research (Bialystok, Luk, Peets, & Yang, 2010). There were no correlations between PPVT-III and any of the other measures, indicating that language differences between the groups did not influence performance on other tasks. Because there were no effects of gender on any group variables, subsequent analyses were collapsed across gender.

Table 7. *Mean scores (and standard deviation) on background measures by language group in Experiment 3 and Experiment 4*

	5-years-old: Experiments 3 & 4				7-years-old: Experiment 4			
	Monolingual		Bilingual		Monolingual		Bilingual	
Gender	Female	Male	Female	Male	Female	Male	Female	Male
N	12	17	16	11	18	16	17	18
Age (in months)	66 (2.9)	65 (5.6)	66 (6.9)	67 (5.9)	82 (2.4)	82 (2.8)	83 (2.2)	83 (3.5)
K-BIT standard score	101.7 (11.6)	105.2 (10.0)	105.8 (14.6)	103.6 (8.8)	102.5 (11.5)	100.9 (14.5)	109.0 (14.8)	99.9 (13.6)
PPVT-III standard score	112.1 (8.1)	111.2 (10.3)	104.6 (9.7)	98.5 (14.9)	103.6 (7.6)	103.9 (6.7)	95.5 (11.6)	96.8 (9.2)

For the pictures task, 3 participants were excluded (2 bilinguals and 1 monolingual) because they did not complete all of the blocks. Accuracy data are reported in Table 8. Nonconflict and conflict blocks were analyzed separately because the conflict block contained a factor for congruence that was not present in the centrally presented nonconflict block. A two-way ANOVA for language group and working memory level (2 vs. 4) on accuracy in the nonconflict block showed a main effect of memory load, with children recalling fewer items in the 2-stimuli condition than in the 4-stimuli condition, $F(1, 51) = 11.41$, $p = .001$, $d = 0.49$, and no difference between language groups and no interaction effect (Fs < 1).

Table 8. *Mean percentages of correct responses (and standard deviations) for the pictures task by language group in Experiment 3.*

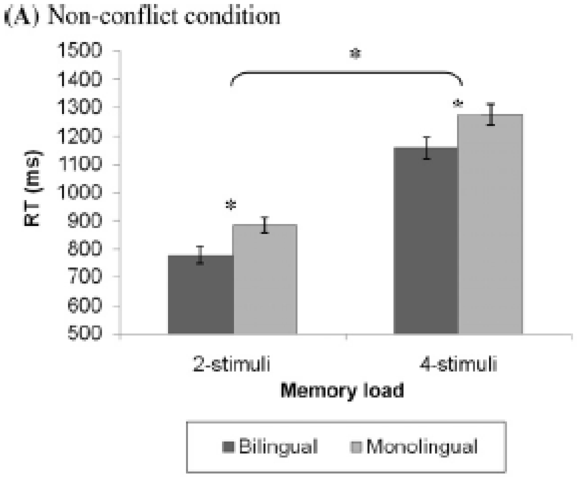
			Monolingual	Bilingual	All
WM	Block Type	Trial Presentation	Mean (sd)	Mean (sd)	Mean (sd)
2-stimuli	Non-Conflict	Center	92.8 (6.9)	91.7 (5.7)	92.3 (6.4)
	Conflict	Congruent	94.5 (5.9)	94.3 (5.7)	94.4 (5.8)
		Incongruent	85.8 (13.9)	90.9 (7.4)	88.2 (11.5)
4-stimuli	Non-Conflict	Center	94.8 (5.1)	96.0 (6.8)	95.3 (5.9)
	Conflict	Congruent	95.1 (6.3)	94.2 (7.2)	94.7 (6.6)
		Incongruent	93.1 (7.2)	95.3 (5.0)	94.1 (6.3)

For the conflict block, a three-way ANOVA for language, working memory level, and congruence revealed a main effect of working memory load (M =91.4, SD =9.1, and M =94.4, SD =6.5, for 2 stimuli and 4 stimuli, respectively), $F(1, 51)$ =12.63, p <.001, d =0.38, a main effect of congruence, $F(1, 51)$ =11.11, p =.001, d =0.43, with higher scores for congruent trials (M =94.5, SD =6.3) than for incongruent trials (M =91.3, SD =8.4), and significant interactions of congruence by language, $F(1, 51)$ =4.56, p =.04, η^2_p =.082, and congruence by working memory load, $F(1, 51)$ =11.09, p =.001, η^2_p =.18. For the congruence by language interaction, there was no effect of congruence for bilinguals (F < 1, congruent $CI_{.95}$ =92–96%, incongruent $CI_{.95}$ =90–96%), but there was a significant effect for monolinguals, $F(1, 27)$ =13.00, p =.001, d =0.39, with higher accuracy in congruent trials ($CI_{.95}$ =93–97%) than in incongruent trials ($CI_{.95}$ =86–92%). Thus, the accuracy of bilinguals was not reduced in incongruent trials as it was for monolinguals. The congruence by working memory load interaction showed that the effect of congruence was found only for the 2-stimulus condition, $F(1, 51)$ =14.85, p < .001, d =0.51 (congruent $CI_{.95}$ =93–96%, incongruent $CI_{.95}$ =85–91%) and not for the 4-stimulus condition (F < 1, congruent $CI_{.95}$ =93–97%, incongruent $CI_{.95}$ =92–96%).

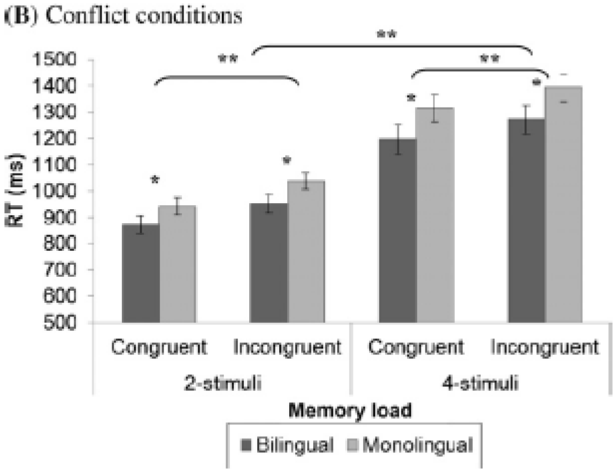
RT data for correct responses are shown in Figure 20. Trials with RTs less than 200 ms and more than 2500 ms were excluded (2.8% of trials). For the nonconflict block, a two-way ANOVA for language group and working memory level showed a main effect of memory load, $F(1, 51)$ =209.93, p < .001, d =2.19, with faster responses in the 2-stimulus condition (M =830 ms, SD

=140) than in the 4-stimulus condition (*M* =1198 ms, *SD* =192), *F*(1, 51) =209.93, $p < .001$, *d* =2.19, and a main effect of language group, *F*(1, 51) =7.18, *p* =.010, *d* =0.62, with faster responses from bilinguals (*M* =962 ms, *SD* =155) than from monolinguals (*M*=1060 ms, *SD* =162) and no interaction.

For the conflict condition, a three-way ANOVA revealed main effects of working memory load, *F*(1, 51) =90.37, $p < .001$, d =1.56, with faster responding to 2-stimulus trials, language group, *F*(1, 51) =4.48, *p* =.039, *d* =0.44, with bilinguals responding faster than monolinguals, *F*(1, 51) =4.48, *p* =.039, *d* =0.44, and congruence, *F*(1, 51) =36.17, $p < .001$, *d* =0.28, with faster responses to congruent trials. There were no significant interactions. Thus, RTs for bilinguals, 2-stimulus conditions, and congruent trials were faster than their counterparts. To evaluate the presence of speed accuracy trade-offs, Pearson correlations were calculated between RTs and accuracy. No significant correlations were found for any of the conditions.



(A) Non-conflict condition



(B) Conflict conditions

Figure 20. *Mean response times (and standard errors) by language group for the pictures task (in milliseconds) in Study 3 for the*

DISCUSSION

Monolingual and bilingual children performed equivalently on a test of fluid intelligence, but monolinguals obtained higher scores than bilinguals on a test of English receptive vocabulary. This pattern is consistent with previous research in which monolinguals typically demonstrate a higher vocabulary in the language of testing (Bialystok et al., 2010; Oller, Pearson, & Cobo-Lewis, 2007). It is important that there were no significant correlations between PPVT-III scores and any of the dependent variables, so this difference did not affect experimental outcomes.

In the nonconflict condition, all children showed a high level of accuracy, with correct responses provided on more than 90% of the trials. Executive function demands were low, with the primary demand being the need to hold arbitrary rules in mind to respond appropriately. The conflict condition produced different results for the two language groups. Whereas incongruent trials were more difficult than congruent trials for monolinguals, the misleading cues did not increase task difficulty for bilinguals. These findings are consistent with evidence from studies using a Simon task (Martin-Rhee& Bialystok, 2008) or flanker task (Carlson & Meltzoff, 2008; Yang et al., 2011) showing an advantage in conflict resolution for bilingual children.

RT data showed that bilingual children were faster than monolinguals even in the simpler nonconflict condition. Because there was no interaction of conflict and working memory load and no evidence of speed–accuracy trade-offs, bilinguals appear to be more efficient in performing the task and in coordinating the demands across the manipulations of executive control and working memory.

Children in both language groups produced more accurate but slower responses to the 4-stimulus condition than to the 2-stimulus condition. This pattern may indicate that children were attending more carefully in the more difficult condition. It is also possible that even the 2-stimulus condition was demanding for this age group (Gerstadt, Hong, & Diamond, 1994) and that bilingual children are more advanced than monolinguals in their progress in developing these skills. For children in this age range, working memory tasks that involve holding in mind two or more items require children to engage extra attentional processes to solve the tasks (Gathercole, Pickering, Ambridge, & Wearing, 2004; Miles, Morgan, Milne, & Morris, 1996; Wilson, Scott, & Power, 1987). The fact that bilingual children were able to maintain their speed advantage in the presence of conflict from incongruent trials or increases in memory load may be evidence of enhancement of working memory. Note, too, that the bilingual advantage on the centrally presented stimuli is similar to the results found by Bialystok and colleagues (2004) for adults, where bilinguals outperformed monolinguals in a condition requiring them to hold four rules in mind and respond correctly to a stimulus presented in the center of the screen. It is also possible that faster RTs in bilinguals indicate faster processing of stimuli, and this may have been elicited by better management of information in working memory.

In sum, bilingual children performed the task more efficiently than monolinguals, responding more rapidly throughout and achieving higher accuracy on the difficult incongruent trials. This pattern was found for both conditions that included low executive control demands and those for which executive control demands were higher. The second study pursued these results by presenting children with a visuospatial span task that manipulated working memory demands in a different way.

EXPERIMENT 4

Experiment 4 used a visuospatial working memory task to minimize the role of linguistic demands because of expected vocabulary differences between monolingual and bilingual children. The task was a span task, so working memory was assessed by evaluating the number of items children could correctly recall. As in Experiment 3, stimulus presentation was manipulated to create conditions that varied in their demands for executive control. Different results have been observed when comparing visuospatial working memory in which the information is presented simultaneously or sequentially. Rudkin, Pearson, and Logie (2007) administered the Visual Pattern Test (VPT; Della Sala, Gray, Baddeley, & Wilson, 1997) and a version of the Corsi blocks task (Corsi, 1972; Milner, 1971) and explored the involvement of executive function in each task. Although both visuospatial working memory tasks require participants to recall the positions of the presented stimuli, the VPT presents all of the stimuli at the same time, requiring only recall of positions, whereas the Corsi blocks task presents the stimuli sequentially, increasing memory demands to maintain and possibly manipulate the order of presentation. Rudkin and colleagues (2007) found that Corsi performance was affected by the inclusion of a dual task, whereas performance on the VPT was not disrupted. This difference was interpreted as evidence that sequential presentation recruits more resources than simultaneous presentation and, therefore, signals the involvement of greater executive functioning for sequential presentation. Not surprisingly, the ability to perform the simpler simultaneous task develops earlier than the ability to perform the more complex sequential task; that is, 5-year-olds are not yet capable of carrying out complex working memory tasks that involve manipulation of information, whereas 7-year-olds have developed this skill (Gathercole et al., 2004; Miles et al., 1996).

In Experiment 3 using a simple task, we showed that monolingual and bilingual children of the same chronological age were at different stages in developing their ability to perform this working memory task. The task in Experiment 4 is more complex and captures the development of the ability to mentally manipulate visuospatial information. This skill has been shown in previous research to develop over 5 to 7 years of age (Gathercole et al., 2004; Miles et al., 1996). Therefore, we included a group of older children to provide a more complete picture of the emerging ability to perform this task by monolingual and bilingual children. In the current study, children were asked to recall the positions of items in a matrix following simultaneous or sequential presentation. In addition to imposing a greater memory burden in that both position and order information are required, the sequential task also requires executive control to monitor two sources of information and update both position and order information (Rudkin et al., 2007). Thus, as in Experiment 3, the children's ability to perform a working memory task can be compared for a condition in which only simple recall is required and a more difficult condition in which memory and executive control demands are higher. If the working memory advantage for bilinguals is independent of other task demands, then the prediction is that bilinguals will outperform monolinguals on both conditions in that working memory is involved in both. If the bilingual advantage in working memory is constrained by other task demands, then bilinguals will demonstrate an advantage only when other executive control demands are high.

METHOD

Participants

The same 56 5-year-olds from Experiment 3 and a new sample of 69 7-year-olds (mean age =6 years 11 months, *SD* =2.76 months) participated in the second study (see Table 7). The new sample was composed of 34 monolinguals (16 boys and 18 girls) and 35 bilinguals (18 boys and 17 girls). All children lived in the same middle-class neighborhoods, and all parents reported having at least some postsecondary education. As in Experiment 3, the bilingual children spoke English at school and in the community and spoke a different language at home. All bilingual children had been exposed to both languages since birth and used them daily. The non-English languages included Arabic (3), Bengali (1), Cantonese (4), Chinese (3), Farsi (1), Hindi (1), Italian (1), Japanese (2), Persian (2), Mandarin (2), Portuguese (1), Punjabi (2), Russian (2), Spanish (1), Tamil (4), Urdu (4), and Vietnamese (1). The language history questionnaire completed by parents indicated that for bilinguals the language spoken by the children at home obtained an average score of 3.0 (SD =0.95), and the language spoken by parents to the children obtained an average score of 4.0 (SD =1.07), indicating a tendency to use the non-English language. The score for monolinguals was consistently 1.

Materials and procedure

The same background measures for receptive vocabulary and nonverbal fluid intelligence from Study 3 were used.

Frogs matrices task. The frogs matrices task (FMT) is a computerized variant of the Corsi blocks task (Berch, Krikorian, & Huha, 1998; Milner, Corsi, & Leonard, 1991) that measures visuospatial working memory. The task was programmed in E-Prime software (Schneider et al., 2002) and included two conditions. In both conditions, children were shown a 3 x 3 matrix on a 15-inch KEYTEC Magic Touch computer and were told that each of the nine cells represented a pond in which frogs had been resting. Frogs were presented either as a group (simultaneous condition) or one at a time (sequential condition), and children needed to remember which ponds had frogs in them. In the sequential presentation condition, the ponds needed to be recalled in the correct order. In the simultaneous presentation condition (Figure 21a), all of the frogs were shown for 2000 ms, followed by a 2000-ms delay with a blank matrix on the screen. At the end of the delay, a “ding” sound was heard, indicating that the child could respond by touching the screen to show the positions that had contained a frog. In the sequential presentation condition (Figure 21b), each frog occupied the pond for 1s. After the last frog disappeared, a “ding” sound indicated that the child could respond by touching each pond in which there had been a frog in the order they had been shown. Testing began with two frogs and increased by one frog after every second trial, producing two trials at each sequence length, to a maximum string length of 6. There were a total of 10 trials per condition.

Memory span was calculated as the longest string length in which the child remembered all of the frogs on at least one of the two trials. Total scores were calculated as the sum of all frogs correctly recalled up to the child's span and then were converted to proportion scores based on the maximum possible for that condition. For the simultaneous condition, the maximum score was 40. If a child was correct on both trials containing two frogs (2 + 2), was correct on one of the trials containing three frogs (3) but missed one of the frogs in the second trial with three frogs (2), and failed on both trials containing four frogs, remembering three frogs in the first trial (3) and two frogs in the second trial (2), then the child's span would be 3 and the total score would be 2 + 2 + 3 + 2 + 3 + 2 =14 or 0.35. For the sequential condition, the total possible was 80 because 1 point was awarded for each correct location and 1 point was awarded for recalling that location in the correct order. Thus, children received separate scores for accuracy (i.e., whether the selected frog was one shown in the trial) and order (i.e., whether the frog was given in the correct sequence).

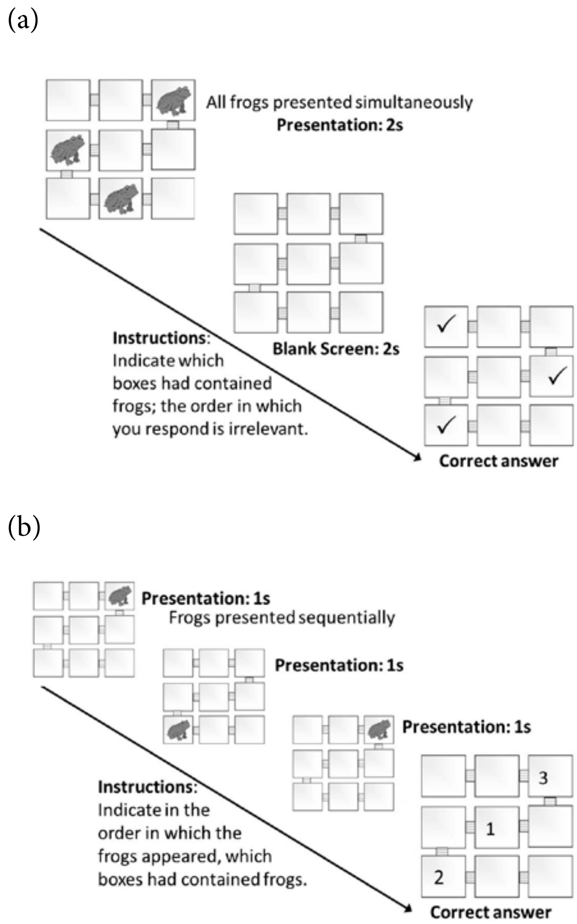


Figure 21. *Sample items for the (a) simultaneous and (b) sequential presentation of the Frogs Matrices Task in Experiment 4.*

Children were tested individually in a quiet room. At the end of each session, children were given stickers and thanked for their participation.

RESULTS

Background scores are reported in Table 7. Within each age group, there was no difference between language groups in age (*F*s < 1). Three-way ANOVAs for gender, language, and age group showed no differences in K-BIT for any factor (*F*s < 1). However, for the PPVT-III standard scores, there were main effects of language, $F(1, 117) = 24.66$, $p < .001$, $d = 0.78$, and age group, $F(1, 117) = 13.80$, $p < .001$, $d = 0.66$, with no differences by gender and no significant interactions. Scores were higher for monolinguals and 5-year-olds. Because PPVT-III scores are standardized by age, we assume that the difference between 5- and 7-year-olds' scores reflects sampling differences. As in Experiment 3, there were no correlations between PPVT-III and the dependent measures, ruling out language group vocabulary differences as a confound in the results. There were no gender effects, so data were collapsed across gender in subsequent analyses.

For the FMT, one 7-year-old monolingual was excluded because his data from the sequential condition were missing due to technical failure. Two measures were calculated for each condition as described above: span and proportion of total correct answers. The data are presented in Table 9. Three-way ANOVAs for condition, age group, and language group were conducted for each measure. The analysis of span indicated main effects of condition, $F(1, 120) = 187.17$, $p < .001$, $d = 1.56$, with higher scores for the simultaneous presentation ($M = 5.3$, $SD = 1.1$) than for the sequential presentation ($M = 3.5$, $SD = 1.2$), and age group, *F*(1, 120) =14.81, *p* =.001, *d* =0.45, with the older children reaching a higher span (*M* =4.6, *SD* =1.0) than the younger children (*M* =4.1, *SD* =1.2). No other main effects or interactions were found

Table 9. *Mean scores (and standard deviations) of span and proportion correct scores for FMT in simultaneous and sequential presentation conditions by age and language group in Experiment 4.*

Measure	Task	5-year-olds		7-year-olds	
		Monolingual	Bilingual	Monolingual	Bilingual
Span	Simultaneous	4.9 (1.3)	5.1 (1.3)	5.5 (0.8)	5.5 (0.9)
	Sequential	3.2 (0.9)	3.3 (1.4)	3.7 (1.0)	3.8 (1.4)
Proportion correct	Simultaneous	.70 (.28)	.79 (.25)	.83 (.23)	.81 (.26)
	Sequential	.41 (.17)	.50 (.26)	.46 (.17)	.61 (.18)

The analysis of proportion correct indicated main effects of condition, *F*(1, 120) =172.59, $p < .001$, *d* =1.22, with higher scores for the simultaneous presentation (*M* =.78, *SD* =.26) than for the sequential presentation (*M* =.50, *SD* =.21), age group, *F*(1, 120) =6.31, *p* =.01, *d* =0.34, with higher scores for the older children (*M* =.68, *SD* =.22) than for the younger children (*M* =.60, *SD* =.24), and language group, *F*(1, 120) =4.17, *p* =.04, *d* =0.35, with higher scores for the bilinguals (*M* =.68, *SD* =.27) than for the monolinguals (*M* =.60, *SD* =.27). There was a significant two-way interaction of condition by language group, *F*(1, 120) =3.73, *p* =.05, η^2_p =.03. Pairwise comparisons revealed that language group differences were significant in the difficult sequential condition, *F*(1, 120) =9.97, *p* =.002, *d* =0.61 (monolinguals: $CI_{.95}$

=.39–.49%; bilinguals: CI.*95* =.50–.60%), but not in the easier simultaneous condition (*F* < 1; monolinguals: CI.*95* =.71–.84%; bilinguals: CI.*95* =.74–.86%). The three-way interaction of language group by age group by condition was also significant, *F*(1, 120) =4.53, *p* =.03, η^2_{p} =.035. For bilinguals, there were no differences in age for the simultaneous condition (*F* <1; 5-year-olds: CI$_{.95}$ =.70–.87%; 7-year-olds: CI$_{.95}$ =.72–.89%), but there was an advantage for older children in the sequential condition, *F*(1, 120) =5.05, *p* =.02, *d* =0.50 (5-year-olds: CI$_{.95}$ =.42–.57%; for 7-year-olds: CI$_{.95}$ =.54–.67%). For monolinguals, older children performed better in the simultaneous condition, *F*(1, 120) =5.73, *p* =.01, *d* =0.41 (5-year-olds: CI$_{.95}$ =.60–.79%; 7-year-olds: CI$_{.95}$ =.76–.93%), but not in the sequential condition, *F*(1, 120) =1.40, *p* =.20, *d* =0.29 (5-year-olds: CI$_{.95}$ =.34–.48%; 7-year-olds: CI$_{.95}$ =.40–.53%). Therefore, 5-year-old bilinguals performed at the same level as 7-year-old monolinguals in the simpler simultaneous condition.

DISCUSSION

As in previous research, children performed better in the simultaneous condition than in the sequential condition (cf. Lecerf & de Ribaupierre, 2005; Mammarella, Pazzaglia, & Cornoldi, 2008; Tucker, Novelly, Isaac, & Spencer, 1986). Moreover, children’s ability to perform these tasks improved over the ages studied (cf. Gathercole et al., 2004; Miles et al., 1996). Although there were no language group differences in span, bilingual children obtained higher scores than monolinguals in both conditions on the more sensitive proportion correct score. The two-way interaction showed that bilingual children obtained higher scores than monolinguals on the more difficult sequential condition, and the three-way interaction revealed that the younger bilingual children performed better than their monolingual counterparts on the simpler simultaneous condition.

GENERAL DISCUSSION

These two studies addressed the question of whether bilingual advantages could be found in working memory and, if so, whether those advantages were tied to other components of executive control such as inhibition and shifting. In both experiments, bilingual children outperformed monolinguals on the working memory tasks, and evidence for this advantage was found across manipulations in the level of other executive control components. In Study 3, the difference was found for both a simple condition in which children needed to hold two or four rules in mind to press a response key and a difficult condition in which the response also required executive control to ignore distraction from a misleading position and shift between trials. In Study 4, the difference was found in a simple condition in which young bilingual children performed at the level of older monolingual and bilingual children and in a difficult condition in which children needed to recall both position and order information and ignore interference from competing positions in the wrong sequence. Notably, however, the advantage for the bilingual children was larger in the more difficult conditions, and the other executive function components, such as performing the incongruent trials in Study 3, were also handled better by the bilingual children. Thus, bilingual children do perform better than monolinguals on working memory tasks, an advantage that is nonetheless related to the other executive function demands of the task. This pattern of results is consistent with the view of unity and diversity described by Miyake and Friedman (2012) and contributes to our understanding of the development of working memory in monolingual and bilingual children and to the relation between working memory and the other executive control components.

Consider first the implications for understanding the development of bilingual children. The results clearly indicate that explanations of developmental or executive function differences between monolingual and bilingual children need to include differences in working memory. Earlier accounts focused on specific components such as inhibition (e.g., Bialystok, 1999), but more recent studies have looked beyond inhibition or a single component explanation (e.g., Bialystok, 2010). The presence of both main effects of working memory advantages for bilingual children and an enhancement of those effects when other executive function demands are present is consistent with the importance of working memory over and above other aspects of executive functioning.

Previous studies examining the working memory ability of monolingual and bilingual children have failed to find clear evidence for a bilingual advantage. One reason for this may be found in the differences in the tasks used in the current studies and those used in previous research. For example, Bialystok and Feng (2010) asked children to recall lists of words, and Engel de Abreu (2011) presented several tasks, all of which involved words or digits. In both cases, performance on the working memory tasks was equivalent for monolingual and bilingual children, but bilingual children generally experience more difficulty than monolinguals in verbal processing. In both of those studies, bilingual children obtained lower scores than monolinguals on tests of receptive and productive vocabulary. This difference in vocabulary may have created a handicap for bilingual children performing verbal tasks, and the equivalent performance may in fact be masking a latent bilingual advantage. In the current studies, the tasks were visual and visuospatial, with very low verbal requirements, minimizing the possibility of a confound with linguistic processing. In this case, bilingual children outperformed monolinguals on the working memory measures.

The second implication of the current results is for conceptions of the relation among components of the executive function. The bilingual advantage in the working memory tasks in the current studies was independent of other task demands, as shown by the main effect of language group in both studies. In Study 3 bilingual advantages were found for both conflict and nonconflict blocks, and in Study 4 bilingual children outperformed monolinguals in total score for both the simpler and more difficult memory conditions. These results point to an effect of bilingualism on working memory that is separate from previously reported advantages in executive functioning. However, the executive control demands of the task in both studies had a significant role in determining the outcomes for working memory. In Study 3 a bilingual advantage in accuracy was found for the difficult incongruent trials, and in Study 4 the young bilingual children showed a better performance than monolinguals in the simple condition, whereas in the more difficult condition the bilingual advantage was equivalent for children at the two age levels. These results suggest that the bilingual advantage might not be attributable to a single component of executive functioning and that working memory alone is not modified by bilingualism; instead, the experience of bilingualism affects an integrated set of abilities in which efficiency is enhanced on cognitively demanding tasks.

This view of a more integrated set of abilities for the executive function is consistent with the position offered by Miyake and Friedman (2012), arguing for both unity and diversity of the traditional components of executive control. Working memory can be manipulated and assessed somewhat independent of other executive control components, but the results from the current studies show that the outcomes depend on the other task demands. It is also consistent with an interpretation offered by Hilchey and Klein (2011), who attribute the bilingual advantage not to a specific component such as inhibition but rather to an overall ability to monitor attention (see also Costa et al., 2009). Thus, the current results endorse a view that attributes an advantage to bilingual children on working memory tasks and also defines a role for other task demands in controlling those outcomes.

The current studies fill an important gap in our understanding of the bilingual mind. Working memory is crucial to cognitive development, and its precocious development by bilingual children is important evidence for developmental effects of experience. The results also contribute to the growing literature on the effect of experience on cognitive outcomes. In this regard, bilingualism is particularly important because, unlike experiences such as musical training and video game playing, bilingual children are not typically preselected for talent or interest. The children in the current studies were bilingual because of a family history of immigration and not because of a talent for learning languages. This is powerful evidence for the role of experience in shaping the mind and directing the course of development.

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Experimental Series III. SIMULTANEOUS INTERPRETATION SELECTIVELY INFLUENCES WORKING MEMORY AND ATTENTIONAL NETWORKS (Experiments 5 & 6)*

Recent research has shown that becoming an expert in a certain domain may lead to a transfer of the acquired skills to other domains requiring similar abilities. Thus, the cognitive skills acquired by professional interpreters after intensive training may also transfer to other domains. Simultaneous interpreters are known to develop high working memory capacity (e.g., Christoffels, de Groot and Kroll, 2006; Signorelli, Haarmann, & Obler, 2012). However, little is known about transfer of other processes such us updating and some aspects of attention also involved in interpretation. In Experiment 5, we found that interpreters outperformed a control group in updating skills, as measured through a dual version of the ***n****-back task (Jaeggi et al. 2007). In Experiment 6, use of the ANTI-V allowed us to reveal that interpreting differentially modulates the interactions between attentional networks. Thus, we found no group differences in conflict resolution, but the interaction between the alertness and orienting networks differed between interpreters and non-interpreters. Taken together, these results suggest that experience in simultaneous interpreting transfer to other domains but this transfer is specific to the cognitive processes more closely involved in the interpreting tasks.*

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Recent studies report that becoming an expert in a certain domain may lead to a transfer of the acquired skills to other domains that require similar abilities. For instance, skilled video-game players develop better attentional processing (Green & Bavelier, 2007), musical training influences executive functioning and fluid intelligence (e.g., Bialystok & Depape, 2009; Habib & Besson, 2009; Schellenberg, 2004) and specific training in certain cognitive functions, such as working memory, has shown to modify attentional processes (e.g., Lilienthal, Tamez, Shelton, Myerson, & Hale, 2013). Of relevance here, bilingual speakers have also been shown to develop efficient cognitive control across non-verbal domains (for a review, see Kroll & Bialystok, 2013).

Simultaneous interpretation is undoubtedly an extremely demanding cognitive activity and, as a consequence, it should influence a number of cognitive functions. Interpreting requires processing (listening to) a given source language while producing (speaking) in a different target language. In addition, interpreters need to concurrently reformulate (translate) the incoming information into the target language. The biggest challenge for this complex task is simultaneity since many processes have to be performed concurrently, which requires an outstanding cognitive control system. To achieve successful interpretation, professionals need to coordinate two languages, maintaining both as active and functional and without producing interference from each other (Christoffels & De Groot, 2004; Danks, Shreve, Fountain, & McBeath, 1997; Gile, 1991, 1997). In addition, they also need to retain and manipulate considerable amounts of information. Therefore, expert interpreters should rely on high level skills for controlling their attentional resources and managing information, which should be reflected in superior performance on tasks that involve resources similar to those recruited by simultaneous interpretation.

Findings from a variety of studies support the hypothesis that working memory (WM) contributes to successful interpreting and that interpreters outperform non-interpreters in WM capacity (Christoffels, De Groot, & Waldorp, 2003; Darò & Fabbro, 1994; Liu, Schallert, & Carroll, 2004; Padilla, Bajo, Cañas, & Padilla, 1995; Tzou, Eslami, Chen, & Vaid, 2012). However, the question of interest is whether this benefit reflects a general advantage in terms of executive control or if this advantage is restricted to memory processes.

WM refers to the processes involved in temporarily storing and manipulating information in mind (e.g., Baddeley, 1986, 2003). Given that interpreting requires the temporary retention and processing of high quantities of verbal information in the source and target languages, many studies have focused on studying the WM skills in interpreters. Most WM models agree that it involves storage components and a control system in charge of coordinating the stored information (Baddeley & Hitch, 1974; Posner & DiGirolamo, 2000; Kane, Bleckley, Conway, & Engle, 2001). Whereas the storage systems seem to be domain-specific for verbal and visuospatial information (Baddeley & Hitch, 1974; Baddeley, 1986), the executive component is thought to be domain-free in the ability to control processing (Engle, 2002). For example, Baddeley's influential model (Baddeley, 1986, 1996, 2000) proposes that WM is composed of two temporary memory stores (the phonological loop and the visual sketchpad), an episodic buffer for rehearsing the stored information, and a central executive that coordinates the active contents and it is responsible for high-level cognitive activities such as planning, coordinating and updating the flow of information, as well as retrieving contents from long-term memory (Baddeley, 1996). Therefore, WM essentially accomplishes two different functions: maintenance and monitoring of active information.

Similarly, interpreting goes beyond the simple maintenance of verbal information since it entails continuous monitoring and updating of the input and output of verbal information. The incoming information needs to be actively understood and manipulated (translated); furthermore, information must be updated so that new information should substitute the one that is no longer relevant. Therefore, one might expect that professional interpreters excel on tasks that tap into the executive component of WM.

To measure WM capacity, most of the research has employed complex-span tasks, which involve both memory and executive processes. Complex-span tasks typically require participants to maintain short lists of information in memory while simultaneously processing other information, such as solving equations (e.g., Turner & Engle, 1989) or reading sentences (e.g., Daneman & Carpenter, 1980). Thus, whilst the central task requires storage of a number of items (short-term memory), the secondary task requires the continuous monitoring and updating of the information in mind. To successfully perform the memory task, the participant needs to either maintain or discharge the information depending on its relevance (i.e. the to-be-recalled word and the digits of the equation to be solved). Consequently, although the critical score in complex-span tasks is the number of items correctly recalled (the so-called memory span), variance in WM span reflects memory skills as well as the ability to manipulate information while avoiding interference caused by the concurrent tasks (e.g., Engle, 2002; Kane et al., 2001; Kane, Conway, Hambrick, & Engle, 2007). Given that WM capacity is a limited resource involved in many of the mental operations performed while interpreting, high WM capacity is crucial for efficient interpreting (De Groot & Christoffels, 2006).

Previous research has found superior WM capacity in interpreters relative to non-interpreters on a variety of span tasks, such as reading span (Christoffels, De Groot, & Kroll, 2006; Padilla et al., 1995; Signorelli, Haarmann, & Obler, 2011; Tzou et al., 2012), digit span (Padilla et al., 1995; Tzou et al., 2012) or listening span tasks (Köpke & Nespoulous, 2006). To evaluate the relative involvement of storage and executive WM components, some researchers have distinguished between simple (storage) and complex span measures (storage plus processing), with contradictory results. For example, Köpke & Nespoulous, (2006) found that whilst interpreters failed to show an advantage on simple-span tasks (requiring only temporal maintenance of information) they outperformed non-interpreters on complex-span tasks, thus suggesting that interpreters' advantages in WM tasks are due to differences in executive control. In contrast, others have found the opposite pattern of results, with equivalent performance of interpreters and non-interpreters on complex WM tasks (listening span task; Liu et al., 2004; Stavrakaki & Megari, 2012), but better performance of interpreters in storage tasks (e.g., digit, word, and nonword span tasks). This finding would suggest that interpreters excel in the ability to maintain information in mind. Therefore, it is unclear from span tasks whether the reported advantages of interpreters in WM capacity reflect higher functioning in storing information, a better ability to manipulate information or a combination of both.

An interesting source of evidence to disentangle the relative involvement of each WM component comes from studies that measure free recall under conditions of articulatory suppression. In this paradigm, the verbal storage is overloaded by asking participants to produce irrelevant speech (e.g., the word "the") while memorizing groups of words. The concurrent articulation prevents participants from subvocally rehearsing so that the encoding of phonological information is consequently disrupted (Baddeley & Larsen, 2007; Baddeley, 1986). Interestingly, this task is closely related to simultaneous interpreting as both activities involve comprehension and language production at the same time. In fact, it has been suggested that interpreting is an extreme form of articulatory suppression (Yudes, Macizo, & Bajo, 2012) and that the two tasks may require similar processes to be solved efficiently.

A number of studies have found that as monolinguals and bilinguals (with no professional experience in interpreting) reduce their recall of words under articulatory suppression conditions, interpreters are unaffected by the production of irrelevant speech (Chincotta & Underwood, 1998; Padilla, Bajo, & Macizo, 2005; Padilla et al., 1995; Yudes et al., 2012). Interestingly, they found that the interpreters' advantage in coordinating comprehension and production seems to rely more on linguistic skills than on WM storage capacity and coordination of cognitive resources. For example, in a series of experiments, Padilla and colleagues (Padilla et al., 2005) compared a group of interpreters, a group of matched high span monolinguals, and a control monolingual group with an average WM span. In Experiment 5 they found that whereas interpreters were unaffected by articulatory suppression, high WM participants showed a normal articulatory suppression effect that was similar to that seen in the control group. This result indicates that large WM capacity may be necessary but not sufficient to coordinate comprehension and production. In Experiment 6 the same participants were asked to study a list of words while performing a visuospatial secondary task. On this occasion all the participants were affected by the concurrent task, showing less recall in the dual-task condition. In addition, the cost of the articulatory suppression effect seems to be modulated by linguistic knowledge of the studied material (Padilla et al., 2005, Experiment 3) and the complexity of articulations (Yudes et al., 2012), thus suggesting that language skills may play a crucial role in the interpreters' superiority in coordinating comprehension and production.

Enhanced linguistic knowledge might also underlie high WM capacity since it has been shown that familiarity with a language influences WM storage capacity (Gathercole, 1995; Gathercole, Pickering, Hall, & Peaker, 2001; Thorn & Gathercole, 2001). These findings, however, are compatible with the idea that efficient monitoring may also play a role in the interpreters' superior WM capacity and coordination of two languages in mind. Given that the former studies in this field essentially employed verbal material, their findings may be reflecting a combination of high language knowledge and enhanced executive-control capacity. However, if executive control is domain-free and is enhanced in interpreters, we should also observe their superiority in non-verbal tasks.

To evaluate the executive nature of the interpreters' WM skills it is necessary to reduce the influence of the storage demands as much as possible, and the *n*-back tasks seem to employ the ideal procedure to achieve this goal. *N*-back tasks are widely used to assess WM updating and monitoring skills while minimizing the storage and verbal components. Different versions of this task, first developed by Gevins and Cutillo (1993), are extensively used to assess the capacity to update and monitor information in a range of different populations (see Owen, McMillan, Laird, & Bullmore, 2005, for a meta-analysis). In the standard paradigm, participants are presented with a series of stimuli and they are told to respond whenever the presented stimulus matches the one that was displayed *n* trials earlier. *N* changes across different conditions and usually ranges between 1, 2, or 3. Given the limited number of to-be-recalled items, the main challenge of the task is much more related to updating the stream of items after the presentation of each new item (i.e., by activating and suppressing information), than storing items. The standard pattern of results obtained is that accuracy and RTs decline with the increase of load (*n*). In this manner, we might be able to evaluate the effects of the experience in professional interpreting on the efficiency of updating and monitoring information while reducing the impact of maintenance and linguistic skills. According to the idea that interpreting entails high demands of monitoring, we would expect interpreters to excel in this task relative to controls. Furthermore, this advantage should be especially evident under highly demanding dual-tasks, in which participants need to manage information coming from different sources or channels. A high level version of this paradigm is the dual *n*-back task (Jaeggi et al., 2007). In this procedure, participants need to recall not only one, but two different streams of stimuli presented through different channels: auditory and visual. Thus, participants need to manage two independent tasks at a time, which is a similar coordination challenge to the management of two languages while interpreting.

Given that updating is thought to be one of the components of the executive-control system (e.g., Miyake & Friedman, 2012; Miyake et al., 2000), interpreting may not only influence WM processes but a widespread network of attentional control. Indeed, different studies suggest that interpreting influences executive control mechanisms (Hervais-Adelman, Moser-Mercer, & Golestani, 2011; Yudes, Macizo, & Bajo, 2011). However, it is unclear if it is a general enhancement or whether it is restricted to processes more closely related to interpreting. On the neurophysiological level, Hervais-Adelman, Moser-Mercer and Golestani (2011) reported that, compared with non-interpreters, interpreters show an increase in gray matter volume in areas related to language (left supramarginal gyrus and left pars orbitalis) and, more importantly for the present purposes, in areas related to executive control (left middle frontal gyrus, left middle temporal gyrus, and rostral anterior cingulate). In a behavioral study by Yudes, Macizo, and Bajo (2011) different components of executive control (cognitive flexibility and inhibitory control) were evaluated in a sample of professional interpreters, bilinguals, and monolinguals. Their results showed that whereas professional interpreters were better than the other two groups in cognitive flexibility and set shifting, there were no group differences in inhibitory control. This result is in accord with findings by Köpke and Nespoulous (2006), who found no advantage for professional interpreters in a Stroop task, which also requires participants to avoid interference from conflicting information. Taken together, these findings suggest that interpreting has positive consequences on executive functions, although they seem to only be evident in attentional skills more closely related to simultaneous interpreting.

One of the aims of the present study was to investigate the link between interpreting and different attentional functions. Although the above-mentioned studies have suggested that interpreting influences executive control, none have investigated its relation to attentional networks. According to Posner and colleagues (Posner & Petersen, 1990; Posner, 1994), attention is composed of three independent but coordinated functions: alertness, orienting, and executive control. Alertness serves the purpose of achieving and maintaining high sensitivity to incoming stimuli, and it involves phasic and tonic alertness (e.g., Posner, 2008). Phasic alertness refers to the increased response readiness for a short period of time following a warning external stimulus, whereas tonic alertness (or vigilance) indicates sustained activation over a period of time (e.g., Roca, Castro, López-Ramón, & Lupiáñez, 2011). The orienting network involves the selection of information from sensory input. The executive control network involves monitoring and solving conflict from interfering information. The Attentional Network Test for Interactions (ANTI; Callejas, Lupiáñez, & Tudela, 2004) represents an excellent tool to assess individual differences in these three attentional networks, and it can be regarded as a combination of cued reaction time (Posner, 1980) and the flanker task (Eriksen & Eriksen, 1974). In this task the warning signal was auditory, instead of being a visual cue, to measure alertness independently whilst non-predictive peripheral cues were presented to obtain the orienting index. The ANTI task has been shown to be a useful tool for studying individual differences in attentional functioning in a variety of research contexts such as childhood development (e.g., (Rueda et al., 2004); dementia (e.g., Fuentes et al., 2010); anxiety (e.g., Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010), mindfulness (e.g., Van den Hurk et al., 2010), driver behavior (López-Ramón, Castro, Roca, Ledesma, & Lupiáñez, 2011; Weaver, Bédard, McAuliffe, & Parkkari, 2009), and sleep deprivation (Roca et al., 2012).

A recent variation of the task (ANTI-Vigilance, ANTI-V; Roca, Castro, López-Ramón, & Lupiáñez, 2011) includes a vigilance task, which directly measures tonic alertness while assessing the functioning of the three attentional networks (alerting, orienting, and executive control). Thus, the employment of this task could allow us to study to what extent the superiority of professional interpreters is restricted to WM or if it also relates to a general enhanced attentional system or to any of its specific networks.

To summarize, the main goal of the present study is to evaluate the influence of simultaneous interpreting on WM monitoring skills and to ascertain whether the interpreter's superiority in WM relates to specific or general superior attentional capabilities. To this end, we conducted two experiments comparing professional interpreters with control participants matched in demographic features, second language proficiency and fluid intelligence, but with no experience in professional interpreting. In the first experiment, we evaluated updating skills with the *n*-back task. We manipulated the monitoring and updating demands of the task by including simple and dual conditions and, additionally, we explored possible benefits from practice by dividing the task into two blocks. Given that simultaneous interpreting involves maintaining two languages active in mind and coordinating comprehension and production, we expect interpreters to outperform non-interpreters in a dual *n*-back task. This task is thought to be highly demanding since it requires the online updating and monitoring of information presented simultaneously from two sources. In our second experiment we assessed three attentional networks (conflict, orientation, and alertness –phasic and tonic/vigilance) using the ANTI-V (Roca et al., 2011). If there is a general superiority of the interpreters in attentional control we should observe smaller effects in all of the attentional measures. In contrast, if only some specific attentional control processes are directly related to experience in interpretation, results would show group differences for some specific attentional indices but not for others. For example, because interpreters keep their two languages active in mind a so that they are not placed in competition, we might expect that interpreting may not affect conflict resolution. In contrast, alertness and orienting can be enhanced by interpreting experience since interpreting requires high levels of alert and high responsiveness to contextual cues during task performance.

EXPERIMENT 5

METHOD

Participants

Thirty-two participants took part in this study: 16 interpreters and 16 control participants. The participants in the control group were highly fluent in a second language but had no professional experience in interpreting or translation. The two groups reported to be comparable in age and in IQ, as reflected by their scores in the Raven's Standard Progressive Matrices test (SPM; Raven, Court, & Raven, 1988) (see Table 10).

All participants were Spanish speakers and reported to be very proficient in a second language; namely, for controls: Arabic (2), Catalan (2), English (4), French (2), German (6), and Italian (1); and for interpreters: English (6), French (6), German (3) and Russian (1). All participants fulfilled a language history questionnaire previously used in our laboratory (see Macizo & Bajo, 2006; Macizo et al., 2010, Yudes et al., 2011) and were asked to self-rate their L1 and L2 across four language skills (speaking, speech comprehension, writing and reading) in a 10 scale (maximum score = 10). Analyses of these parameters revealed that both groups were highly proficient in L1 and L2, with no differences between their self-rated proficiency scores in the two languages (see Table 10).

Materials and procedure

All participants were tested individually in a quiet room after signing a consent form and completing the language history questionnaire.

Table 10. *Mean (and standard deviation) background measures and self-rated language proficiency by language group*

	Int.[1]	Cont.[2] Exp.5	Cont.[2] Exp.6	Exp. 5			Exp. 6		
				F	*p*	η^2_p	*F*	*P*	η^2_p
N	16	16	15						
Age	37 (9.8)	34 (11.4)	35 (10.9)	0.68	.417	.024	0.55	.467	.019
SPM	50 (5.2)	47 (9.4)	49 (9.7)	1.0	.321	.039	0.13	.537	.005
Language proficiency									
L1									
Speaking	9.6 (0.5)	9.7 (0.5)	9.7 (0.5)	0.08	.779	.005	0.10	.760	.005
Oral Comp.	9.8 (0.4)	9.9 (0.3)	9.7 (0.7)	0.36	.555	.022	0.20	.665	.010
Writing	9.8 (0.4)	9.2 (1.6)	9.4 (1.0)	1.27	.275	.070	1.28	.271	.060
Reading	9.9 (0.3)	9.8 (0.7)	9.2 (1.5)	0.27	.610	.016	2.21	.153	.099
L2									
Speaking	9.3 (1.5)	9.4 (0.7)	9.2 (0.8)	0.07	.796	.004	0.07	.794	.003
Oral Comp.	9.6 (1.0)	9.3 (0.9)	9.2 (0.9)	0.40	.537	.023	1.1	.300	.054
Writing	8.6 (1.3)	9.3 (.9)	9.0 (1.0)	2.12	.163	.111	0.66	.426	.032
Reading	8.9 (1.3)	9.6 (0.7)	9.3 (0.9)	1.81	.196	.096	0.89	.362	.042

[1] Intérprete

[2] Control

N-back task. In this task participants were presented with a pseudo-random sequence of stimuli and instructed to respond "yes" to any item that matched the stimulus presented *n* times earlier. The *n* value represents the memory load, which varied from 1 to 3 items. To control for monitoring demands, we administered two versions of the task: single and dual. To reduce possible training effects between modalities, we employed different stimuli in the single and dual tasks. Hence, in the single task stimuli were letters (20 distinct capitalized consonants from the alphabet) presented in the middle of the screen. In the dual task, participants were presented with stimuli from two different channels: visual and auditory. The visuospatial stimuli consisted of blue squares (4×4 cm) that could appear in eight different peripheral locations of the display. For the auditory stimuli, we used eight different syllables (/*k*a̱/, /fa̱/, /xa̱/, /la̱/, /ma̱/, /pa̱/, /ɾa̱/, /ta̱/) presented through a pair of headphones (see Figure 22). In both versions, we manipulated the working memory load by introducing three load conditions. In the 1-back condition participants were required to detect if the current stimuli matched the one immediately preceding it (one trial back). In the 2- and 3-back conditions, the target was any stimuli identical to the one presented two and three trials back, respectively.

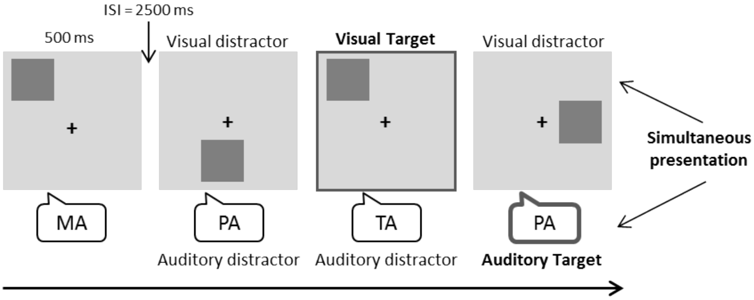

Figure 22. *Schematic representation of a stream of trials in the dual n-back task.*

In the single *n*-back version each letter appeared for 500 ms followed by a blank screen of 3000 ms. Participants were instructed to press "yes" ("1" key in the alphanumeric keyboard) for targets and "no" ("2" key in the alphanumeric keyboard) if the stimulus was a non-target. In the dual *n*-back task (adapted from Jaeggi et al., 2007) visuospatial and auditory stimuli were presented simultaneously (for 500 ms) with an inter-trial interval of 2500 ms. The keys associated with visual and auditory stimuli ("z" and "m" in the keyboard) were counterbalanced between subjects. The four conditions were presented in a fixed order (0-, 1-, 2-, and 3-back) in two blocks. In each block, participants carried out all conditions sequentially.

The task started with the single version of the task with each load condition containing a practice block (20 trials, 7 targets) followed by two experimental blocks (30 trials, 10 targets each) separated by a brief break. The load conditions were presented sequentially starting with the easiest 1-back condition and finishing with the hardest 3-back condition. Then, participants took a break and performed the Raven's Matrices test, followed by the dual version of the task. Because of the complexity of the dual *n*-back task, we introduced a practice 0-back condition in which participants were asked to press the correspondent key whenever they listened to the syllable /*k*a̲/ and to press a different key if they saw the visuospatial stimulus in the upper left corner. This ensured that participants could get familiar with performing two concurrent tasks while eliminating the updating component. After the practice trials, participants engaged in the experimental blocks. As in the single version, participants were presented with two blocks for each load condition. Each block consisted of 30 trials (10 targets and 20 non-targets per modality; the targets could occur either in only one or in the two modalities at the same time). Therefore, we recorded a total of 20 targets per load condition in the single task and 40 targets (20 visuospatial and 20 auditory) for the dual task.

RESULTS AND DISCUSSION

Following recommendations by Haatveit and colleagues (Haatveit et al., 2010), sensitivity was estimated with *d'* from the rates of hits and false alarms. 0 and 1 values were substituted by .01 or .99 respectively to obtain an adequate approximation to the Signal Detection Theory indices. In order to check for practice effects, we compared performance in the first and second blocks. This accuracy measure was subject to an ANOVA with Task (single/dual), Block (first/second), and Load (1-, 2-, 3-back) as repeated measures factors and interpreting experience (interpreters/controls) as a between-subjects factor. Planned comparisons with the Bonferroni correction were performed where appropriate.

The results of this analysis (see Figure 23) showed significant main effects of Task, $F(1, 29) = 118.7$, $MSE = 0.94$, $p < .01$, $\eta^2_p = .81$, Block, $F(1, 29) = 10.5$, $MSE = 0.17$, $p < .01$, $\eta^2_p = .27$, Load, $F(2, 58) = 199.4$, $MSE =0.47$, $p < .01$, $\eta^2_p = .87$, and Group, $F(1, 29) = 5.5$, $MSE =2.47$, $p < .03$, $\eta^2_p = .16$. Planned comparisons revealed that overall interpreters ($M = 3.0$, SD = 1.4) were more accurate than controls ($M = 2.7$, SD = 1.2). Also, participants were more accurate when responding to the single ($M = 3.4$, SD = 1.0) than to the dual task ($M = 2.3$, SD = 1.3), and to the second ($M = 2.9$, SD = 1.2) compared to the first block ($M = 2.8$, SD = 1.3). As expected, it was easier to respond to 1-back ($M = 3.8$, SD = 0.8) than to 2-back ($M = 2.7$, SD = 1.1), which in turn was easier than the 3-back condition ($M = 2.1$, SD = 1.2) (all *p*s < .01).

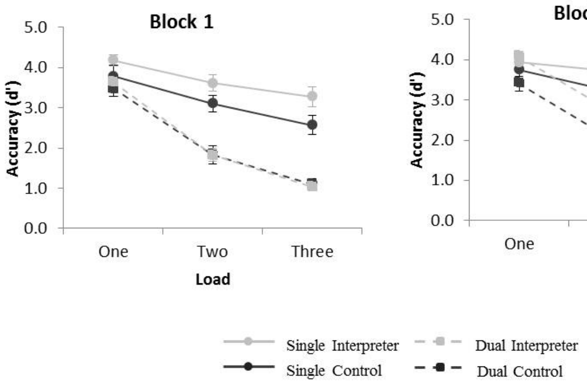

Figure 23. *Mean accuracy (d') of single and dual n-back tasks by block and group in Experiment 5.*

The 3-way interaction Block × Task × Group was statistically significant, $F(1, 29) = 4.862$, $MSE = 0.036$, $p < .05$, $\eta^2_p = .144$. None of the other 3 and 4 way interactions reached significance (all *p*s > .1). To further explore the two way interaction a mixed ANOVA Block × Group was performed for each task (single and dual). The analyses revealed that whereas both groups kept their performance at the same level in the two blocks of the single task (controls: $M = 3.2$, SD = 1.0 in the first block and $M = 3.2$, SD = 0.9 in the second block; interpreters: $M = 3.7$, SD = 0.9 in both blocks), interpreters improved their performance from the first to the second block so that their accuracy in the dual task increased with practice (from $M= 2.2$, SD = 1.3 to $M = 2.7$, SD = 1.3), whereas the control participants scored lower in the two blocks ($M = 2.1$, SD = 1.2 vs. $M = 2.2$, SD = 1.2) relative to the interpreters.

Although all participants showed the standard effect of load and committed more errors in the conditions with more memory load, interpreters were generally more accurate than controls, thus suggesting that they possess better updating skills than non-interpreters. A closer look at the data revealed that the performance of both groups was similar in all conditions except for the second block of the dual task, where interpreters were superior regardless of load condition. Therefore, although performance in the first block of the dual task was low for all participants, only the interpreters were able to benefit from practice and increased their performance from the first to the second block. Thus, when participants needed to perform two concurrent tasks at a time, the performance in the first block was generally very low, particularly in the 2- and 3-back. Nevertheless, interpreters were able to increase their task performance with practice, and to reach good accuracy levels. However, in the easier single task condition, all participants were able to perform *n*-back task to a higher level independently of the block and load condition, and no group differences were observed.

Hence, the results of Experiment 5 suggest that interpreters, relative to control participants matched in language proficiency, showed superior performance in a task requiring monitoring and updating of information. It is worth noting that both groups were comparable in WM amplitude, suggesting that the superior performance of the interpreters in the *n*-back task might result from differences in processes (i.e., updating) that are especially involved in interpreting. Of chief importance is the fact that our finding is compatible with the adaptive control hypothesis (Green & Abutalebi, 2013), which posits that the recurrent use of executive processes to negotiate language activation and language selection modifies the coordination of the precise mechanisms engaged. Consequently, interpreters would show a reorganization of the cognitive functions required by the interpretation task. In Experiment 6, we aimed to further explore if this superior performance is specific to processes involved in interpreting by examining the performance of interpreters and controls in the ANTI-V task. If the interpreters' advantages are not confined to WM, one might suppose that some attentional functions could be modified by training in interpretation. However, if we analyze the processes involved in interpreting, we might expect that experience in interpreting may not equally affect the attentional networks. Due to its complexity, interpreting requires high levels of arousal during task performance. Similarly, interpreting requires high responsiveness to contextual cues to orient their attention to the correct information. Hence, *a priori* this theoretical analysis suggests that the alertness and orienting networks may have a major role to play in the interpreting situation. In contrast, because the two languages need to be continuously active, they are not placed in a conflict situation and do not compete with each other. Hence, interpreters might not show any advantage in conflict resolution indexes. In sum, and based on previous research (Köpke & Nespoulous, 2006; Yudes et al., 2011) we would expect enhancement of the orienting and alert networks but not of conflict resolution.

EXPERIMENT 6

METHOD

Participants

In this study, we tested the same group of interpreters as those employed in Experiment 5, along with a new group of 15 control participants. As in Experiment 5, controls were highly fluent bilinguals with no experience in interpreting. All participants were comparable in age, IQ, and language skills (see Table 10). As in Experiment 5, all bilinguals spoke Spanish along with a different language: Arabic (4), Catalan (2), Croatian (1), English (4), French (1), and German (4).

Materials and procedure

Attention Networks Test for Interaction-Vigilance (ANTI-V). We employed a slightly modified version of the Roca et al. (2011) procedure. The only change with respect to the original task is that we employed arrows as stimuli instead of cars (see Figure 24a). Participants were presented with a black fixation cross presented for a range of 400-1600 ms (that varied randomly) followed by a row of five arrows pointing either left or right (200 ms), containing the central target arrow. The target presentation could be preceded by a warning tone and/or a visual cue (a black asterisk). The distance between the central target arrow and the flankers could be either centered or significantly displaced to the left or right. Also, the vertical and horizontal location of each arrow changed slightly (±4 pixels) across trials to make it harder to distinguish between the centered and the displaced target. Participants had to indicate the direction of the central arrow by pressing “c” for left of “m” for right during a 2000 ms response window (see b for a schematic representation of the conditions constituting the task). In half of the trials the flankers target pointed to the same direction as the central target (congruent condition) and, in the other half, to the opposite direction (incongruent condition). 100 ms before presentation of the stimuli, an asterisk was presented (50 ms) either in the same location as the target (valid visual cue condition), in the opposite location (invalid visual cue condition), or there was no asterisk (no visual cue condition). These three conditions occurred with equal probability. In addition, either a 50 ms auditory warning signal was presented 500 ms before presentation of the stimuli (warning tone condition) or it was not presented (no warning tone condition). Finally, on 25% of the trials the target arrow was significantly displaced to the right or to the left. On these trials, participants were instructed to identify these infrequent stimuli by pressing the spacebar, and to ignore the direction of the central arrow.

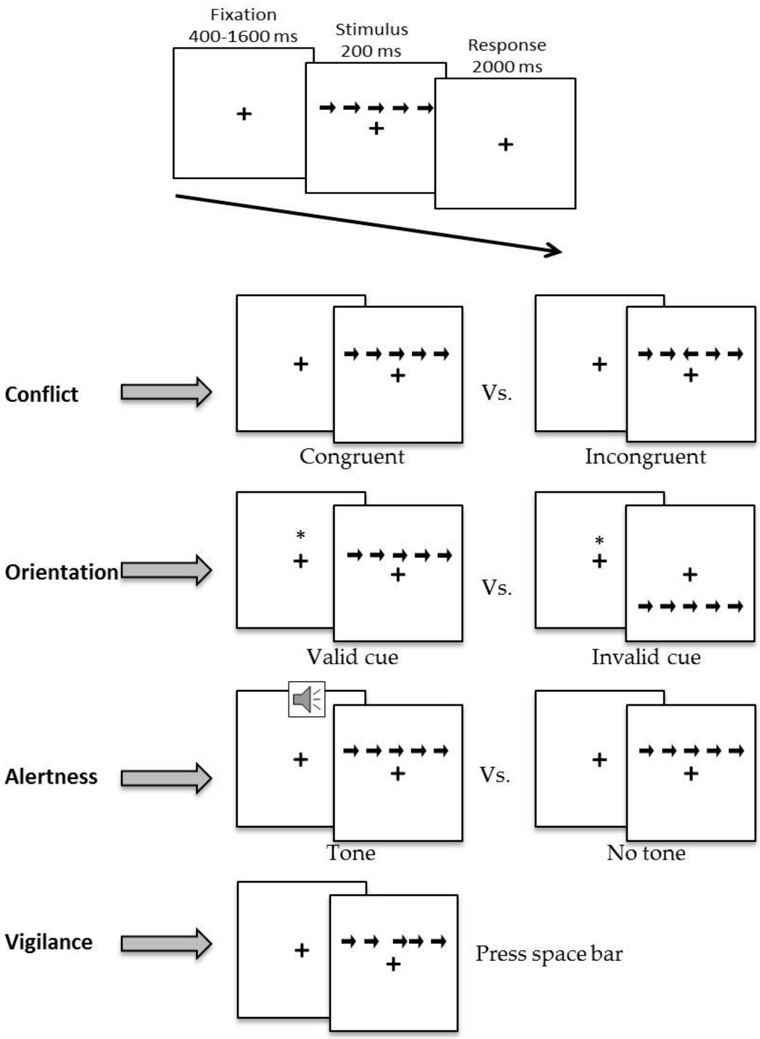

Figure 24. *Attentional Network Task for interactions. (a) Schematic representation of the procedure. (b) Conditions included*

The task was composed of 7 blocks of 64 trials each (336 trials for the usual ANTI conditions and 112 vigilance trials with the displaced target condition). In the practice block, trials were followed by feedback about accuracy. After completing the practice block, there was a pause, but no more rest periods were allowed during the experimental blocks. The task lasted around 40 minutes.

RESULTS AND DISCUSSION

Mean percentage of errors and mean RTs of correct answers only were taken into account for further analyses. Mean RT of correct answers were inspected and values above or below 2.5 standard deviations were discarded (2.7 % of trials). One participant from the control group was excluded due to an error proportion being higher than 3 SD from mean. We performed ANOVAs on accuracy and RT measures with Warning tone (no tone/tone), Visual cue (invalid/no cue/valid) and Congruency (congruent/incongruent) as within-participant factors and Group (interpreter/control) as the between-participant factor. Planned comparisons with the Bonferroni correction were performed where appropriate.

With respect to the vigilance scores, the number of hits and false alarms were used to compute sensitivity (*d'*) and response bias (ß), following SDT procedures. As in Experiment 5, 0 and 1 rates of hits or false alarms were substituted by .01 or .99 respectively to obtain an adequate approximation to the SDT indices (Roca et al., 2012, 2011).

Table 11. *Mean correct reaction time, percentage of errors (and standard deviations) by group. Warning signal (No tone/Tone), Visual cue (Invalid/No cue/Valid) and Congruency (Congruent/Incongruent) experimental conditions have been differentiated.*

		Interpreter		Control	
		No Tone	Tone	No Tone	Tone
Reaction time (ms)					
Invalid	Congruent	694 (113)	676 (101)	701 (132)	693 (143)
	Incongruent	779 (115)	798 (141)	815 (167)	827 (162)
No cue	Congruent	705 (130)	661 (109)	711 (133)	683 (151)
	Incongruent	760 (94)	767 (121)	813 (175)	801 (190)
Valid	Congruent	663 (102)	651 (102)	701 (130)	661 (139)
	Incongruent	744 (119)	746 (119)	801 (203)	774 (190)
Percentage of errors (%)					
Invalid	Congruent	0.5 (1.3)	0.5 (1.3)	1.5 (3.1)	0.3 (1.0)
	Incongruent	2.3 (3.4)	2.2 (3.0)	2.4 (5.6)	4.0 (4.8)
No cue	Congruent	0.7 (1.5)	1.0 (2.3)	1.0 (2.2)	0.0 (0.0)
	Incongruent	3.3 (6.0)	2.2 (4.0)	3.6 (5.1)	2.4 (3.1)
Valid	Congruent	0.7 (2.0)	0.0 (0.0)	2.1 (2.7)	0.0 (0.0)
	Incongruent	2.2 (3.2)	2.5 (3.6)	2.4 (4.0)	0.9 (1.8)
Vigilance measures					
Hits (%)		56.8 (16.1)		60.1 (16.1)	
False alarms (%)		5.6 (5.2)		6.4 (4.6)	
Sensitivity (*d'*)		2.0 (0.5)		1.9 (0.4)	
Response bias (ß)		9.3 (13.3)		5.5 (5.8)	

Reaction time

The analysis on RTs (see Table 11) showed main effects of Warning tone, $F(1, 27) = 11.0$, $MSE = 1215$, $p < .05$, $\eta^2_p = .29$, Visual cue, $F(2, 54) = 11.0$, $MSE = 1207$, $p < .001$, $\eta^2_p = .46$, and Congruency, $F(1, 27) = 123.4$, $MSE = 7344$, $p < .001$, $\eta^2_p = .82$, but no overall differences between interpreters and controls, $F(1, 27) = 0.32$, $MSE = 214025$, $p > .05$, $\eta^2_p = .012$. Participants responded faster when a warning tone was presented (728 ms) relative to when it was absent (741 ms), and when the stimuli were congruent (683 ms) compared with when they were incongruent (785 ms). Planned comparisons of the Visual cue revealed that RTs were faster on valid trials (718 ms) than on invalid trials (748 ms) or no cue trials (738 ms), $p < .001$ with no significant differences between the last two conditions ($p = .174$).

The three-way interaction Warning tone × Visual cue × Group was significant, $F(2, 54) = 3.2$, $MSE = 627.0$, $p < .05$, $\eta^2_p = .11$. Following Callejas, Lupiáñez, Funes, and Tudela (2005), this interaction was further analyzed after removing the no cue conditions, since visual orienting is not involved in this condition (that is, we analyzed only valid and invalid cue conditions). Again, the results of this analysis showed that the interaction was significant, $F(1, 27) = 3.93$, $MSE = 414$, $p = .05$, $\eta^2_p = .13$. Further analyses separated by group, showed that the interaction Warning tone (tone/no-tone) × Visual cue (valid/invalid) was significant for controls, $F(1, 13) = 9.58$, $MSE = 451$, $p < .01$, $\eta^2_p = .42$, but not for interpreters, $F(1, 14) < 1$. This result indicated that, for controls, the Visual cue effect appeared in the tone (43 ms) but not in the no-tone conditions (8 ms), whereas cueing did not modulate Warning tone effects in interpreters (38 ms and 33 ms for tone and no-tone conditions, respectively).

The Warning tone × Congruency interaction was analyzed only for the no-cue condition, in order to discard any influence of the cueing effect, and this was also significant, $F(1, 27) = 7.0$, $MSE= 1143$, $p < .05$, $\eta^2_p = .21$. Pairwise comparisons by congruency condition revealed that the presence of a warning tone diminished RTs in congruent trials (671 ms) compared with no-tone conditions (696 ms), $p < .001$, whereas the tone presentation had no effect on incongruent trials (785 ms in both tone and no-tone conditions), $p = .99$.

Accuracy

The analysis performed on error rates (see Table 11) showed that only the Congruency effect reached statistical significance, $F(1, 27) = 21.0$, $MSE= 14.1$, $p < .0001$, $\eta^2_p = .44$, with participants committing fewer errors in the congruent (0.6% errors) than in the incongruent condition (2.5% errors). There were no significant differences for the Group effect, $F(1, 27) < 1$, $\eta^2_p = .004$. None of the other main effects or interactions resulted in significant differences (all ps > .1).

Vigilance indices

In relation to the vigilance indices (see Table 11), both groups were similar in terms of the number of hits, percentage of false alarms, sensitivity-*d'*, and response bias *(all F*s<1).

In sum, although the vigilance and conflict network did not show between group differences, the 3-way interaction between alertness and orientation networks by group indicated different dynamics for these two attentional networks in the two groups. Whereas the control group showed larger orientation effects when the warning tone was presented, for the interpreters the orientation network was unaffected by warning tones.

GENERAL DISCUSSION

The main purpose of our work was to evaluate the relationship between simultaneous interpreting, the executive components of WM, and attentional functioning. This issue is of special relevance as it may serve to further understand how expertise in a certain domain transfers to other cognitive domains that require similar skills. Some aspects of attention and WM are thought to be necessary skills for successful interpreting (Christoffels & de Groot, 2005; Cowan, 2000; Macnamara, 2012) but, to date, no research has explicitly investigated both aspects of cognition. Interpreters generally excel in span measures (Christoffels, De Groot, & Waldorp, 2003; Darò & Fabbro, 1994; Liu, Schallert, & Carroll, 2004; Padilla, Bajo, Cañas, & Padilla, 1995; Tzou, Eslami, Chen, & Vaid, 2012; but see Chincotta & Underwood, 1998; Köpke & Nespoulous, 2006). Interestingly, attentional control views of WM argue that individual differences in WM capacity reflect a combination of storage capacity and executive processes (Barrett, Tugade, & Engle, 2004; Engle, 2002). Therefore, it seems crucial to investigate specific attentional resources to better understand the mechanics involved in simultaneous interpretation.

The present work first focused on the executive components of WM. The results of Experiment 5 revealed that experience in interpreting appears to enhance WM updating and monitoring capacities as measured by a single and dual *n*-back task with three memory loads each (1-, 2-, and 3-back). The interpreters were generally more accurate than non-interpreters in solving the task. According to the germane models, WM is composed of a storage component and an attentional component (e.g., Baddeley, 1986, 1996, 2000; Kane et al., 2001, 2007). In our experiment, both controls and interpreters decreased their accuracy as the memory load increased, indicating a similar functioning of the storage component. Therefore, the general superior performance of interpreters compared to controls might be mediated by the executive components of WM.

Experiment 6 provides further support for the idea that interpreting influences attentional functioning. The results of the ANTI-V supply valuable information about the nature of the processes that play a role in the interpreters' WM skills. Although interpreters and controls did not show overall difference any of the main attentional networks, the differential interactions between the ANTI-V measures suggest that interpreting modulates the dynamics between attentional processes.

The group differences in the interaction between the alertness and orienting networks suggest that the two groups engaged different attentional networks dynamics. The control group showed larger cuing (orientation) effects when the alerting tone was presented. This result is in accord with previous attentional studies, which suggest that increasing the alertness level by presenting a warning cue makes the orienting effect greater (Callejas et al., 2004; Fuentes & Campoy, 2008; Roca et al., 2012). In contrast, the orientation network of interpreters was unaffected by warning tones. In particular, interpreters benefited from visual orienting cues regardless of whether or not they were presented with the warning signal. One possible interpretation of this effect might be that the interpreter's alertness when performing a task is continuously high so that they would not benefit from factors known to increase the alertness level (e.g., warning signals). However, against this interpretation, participants did not differ in their vigilance scores, indicating similar tonic alertness. An alternative interpretation is that interpreters excel in their focus of attention, so that their orienting network would work highly efficiently regardless of their state of alertness.

Interestingly, there were no differences or interactions regarding the executive control network (incongruent vs. congruent trials) indicating that the interpreters' advantage did not extend to their control in conflict situations. This pattern of results is consistent with other studies that fail to report any professional interpreters' advantages in tasks that require a suppression of interference from conflicting information such as the Stroop (Köpke & Nespoulous, 2006) or the Simon tasks (Yudes et al., 2011). This finding suggests that inhibitory processes are not specifically necessary for simultaneous interpretation (Ibáñez, Macizo, & Bajo, 2010).

The results of Experiment 5, in which we observed better performance in the *n*-back task for interpreters relative to control participants, are also consistent with our explanation of the alerting effects, since high performance in the *n*-back task has been linked with the focus of attention (Lilienthal et al., 2013). In addition, results from the *n*-back task showed that the interpreters (but not controls) benefited from practice in the dual task condition, in which participants needed to operate with two streams of information (auditory and visuospatial). To successfully perform this task, it is necessary not only to maintain and update the incoming information, but to concurrently perform two tasks at a time. Similar to the articulatory suppression paradigms, the dual *n*-back overloads the processes required to perform the task. The difficulty of the dual condition shows up in the dramatic accuracy reduction that all participants experienced in comparison to the single *n*-back task. Notably, interpreters (but not controls) were able to improve their accuracy in the second block. This result suggests that interpreters might have the potential skills to learn how to concurrently deal with high quantities of information.

Taken together, the results from Experiments 1 and 2 provide support for the interpreters' advantages in WM that has been reported in previous studies. In accord with the attentional control proposal put forward by Engle and colleagues (e.g., Engle, 2002; Kane et al., 2001, 2007), variations of WM span are a combination of WM capacity and the ability to manipulate information while coping with the interference generated by concurrent tasks. Earlier studies mainly evaluated WM skills based on span scores, which did not allow for an evaluation of the relative involvement of each WM component. However, the current study dissociates between storing and updating skills, and the results suggest that the interpreters' high WM capacity might be related to executive control components. Furthermore, articulatory suppression studies highlight the interpreters' ability to coordinate comprehension and production tasks but also the modulation of language knowledge in the interpreters' superiority. In our study, the language knowledge requirements are minimal, as none of the employed tasks demands semantic or lexical processing to solve them. Thus, although language knowledge may undoubtedly influence interpreting, it is not the only factor responsible for the interpreter's superiority in memory performance. However, future research should explore the domain-free WM capacity superiority of interpreters by employing non-verbal span tasks (e.g., visuospatial WM tasks).

Additionally, our results support the idea that, more than interference control, it is the focus of attention which mediates the interpreters' coordination of comprehension and production. Thus, modulatory roles in attentional processes seem to be restricted to functions more closely related to simultaneous interpreting. These results may be understood in terms of the recent adaptive control hypothesis of language control proposed by Green and Abutalebi (2013). According to this view, multiple language management may transform the whole cascade of processes in charge of language control. Different language experiences may lead to different language control needs and, consequently, to a different reorganization of the cognitive control network. Interpreting may particularly demand orienting processes as it requires driving the attention to the relevant part of the discourse, but also flexibly redirecting it to the output message (Cowan, 2000). Support for this idea comes from the interpreters' superiority in cognitive flexibility, as measured by the WCST (Yudes et al., 2011). However, it is possible that there is interplay between additional cognitive control mechanisms in order to achieve successful simultaneous interpretation. Given that our study represents a first approach to the study of attentional processes in simultaneous interpretation, it contains some limitations. First, we cannot extract from our data whether the findings are due to the effect of experience in interpretation or to the self-selection of interpreters due to previous cognitive skills. Second, it is not possible to ascertain to what extent the observed attentional changes relate to the necessity to hold two languages active in mind or to other demands of simultaneous interpretation (i.e. the necessity to perform two concurrent tasks). Further research should address these issues by explicitly exploring the differential dynamics among the various cognitive control processes of professional and novice interpreters compared to non-interpreters in a linguistic context. In any case, our data suggest that simultaneous interpretation does not relates to a general enhancement of cognitive functioning, but its benefits seems to be restricted to the concrete mechanisms directly linked to the interpreting task.

To summarize, our set of experiments contribute to the existing literature on cognitive transfer, showing that simultaneous interpretation has positive consequences for WM and attentional processes. To be more specific, our findings complement previous studies that report WM superiority in professional interpreters compared to non-interpreters by emphasizing the role of attentional processes. Thus, interpreters seem to excel in the attentional component of WM, which might be responsible for higher storage capacity. Additionally, the evaluation of the three attentional networks supports the notion that interpreting might relate to modulations in the dynamics between the attentional networks directly related to interpreting, such as orienting and alertness. Future investigations are required to determine the specific influence of interpreting on other aspects of cognitive functioning along with its relation to language control.

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Chapter IV. GENERAL DISCUSSION

The studies included in this thesis aimed to investigate how bilingualism modulates executive functioning under different language control demands and at different developmental stages. Establishing the precise domain-general cognitive mechanisms influenced by bilingual experiences may help us to understand the mechanisms involved in resolving cross-language activation and competition. In addition, conclusions regarding cognitive advantages of bilingualism might extend our existing knowledge about the adaptive and plastic nature of executive functioning. Previous research has mainly addressed the relationship between bilingualism and cognitive control by investigating specific processes (with special emphasis on inhibitory mechanisms). However, in the present work we adopted a multi-component approach on the basis that bilingual language control recruits a more complex neural network composed of relatively independent processes that interact with each other. With this purpose in mind, our experimental series included tasks that required coordination of several cognitive control mechanisms for successful performance. Thus, the six experiments reported here aimed to address two main questions: (i) does bilingualism affect specific components of cognitive control or their dynamics in the executive control network? and (ii) do different bilingual experiences lead to different modulations of cognitive control?

After reviewing previous empirical data and theoretical approaches in the introductory chapters of this thesis, Experiments 1 and 2 reported behavioral and neurophysiological evidence of how bilingualism modulates the dynamics between proactive and reactive control mechanisms. Next, we presented empirical support for an effect of bilingualism on the development of the coordination of executive functioning (Experiments 3 and 4). Finally, in Experiments 5 and 6 we investigated whether the cognitive demands to control languages differentially modulate the interactions between different executive-control mechanisms. Specifically, we compared simultaneous interpreters and non-interpreter bilinguals whose bilingual contexts may recruit different language control skills.

In the next sections we will summarize and discuss the empirical findings obtained in the studies constituting our experimental series. We will organize this chapter around three topics. First, we will discuss the importance of moving from a componential to a more integrative approach in the study of cognitive control in bilingualism. Second, we will discuss the relevance of considering different forms of bilingualism when addressing this topic. The third section will summarize the main implications of our findings for both language and cognitive control.

4.1. CONTROL MECHANISMS AND BILINGUALISM: BEYOND A UNITARY APPROACH.

Both behavioral and neurophysiological evidence indicates that bilinguals activate their two languages in parallel. Recent research has focused on understanding how the bilingual manages to cope with this demanding situation. If both languages are active, some sort of language control mechanism must be in charge of preventing intrusions from the unwanted language while producing and/or understanding the target language. In addition, further evidence suggests that there are cognitive consequences of bilingualism across the lifespan, so that the bilingual's need to manage their languages may modify domain-general cognitive-control skills. The main models of language control in bilingualism propose different loci for language selection, which implies the involvement of different cognitive control mechanisms. Disentangling the cognitive processes modulated by bilingual experience may serve to understand the underpinnings of language control and selection.

According to inhibitory accounts (e.g., Abutalebi & Green, 2007;; Dijkstra & van Heuven, 1998, 2002; van Heuven, Schriefers, Dijkstra, & Hagoort, 2008), language selection occurs once candidates in both languages are active, and it is dependent on the level of competition between the intended and unintended language. Therefore, the stronger the activation of competitors in the unintended language, the stronger the inhibition exerted. Inhibition can be targeted globally to the language when the context clearly signals the language to be spoken or comprehended or it can be applied to specific lexical/semantic representations when they become activated in mixed contexts (De Groot & Christoffels, 2006; Guo, Liu, Misra, & Kroll, 2011). From this perspective, language selection is produced by reactive control, a late correction derived from new competing information. Consequently, bilinguals, relative to monolinguals, would excel in tasks that involve conflict resolution produced by competing alternatives.

In contrast, non-inhibitory accounts (or language-selection models) have put forward the suggestion that lexical selection is sensitive to the language membership of lexical representations, so that only candidates belonging to the target language are considered for selection (Costa, 2005; Costa & Caramazza, 1999; Costa, Miozzo, & Caramazza, 1999; Poulisse & Bongaerts, 1994). Hence, lexical representations of the unintended language do not enter into competition during lexical selection. According to this view, bilingual experience might require preparatory processes involving proactive control (Braver, Gray, & Burgess, 2007; Braver, 2012). As a result, it may modify early attentional mechanisms that select the goals of the task, thus focusing and selecting the required alternative before a competitor is presented.

The inhibitory account can explain the reduction of interference effects in bilinguals relative to monolinguals in conflict tasks (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Blumenfeld & Marian, 2013; Colzato et al., 2008; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa, Hernández, & Sebastián-Gallés, 2008; Garbin et al., 2010; Prior & Macwhinney, 2009; Tse & Altarriba, 2012). However, inhibitory models fail to explain the observed differential performance of bilinguals in comparison with monolinguals in non-conflict tasks, which seems to indicate that language control may recruit cognitive processes beyond inhibition. Therefore, we cannot exclude the idea that bilinguals may also engage additional mechanisms to control their languages.

Following this idea, recent approaches posit that bilingualism may modify a broader cognitive network responsible for language control and selection (Green & Abutalebi, 2013; Kroll & Bialystok, 2013). Following this assumption, single-component approaches may fail to understand the neural processes that support language control and capture the changes that occur in that network across the lifespan. These proposals encourage researchers to consider a multi-component approach in order to understand the full range of processes that mediate bilingual language control. The results of our series of experiments provide empirical support for these hypotheses.

As expected (and in accordance with previous research), inhibitory accounts cannot fully explain the pattern of results obtained in Experiments 1 to 6 since the bilinguals' advantages in executive control arose only when conditions forced coordination of multiple control processes. In the first experimental series (Experiments 1 and 2), the AX-CPT served to observe differential control dynamics of bilinguals and monolinguals. The AX-CPT has been used in the literature on executive function to dissociate proactive and reactive control by differentiating the conditions under which it is possible to anticipate a highly probable event from those conditions where processes that are already engaged must be inhibited. According to the dual mechanisms of control view (Braver & Barch, 2002; Braver et al., 2007; Braver, 2012), an inhibitory strategy would result in a reduced number of errors on AY trials at the cost of a higher proportion of mistakes on BX trials. In contrast, a proactive strategy would result in the opposite pattern, that is, facilitating the performance on BX trials but biasing wrong AY responses. Optimal performance can be achieved only if proactive and reactive control are coordinated so that attention is paid to the cue to proactively prepare for the more likely response, whereas reactive inhibition is triggered when the prepared response should be withhold to the probe. In Experiments 1 and 2 we reported results showing optimal performance for bilinguals so that bilinguals committed fewer errors than monolinguals on AY trials while keeping BX errors at minimum. In addition, these experiments indicated a differential role for inhibitory processes in bilinguals relative to monolinguals (as indicated by delta plots analyses and stop-signal correlations –Experiment 1– and probe-related ERP components –Experiment 2). Thus, bilinguals were able to keep proactive control to the same level as the monolinguals, while more efficiently inhibiting inappropriate responses.

The ERPs analyses in Experiment 2 confirmed that the bilingual advantage was the result of a differential adjustment between proactive and reactive control. The similar amplitudes of the cue-related component (P3a) in bilinguals and monolinguals reveal similar response preparation and goal activation. However, bilinguals engaged more conflict-related monitoring and inhibitory resources than monolinguals (higher probe-N2 and probe-P3b amplitudes) in the AY condition. Interestingly, the higher commitment of reactive control in bilinguals was restricted to AY trials, thus suggesting that exerting higher inhibitory control was not a generalized mechanism to cope with conflict. That is, bilinguals appear to be more flexible than monolinguals in terms of engaging the most effective mechanism to solve the task. In other words, bilingualism seemed to modify the management of their control resources in an adaptive manner. These results agree with evidence from neuroscience studies which indicate that bilingualism leads to a reorganization of nonlinguistic processes associated with executive functions (see Abutalebi & Green, 2007 for a review). This reorganization of the frontal control systems seems to affect the efficiency of executive networks (Gold, Kim, Johnson, Kryscio, & Smith, 2013). The second experimental series (Experiment 3 & 4) revealed that the bilingual children outperformed their monolingual counterparts in WM skills, as measured by the Simon (Experiment 3) and the FMT (Experiment 4) tasks. However, and in line with the first experimental series, the bilingual advantages were especially evident in the most demanding conditions, which required interaction between multiple executive components. Thus, in Experiment 3, bilingual children performed better than monolinguals in the more difficult incongruent trials (which required them to maintain rules active in mind while ignoring distraction from incongruent trials and shifting between congruent and incongruent trials). In Experiment 4, young bilingual children showed better performance than monolinguals in the simple condition, whereas in the sequential condition the bilingual advantage was present at the two age levels. Thus, the results of bilingual and monolingual children clearly indicate that differences in the development of executive functions cannot be entirely explained in terms of single component approaches, and that working memory alone is not modified by bilingualism.

In sum, the results of Experiments 1 to 4 suggest that a single component view of the bilingual advantage cannot fully explain the more complex pattern. A single component view would interpret the outperformance of bilinguals in the AX-CPT and their associated components (Experiments 1 and 2) as simply inhibitory/reactive control, but it would rule out the possibility that the advantage does not appear in the stop-signal task or on the BX trials that more purely require inhibitory control. Importantly the advantage appears when the condition required combined a mixture of proactive and retroactive control. Similarly, a single approach to the results of Experiments 3 and 4 would conclude that bilingual children develop higher WM skills than monolinguals, when looking at their performance in the 4-rules conditions of the Simon task (Experiment 3) and their scores in the FMT (Experiment 4), but it will lose the valuable information extracted from manipulations of the demands of other executive control processes. Likewise, the results from Experiment 6 are also consistent with the need to look at the interaction between different processes. Whilst we found no differences between professional interpreters and bilinguals in each of the attentional networks evaluated with the ANTI-V, alertness and orienting interacted differently in each group. Taken together, these studies offer empirical support for recent proposals that consider it necessary to adopt a multicomponent perspective in order to fully account for the mechanisms involved in juggling between languages in mind (Bialystok, 2010, 2011;

Costa et al., 2009; Green & Abutalebi, 2013; Hilchey & Klein, 2011; Kroll & Bialystok, 2013).

This move to a more complex and integrative view in the study of bilingualism and executive functions is consistent with some theoretical frameworks in the field of cognitive control that reconsider the source of variance in executive functioning. For example, the dual mechanisms control account (Braver & Barch, 2002; Braver et al., 2007; Braver, 2012) proposes that variability in cognitive control arises from differences in the dynamics between proactive and reactive modes of control. Therefore, the nature of individual differences in cognitive control would not be so rooted in differential capacities in specific components but more in modifications in the adjustment between different modes of control. Interestingly, this framework provides a coherent explanation for intra-individual (state related or task related), inter-individual (trait related) or between groups variations in executive function (Braver, 2012), which can easily serve to understand the bilingual advantage. The unity-diversity view offered by Miyake and Friedman (2012) is also consistent with this novel approach in studying cognitive control in bilingualism. From this perspective, cognitive effects of bilingualism may relate not only to the efficiency of the specific aspects of core components, but also to their interactions.

A multi-component approach may help in explaining some of the inconsistences of previous results on inhibitory control and bilingualism (i.e., the overall faster response times of bilinguals compared to monolinguals in conflict tasks in both congruent and incongruent trials). Our contribution extents the proposals by Costa and colleagues (Costa et al., 2009), who consider that different control mechanisms (i.e., conflict monitoring and response inhibition) may be modified by their engagement in language control. However, our data suggest that it is not just the engagement of one process or the other, but the interaction between them, which may make bilinguals more efficient. According to approaches such as the dual mechanisms of control framework, the different control processes need to act collaboratively to achieve the task's goals. In the same manner, successful language control must be achieved by a range of interactive cognitive processes. Consequently, the studies aimed at understanding the mechanisms involved in language control and selection may not be able to explain the whole circuitry involved by focusing on single component analyses. Our results provide further evidence that bilingual experience might affect the cascade of processes involved in a complex neural circuit of cognitive control (Green & Abutalebi, 2013). Whereas our findings are mute with respect to the precise mechanisms engaged in the whole circuitry, they suggest that a multicomponent approach is more appropriate to understand the processes in charge of language control.

Understanding language selection and control as a multi-component function, however, does not seem to be sufficient to account for the lack of replicability of the cognitive consequences of bilingualism. As we discussed in the introductory chapters, one factor that may shed some light on this issue is that most of the previous research treated bilingualism as a categorical variable (Luk & Bialystok, 2013). Based on our findings, we discuss the necessity to take different bilingual situations into account in order to deal with variability and inconsistences.

4.2. THE IMPORTANCE OF BILINGUAL CONTEXT FOR COGNITIVE CONTROL

Tagging participants as bilinguals or monolinguals may fail to distinguish between types of bilingual experiences. Different bilingual contexts are likely to demand different language-control demands and, consequently, may require and modify the functioning of different cognitive processes. Therefore, the consequences for the networks that regulate performance will differ depending on the bilingual experience (Green, 2011; Green & Abutalebi, 2013; Green & Wei, 2014; Wu & Thierry, 2013).

The findings of Experimental series III highlight the importance of considering the context of language use. Simultaneous interpretation is a particular form of bilingualism that requires people to maintain two languages active, and simultaneously use them (usually one for comprehension and another for production). Consequently, the control mechanisms involved in language selection might significantly differ from the ones proposed by other types of bilinguals. Empirical evidence shows that professional interpreters do not engage inhibitory mechanisms to control for languages (Ibáñez, Macizo, & Bajo, 2010). This idea is supported by the similar performance of interpreters and non-interpreters in non-verbal conflict tasks such as the Simon (Yudes, Macizo, & Bajo, 2011) or the Stroop task (Köpke & Nespoulous, 2006). The results of Experiment 5 replicate and extend these findings. First, the absence of differences between interpreters and non-interpreters in the conflict network (as assessed by the ANTI-V) agrees with previous findings of similar inhibitory-control capacities in interpreters and non-interpreters (Köpke & Nespoulous, 2006; Yudes et al., 2011). If interpreting does not require inhibitory strategies, then one could expect non-interpreter bilinguals to be better than interpreters at conflict resolution. However, we must bear in mind that interpreters are also bilinguals. Under Green's adaptive control view, interpreters might adapt their control mechanisms depending on the demands of the situation and, as a consequence, they might engage inhibitory mechanisms if this were the most efficient strategy in a certain non-professional context. In addition, the interactions between the other attentional networks (alertness and orienting) suggest that interpreting differentially affects the dynamics between the control networks. Furthermore, the findings of Experiment 5 support a differential pattern of executive skills in interpreters and non-interpreters; the professional interpreters exhibited better updating and monitoring abilities in the *n*-back task than the non-interpreters.

Our results are in accord with the adaptive control hypothesis (Green & Abutalebi, 2013) in the sense that different bilingual situations may be partially responsible for cognitive control variance in non-verbal cognitive control tasks. Of course, our set of data tells us nothing about the specific mechanisms or networks involved in bilingual language selection in each situation. Despite growing evidence supporting the notion that individual differences in inhibitory control are related to language control (Blumenfeld & Marian, 2011; Festman, Rodriguez-Fornells, & Münte, 2010; Mercier, Pivneva, & Titone, 2013; Rodriguez-Fornells, de Diego Balaguer, & Münte, 2006), the fact that bilinguals show an advantage in coordinating certain processes does not imply that those processes are in charge of controlling language. Particularly in the case of simultaneous interpretation, our results must be interpreted cautiously. For example, the behavioral differences found between interpreters and non-interpreters in ours and other studies or even the changes in gray matter in brain regions associated with cognitive control (Hervais-Adelman, Moser-Mercer, & Golestani, 2011) might occur for different reasons. In particular, these modulations may reflect the diverse cognitive mechanisms associated with different language control strategies (e.g., inhibiting the unrequired language vs. maintaining two languages active at a time). At the same time, differences in cognitive functioning could result from other task related demands which are language independent but inherent in the interpreting situation (such as the need to perform two concurrent tasks). However, even when the task demands may not be directly related to language selection, they are inherent in the interpreting situation. Therefore, research should take into account the possibility that certain bilingual contexts demand specific processes (directly or indirectly related to language control) that are not involved in other bilingual situations. Consequently, this may result in differential outcomes in the cognitive control processes, which should be controlled and explored as a source of variability and as evidence for the adaptive nature of the cognitive control system.

4.3. CONCLUSIONS AND FUTURE RESEARCH QUESTIONS

Our set of experiments produced three main results: (i) bilingualism modifies the dynamics of the processes belonging to a wide network responsible for cognitive control; (ii) bilingualism tunes the coordination of the cognitive control system during its development; and (iii) the modulated processes and dynamics depend on the language control demands derived from the bilingual context of use. In this final section we describe the main implications that these outcomes may have for bilingual language control research on one side, and the executive control field on the other side.

What executive control tells us about bilingualism

The first implication of Experiment 1 to 6 relates to theories regarding language control. Our data suggest that bilingualism modulates the interaction between the processes involved in cognitive control, indicating that bilingual language control involves coordination between the components of this complex cognitive network. Thus, single approaches reducing language control to unitary views may lose valuable information about the processes involved in language selection and control. While inhibitory accounts state that language selection involves reactive control mechanisms, non-inhibitory models put forward the involvement of early attention mechanisms (or proactive control). Some accounts have considered the differential involvement of reactive or proactive mechanisms in language selection, depending on individual differences such as the languages proficiency level (Costa, Santesteban, & Ivanova, 2006; Kroll, Bobb, & Wodniecka, 2006). However, according to certain cognitive control frameworks, these two mechanisms act in a coordinated way and need to be adjusted depending on the demands of the situation to achieve the most efficient cognitive functioning. Consequently, why should language selection diverge from other conflict tasks? Maintaining dichotomous accounts of language control (inhibitory vs. non-inhibitory) may constrain the development of theoretical approaches and research techniques. Language control research may benefit from embracing the more integrative views from the field of cognitive control. Our experiments suggest that bilingual language control models need to consider the involvement of a whole cascade of processes that interact to successfully select the intended language.

Second, the cognitive processes recruited for language control may differ according to a number of variables. Previous research indicates that the level of proficiency may influence the language selection mechanisms (Costa et al., 2006; Kroll et al., 2006). Our experiments with simultaneous interpreters indicate that different bilingual contexts may also modulate the involvement of different executive control mechanisms. Therefore, the theories of language control should account for the specific requirements of specific bilingual situations. This could open the door for new approaches to understand language control, such as considering alternative control mechanisms (Green & Abutalebi, 2013).

The variability in the cognitive control modes for language selection might not only exist at the level of the bilingual environments, but also at a level of individual differences. As stated by Green and Abutalebi (2013, p. 13): "differences in sensitivity to interaction cost, differences in the capacity of cognitive control and differences in circuit neuro-anatomy may all constrain engagement and affect the degree of adaptive change". The relation between individual differences in cognitive control skills and language control is evident in a number of studies (e.g., Festman et al., 2010; Mercier et al., 2013; Roelofs, Piai, & Rodriguez, 2011). Bilinguals not only seem to differ from monolinguals in cognitive control processes, but individual differences within bilinguals themselves can explain their success in controlling languages. Therefore, language control could be exerted by different mechanisms depending on the cognitive resources available for a certain individual. Additionally, the same individual may solve language co-activation by engaging different control mechanisms depending on the bilingual context. Furthermore, individual differences in the capacity to adjust executive components might influence the capacity to modify the cognitive resources depending on the demands of the bilingual context. That is, a "more flexible" individual would engage different control processes in a single-language situation than in a code-switching context, but someone less adaptable would always engage the same control strategy. Future research in language control should further investigate the role of individual differences in executive functioning when studying language control and selection mechanisms.

What bilingualism tells us about executive control

Our work also has implications for the understanding of cognitive functioning. First, our experiments contribute to knowledge concerning the connections between the components of the executive function. In particular, the current results provide novel support for cognitive control theories that propose that a number of control processes act in parallel to achieve task goals (Braver & Barch, 2002; Braver, 2012; Egner, Delano, & Hirsch, 2007). In pursuing a goal, both domain-specific and domain-general processes need to interact (Egner et al., 2007). The first experimental series provided novel evidence favoring the idea of the dual mechanisms control framework proposed by Braver. The dynamic nature of cognitive control has been evidenced in the developmental literature by the differential strategies adopted by the elderly relative to young adults or children. In addition, changing the task's demands has been shown to change the control strategy (see Braver, 2012 for a review). However, our data show that experience may also modify these dynamics within the same task, so that bilinguals seem to be able to flexibly adopt a more proactive or reactive strategy depending on the demands of the trial. Additionally, our results suggest that experience in bilingualism affects an integrated set of abilities, in which efficiency is enhanced on cognitively demanding tasks, which agrees with the unity-diversity model described by Miyake and Friedman (2012).

Second, this work provides evidence for the plasticity of cognitive functioning. As also suggested by Hilchey and Klein (2011), the results of our experimental series leads us to reconsider the idea that monolinguals and bilinguals employ the same mechanisms to solve interference, but rather suggests that a specific process becomes more efficient by linguistic training. Alternatively, our set of findings joins others to suggest that a reorganization in the cognitive system leads to a different engagement of the mechanisms engaged in solving the task. Following the reasoning of Green and Abutalebi (2013), the bilingual experience readjusts the dynamics of the cognitive control processes. In addition, our work indicates that executive functioning can be modulated across the lifespan.

The samples of the first two experimental series were composed of bilinguals who acquired their two languages simultaneously, and early in life. Since bilingualism seems to affect the development of WM during childhood (Experiments 3 and 4), one might suppose that modulations on the cognitive system occur only at the early stages of development and remain stable in the future. However, many studies report that cognitive training during adulthood also influences the cognitive and neural functioning (e.g., Lilienthal, Tamez, Shelton, Myerson, & Hale, 2013; Lustig, Shah, Seidler, & Reuter-Lorenz, 2009; Olesen, Westerberg, & Klingberg, 2004; Padilla, Perez, Andres, & Parmentier, 2013; Tang et al., 2007). Thus, our results of simultaneous interpreting join others to indicate that this may not be the case. Interpreting is a skill acquired in adulthood, when the executive control capacities are thought to be at the peak of their power. Consequently, the modulations in the cognitive system associated with this activity indicate the capacity of reorganization of a matured circuitry. However, their previous bilingual history (the interpreters of our sample also acquired their second language early in life) may somehow interact with the later consequences of interpreting training. In order to account for the adaptive nature of cognitive control in adulthood, future research should investigate how acquiring a second language later in life (or in adulthood) modulates the coordination of executive processes.

Final conclusions

To wrap up, our experimental series provide valuable evidence about bilingualism and executive function. The six studies described here evidence that juggling two languages in one mind may modify cognitive control functioning. Importantly, these modulations are especially evident under high demands of coordination between different cognitive processes in both young adults (Experiments 1 & 2) and children (Experiments 3 & 4). In addition, the specific modulated processes and dynamics have demonstrated to be sensitive to the language control demands derived from distinct bilingual contexts of use (Experiments 5 & 6). Taken together, our findings contribute to better understand bilinguals' language control. They indicate the need to adopt a holistic approach, which should encompass different cognitive control components and individual differences. Additionally, our set of results represents novel support for the modulatory role that experience and expertise play in cognitive control. Hence, our results suggest that an activity like bilingualism may modify the interplays between multiple processes thus enhancing the efficiency of certain neurocognitive networks.

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