Tesis doctoral

Relación entre Control Atencional Estratégico y Memoria de Trabajo: Índices Comportamentales y Electrofisiológicos

Sergio Fernández García

Doctorado en Salud, Psicología y Psiquiatría

Neurociencia Cognitiva

Almería, Noviembre 2021

UNIVERSIDAD DE ALMERÍA

Tesis doctoral

Relación entre Control Atencional Estratégico y Memoria de Trabajo: Índices Comportamentales y Electrofisiológicos

Sergio Fernández García

Doctorado en Salud, Psicología y Psiquiatría

Neurociencia Cognitiva

Almería, Noviembre de 2021

UNIVERSIDAD DE ALMERÍA

TESIS DOCTORAL

RELACIÓN ENTRE CONTROL ATENCIONAL ESTRATÉGICO Y MEMORIA DE TRABAJO: ÍNDICES COMPORTAMENTALES Y ELECTROFISIOLÓGICOS

RELATIONSHIP BETWEEN STRATEGIC ATTENTIONAL CONTROL AND WORKING MEMORY: BEHAVIOURAL AND ELECTROPHYSIOLOGICAL INDICES

Autor:

Sergio Fernández García

Director:

Juan José Ortells Rodríguez

Co-directora:

María del Carmen Noguera Cuenca

DOCTORADO EN SALUD, PSICOLOGÍA Y PSIQUIATRÍA

UNIVERSIDAD DE ALMERÍA

Almería, Noviembre de 2021

Reconocimientos

Los diferentes estudios que forman la presente Tesis Doctoral han sido parcialmente financiados por el Ministerio español de Economía y Competitividad y el Ministerio de Ciencia, Innovación y Universidades (PSI2014-53856-P y PSI2017-83135-P), siendo el Investigador Principal de ambos proyectos el Dr. Juan José Ortells Rodríguez, director de esta Tesis Doctoral. Ninguna de las fuentes de financiación ha intervenido en el diseño de los estudios, ni en la recogida, análisis o interpretación de los datos, tampoco en la redacción de los informes o en la decisión de enviar los manuscritos para su publicación.

La realización de las diferentes investigaciones experimentales que integran la presente Tesis, ha permitido contar con la colaboración y participación activa en las mismas de investigadores de reconocido prestigio internacional en el estudio comportamental (y electrofisiológico) de las relaciones entre la capacidad de Memoria de Trabajo y los Mecanismos de Control Atencional, como son el profesor Jan De Fockert (London Goldsmiths University, UK), la profesora Paloma Marí-Beffa (University of Wales Bangor, Bangor, UK), y el profesor Markus Kiefer (University of Ulm, Germany).

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD

Acknowledgments

The different studies that are included in this doctoral thesis have been partially funded by the Spanish Ministry of Economy and Competitiveness and Spanish Ministry of Science, Innovation and Universities (PSI2014-53856-P and PSI2017-83135-P), being the Principal Researcher of both projects Dr. Juan José Ortells Rodríguez, director of this doctoral thesis. None of the funding sources were directly involved in the design, data collection, analysis or interpretation of data, neither in the writing of the reports nor in the decision to submit the manuscripts for publication.

The carrying out of a number of research projects which consist of this thesis has permitted to count on the collaboration and active participation in them of internationally renowned researchers in the behavioural (and electrophysiological) study of the relationships between Working Memory Capacity and Attentional Control Mechanisms, such as Professor Jan De Fockert (London Goldsmiths University, UK), Professor Paloma Marí-Beffa (University of Wales Bangor, Bangor, UK), and Professor Markus Kiefer (University of Ulm, Germany) .

A mis padres, Leocadia y Antonio

Agradecimientos

A lo largo de estos años he contado con la ayuda de muchas personas que, de forma directa o indirecta, han contribuido al desarrollo de esta tesis y a que estas palabras puedan ser plasmadas aquí:

Gracias a mis directores por guiarme en este camino y prestarme un poco de todo su conocimiento. A Juanjo, que ha sido y es una inspiración para cualquier estudiante, por su pasión y entrega continua. Te debo casi todo lo que he aprendido estos años y te agradezco de corazón todo lo que has hecho por mí, que ha sido mucho. Esta tesis es, en gran parte, culpa tuya y estoy muy feliz y orgulloso de haber contado contigo como director de este proyecto. A Carmen, gracias por los innumerables comentarios, consejos y enseñanzas desde mi comienzo en el Trabajo de Fin de Grado hasta ahora. Has estado disponible para mí siempre que te he necesitado y con una sonrisa en todo momento.

Gracias a los demás profesores que también han puesto su granito de arena, en especial a Lola, Encarna e Isa, durante las reuniones tan instructivas y enriquecedoras que hemos realizado en este tiempo.

Gracias a mis compañeros de laboratorio, por el apoyo constante y la ayuda que me han brindado cuando la pedía, y a todas las personas que han pasado por ahí durante este periodo.

Gracias a cada uno de los estudiantes y amigos que han dedicado un rato de su tiempo para participar en los experimentos que diseñamos y que forman parte de esta tesis.

Gracias a mi familia, en especial a mis padres, Leo y Antonio, y a mi hermano, Raúl, por su eterno amor, vínculo y soporte que dan a mi vida. Sin la estabilidad y el calor que me transmiten, esta tesis habría sido imposible.

Gracias a María José, por su cariño y su ánimo constantes, que me han servido para afrontar esta etapa con una visión más positiva y optimista.

Gracias a David, por su amistad tan especial y por la voluntad que me demuestra cada día para no perder el contacto a pesar de la distancia.

Y gracias a Siara por su fidelidad y compañía. Todo es más colorido y esplendoroso desde que llegó a mi vida.

RELACIÓN ENTRE CONTROL ATENCIONAL ESTRATÉGICO Y MEMORIA DE TRABAJO: ÍNDICES COMPORTAMENTALES Y ELECTROFISIOLÓGICOS.

Índice de Contenidos

Índice de Figuras

Introducción

Estudio 1

Estudio 2

Estudio 3

Discusión

Índice de Tablas

Estudio 1

Estudio 2

Estudio 3

Lista de Abreviaturas y Acrónimos

µV: Microvoltios

A: Lóbulo auricular (electrodo)

AC: *Accuracy*

AD: *Alzheimer's Dementia*

ANCOVA: Análisis de Covarianza

ANOVA: Análisis de Varianza

AS: Atención Selectiva

C: Central (electrodo)

CDA: *Contralateral Delay Activity*

cf.: Confer

cm: Centímetro

Cols.: Colaboradores

CP: Centro-parietal (electrodo)

CPT: *Continuous Performance Test*

CRT: *Cathode Ray Tube*

DA: Demencia tipo Alzheimer

dB: Decibelio (*Decibel*)

DMC: *Dual Mechanisms of Cognitive Control*

doi: *Digital Object Identifier*

EEG: Electroencefalografía (*Electroencephalography*)

e.g.: Exempli gratia

ER: *Error Rates*

ERPs: *Event Related Potentials*

Et al.: Et alii

Etc: Etcetera

Exp: *Experiment*

F: Frontal (electrodo)

FC: Fronto-central (electrodo)

Fp: Fronto-polar (electrodo)

GDS: *Geriatric Depression Scale*

Gnd: Tierra (electrodo)

Hz: Hercio (*Hertz*)

IADL: *Instrumental Activities of Daily Living Scale*

ICA: *Independent Component Analysis*

i.e.: Id est

kΩ: Kiloohmio (*Kiloohm*)

MCP: Memoria a Corto Plazo

MEC: Mini-Examen Cognoscitivo

MLP: Memoria a Largo Plazo

MMSE: *Mini-Mental State Examination*

MT: Memoria de Trabajo

ms: Milisegundos

N[Número]: Componente Negativo

O: Occipital (electrodo)

OSPAN: *Operation Span*

P[Número]: Componente Positivo

P: Parietal (electrodo)

PFC: *Prefontal Cortex*

RGB: *Red Green Blue color model*

RMf / *fMRI*: *Resonancia magnética funcional / Functional magnetic resonance imaging*

RT: *Reaction Time*

SOA: *Stimulus Onset Asynchrony*

T: Temporal (electrodo)

v.g.: Verbi gratia

vs.: Versus

VSAT: *Verbal Scholastic Aptitude Test*

WM: *Working Memory*

WMC: *Working Memory Capacity*

Lista de Símbolos

%: Porcentaje

#: Numeral / Almohadilla (máscara)

º: Grado de ángulo visual

***d*:** D de Cohen

***df*:** *degrees of freedom*

***F*:** F de Fisher

***K*:** Ecuación K de Pashler/Cowan

***M*:** Media (*Mean*)

n: Tamaño de la muestra

η^2: Eta cuadrada parcial

***p*:** Valor de la probabilidad (de la hipótesis nula)

***r*:** Correlación de Pearson

***SD*:** Desviación Estándard (*Standard Desviation*)

***t*:** T de student

&: Et/*Ampersand* (máscara)

Resumen

La Memoria de Trabajo (MT) es el sistema cognitivo que permite retener y manipular activamente una cantidad limitada de información durante un breve periodo de tiempo.

Durante las tres últimas décadas, se han ido acumulando numerosas pruebas que demuestran una estrecha interrelación entre la MT y la Atención Selectiva, entendida como la habilidad para priorizar el procesamiento de los aspectos relevantes del entorno y de bloquear o suprimir el procesamiento de información irrelevante o distractora que compite por el control de la acción. En este sentido, numerosos estudios han demostrado que una menor disponibilidad de recursos de MT, como consecuencia, por ejemplo, del envejecimiento o de realizar una tarea concurrente que demanda una alta carga mental, hace más difícil inhibir o bloquear el procesamiento de distractores competitivos en diferentes situaciones de atención selectiva (v.g., tareas de conflicto atencional).

Más recientemente, algunas investigaciones demuestran que la capacidad diferencial de MT puede modular también operaciones atencionales facilitatorias, como la generación de estrategias atencionales basadas en expectativas. Sin embargo, la mayoría de estos estudios emplean procedimientos experimentales que no permiten disociar entre los efectos comportamentales generados por procesos atencionales estratégicos y los que son el resultado de un procesamiento no-estratégico (automático) de la información. Por otra parte, desconocemos si una capacidad diferencial de MT puede modular determinados correlatos electrofisiológicos de procesos estratégicos de control atencional, pues todas las investigaciones previas en torno a esta problemática se han basado exclusivamente en medidas comportamentales del rendimiento en las tareas atencionales (v.g., tiempos de reacción).

En este contexto se desarrolla la presente tesis doctoral en la que, empleando procedimientos experimentales que permiten obtener efectos cualitativamente diferentes

(v.g., de signo opuesto) inducidos por el procesamiento estratégico vs. no-estratégico de la información, investigamos si una disponibilidad diferencial de recursos de MT puede modular la eficacia (y curso temporal) de procesos de control atencional facilitatorio, tanto a nivel comportamental como electrofisiológico.

Los resultados más relevantes que aportan los tres estudios experimentales que componen esta tesis son los siguientes:

- La modulación que ejerce una carga de MT variable sobre la generación de estrategias atencionales facilitatorias es independiente del tipo de información estimular, siendo por tanto la interacción entre MT y Atención Selectiva de dominio general, utilizando recursos comunes de control atencional más que de dominio específico, como un subsistema de procesamiento verbal.
- Una menor disponibilidad de recursos cognitivos de la MT se relacionaría con una demora en la capacidad para generar estrategias facilitatorias atencionales, independientemente del paradigma atencional estratégico empleado.
- Esta relación entre MT y Atención Selectiva afecta a los procesos facilitatorios atencionales tanto a nivel comportamental como electrofisiológico. En este último caso, la implementación de estrategias controladas basadas en expectativas en una tarea de *priming* estratégico (tipo Stroop) se relaciona con una eliminación del componente asociado al conflicto atencional.

Summary

Working Memory (WM) is a cognitive system which allows to retain and actively manipulate a limited amount of information during a brief time interval. During the last three decades, numerous pieces of evidence demonstrate an interrelation between WM and Selective Attention, which reflects the ability to prioritise the processing of relevant aspects of the environment and to block or suppress the processing of irrelevant or distracting information, which competes for action control. On this matter, multiple studies have shown that a lower availability of WM resources, as a consequence, for example, of aging or performing a concurrent task that demands a high mental work load, makes it more difficult to inhibit or block the processing of competitive distractors in different selective attention situations (e.g., attentional conflict tasks).

More recently, some research shows that the differential capacity of WM can also modulate facilitatory attentional operations, such as the attentional expectancy-based strategies. Nevertheless, most of these studies use experimental procedures which do not permit to dissociatie between the behavioural effects generated by strategic attentional processing and those which are the result of non-strategic (automatic) information processing. On the other hand, we do not know whether a differential capacity of WM can modulate electrophysiological correlates of strategic processes of attentional control, since all previous related research has been based on behavioural measures of attentional tasks performance (e.g., reaction times) exclusively.

In this context, the present doctoral thesis is developed, in which using experimental procedures which allow obtaining qualitatively different effects (e.g., opposite sign) induced by strategic vs. non-strategic processing of information, it is investigated whether a differential availability of WM resources can modulate the efficacy (and time course)

of facilitatory attentional control processes, both at a behavioural and electrophysiological level.

The most relevant results provided by the three experimental studies which integrate this thesis are as follows:

- The modulation that a variable WM load exerts on the development of expectancy-based facilitatory attentional strategies, is independent of the kind of stimulus information (e.g., verbal vs. visuospatial) to be processed in the memory task. This finding suggests that the interaction between WM and Selective Attention would be of general domain, thus reflecting the use of common resources of attentional control, rather than of specific domain, as a verbal processing subsystem.
- A lower availability of WM cognitive resources would be related to a delay in the ability to generate attentional facilitation strategies, regardless of the used strategic attentional paradigm.
- This relationship between WM and Selective Attention is observed on both behavioural and electrophysiological correlates of facilitatory attentional processes. In particular, the implementation of expectancy-based controlled processes in a strategic (Stroop-priming) task is related to the elimination of the electrophysiological component associated with attentional conflict.

I

Introducción

1. Atención Selectiva como modo de Control Atencional

La habilidad para adaptarse de forma eficaz a un entorno dinámico y cambiante requiere de ciertas competencias, como la capacidad para administrar nuestros recursos cognitivos dependiendo de las demandas de cada situación. Esta adaptación implica con frecuencia focalizar la atención sobre cierta información o aspectos que son relevantes para nuestros propósitos, mientras se ignoran aquellos otros que resultan irrelevantes o que compiten directamente con la información relevante. A esta capacidad de control atencional se le denomina **Atención Selectiva** (en adelante AS), e implica procesos inhibitorios y facilitatorios.

A lo largo de los años la atención ha sido concebida de diferentes formas: un mecanismo que permite seleccionar información (Broadbent, 1958), un conjunto de recursos cognitivos y esfuerzo (Kahneman, 1973), o un sistema para mantener una cierta actividad mental (Parasuraman, 1984). Uno de los aspectos más estudiados ha sido la capacidad para atender selectivamente a un estímulo relevante, al mismo tiempo que inhibimos todos los demás que pueden entorpecer o impedir el correcto procesamiento del mismo (Castillo-Moreno y Paternina-Marin, 2006).

Esta última idea pone de manifiesto la necesidad de conocer el efecto de interferencia que ciertos estímulos distractores pueden ejercer en el procesamiento de la información relevante. Diversas investigaciones evidencian que inhibir conductas que normalmente son automáticas y realizar otras que no lo son, genera un conflicto de control atencional que repercute en el rendimiento de determinadas tareas (Cohen Kadosh y cols., 2011; Lu y Proctor, 1994).

Para explorar este tipo de control atencional se han empleado diversas tareas cognitivas. Uno de los procedimientos experimentales más utilizados para investigar la capacidad para ignorar (e inhibir) información distractora en situaciones de selección atencional es el paradigma de *priming* negativo (Tipper, 1985). En este tipo de paradigma, se presenta un ensayo previo (*prime*) tradicionalmente compuesto por dos estímulos superpuestos (o espacialmente cercanos), y el participante debe atender y responder a uno de ellos (el *target*) e ignorar el otro estímulo distractor simultáneo. En un ensayo de prueba (*probe*) consecutivo se presentan de nuevo dos estímulos, debiendo el participante responder a uno de ellos (el *target*) e ignorar el otro, que actúa como distractor. El *target* del ensayo de prueba puede ser diferente de los dos estímulos del ensayo previo (condición control), o bien ser el mismo que (o relacionado con) el estímulo *target* (condición repetición atendido), o el estímulo distractor (condición repetición ignorado) del ensayo previo. El resultado más interesante que se encuentra es que las respuestas al *target* del ensayo de prueba son más *lentas* y/o menos precisas, cuando este mismo estímulo (u otro semánticamente relacionado) se presentó como un distractor ignorado en el ensayo previo, en comparación con la condición control en la que los estímulos de ambos ensayos son diferentes. A esta demora en la respuesta se le denominó *priming* negativo, por contraposición al efecto de *priming* (positivo) o de facilitación, que implica respuestas más rápidas a un *target* cuando este (o un estímulo relacionado) se presentó como un estímulo relevante atendido en un ensayo previo. La explicación más extendida del efecto de *priming* negativo es que reflejaría un proceso de inhibición atencional de las representaciones preactivadas de la información distractora presentada en el ensayo previo (para otras explicaciones alternativas no inhibitorias de este efecto, ver por ejemplo Milliken y cols., 1998; Neill y cols., 1992).

El paradigma de *priming* negativo cuenta con numerosas versiones que suelen incluir la presencia de distractores, junto con el estímulo *target*, tanto en el ensayo previo como en el ensayo de prueba, para favorecer una situación de selección atencional en la que se atiende a un estímulo (*target*) mientras se ignora otro que distrae (Chiappe y

MacLeod, 1995; Fox, 1995; May y cols., 1995). Sin embargo, investigaciones más recientes han demostrado efectos consistentes de *priming* negativo incluso cuando el *target* se presenta sin estímulos distractores tanto en el ensayo previo, como en el ensayo de prueba. Esto se debe a que la inclusión de distractores es solo una forma de inducir un estado selectivo atencional, pero no es la única. Determinadas condiciones experimentales como el tiempo de presentación del estímulo previo, el intervalo de asincronía temporal *prime-target*, el tipo de tarea sobre el *target* y/o las instrucciones atencionales sobre cómo procesar la información previa, también pueden favorecer una situación de selección atencional (v.g., Frings y Wentura, 2005; Noguera y cols., 2015; Noguera y cols., 2007; Ortells, Noguera y cols., 2016).

Otra de las tareas experimentales tradicionalmente empleadas para abordar el mecanismo de selección atencional es la tarea de flancos, en la que los estímulos distractores se presentan espacialmente separados del *target* (Eriksen, 1995; Eriksen y Eriksen, 1974). Usualmente, los participantes deben identificar y responder a un estímulo *target* central flanqueado por estímulos distractores (v.g., responder a la letra H acompañada de dos letras "S" a cada lado), que pueden causar mayor o menor interferencia para responder correctamente dependiendo, entre otros factores, del grado de proximidad entre distractores y estímulo *target*, o de la mayor similitud (v.g., N N H N N) o menor similitud (v.g., S S H S S) entre ambos. Estas condiciones de presentación generan una situación de conflicto atencional que es necesario resolver, por ejemplo, mediante la actuación de operaciones inhibitorias sobre la información distractora activada, para impedir que esta interfiera con la respuesta al estímulo *target*.

Al igual que las dos tareas anteriores, otra de las más ampliamente utilizadas y versionadas es la diseñada por Stroop en 1935. Originalmente, en su estudio incluyó parches de color y palabras impresas en tinta de color que podía coincidir con el significado de la propia palabra (v.g., “AZUL” en color azul) o ser incongruente (v.g., “AZUL” en color rojo). Los participantes tenían que nombrar el color de la tinta (dimensión relevante) e ignorar su significado en el caso de las palabras (dimensión irrelevante). Los resultados mostraron un efecto de interferencia semántica o tipo Stroop, esto es, una mayor latencia para nombrar el color de una palabra incongruente entre color de la tinta y significado, que para nombrar el color de un parche o leer una palabra en tinta negra. En el contexto de la AS, estos resultados se interpretarían como que la tarea de reconocer el color, por ser menos habitual, requeriría un mayor esfuerzo atencional que la tarea de lectura, un proceso más automático en el caso de expertos lectores. También es posible que la activación del significado de la palabra (dimensión irrelevante) compita por el control de la respuesta (nombrar el color) y, por tanto, sea necesario bloquearlo de alguna forma (v.g., mediante la actuación de mecanismos inhibitorios; Lamers y cols., 2010).

Este efecto de interferencia tipo Stroop ha sido ampliamente replicado en sucesivas versiones de la tarea y con diversos tipos de estímulos conflicto, incluyendo tareas Stroop numéricas (Foreman y cols., 1989; Wolach y cols., 2004), espaciales (Lu y Proctor, 1995; Shor, 1970; White, 1969), o versiones con estímulos emocionales (Hart y cols., 2010; Meier y Robinson, 2004).

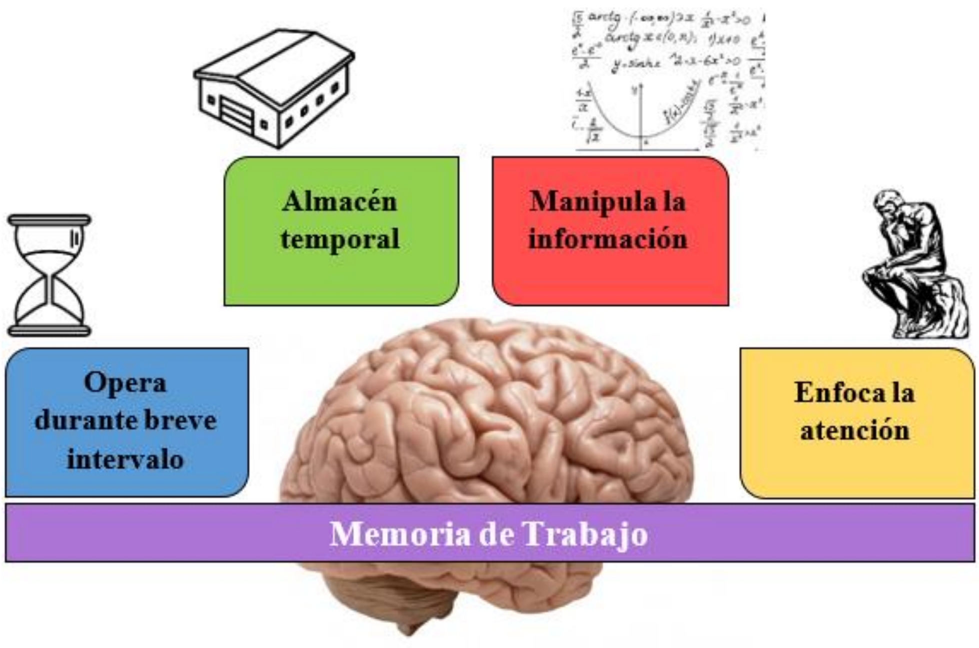
Durante las últimas décadas se han desarrollado diferentes líneas de investigación cuyos resultados han puesto de manifiesto que la capacidad de ignorar y/o inhibir información distractora en situaciones de AS como las que se observan en tareas de conflicto atencional, como la interferencia tipo Stroop o de flancos, o en tareas de *priming* negativo, resulta directamente modulada por la mayor o menor disponibilidad de recursos de la denominada Memoria de Trabajo. Cabe destacar, en este sentido, la aproximación que vienen desarrollando Randall Engle y colaboradores, quienes defienden que la capacidad de la Memoria de Trabajo sería un indicador altamente predictivo del rendimiento en tareas de AS, y de la habilidad para afrontar situaciones que requieren controlar la interferencia de distractores irrelevantes en tareas de conflicto atencional (Engle, 2002; Kane y Engle, 2003; Kane y cols., 2007).

2. La noción de Memoria de Trabajo

La **Memoria de Trabajo** (en adelante MT) es un sistema cognitivo que nos permite, entre otras funciones, retener activamente una cantidad limitada de representaciones durante un breve periodo de tiempo, de forma que puedan ser manipuladas y/o reorganizadas con esquemas previos almacenados (Baddeley, 1986). La Figura 1 representa gráficamente las principales características de la MT.

Figura 1.

Principales funciones y características de la Memoria de Trabajo.

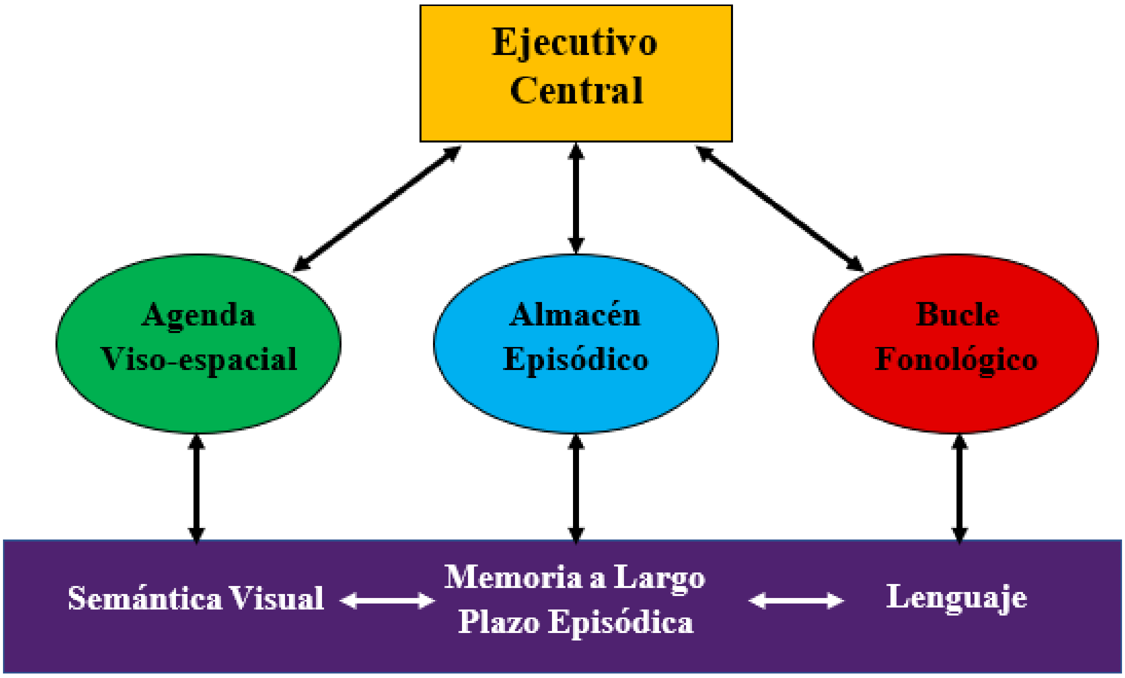


Baddeley y Hitch (1974) desarrollan un modelo funcional de MT, como alternativa al sistema de Memoria a Corto Plazo (MCP) surgido en el contexto de los modelos estructurales, que concibe la memoria como una estructura que almacena información y permite recuperarla cuando se necesita (v.g., modelo multi-almacén de Atkinson y Shiffrin, 1968), y que muchos autores comenzaban a cuestionar por los inconsistentes resultados sobre su relación con el desempeño de tareas complejas (v.g., Crowder, 1982), y por habérsele atribuido como principal función la de mediar el almacenamiento de la información en la Memoria a Largo Plazo (MLP). La MT que proponen Baddeley y Hitch (1974) representa un sistema con un carácter más activo y adaptativo, alejado de la idea de un simple almacén de información que suponía la MCP, el cual permite al organismo retener temporalmente y manipular activamente información relevante dirigida a una acción.

Dicha MT sería además de naturaleza "multi-componencial", estando integrada por componentes de memoria disociables que intercambian recursos. En el modelo que proponen Baddeley y Hitch (1974; Baddeley 1996; 2000; ver la Figura 2) la MT estaría constituida por un sistema de control atencional, el *Ejecutivo central*, unido a tres subsistemas: la *Agenda viso-espacial*, el *Bucle fonológico-articulatorio*, y el *Almacén episódico* (añadido posteriormente). La Agenda viso-espacial es responsable de fraccionar los componentes separando la información visual, espacial y kinestésica, asociadas a áreas del hemisferio derecho como la corteza motora asociativa, la corteza visual asociativa y la circunvolución frontal inferior. El Bucle fonológico-articulatorio contiene información verbal y acústica mediante un almacén temporal y un sistema articulatorio, situados principalmente en las áreas de Broca (lóbulo frontal) y Wernicke (lóbulo temporal). El Almacén episódico tendría como funciones almacenar, integrar y manipular información multidimensional, además de servir como interfaz de los demás subsistemas y conectar esta información con la MLP. Este subsistema se localiza en zonas frontales del hemisferio derecho del cerebro. El Ejecutivo central, con funciones de control atencional y de coordinación del resto de subsistemas, se asociaría principalmente a áreas de la corteza prefrontal.

Figura 2.

Representación gráfica del modelo de Memoria de Trabajo propuesto por Baddeley (2000), que incluye un sistema de control atencional, el Ejecutivo central, que a su vez regula y coordina tres subsistemas de procesamiento: la Agenda viso-espacial, el Almacén episódico y el Bucle fonológico. Estos subsistemas se encargan de retener y procesar información de diferente índole y, sobre todo a través del Almacén episódico, pueden enviar la información más relevante a la MLP.



A raíz de este modelo, han surgido numerosas investigaciones cuyo objetivo ha sido estudiar la interacción entre procesamiento y almacenamiento que tiene lugar en la MT, observando que existen diferencias en la capacidad de MT que unos individuos tienen respecto a otros y que esta capacidad resulta esencial para realizar una amplia variedad de tareas como aprender, seguir instrucciones, razonar o resolver problemas (v.g., Cantor y Engle, 1993; Cantor y cols., 1991; Engle y cols., 1992).

Daneman y Carpenter (1980) encontraron las primeras diferencias inter-individuales importantes de capacidad de MT empleando una tarea de amplitud ("span") lectora. En esta tarea, los participantes leían una serie de frases, sin relación entre ellas, mientras tenían que mantener en su memoria la última palabra de cada frase. Las personas que recordaban más palabras también eran las que realizaban lecturas más rápidas y eficaces, de lo que se puede inferir que la capacidad de MT tiene una relación muy estrecha con procesos y tareas más complejas. De hecho, la capacidad de MT ha demostrado ser altamente predictiva del rendimiento en tareas cognitivas de alto nivel, como comprensión lectora y auditiva (Daneman y Carpenter, 1983), seguir instrucciones (Engle y cols., 1991), aprender vocabulario (Daneman y Green, 1986), razonamiento (Kyllonen y Christal, 1990), o tomar notas (Kiewra y Benton, 1988), entre otras.

Para abordar y explicar esta correlación entre capacidad de MT y procesos cognitivos de alto nivel de forma más exhaustiva, surgieron investigaciones como la realizada por Engle y colaboradores (1992). El principal objetivo del estudio fue averiguar si el tiempo que las personas invierten en memorizar determinadas palabras, guarda relación con su posterior recuerdo y con la puntuación obtenida en un test de aptitudes verbales (Verbal Scholastic Aptitude Test; VSAT). Los resultados mostraron que las personas de alta capacidad de MT memorizaban más palabras y obtenían también mejor puntuación en el VSAT, y esta correlación era independiente del tiempo empleado para memorizar. Estos datos sugieren que las diferencias individuales en capacidad de MT no dependen de la eficacia en el procesamiento de los estímulos, sino de los recursos disponibles para recuperar información de la MLP (ver también, Conway y Engle, 1996).

3. Relación entre Atención Selectiva y Memoria de Trabajo

Los resultados de los estudios descritos en el apartado anterior promovieron el desarrollo de diferentes líneas de investigación cuyos resultados mostraban que los individuos de alta y baja capacidad de MT, diferían también en su habilidad para inhibir o bloquear información distractora o irrelevante en diferentes tareas de AS (v.g., Conway y Engle, 1994; Conway y cols., 1999; Engle, 2002; Engle y Kane, 2004; Kane y cols., 2001; Kane y cols., 2007). Entre dichas líneas de investigación, cabe destacar la que emplea la metodología de los “grupos extremos” y la que utiliza el paradigma de “tarea dual” como procedimiento experimental.

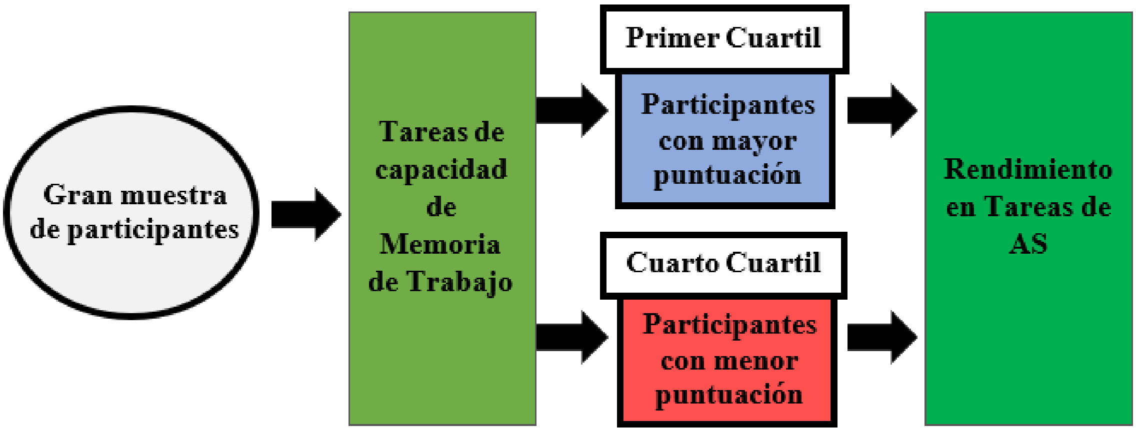
3.1 Estrategia Metodológica de “Grupos Extremos”

Este tipo de investigaciones incluye siempre una fase previa en la que se evalúa la capacidad de MT de una amplia muestra de participantes mediante diferentes tareas que requieren de este sistema de memoria, como las de amplitud (*span*) compleja de operaciones aritméticas, o las de amplitud de simetría visual (Draheim y cols., 2016; Harrison y cols., 2013). La muestra es distribuida en grupos “extremos” de alta vs. baja capacidad de MT, según se encuentren sus puntuaciones en dichas tareas incluidas en el primer y cuarto cuartil de la distribución, respectivamente. De esta forma, en una segunda fase se puede analizar un posible patrón de ejecución diferencial de ambos grupos en tareas de AS (v.g., tareas tipo Stroop, de flancos, o de *priming* negativo). La Figura 3 representa gráficamente esta metodología.

Los resultados de los estudios que emplean esta metodología muestran que las personas con alta capacidad de MT suelen ser más eficaces para ignorar de forma activa y/o bloquear el procesamiento de la información irrelevante, en comparación con las personas con menor capacidad de MT (Ahmed y De Fockert, 2012; Conway y cols., 1999; Ortells, Noguera y cols., 2016).

Figura 3.

Descripción gráfica de las fases que se emplean en la metodología de "grupos extremos".



Un ejemplo referente de este tipo de investigación es el estudio realizado por Kane y Engle (2003) en el que, a través de cinco experimentos, los autores contaron con la colaboración de alrededor de 400 participantes, los cuales realizaron previamente una tarea de amplitud compleja de operaciones aritméticas (en inglés *Operation Span* – OSPAN *task*) para evaluar su capacidad de MT verbal. En esta tarea los participantes debían retener una cantidad variable, normalmente entre 2 y 7, de estímulos verbales (v.g., letras o palabras sencillas) para su posterior recuerdo en orden secuencial. Mientras los participantes trataban de memorizar estos ítems, también debían resolver una serie de operaciones aritméticas simples (sumas, restas, multiplicaciones y divisiones), indicando si el resultado que se presentaba era correcto o incorrecto. Para evitar que el participante se centrase en una de las tareas en detrimento de la otra, se le instruía para que tratase de ser preciso en ambas, de manera que solo se consideraban válidas las puntuaciones de aquellas personas que obtuvieran un porcentaje de aciertos superior al 85% en la tarea de operaciones. Este tipo de tareas no sólo requiere retener de forma pasiva un conjunto de estímulos, sino que demanda también operaciones de control atencional (y, por tanto, consumen recursos atencionales de los disponibles) que permiten el procesamiento y manipulación activa de la información almacenada en la MT (Engle, 2001; 2002).

De la muestra total de participantes en el estudio de Kane y Engle (2003), solamente aquellos con puntuaciones más altas (primer cuartil) y bajas (cuarto cuartil) en la tarea OSPAN realizaron posteriormente una tarea tipo Stroop que incluía tres tipos de ensayos (congruente, incongruente y neutral) y dos tipos de proporciones de congruencia (experimentos 1-3: 0% vs. 75% de ensayos congruentes; experimento 4: 20% vs. 80% de ensayos congruentes). Los autores observaron que los participantes con baja capacidad de MT cometían muchos más errores cuando la proporción de ensayos congruentes era de entre 75-80%, y eran más lentos con una proporción de entre 0-20% de congruencia, en comparación con los participantes con alta capacidad de MT, los cuales mostraron un menor efecto de interferencia de la información distractora.

Coherente con esta línea, los estudios sobre envejecimiento normal aportan pruebas indirectas de esta relación entre MT y AS, al demostrar que las personas mayores, al deteriorarse su capacidad de MT a causa de la edad, son más lentas y necesitan más tiempo para suprimir la información irrelevante en diferentes tareas de AS, mostrando un patrón similar al observado en adultos jóvenes con baja capacidad de MT (Gazzaley, 2012; Gazzaley y cols., 2008; Gazzaley y Nobre, 2012; Jost y cols., 2011; Zanto y Gazzaley, 2014).

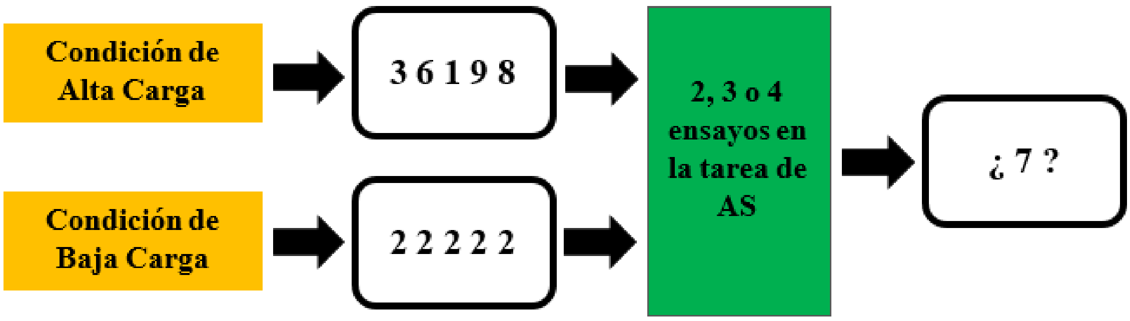
Basándose en estos datos, Engle y colaboradores propusieron la **Teoría del Control Atencional de la Memoria de Trabajo** según la cual, las diferencias individuales en capacidad de MT reflejarían principalmente variaciones en la habilidad de control atencional de dominio general (es decir, con independencia de la naturaleza de la tarea). Esta habilidad atencional sería necesaria para mantener activo el objetivo de la tarea, restringiendo el foco atencional al objetivo relevante y bloqueando el acceso a la información irrelevante (Engle y Kane, 2004; Kane y cols., 2007).

3.2. Estrategia Metodológica de "Tarea Dual"

Una segunda línea de investigación relevante utiliza un paradigma de "tarea dual" que combina una tarea de MT, que demanda una mayor o menor carga mental (v.g., memorizar series de números o letras) con una que requiera selección atencional (v.g., tipo Stroop). El objetivo de esta estrategia es explorar si la magnitud de la interferencia que ejerce un distractor en la tarea de AS, resulta afectada por la manipulación de la carga de MT (ver Figura 4). Los estudios en los que se ha empleado este tipo de paradigma muestran que, cuando la carga de memoria es alta (v.g., memorizar 5 dígitos al azar), los participantes presentan mayor efecto de interferencia de la información distractora en diferentes tareas de AS (en términos de latencia de respuesta y tasa de precisión), en comparación con condiciones de carga baja (v.g., memorizar 5 dígitos iguales o consecutivos) (De Fockert, 2013; De Fockert y cols., 2010; Lavie y De Fockert, 2005).

Figura 4.

Descripción gráfica de las fases que se emplean en el paradigma de "tarea dual".



Un ejemplo representativo de esta metodología es la investigación llevada a cabo por De Fockert y colaboradores (2001), cuyo objetivo era comprobar si una alta vs. baja carga de MT afectaba al procesamiento de los estímulos distractores en una tarea de control atencional. Para ello, combinaron una tarea de MT, que requería memorizar secuencias de 5 dígitos de dificultad variable, con una tarea atencional tipo Stroop en la que usaban nombres y caras de personajes famosos. En la tarea de MT existían dos condiciones: una de baja carga (v.g., 5 dígitos en orden secuencial, 0 1 2 3 4) y una de alta carga (v.g., 5 dígitos en orden aleatorio, 8 3 6 2 7). En ambas condiciones los participantes debían recordar dichas secuencias de dígitos mientras realizaban la tarea de AS, que consistía en responder si el nombre que aparecía en la pantalla pertenecía a un político reconocido o a un cantante famoso. Sin embargo, junto el nombre aparecía una cara distractora que debían ignorar. Esta cara podía pertenecer a la misma categoría (político vs. cantante) que la del nombre que aparecía junto a ella (condición congruente), o ser de distinta categoría (condición incongruente). Tras dos, tres o cuatro ensayos aparecía un dígito *target* (v.g., "6" del ejemplo anterior) y los participantes debían indicar cuál era el número que seguía a este dígito en la secuencia que previamente memorizaron (respuesta correcta "2").

Los resultados mostraron un mayor efecto de interferencia del distractor y tiempos de respuesta más altos en la condición de alta carga, en comparación con la de baja carga de MT. El registro de la actividad cerebral mediante la técnica de resonancia magnética funcional (RMf; en inglés, *functional magnetic resonance imaging* - fMRI) demostró además que, en condiciones de alta carga de MT, existía un aumento significativo en los niveles de activación de ciertas áreas de la corteza frontal (v.g., giros frontales inferior y medio y el giro pre-central), unido a una mayor actividad en regiones cerebrales asociadas al procesamiento de las caras distractoras (v.g., giro fusiforme). Estos datos sugieren que los participantes tenían más dificultades para bloquear el procesamiento de los distractores en la tarea atencional Stroop (las caras) bajo condiciones de alta carga en la tarea concurrente de MT.

Estos resultados se pueden abordar desde la **Teoría de la Carga Atencional** de Lavie y colaboradores (2004), según la cual una carga alta de memoria reduciría o agotaría los recursos cognitivos disponibles de la MT, ya que son limitados, siendo fundamentales para diferenciar la información relevante de la irrelevante. En consecuencia, la respuesta al estímulo *target* sería más susceptible a la influencia de información irrelevante o distractora cuando la carga de MT fuese alta, o en personas con una baja capacidad de MT (v.g., ancianos), pues en ambos casos existirían menos recursos cognitivos disponibles.

4. Memoria de Trabajo y Estrategias Atencionales Facilitatorias

Los datos procedentes de estas dos líneas de investigación demuestran claramente que una reducción en la disponibilidad de recursos de la MT se asocia con una mayor dificultad para ignorar activamente la información irrelevante, que compite directamente con el procesamiento de estímulos relevantes en tareas de AS. Esta habilidad para ignorar información distractora requiere adoptar estrategias que impliquen, por ejemplo, la actuación de mecanismos de control que inhiban la representación mental activada de dicha información, para impedir que acceda al control de la acción/respuesta (Lavie, 2001; Lavie y cols., 2004).

Sin embargo, se ha investigado mucho menos la influencia de estas variaciones, en la disponibilidad de recursos de MT, sobre la eficiencia de operaciones atencionales de carácter facilitatorio, como las relacionadas con el procesamiento estratégico basado en expectativas. Esto es, cabe preguntarse si el hecho de tener una menor capacidad de MT, o realizar una tarea de MT de alta carga, influye en la capacidad para generar y desarrollar estrategias atencionales de carácter facilitatorio. ¿Puede una persona con baja capacidad de MT generar una expectativa sobre un determinado estímulo posterior, que le permita responder a éste de forma eficaz, de forma similar a como lo haría un individuo con alta capacidad? Y en la medida que el envejecimiento se asocia a una capacidad reducida de recursos de MT, ¿mostrarían las personas mayores un rendimiento distinto al de los jóvenes en tareas atencionales que requieren generar expectativas?

Un ejemplo de estrategia atencional facilitatoria relacionada con la generación de expectativas lo encontramos en la tarea de *priming* semántico. Los participantes deben dar algún tipo de respuesta (v.g., decisión léxica; categorización semántica) a un estímulo *target* (v.g., la palabra PERRO) que es precedido (o acompañado) por un estímulo *prime*, el cual puede estar relacionado semánticamente con el *target* (v.g., GATO), o pertenecer a una categoría semántica diferente (v.g., LIBRO). Se obtiene un efecto de "facilitación" o *priming* semántico cuando las respuestas al *target* son más rápidas y/o precisas en los ensayos relacionados, en comparación con los ensayos no-relacionados. Este efecto de *priming* "facilitatorio" puede ser el resultado tanto de procesos automáticos de preactivación en la memoria semántica, como de procesos de carácter controlado y estratégico, como los basados en la generación de expectativas (Neely, 1991; Posner y Snyder, 1975).

El *priming* automático surge cuando un estímulo *prime* activa de forma inmediata e involuntaria su representación semántica, activación que se propagaría a otras representaciones relacionadas, entre las que se encontraría la correspondiente al *target* en un ensayo relacionado, reduciendo su umbral de reconocimiento y facilitando la identificación y respuesta al mismo. Dicho efecto se considera automático si ocurre en ausencia de atención consciente, en intervalos temporales de asincronía (en inglés, *Stimulus Onset* Asynchrony - SOA) *prime-target* muy cortos que impiden procesos estratégicos, y no resultaría afectado (interferencias) por otras tareas concurrentes, además de ser independiente de la capacidad de MT.

Por el contrario, el *priming* controlado tiene lugar cuando es el resultado de algún procesamiento estratégico, como puede ser generar potenciales estímulos *target* relacionados con un estímulo *prime* (también llamado proceso proactivo; ver Neely, 1991; Neely y cols., 1989). A diferencia del *priming* automático, el *priming* controlado requiere atención consciente, el uso de intervalos de SOA *prime-target* de mayor duración para permitir el desarrollo de procesos controlados, y puede verse afectado negativamente por la realización de una tarea cognitiva simultánea y/o por una menor capacidad de MT de los participantes.

Los resultados de algunos estudios recientes que emplean un paradigma de *priming* semántico sugieren que, bajo condiciones en las que se instruye a los participantes a utilizar estrategias controladas como la generación de expectativas (v.g., alta proporción de ensayos en los que el estímulo *prime* y *target* están relacionados), el desarrollo de dichas estrategias puede verse modulado por variaciones en disponibilidad de recursos de MT. Así, la magnitud de los efectos de *priming* controlado puede reducirse significativamente en individuos con baja capacidad de MT, o bien cuando se realiza una tarea simultánea de memoria que demanda una alta carga (Heyman y cols., 2014; Hutchison y cols., 2014).

Un ejemplo de cómo las diferencias inter-individuales en la capacidad de MT influyen en las estrategias atencionales facilitatorias fue la investigación realizada por Hutchison y colaboradores (2014). Los participantes debían realizar una tarea de decisión léxica (palabra vs. no-palabra) sobre un estímulo *target*, el cual era precedido por un estímulo *prime* que podía estar relacionado o no con el *target*. Los autores incluyeron 3 tipos de relación semántica entre ambos estímulos, simétrica (v.g., hermano-hermana), hacia delante (v.g., atómica-bomba), y hacia atrás (v.g., fuego-llama), y también manipularon el intervalo de asincronía (SOA) *prime-target* a dos niveles: corto (250 ms) vs. largo (1.250 ms). Además, toda la muestra fue previamente evaluada mediante una batería de pruebas que examinaba su capacidad de MT y control atencional (v.g., Tareas Ospan, Antisacada y tipo Stroop). Los participantes con una alta capacidad de MT mostraron un efecto de *priming* de mayor magnitud en la condición de relación semántica *prime-target* “hacia delante”, en comparación con el obtenido por los participantes con baja capacidad. Sin embargo, en este último grupo se observó un mayor efecto de *priming* cuando la relación semántica *prime-target* se establecía en dirección opuesta (hacia atrás). En la condición de relación semántica simétrica, ambos grupos mostraron un efecto de facilitación de magnitud similar. Este efecto de *priming* se encontró en los dos valores de SOAs, con respuestas más rápidas y mayor porcentaje de aciertos en ensayos relacionados, frente a los no-relacionados. Los investigadores concluyen que las personas de alta capacidad son más propensas a realizar un control cognitivo de tipo proactivo, que les permite generar y mantener la información en su MT, mientras que los de baja capacidad emplearían un control de carácter más reactivo al detectar y preparar una respuesta a la información después de su aparición (ver Braver, 2012; Braver y cols., 2007).

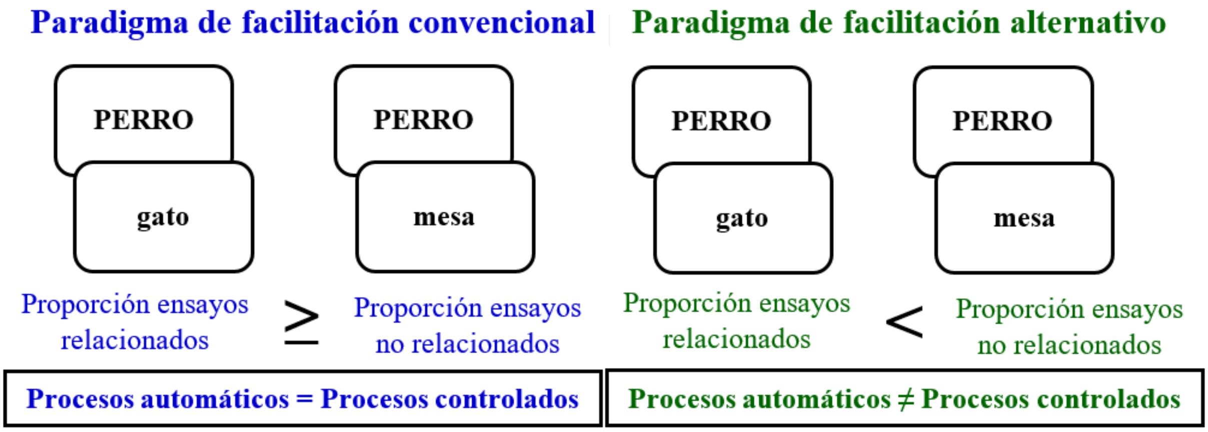
En otro estudio llevado a cabo por Heyman y colaboradores (2014), se comprobó cómo la manipulación de la carga de MT también modulaba las estrategias atencionales facilitatorias. En esta investigación, emplearon la misma tarea de decisión léxica usada por Hutchison y colaboradores, con 3 tipos de relación (v.g., simétrica, hacia delante y hacia atrás). Sin embargo, en esta ocasión la tarea de *priming* se realizaba de forma concurrente con una tarea de memoria espacial, en la que los participantes debían memorizar las localizaciones espaciales de cuatro puntos repartidos aleatoriamente (condición de alta carga) o formando una línea (condición de baja carga) en una matriz 4x4. Finalmente, tras 5 ensayos de la tarea de decisión léxica, los participantes tenían que marcar, con la ayuda del ratón, las casillas de la matriz en las que se habían presentado los puntos. Los datos mostraron que la mayor o menor carga de la tarea de MT interfería con el efecto de *priming* prospectivo (v.g., asociaciones hacia delante), disminuyendo, incluso desapareciendo, dicho efecto estratégico en situaciones de alta carga frente a baja carga. Esto no ocurrió en el *priming* simétrico o retrospectivo (v.g., asociaciones hacia atrás), que se mantuvo constante e independiente de la carga de MT. Estos resultados sugieren que los procesos prospectivos, como la generación de expectativas, requieren de cierto control o recursos atencionales y dependen de la capacidad de MT, mientras que los retrospectivos son más independientes de las limitaciones de capacidad de MT y se realizan relativamente sin esfuerzo.

Es preciso observar que los escasos estudios previos que han demostrado que variaciones en la capacidad (o recursos) de la MT pueden influir también en el procesamiento atencional estratégico de la información, emplean tareas de *priming* en las que los efectos comportamentales, que resultan de un procesamiento controlado y estratégico del *prime* (v.g., generación de expectativas), serían del *mismo tipo* (efecto de facilitación) que los inducidos por procesos automáticos (v.g., propagación de la activación en memoria semántica). Esto sucedería, por ejemplo, en procedimientos convencionales de *priming* en los que la proporción de ensayos relacionados es igual (o mayor) que la de ensayos no-relacionados (ver Figura 5). En estas circunstancias, sería difícil determinar si la reducción de los efectos de *priming* que se observa bajo condiciones de alta carga de MT, o en personas con baja capacidad de MT, se debe a un uso menos eficiente de estrategias basadas en expectativas, o bien a una reducción del procesamiento automático del estímulo *prime*[1].

[1] Estudios recientes, principalmente realizados por Kiefer y colaboradores, han demostrado que incluso procesos inconscientes y supuestamente automáticos pueden ser objeto de algún tipo de supervisión o control atencional, aunque de una forma indirecta. Esto ha sido desarrollado como el **Modelo de Sensibilización Atencional** (Kiefer, 2012; Kiefer y Martens, 2010; Martens y cols., 2011; para una revisión, ver Kiefer y cols., 2012).

Figura 5.

Representación gráfica de un paradigma de *priming* en el que se presenta un estímulo *prime* (PERRO) seguido de un estímulo *target* relacionado (gato) vs. no-relacionado (mesa). Cuando los ensayos relacionados se presentan en una proporción igual o mayor (paradigma de facilitación convencional), la actuación de procesos automáticos y controlados va en el mismo sentido. En cambio, cuando se aumenta la proporción de ensayos no-relacionados respecto a los relacionados (paradigma de facilitación alternativo), se favorece la puesta en marcha de estrategias para responder a la categoría contraria, observándose resultados cualitativamente diferentes producidos por procesos automáticos vs. controlados.



5. Diferencias cualitativas entre Procesamiento Controlado y Automático

Con el fin de subsanar esta posible limitación, se han diseñado variantes del procedimiento de *priming* en los que el procesamiento estratégico (controlado) vs. no-estratégico (automático) del *prime* puede tener consecuencias comportamentales cualitativamente diferentes, como serían efectos de *priming* de signo opuesto.

Un ejemplo ilustrativo es la tarea de categorización semántica utilizada por Ortells y colaboradores (2003). En cada ensayo se presenta una palabra *prime* (v.g., TORO) que es seguida, en un elevado número de ensayos (80%), por una palabra *target* de una categoría semántica diferente (v.g., mano), mientras que sólo en un reducido número de ensayos (20%) el *target* es un fuerte asociado de la misma categoría semántica que la del *prime* (v.g., vaca). Los participantes conocen esta proporción diferencial de ensayos no-relacionados y relacionados y, además, se les anima a usar estratégicamente la información del *prime* para anticipar la categoría del *target* que, en este caso, sería la opuesta a la del *prime* con una alta probabilidad (80%). En estas condiciones, un procesamiento estratégico (basado en expectativas) del *prime* induciría respuestas más rápidas a un *target* no-relacionado que a un *target* relacionado, es decir, una inversión estratégica del *priming* facilitatorio convencional.

Pero cuando se impide el desarrollo de dichas estrategias atencionales, como sucedería cuando el *prime* se presenta de forma subliminal y/o se usa un intervalo de SOA *prime-target* relativamente corto (v.g., igual o inferior a 300 ms), entonces solamente sería posible observar un efecto de facilitación convencional (respuestas más rápidas a un *target* relacionado que a un *target* no-relacionado), que resultaría del procesamiento automático del estímulo *prime*. Este fue precisamente el patrón diferencial (opuesto) de efectos de *priming* que observaron Ortells y colaboradores (2003) cuando se inducía un procesamiento estratégico vs. no-estratégico del *prime*.

Un patrón similar de efectos cualitativamente diferentes, dependiendo del procesamiento consciente vs. no-consciente del *prime*, fue observado por Merikle y Joordens (1997) con una tarea *priming*-Stroop secuencial que incluía mayor proporción de ensayos *prime-target* incongruentes (75%), que congruentes (25%; ver también Merikle y Cheesman, 1987; Merikle y cols., 1995). En cada ensayo se presenta muy brevemente (33 ms) una palabra *prime* (v.g., ROJO o VERDE) que es seguida inmediatamente, o tras una breve demora, por una máscara visual (&&&&&&) con el objetivo de impedir, o de permitir, respectivamente, la identificación consciente del *prime*. Los autores encontraron una inversión del efecto Stroop (v.g., respuestas más rápidas en ensayos incongruentes que congruentes) en la condición de máscara demorada, al responder los participantes según la información predictiva del *prime*. Sin embargo, en la condición de máscara inmediata, a pesar de conocer la mayor proporción de ensayos incongruentes, los participantes no adoptaron una respuesta estratégica basada en esta información predictiva, al no poder procesarla de forma consciente, mostrando un efecto estándar de interferencia Stroop (v.g., respuestas más lentas en ensayos incongruentes que congruentes). Estos resultados sugieren que, sin la identificación consciente del estímulo *prime*, no es posible poner en marcha ningún tipo de estrategias para anticipar la respuesta y ésta reflejaría fundamentalmente un procesamiento automático del prime.

Unos resultados similares fueron observados por Daza y colaboradores (2002), quienes demostraron, además, que los efectos Stroop inducidos por la percepción consciente vs. no-consciente del *prime* no sólo eran de signo opuesto, sino que mostraban también un curso temporal muy diferente. Los autores emplearon una tarea Stroop, similar a la del estudio de Merikle y Joordens (1997), con un mayor porcentaje de ensayos incongruentes (75%) que congruentes (25%), y en la que la palabra *prime* podía ir seguida por una máscara inmediata (procesamiento no consciente del *prime*) o demorada (procesamiento consciente). Y se incluyeron 4 niveles de SOA *prime-target* (300, 400, 500 y 700 ms).

El patrón de resultados fue diferente en función de la condición de enmascaramiento. La condición de máscara inmediata producía un efecto de interferencia Stroop cuando el SOA era de 300 y 400 ms, pero no en intervalos más largos (v.g., los tiempos de reacción eran similares en ambas condiciones). Por el contrario, cuando la presentación de la máscara permitía el procesamiento consciente de la palabra *prime* encontraron que, a medida que aumentaba el intervalo de SOA *prime-target*, se incrementaba la probabilidad de observar una inversión estratégica de la interferencia Stroop. Con un nivel de SOA de 300 ms, la diferencia entre las condiciones congruente e incongruente no fue significativa. Sin embargo, con un intervalo temporal de 700 ms, la latencia de respuesta fue menor en los ensayos incongruentes que en los congruentes. Estos resultados son consistentes con los obtenidos en otros estudios que emplearon tareas convencionales de *priming* semántico (v.g., Fuentes y Tudela, 1992; Neely, 1977), al mostrar que un mayor SOA *prime-target* facilitaría el desarrollo de procesos controlados y la implementación de estrategias basadas en expectativas.

6. Procesos Atencionales Controlados y Automáticos en el Paradigma de *Priming* Estratégico

Una tarea *priming*-Stroop similar con una mayor proporción de ensayos incongruentes que congruentes fue también empleada por Froufe y colaboradores (2009), para investigar si el envejecimiento normal y patológico (demencia tipo Alzheimer, DA), puede afectar no sólo a la capacidad para inhibir información irrelevante, sino también a la habilidad para implementar estrategias atencionales basadas en expectativas (que supondrían contrarrestar reacciones automáticas rutinarias y bien establecidas).

En su estudio participó un grupo de 27 adultos jóvenes (con una media de edad de 20.3 años), un grupo de 25 adultos mayores (con una edad promedio de 76.3 años), y un grupo de 15 adultos mayores diagnosticados de DA (con una edad media de 76.2 años). En cada ensayo se presenta una palabra *prime* (VERDE o ROJO) seguida, después de 1125 ms, por un *target* (un parche de color rojo o verde) que los participantes deben identificar. Como en los estudios previos de Merikle y Joordens (1997) y Daza y colaboradores (2002), en la mayoría de las ocasiones, el color al que hacía referencia la palabra *prime* era el opuesto al color del parche que le seguía (84% de ensayos incongruentes), mientras que sólo en un bajo porcentaje de ensayos ambos estímulos hacían referencia al mismo color (16% de ensayos congruentes). Los participantes fueron previamente informados de esta proporción diferencial de ensayos incongruentes y congruentes.

Froufe y colaboradores (2009) encontraron un patrón de resultados muy diferente en función de la edad de los participantes: el grupo de adultos jóvenes mostró una inversión "estratégica" de la interferencia Stroop (respuestas más rápidas en los ensayos incongruentes que en los congruentes), demostrando que eran capaces de usar la información del estímulo *prime* de forma estratégica y anticipar el color del parche que debían identificar. Los adultos mayores sin DA también mostraron una tendencia de inversión del efecto Stroop, si bien no fue estadísticamente significativa. Por el contrario, en el grupo de adultos mayores con DA se observó un efecto "convencional" de interferencia Stroop (respuestas más lentas en ensayos incongruentes frente a congruentes), lo que sugiere que la DA conllevaría una pérdida adicional de la capacidad para generar procesos estratégicos basados en expectativas (ver también Langley y cols., 2001). En el estudio de Froufe y colaboradores (2009) se asume de forma implícita que la DA y, en general, el envejecimiento, se asociaría con una reducción de la capacidad de MT.

En un trabajo más reciente, Ortells y colaboradores (2017) emplearon una tarea *priming*-Stroop similar a la anterior, pero los participantes debían realizar al mismo tiempo una tarea de MT verbal, que demandaba mayor (o menor) carga mental. Esto les permitió explorar de forma más directa si la mayor o menor disponibilidad de recursos de MT afecta a la habilidad para implementar estrategias atencionales basadas en expectativas. Los participantes respondían a un *target* (un parche de color verde vs. rojo) que era precedido por una palabra *prime* de color (ROJO vs. VERDE), siendo los ensayos incongruentes más frecuentes (80%) que los ensayos congruentes (20%). A su vez, la palabra *prime* era precedida por una secuencia de cinco dígitos iguales (condición de baja carga), o de cinco dígitos aleatorios (condición de alta carga) que los participantes debían retener. Después de dos, tres o cuatro ensayos de la tarea *priming*-Stroop, aparecía un dígito de prueba y los participantes debían contestar si estaba presente o no en la secuencia que habían memorizado previamente. El principal hallazgo fue una interacción entre la congruencia *prime-target* y la carga de MT. En concreto, se observó una inversión estratégica del efecto Stroop en la condición de baja carga de MT, y un efecto opuesto de interferencia Stroop (respuestas más lentas en los ensayos incongruentes) en alta carga de MT.

Estos resultados replican y extienden los de algunos estudios previos (v.g., Hutchison y cols., 2014; Heyman y cols., 2014), al demostrar que la disponibilidad de recursos cognitivos en la MT es crucial para realizar con éxito tareas que requieren procesos estratégicos basados en expectativas. Y, además, en claro contraste con estos estudios, el procedimiento de *priming* empleado por Ortells y colaboradores (2017) permite obtener efectos comportamentales diferentes (de signo opuesto) bajo condiciones que facilitan o impiden un procesamiento estratégico de la información.

7. Mecanismos electrofisiológicos subyacentes de la interacción entre MT y AS

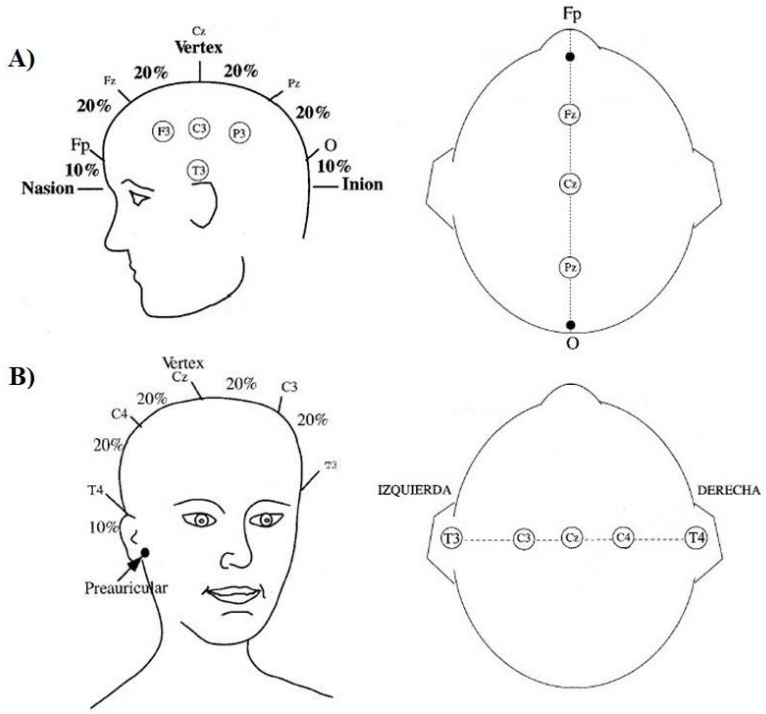
Hasta la fecha, la forma más usual de abordar la interacción entre MT y AS ha sido mediante estudios conductuales como los descritos en apartados anteriores. Sin embargo, desde la pasada década se ha comenzado a explorar también dicha relación mediante técnicas de neuroimagen, como la de los Potenciales Relacionados con Eventos (más conocidos por sus siglas en inglés, *Event Related Potentials* - ERPs), aunque la mayoría de los estudios se ha focalizado en procesos atencionales inhibitorios en paradigmas de conflicto o interferencia (Jongen y Jonkman, 2011; Qi y cols., 2014, Spronk y Jonkman, 2012; Zhao y cols., 2014).

Con la técnica ERP se registran las ondas de actividad eléctrica (cambios de voltaje) que se generan en el cerebro asociadas al procesamiento (perceptivo, motor o cognitivo) inducido por un determinado estímulo (Coles y Rugg, 1995; Luck, 2005). Para registrar esta actividad eléctrica de la corteza cerebral, se emplea un casco o gorro compuesto por un conjunto de electrodos activos que se coloca a la persona. La señal que se registra en cada electrodo representa la diferencia de potencial entre la actividad que detecta cada electrodo y uno de referencia situado en una zona neutral con muy poca o ninguna actividad eléctrica (v.g., en la zona central de la cabeza, la nariz o la oreja). Dado que las señales corticales son muy débiles (de apenas unos pocos microvoltios), es necesario utilizar un amplificador para que el ordenador pueda registrarlo y almacenarlo.

La localización de los electrodos en el cráneo se define a partir de dos ejes de coordenadas: el primero une el nasión (la parte anterior o frontal del cráneo) y el inión (parte posterior u occipital), y el segundo une los dos puntos preauriculares de los pabellones auditivos. En la intersección entre ambos ejes se encuentra el punto central o vertex. En la Figura 6 se pueden apreciar ambos ejes y su punto de inicio y fin.

Figura 6.

Representación gráfica de los ejes empleados para la correcta localización y situación de los electrodos. En la parte A aparece el eje antero-posterior que comienza en el nasión y termina en el inión. En la parte B se traza eje que une ambos puntos preauriculares de los pabellones auditivos izquierdo y derecho. En la zona media de ambos ejes se encuentra el vertex (imagen extraída de Barea Navarro, s.f.).

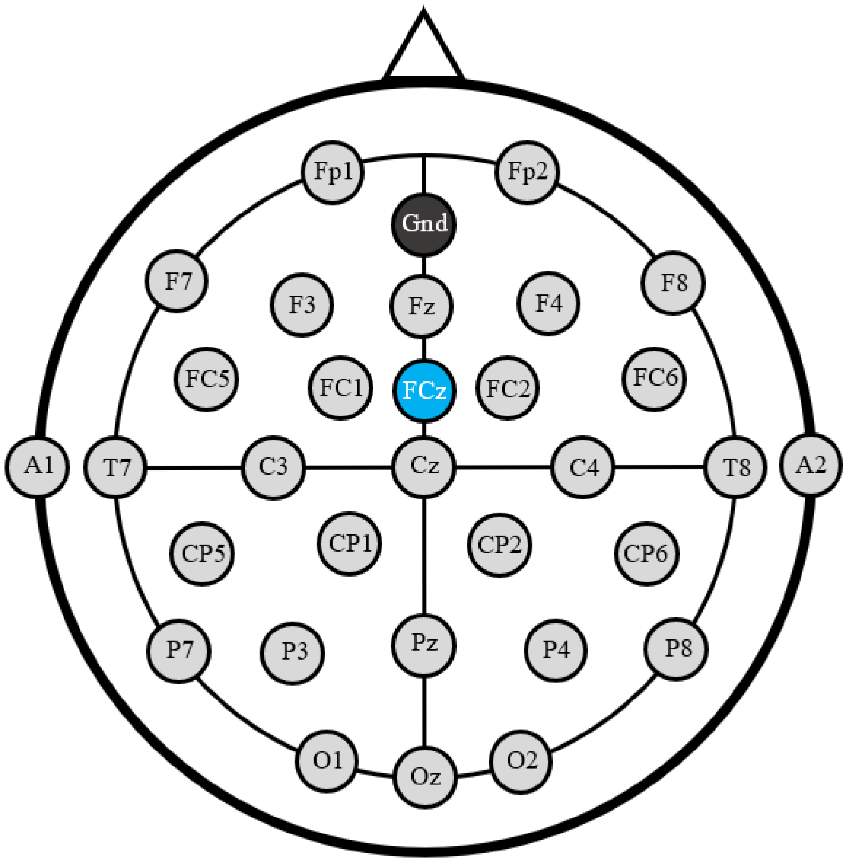


El número de los electrodos que se usan depende del tipo de datos que se necesiten registrar. El número mínimo requerido es tan solo de 32 electrodos, pero existen más sistemas múltiplos de este número (v.g., sistemas de 64, 128 o 256 electrodos) que son más completos y específicos (Coles y Rugg, 1995). Es preferible contar con el mayor número de electrodos posible, aunque si éste es muy elevado puede ocasionar ciertos problemas, como el tiempo invertido en optimizar el registro de cada electrodo, una alta probabilidad de que uno de ellos registre mal o sea defectuoso, o el hecho de que se puedan producir puentes entre electrodos que están muy juntos (Picton y cols., 2000).

Los nombres de los electrodos vienen dados por su posición respecto a estos dos ejes antes mencionados. Se utilizan tres tipos de electrodos: (a) electrodos activos, situados en el lugar dónde queremos medir la actividad eléctrica; (b) electrodo de referencia, colocado en un lugar lo más neutro posible con poca influencia de actividad eléctrica (usualmente la zona medial del cerebro); y (c) un electrodo de tierra. Mediante el amplificador, el electrodo de referencia (normalmente se escoge el FCz, o A1 y A2) y el de tierra (electrodo Gnd) se emplean para eliminar la actividad eléctrica exterior, también conocida como ruido ambiente. En la Figura 7 se representa un sistema de 32 electrodos y sus respectivas posiciones en la superficie craneal (Luck, 2005; Picton y cols., 2000).

Figura 7.

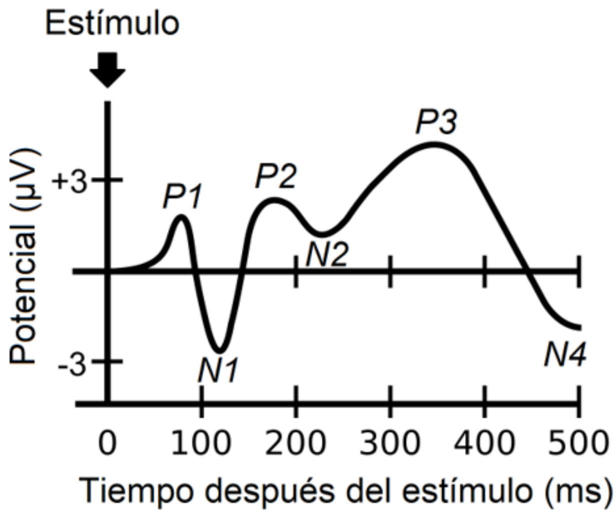
Esquema de posicionamiento y nomenclatura en un sistema de 32 electrodos según el sistema internacional 10-20 (**Fp** = Fronto-polar; **F** = Frontal; **FC** = Fronto-central; **C** = Central; **T** = Temporal; **A** = Auriculares; **CP** = Centro-parietal; **P** = Parietal; **O** = Occipital; **Gnd** = Tierra).



En función del paradigma que se esté empleando, a través del promediado de electrodos se pueden detectar diferencias de voltaje o componentes (v.g., mayor o menor amplitud de onda) que son provocadas por la presentación de estímulos en las diferentes condiciones experimentales. Estas diferencias se traducen en secuencias de “picos” y “valles” de voltaje, que se generan a partir del estímulo, y que son clasificados según la polaridad (v.g., P si es positivo o N si es negativo) y la latencia temporal (milisegundos en los que se alcanza el pico o máxima amplitud: 100, 200, 300…) del componente (v.g., N100 o N1, P300 o P3). Por ejemplo, el componente N100 (o N1) hace referencia a que la onda tiene un potencial negativo y alcanza su máxima “amplitud de pico” alrededor de 100 ms después de la presentación del estímulo. En la Figura 8 aparece un ejemplo de una onda con algunos de los componentes más representativos en función de su polaridad y del tiempo transcurrido tras la aparición del estímulo (Woodman, 2010).

Figura 8.

Ejemplo gráfico de una respuesta electrofisiológica en milisegundos (ms) ante la aparición de un estímulo y los componentes de la onda que suelen apreciarse al comparar las distintas condiciones experimentales.



Numerosas investigaciones, empleando paradigmas de conflicto atencional (v.g., tareas tipo Stroop, de Flancos), han relacionado la interferencia generada por los distractores competitivos en tareas de conflicto atencional con el componente N2, definido como una onda con un voltaje más negativo (o menos positivo) que se observa en los ensayos incongruentes, respecto a los congruentes, preferentemente en electrodos fronto-centrales, y cuyo pico máximo suele situarse entre los 200 y los 350 ms después de la presentación del estímulo *target* (Clayson y Larson, 2011; Folstein y Van Petten, 2008; Ridderinkhof y cols., 2004; Tillman y Wiens, 2011; Wendt y Luna-Rodríguez, 2009).

Es preciso observar que la mayoría de los estudios electrofisiológicos, que incluyeron paradigmas de *priming*, utilizaron principalmente tareas léxico-semánticas en un procedimiento "convencional", en el que la proporción de ensayos relacionados es similar (o superior) a la de ensayos no-relacionados (Franklin y cols., 2007; Hill, Ott y Weisbrod, 2005; Kiefer, 2005; Ortells, Kiefer y cols., 2016; para una revisión ver Kutas y Federmeier, 2011). En estas condiciones convencionales, un procesamiento estratégico del estímulo *prime* podría dar lugar a efectos comportamentales y electrofisiológicos de diferente magnitud, a los observados con un procesamiento no-estratégico (automático) del *prime*. Sin embargo, no sería posible observar efectos conductuales (o electrofisiológicos) cualitativamente diferentes (v.g., de signo opuesto).

Una posible excepción es el estudio realizado por Gajewski y colaboradores (2008), en el que manipulan la proporción diferencial de ensayos relacionados y no-relacionados con el fin de inducir una respuesta estratégica basada en expectativas. Los autores emplearon una tarea de *priming* secuencial con letras (v.g., 'X' vs. 'O') que aparecían como estímulos *prime* y *target*. La letra que se presentaba como estímulo *prime* podía aparecer también como estímulo *target* (lo que denominaron ensayos compatibles), o ser distinta (ensayos incompatibles). Se manipuló la validez predictiva del *prime* respecto a la identidad del estímulo *target* en tres bloques diferentes: la letra previa podía predecir correctamente la letra *target* en el 80% de los ensayos (Bloque 1), en el 50% (Bloque 2), o en el 20% (Bloque 3).

A nivel conductual, el principal hallazgo fue una interacción entre Validez y Compatibilidad. Cuando la validez de la letra *prime* fue del 80%, la latencia de respuesta aumentó y la precisión dismuniyó en los ensayos incompatibles de forma significativa. En la condición de validez del 50%, los tiempos de reacción y los errores fueron similares en los dos tipos de ensayos. Sin embargo, cuando el estímulo *prime* solamente predecía en un 20% un ensayo compatible, encontraron una inversión significativa del efecto, con respuestas más rápidas y menos errores en los ensayos incompatibles que en los compatibles.

Los resultados electrofisiológicos mostraron un componente N2 en electrodos centrales entre los 200 y los 320 ms después de la aparición del estímulo *target*. Dicho componente se observó en ensayos incompatibles (respecto a los compatibles) cuando la validez del estímulo *prime* era del 80%, y también en los ensayos compatibles cuando la validez era del 20%. No observaron diferencias de amplitud entre condiciones con una validez predictiva del 50%. Estos resultados podrían indicar que un componente N2 puede observarse también en situaciones “relativamente inesperadas” que, al contradecir las expectativas generadas por los participantes, pueden producir también un nivel alto de conflicto.

La presente investigación pretende explorar también correlatos EEG asociados a la implementación de estrategias basadas en expectativas, pero empleando para ello otras tareas de *priming* estratégico (v.g., tarea *priming*-Stroop) que ya han demostrado su adecuación para obtener efectos conductuales de *priming* de signo opuesto en función de diferentes variables (v.g., nivel de consciencia del *prime*; intervalo corto vs. largo de SOA *prime-target*; mayor vs. menor disponibilidad de recursos de MT).

II

Planteamiento y Objetivos

Los resultados de estudios como los descritos hasta el momento aportan numerosas pruebas acerca de la estrecha relación existente entre la MT y procesos atencionales, tanto inhibitorios como facilitatorios. Empleando diversos procedimientos experimentales se ha demostrado que variaciones en la disponibilidad de recursos cognitivos, como resultado de una carga diferencial de MT (Ortells y cols., 2017), del envejecimiento normal o patológico (Froufe y cols., 2009), o de una mayor o menor capacidad de MT (v.g., Jost y cols., 2011), influyen en el rendimiento de los participantes en diferentes tareas de selección atencional que implican no solo atender a la información relevante, sino también ignorar (v.g., inhibiendo) aquella otra que resulta irrelevante y que compite con el control de la acción.

No obstante, no está del todo claro a través de qué mecanismos interactúan la MT y la AS. Una cuestión por resolver hace referencia a cómo interfiere una tarea que implica una alta carga de MT, con la realización de la tarea de selección atencional. ¿Ejecutar una tarea de MT, en condiciones de alta carga, supondría una mayor demanda de recursos cognitivos de dominio "general" (o inespecífico) necesarios también para realizar la tarea atencional? o, por el contrario, ¿la carga de MT interferiría en el rendimiento de la tarea de AS sólo cuando ambas tareas requiriesen un mismo tipo de recurso de dominio específico (v.g., de naturaleza verbal o no-verbal)?

Obsérvese, por ejemplo, que en el estudio de Ortells y colaboradores (2017) los resultados mostraron una eliminación de efectos estratégicos en la tarea atencional (inversión de la interferencia Stroop) bajo condiciones de alta carga de MT. En la medida en que los participantes tenían que memorizar una secuencia de números, al mismo tiempo que debían prepararse para responder al color contrario al de la palabra previa en la tarea *priming*-Stroop, cabe preguntarse si dichos resultados reflejaron fundamentalmente procesos de interferencia específicos de tipo verbal. Para establecer mejor si el efecto observado de la carga de memoria es de dominio general (recursos de control atencional), y no de dominio específico (interferencia verbal), sería importante demostrar que el desempeño en una tarea de MT no verbal (v.g., de tipo espacial), bajo condiciones de alta carga, también impide la generación de estrategias basadas en expectativas en la tarea de *priming*-Stroop, al igual que mostraron recientemente Ortells y colaboradores (2017) manipulando la carga de MT en una tarea de tipo verbal. Esta cuestión será abordada en la presente tesis doctoral.

Un segundo aspecto que consideramos importante en la presente tesis, es comprender cómo afectaría la capacidad de MT al curso temporal de las estrategias facilitatorias. Estudios previos sugieren que una baja capacidad de MT (por ejemplo, a causa del envejecimiento normal) se relaciona con un enlentecimiento de la puesta en marcha de mecanismos inhibitorios (Cashdollar y cols., 2013; Hasher y cols., 1999; Lustig y cols., 2007). Teniendo esto en cuenta, es posible que una menor disponibilidad de recursos de MT ralentizara también el desarrollo de estrategias atencionales facilitatorias, como las basadas en expectativas.

Una forma de investigar el curso temporal de dichos procesos estratégicos sería manipular el intervalo de asincronía temporal (SOA) entre estímulos *prime-target,* empleando procedimientos de *priming* en los que el procesamiento estratégico basado en expectativas pueda generar efectos comportamentales cualitativamente distintos al procesamiento no-estratégico (automático) del *prime*. Uno de estos procedimientos es la tarea *priming*-Stroop, que incluye una proporción mucho mayor (v.g., 80%) de ensayos incongruentes que congruentes (v.g., Daza y cols., 2002; Froufe y cols., 2009; Merikle y Joordens, 1997; Ortells y cols., 2017). Otra tarea de *priming* estratégico que implica la presentación de un mayor número de estímulos diferentes que la tarea Stroop y que demanda, además, un procesamiento de alto nivel (semántico) de la información, sería la tarea de *priming* semántico estratégico empleada originalmente por Ortells y colaboradores (2003). Nuevamente existía una mayor proporción de ensayos no-relacionados (TIGRE-ZAPATO) que relacionados (TIGRE-LEÓN), con el fin de obtener efectos conductuales opuestos (facilitación semántica *vs.* inversión estratégica del *priming*) inducidos por el procesamiento automático vs. controlado del *prime* (Ortells y cols., 2003; Ortells y cols., 2012; Ortells y cols., 2013).

El empleo de este tipo de tareas de *priming* estratégico con diferentes intervalos de asincronía *prime-target*, permitiría explorar si la disponibilidad diferencial de recursos de MT podría afectar no sólo a la eficacia, sino también al curso temporal de las estrategias atencionales basadas en expectativas.

Una tercera cuestión importante es esclarecer si las variaciones en los recursos de MT, resultantes de una carga diferencial de MT (o de diferencias inter-individuales en la capacidad de MT), pueden también afectar a determinados correlatos electrofisiológicos del *priming* estratégico asociados al desarrollo de expectativas. La mayor parte de las investigaciones electrofisiológicas (ERPs) que ha abordado la relación entre MT y AS, ha focalizado su interés en las funciones atencionales inhibitorias (De Fockert y cols., 2001; Tsuchida y cols., 2012). Por tanto, resultaría de interés averiguar si variaciones en la disponibilidad de recursos de MT pueden afectar al procesamiento estratégico facilitatorio no sólo a nivel conductual, sino también a nivel de correlatos electrofisiológicos de dicha actuación estratégica. Para inducir la adopción de estrategias controladas es necesario crear situaciones en las que exista un mayor número de ensayos incongruentes (vs. congruentes), o de ensayos no-relacionados (vs. no-relacionados), e incluir demoras temporales relativamente largas entre los estímulos *prime* y *target* (Daza y cols., 2002; Ortells y cols., 2012; Ortells y cols., 2013). Esperamos que esta clase de manipulaciones conductuales también genere cambios en el tipo de onda subyacente a estas tareas.

Tomando en cuenta los resultados de estudios previos sobre la interacción entre MT y AS, nuestras **principales hipótesis** son las siguientes:

A) El efecto modulador de la carga de MT, que se ha observado cuando se realiza una tarea *priming*-Stroop con otra concurrente de memoria verbal, también podría ocurrir en otras de *priming* estratégico que incluyen tareas concurrentes de carga de MT de tipo visuoespacial. Si el efecto de la carga de MT en el procesamiento estratégico es de dominio general (recursos de control atencional), se debería obtener interferencia en la tarea atencional bajo condiciones de alta carga, tanto con una tarea de MT verbal como con una de MT visuoespacial. Sin embargo, si el efecto de la carga de MT es más bien de dominio específico (produciendo una interferencia verbal), la condición de alta carga de la tarea mnémica verbal debería afectar más negativamente, que la tarea espacial, al rendimiento de los participantes en la tarea atencional.

B) Las diferencias individuales en capacidad de MT (v.g., jóvenes de alta vs baja capacidad; adultos jóvenes vs adultos mayores) parecen influir no sólo en la eficacia, sino también en el curso temporal de los mecanismos atencionales inhibitorios. Así, las personas con una menor capacidad de MT parecen necesitar más tiempo para inhibir o bloquear distractores irrelevantes en diferentes tareas de AS y de MT (Cashdollar y cols., 2013; Hasher y cols., 1999; Lustig y cols., 2007). Tomando en consideración estos resultados, una segunda hipótesis que planteamos en la presente tesis es que una menor capacidad de MT podría ralentizar también la puesta en marcha de estrategias atencionales facilitatorias basadas expectativas. En concreto, las personas mayores, que suelen mostrar por lo general una menor capacidad de MT que los jóvenes, podrían necesitar intervalos temporales de asincronía *prime-target* relativamente largos para mostrar efectos significativos resultantes de un procesamiento estratégico en diferentes tareas de *priming*. En intervalos de asincronía temporal *prime-target* relativamente cortos, dichos efectos de *priming* estratégico deberían mostrarlos únicamente las personas con mayor capacidad de MT.

C) La disponibilidad variable de recursos de control cognitivo a causa de una mayor vs. menor carga en una tarea de MT concurrente, y/o de diferencias individuales en la capacidad de MT, debería inducir cambios no solo a nivel comportamental, sino también en algunos marcadores cerebrales (ERPs) asociados con el procesamiento de estrategias atencionales basadas en expectativas en tareas de *priming* estratégico.

El uso de este tipo de paradigmas, que favorece la generación de estrategias, en experimentos ERP podría reflejar a nivel electrofisiológico lo que ya ocurre a nivel conductual. Esperamos que las estrategias conductuales inducidas por un mayor número de ensayos incongruentes en una tarea tipo *priming*-Stroop se traduzcan, a nivel electrofisiológico, en una reducción significativa (o eliminación) del índice electrofisiológico de conflicto cognitivo asociado al efecto conductual de interferencia Stroop (v.g., N200), o incluso en una inversión de la onda negativa característica de estas situaciones. Es decir, si manipular la proporción de ensayos incongruentes, para que estos sean más frecuentes que los congruentes, induce una inversión estratégica de la interferencia Stroop (v.g., respuestas más rápidas y precisas en ensayos incongruentes), esperamos observar también la ausencia o inversión en la onda típica del efecto Stroop (N200). Téngase en cuenta que, usualmente, son los ensayos incongruentes los que generan una situación de conflicto, ya que los estímulos *prime* y *target* son distintos. Pero cuando se incrementa significativamente el número de estos ensayos, frente a los congruentes, entonces se convierten en esperados y la persona que usa esta información adopta una respuesta estratégica más eficaz, esto es, anticipa la aparición de un ensayo incongruente y se prepara para responder en consecuencia, reduciendo así la situación de conflicto. Ahora bien, ¿qué sucede con los ensayos congruentes si estos son menos frecuentes? Precisamente ahora por inesperados generan una situación de conflicto. Así, una inversión comportamental de la interferencia Stroop podría inducir una onda más negativa (o menos positiva) en los ensayos congruentes. Esto nos indicaría que, en este caso, el conflicto para los sujetos residiría en los ensayos congruentes, donde habitualmente las respuestas son más rápidas y precisas (Bermeitinger y cols., 2008).

Por otro lado, esperamos encontrar un componente N200 en las tareas tipo *priming*-Stroop, en aquellas condiciones que dificulten la generación de expectativas, como cuando se usan demoras entre estímulos *prime*-*target* muy breves (< 300 ms), o con una alta carga de MT. La posibilidad de realizar experimentos ERP con la tarea de *priming*-Stroop nos permitirá explorar posibles correlatos electrofisiológicos asociados con estrategias de atención basadas en la expectativa.

El presente proyecto de tesis pretende explorar la asociación entre la disponibilidad de recursos de la MT y el procesamiento controlado estratégico (basado en expectativas), tanto a nivel conductual como electrofisiológico. Los **objetivos específicos** son:

Objetivo 1: Esclarecer si la modulación de la carga de la MT verbal sobre las estrategias atencionales facilitatorias, observada por algunos estudios recientes (v.g., Ortells y cols., 2017), puede obtenerse también cuando se emplean tareas concurrentes de MT no-verbal (v.g., de tipo espacial). Esto permitiría dilucidar si la interacción entre MT y la AS es de dominio general (recursos de control atencional) o específico (v.g., interferencia verbal).

Objetivo 2: Explorar y comprobar si una menor disponibilidad de recursos cognitivos de la MT (por una alta carga y/o una menor capacidad) puede afectar no sólo al desarrollo de operaciones atencionales inhibitorias (Cashdollar y cols., 2013; Lustig y cols., 2007), sino también al curso temporal del procesamiento atencional basado en expectativas en diferentes tipos de tareas de *priming* estratégico.

Objetivo 3: Averiguar si una capacidad (o disponibilidad) diferencial de MT podría afectar al procesamiento estratégico no sólo a nivel conductual, sino también en algunos correlatos ERPs asociados a estrategias atencionales basadas en expectativas.

Los objetivos detallados se abordan a través de tres estudios experimentales que se expondrán en los siguientes capítulos. En concreto, el objetivo específico 1 se acomete con el primer estudio titulado *Expectancy-Based Strategic Processes Are Influenced by Spatial Working Memory Load and Individual Differences in Working Memory Capacity*, y publicado en 2018 (*Frontiers in Psychology: section Cognition*). En este trabajo se emplea una tarea *priming*-Stroop concurrente con una de memoria espacial para determinar si, en una situación de alta carga, esta tarea mnémica no verbal influye (o no) en la capacidad para generar una respuesta estratégica basada en expectativas, como se ha observado con una tarea de memoria verbal (Ortells y cols., 2017). Los participantes tienen que identificar el color de un *target* (un parche de color rojo vs. verde) que es precedido por un estímulo previo (la palabra VERDE o ROJO), con una proporción de ensayos *prime-target* incongruentes mayor (80%) que congruentes (20%). Esta tarea *priming*-Stroop se combina con dos tipos de tareas de memoria espacial en dos experimentos diferentes: En el Experimento 1, los participantes tienen que retener cuatro flechas que apuntan en la misma dirección (condición de baja carga), o en direcciones aleatorias (condición de alta carga). En el Experimento 2, las flechas se sustituyen por cuatro puntos dentro de una matriz 4x4 que se distribuyen en una línea continua (baja carga), o de forma aleatoria en la matriz (alta carga). Además, en ambos experimentos los participantes realizaron previamente una tarea de localización del cambio visual, lo que permitió evaluar la capacidad (alta vs. baja) de MT de cada uno de ellos.

Los resultados muestran que, en la condición de alta carga de MT, los participantes no son capaces de implementar estrategias y presentan un efecto convencional de interferencia Stroop (respuestas más rápidas a ensayos congruentes que incongruentes), independientemente de su capacidad de MT. Sin embargo, en la condición de baja carga, las estrategias basadas en expectativas se ven parcialmente moduladas por la capacidad de MT: solo las personas de alta capacidad consiguen hacer uso de estrategias para responder e invierten el patrón convencional (respondiendo más rápido a ensayos incongruentes que congruentes), mientras que los de baja capacidad muestran la típica interferencia Stroop. Este patrón de resultados demuestra que la implementación de estrategias también se ve afectada por una tarea no verbal de MT, lo que indicaría que la interacción entre la MT y procesos atencionales facilitatorios es de dominio general y emplea recursos comunes de control atencional.

El objetivo específico 2 se aborda en el segundo estudio, llamado *The implementation of expectancy-based strategic processes is delayed in normal aging*, publicado en 2019 (*PLoS ONE*), que examina si el tiempo necesario para generar estrategias es diferente en adultos jóvenes, respecto a mayores sanos. Con este fin, se utilizan diferentes tareas estratégicas a lo largo de cuatro experimentos, todas ellas con una mayor proporción de ensayos incongruentes o no-relacionados (80%), que de ensayos congruentes o relacionados (20%).

En los Experimentos 1 y 2 se emplea una tarea *priming*-Stroop similar a la de nuestro Estudio experimental 1, en el que una palabra *prime* (ROJO vs. VERDE) es seguida por un estímulo *target* (parche de color verde o rojo) cuyo color deben identificar los participantes, con los ensayos *prime-target* incongruentes siendo mucho más frecuentes que los congruentes. En los Experimentos 3 y 4 se utiliza una tarea de *priming* semántico estratégico con imágenes, en la que hay que identificar la categoría de la imagen *target* (animal vs. objeto) precedida por otra imagen previa (*prime*), la cual pertenece a una categoría semántica diferente en un alto porcentaje de ensayos (80% no-relacionados), mientras que en el 20% de ensayos (relacionados) ambas imágenes son altos asociados de la misma categoría.

Para explorar el efecto que el curso temporal ejerce sobre el desarrollo de las expectativas a través de estos experimentos, se manipulan diferentes niveles de SOAs o intervalos temporales entre estímulo previo y *target*: 400, 1000 y 2000 ms. Antes de llevar a cabo la tarea de *priming*, en todos los experimentos los grupos de jóvenes y mayores realizan tanto la tarea de localización del cambio visual, para medir su capacidad de MT, como la denominada tarea antisacada, que evalúa su capacidad de control atencional inhibitorio.

En todos los experimentos de este estudio encontramos que, en comparación con los jóvenes, los mayores muestran un porcentaje inferior de aciertos y respuestas más lentas en las tareas de capacidad de MT y de control atencional. Este rendimiento diferencial que muestran los grupos de mayores en dichas tareas, también se observa en las tareas de *priming* estratégico. Así, los mayores muestran una incapacidad para implementar estrategias basadas en expectativas en intervalos temporales de SOA *prime-target* de duración media (1.000 ms), intervalos de SOA en los que los jóvenes ya suelen mostrar efectos significativos de *priming* estratégico. Sin embargo, en un intervalo de SOA suficientemente largo (2.000 ms), los adultos mayores también son capaces de poner en marcha procesos estratégicos y mostrar efectos significativos de inversión estratégica del *priming*, de una magnitud similar a la de los jóvenes. Esto sugiere que los mayores, más que ser incapaces de generar estrategias basadas en expectativas, parecen necesitar un mayor tiempo que los jóvenes, para poder responder de forma estratégica en una tarea atencional.

En el tercer y último estudio, titulado *Working memory capacity modulates expectancy-based strategic processing: Behavioral and electrophysiological evidence*, publicado en 2021 (*Biological Psychology*), se aborda el objetivo específico 3. Para ello, se registra la actividad electrofisiológica cerebral de los participantes mientras realizan una tarea *priming*-Stroop con una mayor frecuencia de ensayos incongruentes (75%) que congruentes (25%), en la que también se manipula el intervalo de asincronía temporal (SOA) *prime-target* a dos niveles (300 vs. 700 ms). Al igual que en nuestros anteriores estudios experimentales, todos los participantes realizan previamente la tarea de localización del cambio visual, lo que nos permite distribuirlos en alta vs baja capacidad de MT, según la puntuación obtenida en dicha prueba.

Los resultados obtenidos a nivel conductual indican que, en el SOA *prime-target* de 300 ms, todos los participantes muestran un efecto estándar de interferencia Stroop, independientemente de su capacidad de MT. No obstante, en el SOA más largo de 700 ms, la implementación de estrategias es modulada por la capacidad de MT: los participantes con mayor capacidad de MT ponen en marcha procesos controlados e invierten el efecto de interferencia típico, al mostrar tiempos de reacción menores en ensayos incongruentes que congruentes. Por el contrario, los participantes con baja capacidad de MT mostraron de nuevo un efecto de interferencia Stroop en el SOA de 700 ms, lo que parece reflejar la actuación de procesos más automáticos.

A nivel electrofisiológico se encuentra un patrón similar de resultados: en el SOA corto (300 ms), todos los participantes muestran un componente N2 (asociado a conflicto atencional) con una mayor amplitud en ensayos incongruentes, en comparación a los congruentes. Sin embargo, en el SOA largo de 700 ms, los participantes de baja capacidad siguen mostrando este componente N2, mientras que el grupo de alta capacidad consigue reducir e incluso eliminar dicho componente ERP. De estos datos se puede inferir que las diferencias individuales en capacidad de MT modulan el procesamiento conflictivo a través de distintos mecanismos atencionales.

La tesis se presenta por compendio de publicaciones, siguiendo la normativa establecida en la Normativa de Estudios Oficiales de Doctorado, aprobada por el Consejo de Gobierno de 29 de Octubre de 2020. Artículos publicados:

Ortells, J. J., De Fockert, J. W., Romera, N., & Fernández, S. (2018). Expectancy-Based Strategic Processes Are Influenced by Spatial Working Memory Load and Individual Differences in Working Memory Capacity. *Frontiers in Psychology, 9*, 1239. doi: 10.3389/fpsyg.2018.01239.

Category: Psychology, Multidisciplinary.

JCR: 2.321; Q2 (JCR year: 2016).

Noguera, C., Fernández, S., Álvarez, D., Carmona, E., Marí-Beffa, P., & Ortells, J. J. (2019). The implementation of expectancy-based strategic processes is delayed in normal aging. *PloS one, 14*(3), e0214322. doi: 10.1371/journal.pone.0214322

Category: Multidisciplinary Sciences.

JCR: 2.766; Q1 (JCR year: 2017).

Fernández, S., Ortells, J. J., Kiefer, M., Noguera, C., & De Fockert, J. W. (2021). Working memory capacity modulates expectancy-based strategic processing: Behavioral and electrophysiological evidence. *Biological Psychology, 159*, 108023. doi: 10.1016/j.biopsycho.2021.108023

Category: Psychology, Experimental.

JCR: 2,763; Q1 (JCR year: 2019).

III

Estudio Experimental I

Estudio 1. Expectancy-based strategic processes are influenced by spatial working memory load and individual differences in working memory capacity[1]

[1]Manuscript published as:

Ortells, J. J., De Fockert, J. W., Romera, N., & Fernández, S. (2018). Expectancy-Based Strategic Processes Are Influenced by Spatial Working Memory Load and Individual Differences in Working Memory Capacity. *Frontiers in Psychology*, *9*, 1239. doi: 10.3389/fpsyg.2018.01239.

Expectancy-based strategic processes are influenced by spatial working memory load and individual differences in working memory capacity

Juan J. Ortells[1*], Jan W. De Fockert[2], Nazaret Romera[1], and Sergio Fernández[1]

[1]*University of Almería, Spain*

[2] *Goldsmiths, University of London, London, UK*

Abstract

The present research examined whether imposing a high (or low) working memory (WM) load in different types of nonverbal WM task could affect the implementation of expectancy-based strategic processes in a sequential verbal Stroop task. Participants had to identify a colored (green vs. red) target patch that was preceded by a prime word (GREEN or RED), which was either incongruent or congruent with the target color on 80% and 20% of the trials, respectively. Previous findings have shown that participants can strategically use this information to predict the upcoming target color, and avoid the standard Stroop interference effect. The Stroop task was combined with different types of nonverbal WM task. In Experiment 1, participants had to retain sets of four arrows that pointed either in the same (low WM load) or in different directions (high WM load). In Experiment 2, they had to remember the spatial locations of four dots which either formed a straight line (low load) or were randomly scattered in a square grid (high load). In addition, participants in the two experiments performed a change localization task to assess their WM capacity (WMC). The results in both experiments showed a reliable congruency by WM load interaction. When the Stroop task was performed under a high WM load, participants were unable to efficiently ignore the incongruence of the prime, as they consistently showed a standard Stroop effect, regardless of their WMC. Under a low WM load, however, a strategically-dependent effect (reversed Stroop) emerged. This ability to ignore the incongruence of the prime was modulated by WMC, such that the reversed Stroop effect was mainly found in higher WMC participants. The findings that expectancy-based strategies on a verbal Stroop task are modulated by load on different types of spatial WM tasks point at a domain-general effect of WM on strategic processing. The present results also suggest that the impact of loading WM on expectancy-based strategies can be modulated by individual differences in WMC.

Keywords: Working memory load, Stroop priming effects, expectancy-based strategic processes, spatial working memory, individual differences in working memory capacity

1. Introduction

There is now a large body of evidence for a close association between working memory (WM) and selective attention (e.g., Gazzaley and Nobre, 2012; Lavie et al., 2004). Much of this evidence comes from demonstrations that WM resources are critical in achieving efficient selective behaviour, which involves focusing attention on task-relevant information, while ignoring or blocking the processing of competing distractors. Studies on cognitive ageing demonstrate that older adults, who usually perform worse than young adults in WM tasks (e.g., Gazzaley, 2012), also show a reduced ability to efficiently ignore and overcome the influence of irrelevant information in selective attention tasks (e.g., De Fockert, 2005; De Fockert et al., 2009; see Zanto and Gazzaley, 2014, for a review). A similar impaired performance in attention tasks (e.g., Stroop; negative priming) has frequently been observed in young adults when their cognitive resources are limited due either imposed WM load (e.g., De Fockert et al., 2010; De Fockert et al., 2001; Lavie and De Fockert, 2005; see De Fockert, 2013, for a review), or a lower WM capacity (e.g., Kane et al., 2007; Kane and Engle, 2003; Ortells et al., 2016).

Although much less investigated, some recent studies have reported evidence that an efficient implementation of controlled facilitatory strategies like expectancy generation also relies on the availability of cognitive control resources, such as WM (e.g., Heyman et al., 2014; Hutchison et al., 2014; Ortells et al., 2017).

In a recent study, Ortells et al. (2017) used the combined WM/selective attention paradign originally developed by De Fockert et al. (2001) in a Stroop-priming task which allows measuring of qualitatively different behavioral effects resulting from strategic vs. non-strategic processing. In this task, participants are required to identify the color (e.g., red) of a target patch which is preceded by either an incongruent (e.g., GREEN) or a congruent (RED) prime word, on 80% and 20% of the trials, respectively. As participants foreknow ledged that the incongruent prime-target pairs were much more frequent than the congruent ones, and there are only two possible colors, a useful strategy would be to prepare to respond to the opposite target color to that of the prime. By implementing that strategy, participants perform much better on incongruent than on congruent trials, thus showing a reversed Stroop effect (e.g., Merikle and Joordens, 1997; Ortells et al., 2017; see also Logan et al., 1984). This Stroop task was combined with a verbal WM task of either high or low load. Participants were required to memorize sequences of digits that were presented before the prime word display, which consisted of either five repetitions of the same digit (low WM load), or five different random digits (high WM load). After performing either two, three, or four Stroop trials, participants were required to decide whether or not a single probe digit was a part of the previously memorized digit-set.

Ortells et al. (2017) found that the implementation of expectancy-based attention strategies in that version of the Stroop task critically depended on the availability of WM resources, as there was a reliable congruency by WM load interaction. Thus, when the WM task demanded a low load, participants were able to strategically process the prime to anticipate the target color, as their responses were reliably faster on incongruent than on congruent trials. This reversed Stroop effect replicates that usually observed by previous studies using this task (e.g., Daza et al., 2002; Merikle and Joordens, 1997). In clear contrast, the strategic effect was not observed when participants performed the Stroop-priming task under high WM load, as their responses were significantly slower on incongruent than on congruent trials (i.e., a standard Stroop interference effect). A similar Stroop interference effect for a highly frequent incongruent condition is usually found under task conditions that render predictive strategies difficult to implement. This is the case, for example, when a relatively short prime-target SOA interval is used in the sequential Stroop task, and/or when the prime stimulus is subliminally presented, thus impeding its conscious identification (e.g., Daza et al., 2002; Ortells et al., 2006).

The results by Ortells et al. (2017) replicate and extent those obtained by other recent studies, in showing that limiting the availability of cognitive (WM) resources with a WM task demanding a high load, can induce a less efficient strategic processing of goal-relevant information (e.g., Hutchison et al., 2014; Heyman et al., 2014).

Note, however, that in Ortells et al.'s study WM load was manipulated by means of a verbal task consisting of retaining sequences of digits. This memory task could encourage participants to use verbal coding strategies (e.g., rehearsal) to retain the digit set while performing the Stroop trials. Such verbal coding processes could be particularly useful during the high WM load condition, which require participants to memorize random sets of digits. If this were indeed the case, then the elimination of the strategic effect (reversed Stroop) that was reported by Ortells et al. with a high WM load could mainly reflect a greater functional overlap between the Stroop and the digit WM tasks, as both tasks would rely on verbal coding processes.

In fact, several prior studies have reported evidence that the type of concurrent WM load modulates the relative impact of cognitive load on performance in selective attention tasks (e.g., Kim et al., 2005; Park et al., 2007; see also Minamoto et al., 2015). For example, by using several variants of the Stroop task and different types of verbal and spatial WM load tasks, Kim et al. (2005) demonstrated that a higher WM load impaired selective attention processing, leading to an increased Stroop interference, when a verbal WM load was used (i.e., retaining series of letters). In clear contrast, the Stroop interference remained unaffected by a spatial WM load task (i.e., retaining the spatial locations of four randomly scattered squares) which did not overlap with either target or distractor processing in the Stroop task (see also Park et al., 2007). In contrast to load theory, which assumes that loading WM influences selective attention by disrupting general cognitive (inhibitory) control (Lavie et al., 2004), the above results rather suggests a specialized load account, according to which the impact of WM load on selective attention critically depends on whether or not load overlaps with target (or distractor) processing in the attention task.

1.1. The present study

The main aim of this research is to establish whether the effects of WM load on expectancy-based strategic processes are domain-specific and limited to situations in which there is clear overlap in terms of task requirements (e.g., a digit WM task combined with a Stroop task involving color words, two tasks that likely rely on verbal coding), or whether loading WM also affects those strategic procesess when there is little functional overlap between the two tasks. This would suggest that the role of WM in strategic processing is relatively domain-general, for example based on shared attentional control resources.

To do so, in two Experiments we used different types of spatial memory tasks to load WM while observers performed a strategic Stroop task. Our predictions were that, if WM plays a domain-general role in expectancy-based strategic processing, then loading non-verbal spatial WM should modulate verbal Stroop effects. Conversely, if the role of WM in expectancy-based strategic processing is more domain-specific, then the lack of functional overlap between spatial WM task and the Stroop task should mean that loading WM in the present study will modulate the strategic Stroop effect to a lesser degree than we found when using a verbal WM task (Ortells et al., 2017). Indeed, previous work investigating effects of verbal vs. non-verbal WM load on visual detection found opposite effects of load on detection of a task-unrelated visual stimulus, with an improved detection under high verbal WM load, and a reduced detection under high visual WM load (Konstantinou and Lavie, 2013).

It is also interesting to note that whereas a reliable reversed Stroop in the Stroop-priming task was observed by Ortells et al. (2017) when the concurrent verbal WM task demanded a low load, this was not the case for all participants in their study. Further data inspection revealed that more than a third of their participants (9 out of 26 participants in the study) showed a conventional Stroop interference effect not only with a high WM load, but also with a low WM load. It appears that these participants were unable to strategically anticipate the target color (i.e., the opposite to that of the prime word) even when the WM task demanded a low load.

This pattern of inter-individual differences resembles that observed by Froufe et al. (2009) between young and elderly people. In this study, two groups of older adults (one with Alzheimer's dementia -AD), and one group of younger adults carried out a sequential Stroop task very similar to that of Ortells et al. (but under single-task conditions), as the proportion of incongruent prime-target pairs was much higher (84%) than that of congruent pairs (16%), and participants were informed of these proportions at the beginning of the experiment. Froufe et al. (2009) found that the younger adults responded reliably faster to the incongruent than to the congruent targets (reversed Stroop), which confirms that they were able to efficiently implement expectancy-based strategic actions in this task. In clear contrast, a non-significant reversed Stroop was found in elderly people without AD, whereas the older adults with AD responded significantly slower to incongruent than to congruent targets (standard Stroop interference). This later finding suggests that, in addition to any decline in strategic processing associated with normal ageing, AD is associated with a further reduction in capacity to implement expectancy-based strategies.

Based on these results, one could speculate that healthy young adults showing Stroop interference, instead of reversed Stroop, under the low load condition in Ortells et al.' study, could have had lower WM capacity (WMC) than the remaining participants who showed a reversed (strategic) Stroop with a low WM load. However, WMC of participants was not assessed by Ortells et al. (2017). Whereas a few previous studies have examined the combined effect on performance of limiting WM by both imposed WM load and individual differences in WMC (e.g., Ahmed and De Fockert, 2012; Kane and Engle, 2003; Rosen and Engle, 1997), to our knowledge, the interactive impact of these two factors on strategic processing has not been investigated previously. Consequently, a second aim of the present research was to explore whether individual differences in WMC could modulate the impact of loading WM on expectancy-based strategic processes.

To this end, participants in our experiments also performed a change localization task (e.g., Johnson et al., 2013). On each trial a sample array containing four colored shapes was briefly presented (e.g., 100 ms), and followed after a short delay (e.g., 900 ms) by a test array, which was similar to the previous sample display except that one of the four items had changed colors, and participants had to select the location of the change. This is a very simple task in which there is no task switching or time pressure, and guessing effects are minimized by the fact that chance level is 25% instead of 50% (Johnson et al., 2013). But importantly, like it is the case with complex span tasks frequently used to asses WMC (e.g., Operation Span Task), performance in the change detection/localization tasks has been shown to have strong relationships with broader measures of higher cognitive abilities, including fluid intelligence, and attention control capacities, in both healthy adults and several clinical (e.g., people with schizophrenia) populations (e.g., Cowan et al., 2005; Fukuda et al., 2010; Johnson et al., 2013; Shipstead et al., 2015).

2. Experiment 1

We used in this experiment the same Stroop-priming task as the one used by Ortells et al. (2017), but this task was now combined with a non-verbal (spatial) WM task of either low or high load. The memory set preceding the prime word consisted of four arrows, the orientation of which had to be retained by participants (see Chao, 2011, Experiment 7, for a similar spatial WM task). The four arrows could either all point in the same direction (low WM load condition) or in different random directions (high WM load condition). After performing a variable number (two, three or four) of Stroop-priming trials, a single probe arrow was displayed and observers were required to decide whether or not that arrow had been presented in the previously memorized arrow-set. To the extent that the effects of loading spatial WM on expectancy-based strategies are mainly domain-general (e.g., based on shared attentional resources) rather than domain-specific, we again expected to find a Stroop interference effect when the spatial WM task would involve a high load. By contrast, a reversed strategic Stroop effect should be observed when the load of the spatial WM task was low.

On the other hand, to the extent that strategic planning for a likely target under dual-task conditions requires that cognitive control resources are maximally available, that is, under low WM load and in high WMC individuals, we expect to obtain a reliable three-way interaction between prime-target congruency, WM load and WMC. In line with previous findings by Ortells et al. (2017), we predict that under high WM load all participants, regardless of their WMC, will be unable to efficiently ignore the incongruence of the prime and therefore show a standard Stroop effect. When the load of the concurrent WM task is low however, the ability to ignore the incongruence of the prime could be modulated by WMC, such that a reversed Stroop effect should be found in participants with a higher WMC.

2.1. Material and Methods

2.1.1. Participants

Forty-four right-handed undergraduate students (28 women; age range = 19–30 years, *M* = 20.73, *SD* = 2.54) from the University of Almería received course credits for their participation in the experiment, with all them having normal or corrected-to-normal vision. The sample size was greater than used by previous studies using this strategic Stroop-priming task (e.g., Froufe et al., 2009; n = 27; Ortells et al., 2017; n = 26), and very similar to that used by other studies that had addressed the combined effect on performance of both WM load and individual differences in WMC (e.g., Ahmed and De Fockert, 2012; n = 43). The experiments of the present research were conducted in compliance with the Helsinki Declaration, and with the ethical protocols and recommendations of the "Code of Good Practices in Research", "Commission on Bioethics in Research from the University of Almería". All participants in this and the remaining experiment signed informed consents before their inclusion, with the protocol being approved by the "Bioethics Committee in Human Research" from the University of Almería.

2.1.2. Stimuli and Apparatus

The stimuli were displayed on a 17-in. CRT monitor controlled by a computer running E-prime 2.0 software (Psychology Software Tools). Viewing distance was approximately 60 cm. In the change localization task, participants were presented with visual arrays containing four colored circles displayed against a grey background (60, 60, 50), with each circle subtending a diameter of about 0.96º (see Figure 1). The four colors were randomly selected from a set of nine different colors with the following red, green, and blue values: black (0, 0, 0), blue (0, 0, 255), cyan (0, 255, 255), green (0, 255, 0), magenta (255, 0, 255), orange (255, 113, 0), red (255, 0, 0), white (255, 255, 255), and yellow (255, 255, 0). The four colored circles presented on each trial were randomly displayed in each of the four quadrants of the screen, with the distance between fixation and the nearest and farthest circles subtending about 3.36º and 4.8º, respectively.

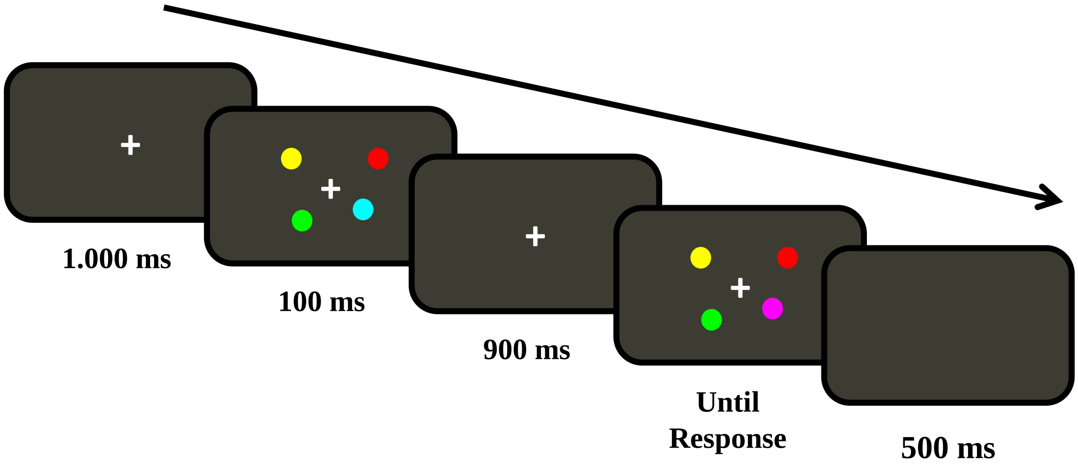


Figure 1. Sequence of events of a trial in the change localization task.

The experimental trials of the WM/Stroop-priming task consisted of a WM (arrow direction recall) and an attention (Stroop-priming) component (see Figure 2 below for sample trial sequences). For the WM component, sets of four arrows pointing in eight possible different directions (up, down, left, right, up-left, up-right, down-left, down-right) were centrally displayed in white in a horizontal line, with each arrow subtending a visual angle of about 0.76º wide and about 0.96º high. In the low WM load condition, the four arrows pointed in the same direction. In the high WM load condition, the four arrows pointed in four different directions, which were generated randomly from the eight possible directions. The memory probe consisted of a centrally presented single white arrow. For the Stroop-priming component, the prime stimuli consisted of the color words 'ROJO' (RED) or 'VERDE' (GREEN) displayed in white color in Courier new font size

22 (each character at about 0.35º wide and 0.52º high). The target consisted of a rectangle displayed in either red (255, 0, 0) or green (0, 255, 0) color at fixation, and subtending about 7.39º horizontally and 2.6º vertically. All stimuli presented in the WM/Stroop-priming task were displayed against a black background.

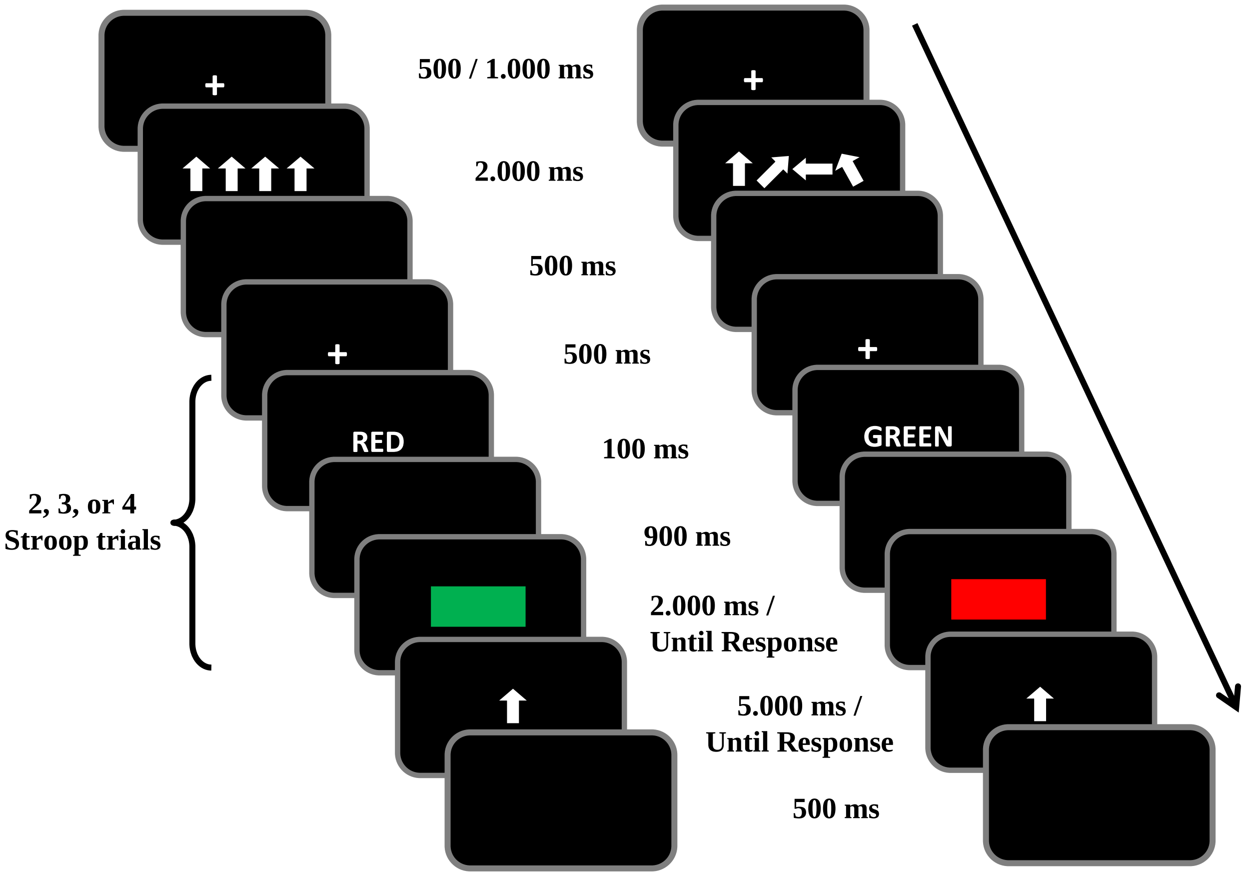


Figure 2. Examples of incongruent trials in the Stroop task under low **(Left)** and high **(Right)** working memory load in Experiment 1.

2.1.3. Design and Procedure

Participants performed a single experimental session lasting about 40-45 minutes. Each participant first completed a version of the change localization task (e.g., Johnson et al., 2013) to measure their WMC. Each trial started with a central fixation point (+) that remained on the screen until the end of the trial. After 1000 ms, a sample array displaying four colored circles (each circle colored in a different color) was presented for

100 ms. After a 900 ms blank screen, a test array appeared, which was similar to the previous sample array except that one of the four circles had changed color, and participants had to indicate the location of the change using the computer mouse (see Figure 1). Participants performed 12 practice trials and two experimental blocks of 32 trials per block, with a break interval between the two experimental blocks. A variant of the Pashler/Cowan K equation (e.g., Cowan et al., 2005) was used to assess participants' WM capacity (WMC). As each stimulus array contains four circles and each test array always contains a circle that changed color, the proportion of correct responses from each participant was multiplied by four to calculate their WMC (*K* score).

After completing the change localization task, each participant performed the combined WM/Stroop-priming task. The timing of the specific stimulus events on each trial was as follows: (1) Fixation display (+) presented for a variable duration (500-1000 ms); (2) Memory set presented for 2000 ms, which contained four arrows pointing in either the same (low WM load) or different directions (high WM load); (3) Blank screen presented for 500 ms; (4) Stroop-priming trials (see below for details); (5) Memory probe display (a single arrow) presented for 5000 ms or until response. Participants had to decide whether or not the arrow probe had been present in the previously memorized arrow-set by pressing the '1' or '2' keys with the middle and index fingers of their left hand, respectively (key mappings counterbalanced across participants). The probe arrow was either present or absent in the memory set on the same number of trials, and when it was present, it could occur with the same probability in any of the four positions. Following the participant's response to the arrow probe a new trial began after an inter-trial interval (blank screen) of 500 ms.

On each WM trial and following the memory set, participant performed a variable number (two, three or four) of Stroop trials, with the timing of the specific stimulus events on each Stroop trial being as follows: (1) Blank screen presented for 500 ms; (2) Prime word [‘ROJO’ (RED) or ‘VERDE’ (GREEN)] displayed for 100 ms (in white letters); (3) Blank screen presented for 900 ms; (4) Target stimulus (a red or green central rectangle) which remained on the screen until response. The participants responded to the rectangle color by pressing the ‘b’ and the ‘n’ keys with the index and middle fingers of their right hand. The two keys were labelled RED and GREEN with red and green stickers (key-label mappings counterbalanced across participants). The response to the target was followed by either the next Stroop trial, or the memory probe display. The prime and target stimuli referred to either the same color (congruent) or different colors (incongruent) on 20% and 80% of the trials, respectively. At the beginning of the experiment, participants received information about that differential proportion of congruent and incongruent pairs, and were actively encouraged to strategically use that information to optimize their performance in the Stroop task.

The combined WM/Stroop-priming task included 36 practice trials (18 for low and 18 for high WM load) followed by 180 experimental trials divided in two blocks, with 90 trials for each WM load condition (with the order of the two load blocks being counterbalanced across participants). There were 30 WM trials for each load block, with a same number of WM trials (10) containing either two, three, or four Stroop-priming trials (each participant received a different random order of the 30 WM trials). The 90 Stroop trials of each WM load block included 72 incongruent (80%), and 18 congruent (20%) trials. Once a WM load block was initiated, it ran to completion.

2.2. Results and Discussion

Participants’ responses to the memory probe showed the effectivity of our WM load manipulation. Mean correct RTs to the arrow probe were significantly slower in the high WM load (*M* = 2007 ms; *SD* = 522) compared to the low WM load block (*M* = 1688 ms; *SD* = 457; t (43) = 4.68, $p < .001$; $d = .65$). Mean accuracy was also reliably lower in the high (*M* = .70; *SD* = .11) than in the low WM load condition (*M* = .93; *SD* = .062; t (43) = 15.12, $p < .001$; $d = 2.41$). The results of further ANCOVA analyses in which *K* scores in the change localization task were treated as a continuous covariate, showed no reliable interaction between WM load and WMC either in reaction times (F (1, 42) = 1.3, $p > .26$) or in response accuracy ($F < 1$), thus suggesting that memory task performance was not modulated by individual differences in WMC (see Ahmed and De Fockert, 2012; Experiment 1, for a similar result).

For the analysis of responses in the Stroop task, were excluded trials with target responses that were incorrect (1.78%) or faster than 200 ms (.47%). In addition, we included in this analysis only those trials on which the response to the arrow memory probe was correct**.** Mean RTs and error rates were entered into two 2 x 2 Analyses of Variance (ANOVAs), with WM load (low, high) and prime-target congruency (congruent, incongruent) and as within-participants factors[1]. Mean correct RTs and error rates as a function of congruency and WM load conditions are depicted in Table 1.

Table 1. Mean (SD) correct reaction times (in milliseconds) and error percentages (in %) for congruent and incongruent trials in the Stroop task, under Low and High WM load in Experiment 1.

	Prime-target Congruency		
	Congruent	Incongruent	Stroop-priming
Working Memory Load			
Low Load	546 (111.2) 1.09 (2.9)	550 (100.8) 1.02 (2.2)	- 4
High Load	559 (114.4) 1.11 (3.2)	603 (106.9) 1.18 (3.3)	- 44

The ANOVA on error rates revealed no reliable effects (all *F*s < 1). The RT ANOVA showed a significant effect of WM load (F (1, 43) = 5.57, p = .023, η^2 = .11), such that responses were slower in the high load (M = 581 ms) than in the low WM load condition (M = 548 ms). The main effect of congruency reached also significance (F (1, 43) = 6.88, p = .012, η^2 = .14), with slower responses on incongruent (M = 576 ms) than on congruent (M = 552 ms) trials (i.e., a standard Stroop interference effect). In addition, the two factors reliably interacted (F (1, 43) = 6.02, p = .018, η^2 = .12), such that different Stroop effects emerged for high and low WM load conditions. Imposing a high load on the WM task induced reliably slower responses (by 44 ms) on incongruent than on congruent trials in the Stroop-priming task (t (43) = 3.28, p = .002, d = .496). Whereas this latter finding replicates that reported by Ortells et al. (2017) with a verbal WM task, no reliable reversed Stroop effect when our WM task demanded a low load (t < 1; see Table 1).

In order to know whether the strategic use of congruency proportion in the Stroop-priming task was modulated by individual differences in WMC, we conducted a further ANCOVA treating WM load and congruency as within-participants factors, and WMC (*K* scores) as a continuous covariate variable (for similar analyses see Hutchison, 2007; Richmond et al., 2015). The results showed again a main effect of prime-target congruency (F (1, 42) = 5.84, p = .02, η^2 = .12), which was qualified by a reliable congruency x WMC interaction (F (1, 42) = 4.13, p = .049, η^2 = .09, and of more interest, by a WM load x Congruency x WMC three-way interaction (F (1, 42) = 4.27, p = .045, η^2 = .092). To decompose this latter interaction, we analyzed the single congruency x WMC interaction separately for high and low WM load conditions (see Figure 3).

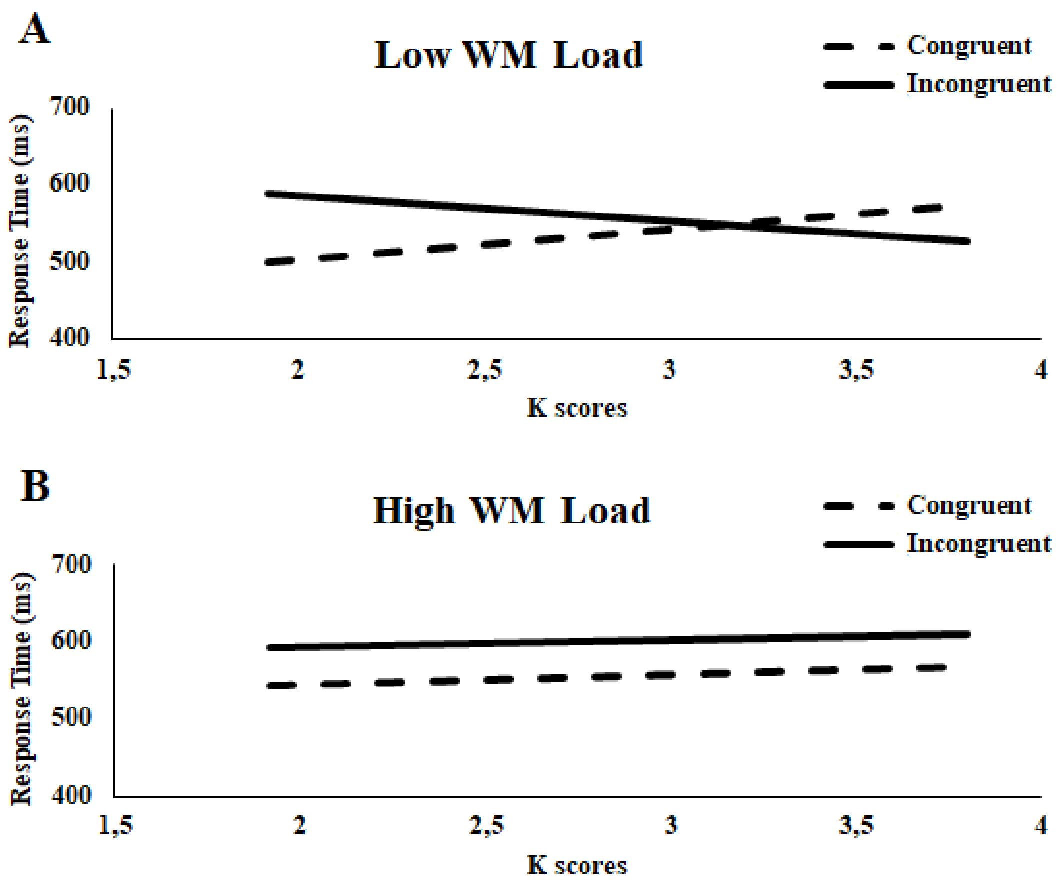


Figure 3. Participants' response times (ms) for congruent and incongruent conditions in the Stroop task as a function of WMC (*k*) scores under low **(A)** and high **(B)** WM load in Experiment 1.

As shown in Figure 3, under a high WM load no reliable congruency x WMC interaction was ever found (F < 1), with participants consistently showing an interference Stroop effect irrespective of their WMC (see also Figure 4[2]). Under a low WM load, however, there was a reliable crossover interaction between congruency and WMC (F (1, 42) = 12.24, p < .001, η^2 = .23), which shows that only participants with higher WMC were capable of an efficient strategic use of congruency proportions, giving rise to a reversed Stroop-priming effect. In clear contrast, participants with lower WMC showed an opposite Stroop interference effect, even though the concurrent WM task imposed a low load. Thus, the probability to find an expectancy-based priming effect (i.e., reversed Stroop) is positively correlated with WMC under a low WM load (r = .46, p = .002) but not under high WM load (r = .002, p > .88).

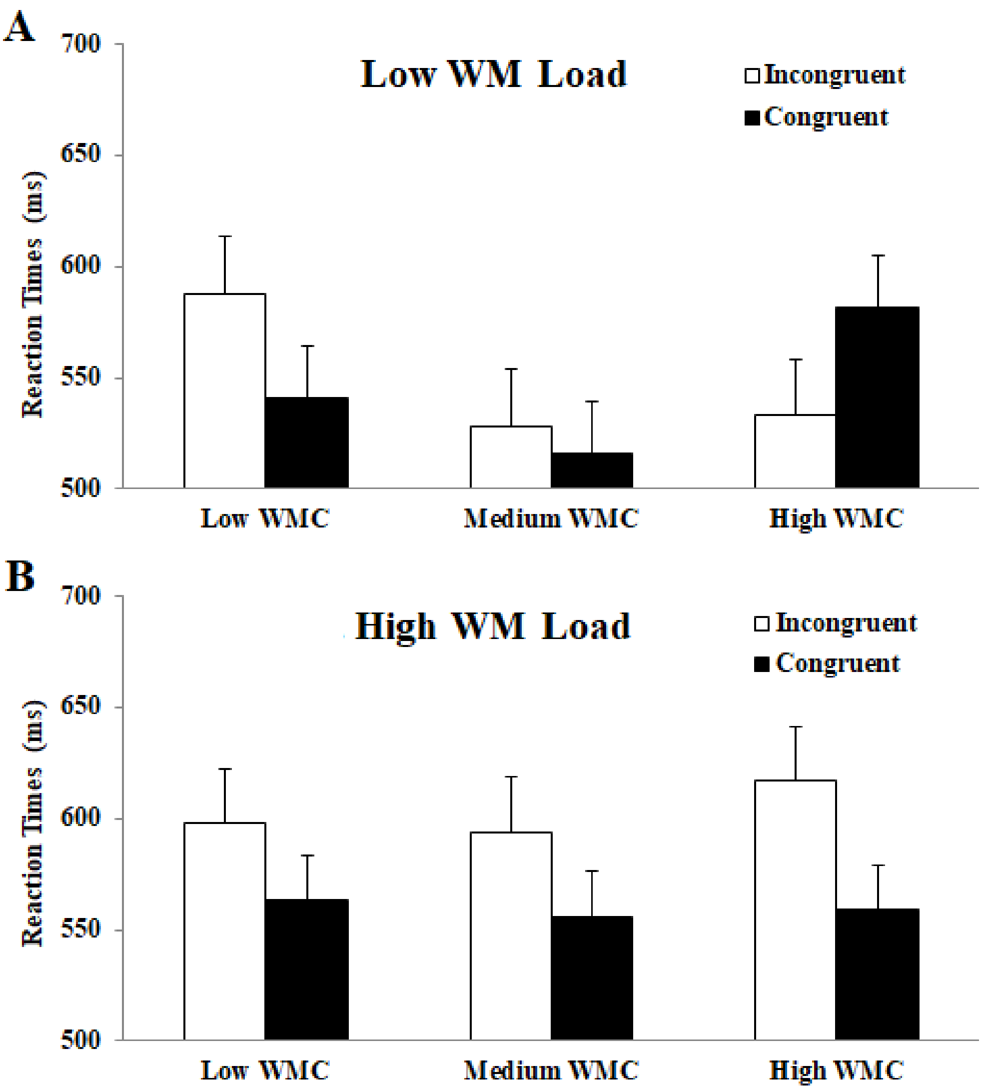


Figure 4. Mean reaction times (and standard error of the mean) for congruent and incongruent prime-target pairs as a function of WM load (**A**: low load; **B**: high load) and WMC group (low-, medium-, and high-WMC) in Experiment 1.

3. Experiment 2

In Experiment 1, we interleaved the strategic Stroop-priming task used by Ortells et al. (2017) with a WM load task which required participants to memorize the spatial directions of four arrows pointing either in a same direction (low load) or in four different random directions (high load). Although this non-verbal WM task was similar to that used in other previous studies (e.g., Chao, 2011; Experiment 7), it could however be questioned whether this particular task was truly spatial. Note on this respect that in both high and low load conditions, the four arrows always appeared in fixed spatial locations and they were ordered from left to right similarly to verbal information. Given those presentation conditions, one could argue that participants in our experiment might still be using some kind of verbal coding strategy to memorize the arrow sets. For example, they could use verbal rehearsal of lists of directions words like “up, up, up, up”, and “up, right-up, left, left-up”, to retain in verbal WM the low and high WM sets presented in Figure 2, respectively[3]. If that was really the case, then it would be difficult to establish whether the impact of WM load on expectancy-based strategic processes that was found in our experiment, was truly reflecting a domain-general, rather than a more domain-specific effect.

Based on these lines of argument, in the present experiment we used a different WM loading task that involved stimuli that are more unequivocally spatial and non-verbal than those used in Experiment 1. Accordingly, our Stroop task was now combined with a WM task that required observer to memorize the spatial locations of four dots presented in a 4 x 4 square grid. In a low load condition, the four dots always form a symmetrical pattern (i.e., a straight line), whereas in a high load condition, they are randomly scattered in the square grid. After running 2, 3, or 4 Stroop-priming trials, a single memory probe dot is presented in the square grid, and participants had to decide whether it is occupying or not any of the four spatial locations previously occupied by the remembered dots. This kind of WM loading task has been used by several prior studies to investigate whether attentional processes can be affected by load manipulations in a concurrent spatial WM task (e.g., Heyman et al., 2014; Kim et al., 2005; Smith and Jonides, 1998; see also Thomas, 2013).

3.1. Material and Methods

3.1.1. Participants

Forty right-handed undergraduate students (12 men; age range = 19-33 years, *M* = 21.42, *SD* = 3.21) from the University of Almería received course credits for their participation in the experiment, with all them having normal or corrected-to-normal vision.

3.1.2. Stimuli and Apparatus

These were similar to those used in Experiment 1, with the only difference being the WM component of the combined WM/Stroop-priming task. For the WM component, a 4 x 4 square grid (about 10.56º wide and high) containing four black filled dots (1.44º diameter) was centrally displayed. The four dots either formed a simple symmetrical pattern (i.e., a straight line; low WM load condition), or they were randomly scattered in different spatial locations in the square grid (high WM load condition), with the restriction that the dots had no adjacent neighbours in either vertical or horizontal directions. The memory probe consisted of a square grid containing a single black filled dot (1.44º diameter).

3.1.3. Design and Procedure

These were the same as those used in Experiment 1, with the difference that the WM loading task now consisted of memorizing the spatial locations of four dots that were simultaneously displayed in a 4 x 4 square grid for 2000 ms. In the low WM load condition, the four dots formed a straight line (see Figure 5), whereas in the high WM load trials, the dots were randomly displayed in the square grid (see Heyman et al., 2014; Kim et al., 2005, for similar spatial WM load tasks). After performing two, three, or four Stroop trials, a single dot was present for 5000 ms or until response in the square grid.

Participants had to press the ‘1’ or ‘2’ keys to decide whether the probe dot either appeared in one of the locations occupied by the memorized dots or it was presented in a different (unoccupied) location to those of the memorized dots (key mappings counterbalanced across participants). Following the participants’ responses to the dot probe a blank screen was presented for 500 ms (inter-trial interval). The dot probe was equally likely to appear in either the same location or a different location to those of the memorized dots. As in Experiment 1, participants knew that the incongruent trials were much more frequent (80%) than the congruent trials (20%) in the Stroop task, and were encouraged to strategically use the prime word to anticipate the target color. The combined spatial WM/Stroop-priming task again included 36 practice (18 for each WM load condition) and 180 experimental trials divided in two blocks: 90 trials for the high WM load and 90 for the low WM load block (block order counterbalanced between participants). Participants performed 30 WM trials of each load block, and each WM trial included two, three or four Stroop trials (10 WM trials each).

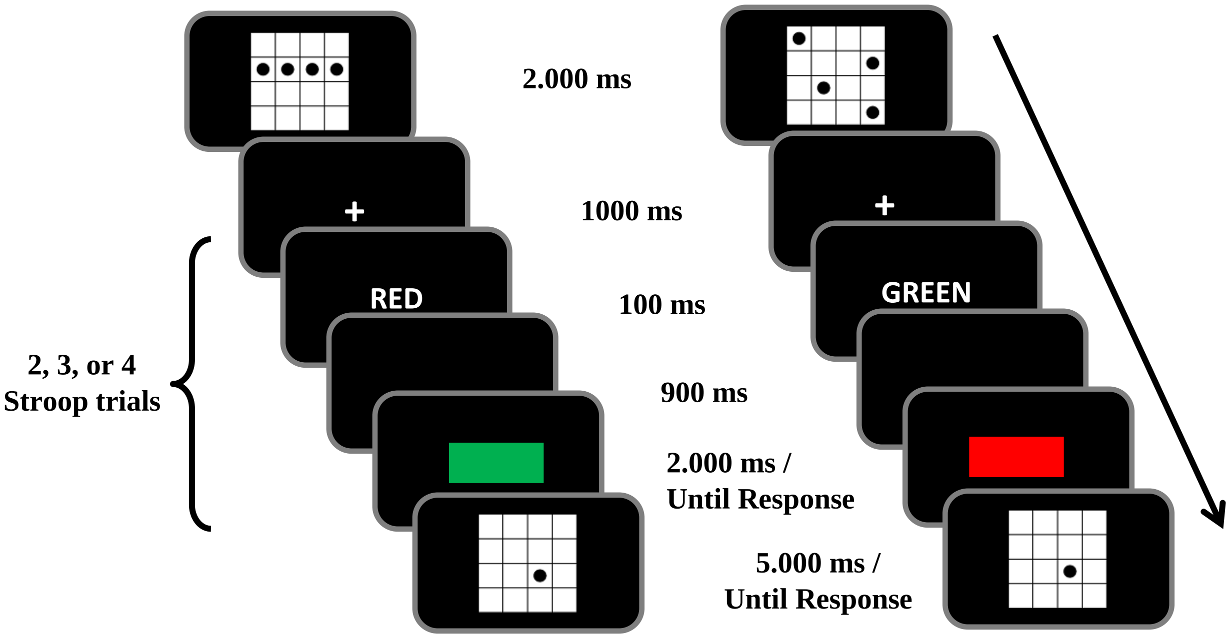


Figure 5. Examples of trials under low **(left)** and high **(right)** load in the spatial working memory task in Experiment 2.

3.2. Results and Discussion

Participants' responses to the memory probe demonstrated again the effectivity of our manipulation to load spatial working memory. Mean correct response times to the dot probe were significantly slower in the high WM load condition (*M* = 1809 ms; *SD* = 525) compared to the low WM load condition (*M* = 1647 ms; *SD* = 302; t (39) = 2.67, $p < .011$; d = .42). Mean accuracy was also reliably lower for high (*M* = .79; *SD* = .10) than for low WM load trials (*M* = .93; *SD* = .06; t (39) = 9.02, $p < .001$; d = 1.47). The results of further ANCOVAs treating participants' *K* scores in the change localization task as a continuous covariate, showed that WMC did not interact with WM load in response times to the memory probe (F (1, 38) = 1.59, $p > .215$), as found in Experiment 1. Yet, the WM load by WMC interaction reached statistical significance in probe accuracy rates (F (1, 38) = 7.63, p = .009, η^2 = .17). The analysis of this interaction showed that a greater WMC was associated with a decreased difference in accuracy rates between low and high WM conditions, as revealed by a reliable negative correlation between both variables (r = -.40, p = .012). A similar interaction between WM load and WM capacity in probe response accuracy has previously been reported by some studies examining the combined effect of both factors on selective attention (e.g., Ahmed and De Fockert, 2012; Experiment 2).

To analyze participants' performance in the Stroop task, mean correct RTs and error rates were again entered into two 2 x 2 ANOVAs treating congruency (congruent, incongruent) and WM load (low, high) as within-participants factors.

The ANOVA on error rates only revealed a significant main effect of prime-target congruency (F (1, 39) = 6.15, p = .018, η^2 = .14), with a reduced error rate on incongruent (*M* = 2.14) than on congruent (*M* = 3.07) trials (i.e., a reversed, strategic- Stroop effect). The RT ANOVA showed a significant congruency by WM load interaction (F (1, 39) = 28.5, $p < .001$, η^2 = .42), which revealed opposite behavioral effects under low and high load in the WM task. As shown in Table 2, when participants were required to remember series of dots forming a symmetrical pattern (low load), they could use the prime information in a strategic manner in the Stroop task, as their responses on incongruent trials were faster (by 21 ms) than on congruent trials (*t* (39) = 2.53, *p* = .016, *d* = .38). Yet, when participants had to remember the spatial locations of dots randomly scattered on a matrix (high load), they responded slower (by 27 ms; see Table 2) on incongruent than on congruent trials (i.e., standard interference effect; *t* (39) = 2.61, *p* = .013, *d* = .41). This finding replicates that obtained in our Experiment 1 using a different spatial WM task, as well as the results reported by Ortells et al. (2017) with a verbal WM task.

Table 2. Mean (SD) correct reaction times (in milliseconds) and error percentages (in %) for congruent and incongruent trials in the Stroop task, under Low and High WM load in Experiment 2.

	Prime-target Congruency		
	Congruent	Incongruent	Stroop-priming
Working Memory Load			
Low Load	530 (120.4) 3.2 (4.7)	509 (116.1) 1.9 (2.4)	+ 21
High Load	516 (114.6) 2.7 (3.9)	543 (122.7) 2.5 (3.5)	- 27

With regard to the combined effect of WM load and WMC on the strategic Stroop effect, even though the pattern of Stroop effects as a function of WM load and WMC was similar to Experiment 1, with strategic Stroop effects only being apparent in high WMC individuals who were experiencing low WM load, the three-way interaction between WM load, Congruency, and WMC did not reach significance this time ($F < 1$).

4. General Discussion

In this study we used a sequential Stroop-priming task with a differential proportion of incongruent (80%) and congruent trials (20%), which was interleaved with different types of non-verbal WM tasks demanding either a low or a high load. There were two relevant findings in our study.

Firstly, in both Experiment1 and 2 we found a reliable WM load by congruency interaction, which revealed that participants' performance in the Stroop-priming task was clearly influenced by WM load. When the WM task demanded a high load, participants appeared unable to strategically use the information provided by the prime word to anticipate their responses to the color target, as their responses were slower to incongruent than to congruent targets (i.e., a standard Stroop interference effect). The same Stroop interference pattern was observed across two experiments, and irrespective of whether the non-verbal WM task required participants to remember either the orientations of arrow-sets (Experiment1) or the spatial locations of different dots displayed in a square grid (Experiment 2).

A similar Stroop congruency by WM load interaction was also reported by Ortells et al. (2017). Yet, that study manipulated WM load by means of a verbal task (i.e., memorizing sequences of digits), and one therefore cannot rule out the possibility that the absence of the strategic effect (reversed Stroop) found by these authors under a high WM load, could at least partly be attributed to verbal interference processes from the concurrent WM task. But this does not appear to be the case in the current research, especially in Experiment 2. Regarding the WM loading task used in our Experiment 1, we cannot completely rule out the possibility that participants might have employed some kind of verbal coding strategy to memorize the directions of series of arrow sets that always appeared in fixed spatial locations and ordered from left to right, similarly to verbal information. But the same argument could not be applied to the high load condition of the WM task used in Experiment 2, which required participants to memorize the spatial locations of four dots that were randomly displayed on a 16-square grid. Strategies involving verbal coding would have been unavailable for that task. Overall, the findings of Experiments 1 and 2 thus replicate and extend those reported by Ortells et al. (2017) and provide stronger tests that the effects of WM load on expectancy-based strategic procesess are mainly domain-general (attention control resources) rather than domain-specific (verbal interference).

On the other hand, whereas a few previous studies had examined the combined influence on performance of limiting WM resources by both loading WM and individual differences in WMC (e.g., Ahmed and De Fockert, 2012; Kane and Engle, 2003; Rosen and Engle, 1997), the interactive impact of these two factors on strategic processing of task-relevant information in selective attention had not been previously investigated.

A second key finding of our study was that the influence of loading WM on expectancy-based strategic processes was at least partially modulated by individual differences in WMC. In Experiment1, and to some extent also in Experiment 2, we found that imposing a high load in a concurrent non-verbal WM task disrupted the implementation of expectancy-based strategies in a similar way irrespective of whether participants had an either high or low WMC (as revealed by their performance in the change localization task). Thus, when the spatial WM task demanded a high load, observers were unable to strategically use the trial probability information, and they responded slower to the incongruent than to the congruent trials (i.e., a standard Stroop interference effect) irrespective of their WMC. In clear contrast, when the WM task demanded a low load, the probability to efficiently process the task-relevant information in a strategic manner appeared to depend on WMC, as only high-WMC participants showed reliably faster responses to incongruent than to congruent targets in the Stroop-priming task. But a different result pattern was observed in low WMC individuals, who showed an opposite Stroop interference effect in Experiment 1 (and a similar pattern of effects in Experiment 2, though this time the omnibus three-way interaction was absent), even when performing the Stroop-priming task under a low WM load (see Figure 4).

It should be noted that the reliable three-way interaction between WM load, congruency and WMC observed in Experiment 1, did not reach statistical significance in Experiment 2. Whereas the reasons for that discrepancy remain unclear, several observations seem pertinent here. First, as in Experiment 1, we also found in Experiment 2 a reliable correlation between participants' WMC (*k* scores) and the reversed Stroop-priming effect under low WM load (r = .35, p = .028), but not under a high load. Thus, only participants with a higher WMC were able to show a reliable reversed Stroop under low load, thus replicating the findings of Experiment 1. Secondly, it is interesting to note that the overall mean WMC score for participants in Experiment 2 was higher (k = 3.28) than the mean score found in Experiment 1 (k = 3.09), with this difference being marginally significant (t (82) = 1.85, p = .068, d = .40). In fact, more than half of participants in Experiment 2 included in the medium-WMC group (8 from 14 participants), could have been classified as individuals with a higher-WMC in Experiment 1. Further research addressing the combined influence of loading WM and individual differences in WMC could use an extreme-group approach. This would address whether participants with WMC scores falling within the upper and lower quartiles really show a differential impact of WM load on expectancy-based strategic processes.

In order to explain the deficits in cognitive control usually shown by older adults and several clinical populations (e.g., schizophrenia patients), Braver and colleagues have developed the dual-mechanisms control (DMC) model (e.g., Braver et al., 2001; Braver et al., 2007; see Braver, 2012, for a review). This theory assumes that intentional or goal directed behavior can be the result of two different modes of cognitive control: proactive and reactive control. Proactive control reflects a preparatory and resource demanding type of control in which a predictive cue is used by individuals to prepare a specific response to a future target. This control mode requires active maintenance of the goal-relevant information in an accessible state, in order to efficiently focus attention on that information while ignoring competing distractors. In contrast, reactive control involves a backward-acting and less effortful process, in which the target onset would automatically induce the retrieval of the relevant information (e.g., appropriate actions) from long-term memory.

By using different tasks and experimental procedures (e.g., the AX-Continuous Performance Test, AX-CPT) to assess the DMC theory, numerous studies have reported evidence that older adults as well as younger adults with a low WMC are less likely to efficiently use a proactive cognitive control mode than young adults high in WMC (e.g., Braver et al., 2007; Hutchison et al., 2014; Redick, 2014; Richmond et al., 2015; Wiemers and Redick, 2018).

The current results fit fairly well with the DMC framework by Braver et al. Performing the Stroop-priming task with a concurrent WM task that imposed a high load could impede participants to efficiently represent the task instructions in their working memory, thus explaining the absence of a strategic effect (reversed Stroop) that was observed under that WM load condition. In a similar vein, the fact that only higher WMC individuals were able to show an expectancy-based strategic effect (i.e., reversed Stroop) under a low WM load, would also be consistent with the idea that an adequate implementation of proactive control would require a high WMC, whereas participants with a low WMC are more likely to use a reactive control mode.

The observed differences between high and low WMC participants in our study also resemble those previously observed by Froufe et al. (2009) between young adults and elderly people using a similar Stroop-priming task. These authors found that only the young group were able to efficiently implement expectancy-based strategic actions under single-task conditions, and showed a reliable reversed Stroop effect. However, the older participants showed either a non-significant reversed Stroop effect, or an opposite standard Stroop interference, as occurred in the elderly group with AD. As argued by the executive attention model of WM proposed by Engle and colleagues (e.g., Engle and Kane, 2004; Kane et al., 2007), having a low WMC could have a similar effect to using a WM task demanding a high load, as individuals with more limited WM resources should also show a reduced capacity for attentional control.

5. Conclusion

The results of the present study, along with those recently reported by Ortells et al. (2017), clearly demonstrate that imposing a high WM load disrupts the implementation of expectancy-based strategic processes, irrespective of the nature of the concurrent WM task. Overall, these results replicate and extend recent demonstrations that reducing the availability of WM resources with a high WM load not only interferes with the ability to inhibit or suppress distracting information, but it also leads to less efficient strategic processing of task-relevant information in selective attention tasks (e.g., Heyman et al., 2014; Hutchison et al., 2014; Ortells et al., 2017; see also Kalanthroff, et al., 2015).

Our study also demonstrates for first time that the effect of loading WM on expectancy-based strategies can be modulated to some extent by individual differences in

WMC. Thus, an efficient implementation of facilitatory attention strategies under dual-task conditions might require that cognitive control resources are maximally available, that is, under low WM load conditions, and in high WMC individuals.

Author contributions

JO and JDF developed the concept and the design of the experimental work. NR, SF, and JO actively participated in the implementation of the experimental tasks, data collection and data analyses in the two experiments. All the authors supervised the processes of accomplishing the study, contributed to writing and reviewing the manuscript, as well as to approving the final version of the manuscript.

6. References

Ahmed, L., and De Fockert, J. W. (2012). Focusing on attention: the effects of working memory capacity and load on selective attention. *PLoS ONE,* 7, 1-11 doi: 10.1371/journal.pone.0043101

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

Braver, T. S., Barch, D. M., Keys, B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., et al. (2001). Context processing in older adults: Evidence for a theory relating cognitive control to neurobiology in healthy aging. *J. Exp. Psychol. Gen.* 130, 746-763. doi: 10.1037//0096-3445.130.4.746

Braver, T. S., Gray, J. R., and Burgess, G. C. (2007). "Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control," in *Variation in working memory,* eds. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, and J. N. Towse (New York, NY: Oxford University Press), 76-106.

Chao, H. F. (2011). Active inhibition of a distractor word: The distractor precue benefit in the stroop color-naming task. *J. Exp. Psychol. Human*, 37, 799-812. doi: 10.1037/a0022191

Cowan, N., Elliott, E. M., Saults, J. S., Morey, C. C., Mattox, S., Hismjatullina, A., and Conway, A. R. A. (2005). On the Capacity of Attention: Its Estimation and Its Role in Working Memory and Cognitive Aptitudes. *Cog Psychol.* 51, 42-100. doi: 10.1016/j.cogpsych.2004.12.001

Daza, M. T., Ortells, J. J., and Fox, E. (2002). Perception without awareness: Further evidence from a Stroop priming task. *Percept Psychophys.* 64, 1316-1324. 64: 1316. doi:10.3758/BF03194774

De Fockert, J. W. (2005). Keeping priorities: the role of working memory and selective attention in cognitive aging. *Sci. Aging Knowledge Environ*. 44, pe34.

De Fockert, J. W. (2013). Beyond perceptual load and dilution: A review of the role of working memory in selective attention. *Front. Psychol.* 4, 1-11. doi: 10.3389/fpsyg.2013.00287

De Fockert, J. W., Mizon, G. A., and D'Ubaldo, M. (2010). No negative priming without cognitive control. *J. Exp. Psychol. Human,* 36, 1333-1341. doi:10.1037/a0020404

De Fockert, J., Ramchurn, A., Van Velzen, J., Bergström, Z., and Bunce, D. (2009). Behavioural and ERP evidence of increased interference in old age. *Brain Res*. 1282, 67–73.

De Fockert, J.W., Rees, G., Frith, C. D., and Lavie, N. (2001). The role of working memory in visual selective attention. *Science,* 291, 1803–1806.

Froufe, M., Cruz, I., and Sierra, B. (2009). (dis)Función ejecutiva en personas mayores con y sin Alzheimer: Actuación estratégica basada en expectativas. *Psicológica, 30*, 119-135.

Fukuda, K., Vogel, E., Mayr, U., and Awh, E. (2010). Quantity, not quality: The relationship between fluid intelligence and working memory capacity. *Psychon. Bull. Rev*. 17, 673–679. doi: 10.3758/17.5.673

Gazzaley, A. (2012). "Top-down modulation deficit in the aging brain: An emerging theory of cognitive aging", in *Principles of Frontal Lobe Function (*2nd edn), eds. D. T. Stuss and R. T. Knight (New York: Oxford University Press), 593–608.

Gazzaley, A., and Nobre, A. C. (2012). Top-down modulation: Bridging selective attention and working memory. *Trends Cog. Sci.* 16, 129-135. doi: 10.1016/j.tics.2011.11.014

Heyman, T., Van Rensbergen, B., Storms G., Hutchison, K. A., and De Deyne, S. (2014).

The influence of Working Memory Load on Semantic Priming. *J. Exp. Psychol. Learn. 41*, 911–920. doi:10.1037/xlm0000050

Hutchison, K. A. (2007). Attentional control and the relatedness proportion effect in semantic priming. *J. Exp. Psychol. Learn.* 33, 645-662. doi: 10.1037/0278-7393.33.4.645

Hutchison, K. A., Heap, S. J., Neely, J. H., and Thomas, M. A. (2014). Attentional control and asymmetric associative priming. *J. Exp. Psychol. Learn.* 40, 844-856. doi:10.1037/a0035781

Johnson, M. K., McMahon, R. P., Robinson, B. M., Harvey, A. N., Hahn, B., Leonard, C. J., Luck, S. J., and Gold, J. M. (2013). The relationship between working memory capacity and broad measures of cognitive ability in healthy adults and people with schizophrenia. *Neuropsychology*, 27, 220-229. doi: 10.1037/a0032060

Kalanthroff, E., Avnit, A., Henik, A., Davelaar, E. J., and Usher, M. (2015). Stroop proactive control and task conflict are modulated by concurrent working memory load. *Psychon. Bull. Rev.* 22, doi: 10.1037/a0032060

Kane, M. J., Conway, A. R. A., Hambrick, D. Z., and Engle, R.W. (2007). “Variation in working memory capacity as variation in executive attention and control”, in *Variation in working memory*, eds. A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, and J. N. Towse (New York, Oxford University Press), 21-48.

Kane, M. J., and Engle, R. W. (2003). Working-memory capacity and the control of attention: the contributions of goal neglect, response com- petition, and task set to Stroop interference. *J. Exp. Psychol. Gen.* 132, 47–70.

Kim, S.Y, Kim, M. S, & Chun, M. M. (2005). Concurrent working memory load can reduce distraction. *Proc. Natl. Acad. Sci*. 102, 16524-16529. doi:10.1073-pnas.0505454102

Konstantinou, N., and Lavie, N. (2013). Dissociable roles of different types of working memory load in visual detection. *J. Exp. Psychol. Human*, 39, 919-924. doi: 10.1037/a0033037

Lavie, N., and De Fockert, J. W. (2005). The role of working memory in attentional capture. *Psychon. Bull. Rev.* 12, 669–674.

Lavie, N., Hirst, A., de Fockert, J. W., and Viding, E. (2004). Load Theory of Selective Attention and Cognitive Control. *J. Exp. Psychol. Gen.* 133, 339-354. doi: 10.1037/0096-3445.133.3.339

Logan, G.D., Zbrodoff, N.J., and Williamson, J. (1984). Strategies in the color-word Stroop task. *Bull Psychon Soc.* 22, 135-138.

Merikle, P. M., and Joordens, S. (1997). Parallels between perception without attention and perception without awareness. *Consciousness and Cognition*, 6, 219-236.

Minamoto, T., Shipstead, Z., Osaka, N, and Engle, R. E. (2015). Low cognitive load strengthens distractor interference while high load attenuates when cognitive load and distractor possess similar visual characteristics. *Atten. Percept. Psychophys.* 77, 1659-1673. doi: 10.3758/s13414-015-0866-9.

Ortells, J. J., Álvarez, D., Noguera, C., Carmona, E., and De Fockert, J. W. (2017). The Influence of Working Memory Load on Expectancy-Based Strategic Processes in the Stroop-Priming Task. *Front. Psycho.* 8, 1-8. doi: 10.3389/fpsyg.2017.00129

Ortells, J. J., Noguera, C., Álvarez, D., Carmona, E., and Houghton, G. (2016). Individual differences in working memory capacity modulates semantic negative priming from single prime words. *Front. Psycho.* 7, 1-14. doi: 10.3389/fpsyg.2016.01286

Ortells, J. J., Vellido, C., Daza, M. T., and Noguera, C. (2006). Semantic priming effects with and without perceptual awareness. *Psicológica, 27*, 225-242.

Park, S., Kim, M. S, and Chun, M. M. (2007). Concurrent working memory load can facilitate selective attention: evidence for specialized load. *J Exp Psychol Hum.* 33, 1062-75. doi: 10.1037/0096-1523.33.5.1062

Redick, T. S. (2014). Cognitive control in context: Working memory capacity and proactive control. *Acta Psychol.* 145, 1-9. doi: 10.1016/j.actpsy.2013.10.010

Richmond, L. L., Redick, T. S., and Braver, T. S. (2015). Remembering to prepare: The benefits (and costs) of high working memory capacity. *J. Exp. Psychol. Learn.* 41, 1764–1777. doi:10.1037/xlm0000122

Rosen, V. M., and Engle, R. W. (1997). The role of working memory capacity in retrieval. *J. Exp. Psychol. Gen. 126*, 211-227. doi: 10.1037/0096-3445.126.3.211.

Shipstead, Z., Harrison, T. L., and Engle, R. W. (2015). Working memory capacity and the scope and control of attention. *Atten. Percept. Psychophys*. 77, 1863-80. doi: 10.3758/s13414-015-0899-0

Smith, E. E, and Jonides, J. (1998). Neuroimaging analyses of human working memory. *Proc. Natl. Acad. Sci*. 95. 12061-12068. doi: 10.1073-pnas.95.20.12061

Thomas, L. E. (2013). Spatial working memory is necessary for actions to guide thought. *J. Exp. Psychol. Learn. Mem. Cogn*. 39, 1974-1981. doi: 10.1037/a0033089

Zanto, T. P., and Gazzaley, A. (2014). "Attention and Ageing" in *The Oxford Handbook of Attention,* eds. A. C. Nobre, and S. Kastner (New York, NY: Oxford University Press), 927-971. doi: 10.1093/oxfordhb/9780199675111.013.02

Wiemers, E. A., and Redick, T. S. (2018). Working memory capacity and intra-individual variability of proactive control. *Acta Psychol.* 182, 21-31. doi: 10.3758/s13414-015-0899-00

Acknowledgments

This work was supported by Ministerio de Economía y Competitividad (Government of Spain) with research grants PSI2014-53856-P and PSI2017-83135-P (Experiment 2) to Juan J. Ortells. Correspondence concerning this article should be addressed to Juan J. Ortells, Departamento de Psicología. Universidad de Almería. 04120. Almería. Spain (Email: jortells@ual.es).

7. Footnotes

Note 1. A fairly similar result pattern was found in a further analysis on the Stroop-priming data, in which we included those trials with incorrect responses to the arrow memory probe. Thus, the effects of WM load (F (1, 43) = 5.01, p = .030, η^2 = .104) and congruency (F (1, 43) = 4.49, p = .040, η^2 = .095) were again significant, as well as the WM load x congruency interaction (F (1, 43) = 6.85, p = .012, η^2 = .14), and more relevant, the three-way interaction between WM load, congruency and WMC (F (1, 42) = 5.92, p = .019, η^2 = .124). Further analyses of the latter interaction showed a crossover congruency x WMC interaction under low load (F (1, 42) = 10.73, p = .002, η^2 = .204), which showed opposite Stroop-priming effects as a function of participants' WMC. Yet, no reliable congruency x WM interaction was found under high WM load (F < 1), such that an interference Stroop effect was always found irrespective of WMC.

Note 2. Whereas the ANCOVA analysis consider the full range of WMC scores, for a better visual understanding of that analysis, Figure 4 shows participants divided into high- (k > 3.36), medium- (k < 3.32), and low-WMC (k < 3.08) groups by using a tertile split (see Richmond et al., 2015 for a similar approach).

Note 3. We would argue that it is highly unlikely that such a kind of verbal rehearsal could be a useful retention strategy in our experiment. Note that all of our participants were Spanish native speakers. Whereas the direction words "up", "down", "left" and "right" are pronounced as monosyllabic words in English language, this is not the case regarding Spanish language, as all of those words involve three syllables (up = a-rri-ba; down = a-ba-jo; left = iz-quier-da; right = de-re-cha), Consequently, a Spanish native speaker would need much more time than an English speaker to retain in WM four direction words by using verbal rehearsal. We nonetheless decided to run Experiment 2 with a WM task that is even less likely to involve verbal coding.

IV

Estudio Experimental II

Estudio 2. The implementation of expectancy-based strategic processes is delayed in normal aging[2]

[2]Manuscript published as:

Noguera, C., Fernández, S., Álvarez, D., Carmona, E., Marí-Beffa, P., & Ortells, J. J. (2019). The implementation of expectancy-based strategic processes is delayed in normal aging. *PloS one*, *14*(3), e0214322. doi: 10.1371/journal.pone.0214322

The implementation of expectancy-based strategic processes is delayed in normal aging

Carmen Noguera[1*], Sergio Fernández[1], Dolores Álvarez[1], Encarna Carmona[1], Paloma Marí-Beffa[2], and Juan J. Ortells[1]

[1] Department of Psychology, University of Almería, Almería, Spain

[2] School of Psychology, University of Wales Bangor, Bangor, Gwynedd, UK

Abstract

The present research examined if the time needed to implement expectancy-based strategic processes is different in younger and healthy older adults. In four experiments participants from both age groups performed different strategic priming tasks. These included a greater proportion of incongruent (or unrelated; 80%) than of congruent (or related; 20%) trials. With this procedure performance is worse for congruent (less frequent) than for incongruent (more frequent) trials, thus demonstrating that the relative frequency information can be used to predict the upcoming target. To explore the time course of these expectancy-based effects, the prime-target SOA was manipulated across experiments through a range of intervals: 400, 1000 and 2000 ms. Participants also performed a change localization and an antisaccade task to assess their working memory and attention control capacities. The results showed that increases in age were associated with (a) a slower processing-speed, (b) a decline in WM capacity, and (c) a decreased capacity for attentional control. The latter was evidenced by a disproportionate deterioration of performance in the antisaccade trials compared to the prosaccade ones in the older group. Results from the priming tasks showed a delay in the implementation of expectancies in older adults. Whereas younger participants showed strategic effects already at 1000 ms, older participants consistently failed to show expectancy-based priming during the same interval. Importantly, these effects appeared later at 2000 ms, being similar in magnitude to those by the younger participants and unaffected by task practice. The present findings demonstrate that the ability to implement expectancy-based strategies is slowed down in normal aging.

1. Introduction

It well established that many aspects of cognition decline with normal aging, including attention, working memory (WM), and episodic memory (e.g., Craik & Salthouse, 2000; see Zanto & Gazzaley, 2014, for a review). In an attempt to provide a potentially unifying underlying mechanism that could explain the diversity of age-related cognitive deficits, several alternative hypotheses have been proposed.

An influential account is the processing speed hypothesis of cognitive aging (e.g., Salthouse, 1996), which attributes age-related cognitive decline to a general slowing of information processing. This slowing in cognitive processing speed has been found for example in several perceptual speed tasks involving visual search, elementary comparison, and substitution operations (e.g., Levitt, Fugelsang, & Crossley, 2006; Salthouse, 2000).

Another leading alternative, though not incompatible hypothesis suggests that cognitive deficits associated with aging would mainly be the result of an inability to inhibit or control for interference from task-irrelevant (external or internal) information (e.g., Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999; see Lustig, Hasher, & Zacks, 2007, for a review). Evidence supporting the inhibitory account of cognitive aging comes from a variety of experimental tasks thought to draw on inhibitory (top-down) control. Thus, older adults usually display less efficient inhibition of dominant but inappropriate reactions, as it is for example the case in the antisaccade task (e.g., Butler, Zacks, & Henderson, 1999). Performance by older adults is also poorer than for younger ones on WM tasks that require actively holding the relevant information in an easily accessible form, especially in the face of distraction or interference (e.g., Cashdollar, Fukuda, et al., 2012; see Gazzaley, 2012 for a review).

Older adults can also show impoverished inhibitory memory control relative to younger subjects in different episodic memory tasks (e.g., intentional or directed forgetting; see for example Aguirre et al., 2014; Anderson, Kuhl & Mayr, 2011), as well as in selective attention tasks that require active rejection of distracting information. This can explain why interference effects from irrelevant distractors in conflict tasks (e.g., Stroop; Eriksen-type flanker) are usually increased in old age (e.g., De Fockert, 2005; De Fockert, Ramchurn, Van Velzen, Bergström, & Bunce, 2009; Mayas, Fuentes, & Ballesteros, 2012; West & Allain, 2000). In a similar vein, older adults, like younger subjects with lower WM capacity (WMC), can have greater difficulty to prevent or suppress the processing of to-be-ignored distractors in negative priming tasks (e.g., Marí-Beffa, Hayes, Machado, & Hindle, 2005, Mayas et al., 2012; see also Ortells, Noguera, Álvarez, Carmona, & Houghton, 2016).

On the other hand, several other lines of evidence suggest that the development of facilitatory strategies of the type required to consciously expect forthcoming targets would also be affected by a reduced availability in WM resources, as it could be the case in older people (e.g., Froufe, Cruz, & Sierra, 2009; Langley et al., 2001; but see Burke et al., 1987; Chiarello et al., 1985), or in younger adults with a lower WM capacity. In this later case, some recent priming studies have shown that, when the manipulation promotes the generation of expectancy-based strategies (e.g., with long prime-target interval; increased proportion of related pairs), these controlled semantic priming effects can be significantly diminished (or even eliminated) for participants with low attention control, low WMC (e.g., Kane & Engle, 2003; Henry & Crawford, 2004), or under high WM load (e.g., Shivde & Thompson-Schill, 2004; i.e., a high relatedness proportion; Mummery, Shallice, & Price, 1999; Rossell, Price, & Noble, 2003). Several neuroimaging studies report in fact evidence that Prefrontal cortex (PFC), an area (along with the anterior cingulate cortex) known to reflect attention control (e.g., Hutchison, Heap, Neely &

Thomas, 2014), is highly active when semantic information has to be generated and maintained over a delay in working memory (e.g., Hutchison, 2007; Heyman, Van Rensbergen, Storms, Hutchison & De Deyne, 2014), or during semantic priming tasks performed under strategic conditions (i.e., a high relatedness proportion) (Ortells, Álvarez, Noguera, Carmona & De Fockert, 2017; Ortells, De Fockert, Romera, & Fernández, 2018).

Note however that most of previous work investigating a possible dependence of strategic priming on WM resources, has used a conventional facilitation paradigm in which both the controlled and automatic processes (e.g., expectancy generation vs spreading of activation) produce the same behavioral pattern, that is, improved performance or facilitatory priming. Therefore, results from these studies showing changes in facilitation cannot be fully to be attributed to one process or another. Recently, we have developed an alternative priming task with the idea of producing qualitatively different behavioral effects depending on whether the processing of information is strategic or not (e.g., Ortells et al., 2017; see also Ortells et al., 2018). To do so we used a Stroop-priming task in which a prime word (GREEN or RED) was followed by a coloured target (red vs. green) that participants had to identify. The prime word and target color were congruent or incongruent on 20% and 80% of the trials respectively, with instructions highlighting this proportion manipulation. The greater proportion of incongruent trials should bias participants to respond to the color opposite to that referred by the prime word. This anticipatory strategy should counteract the impact of automatic word reading, resulting in a strategic reversal of the Stroop effect with faster responses on incongruent than on congruent trials.

Importantly for the present goals, in one of the studies (e.g., Ortells et al., 2017), the Stroop-priming task was interleaved with a concurrent verbal WM task demanding either a low load (memorizing a sequence of a same digit repeated five times), or a high load (retaining sequences of five different random digits). Ortells et al. found a substantial crossover interaction between prime-target congruency and working memory load. When participants performed the Stroop task under low WM load, a reliable reversed Stroop was observed demonstrating that they were able to strategically use the predictive information provided by the prime word to anticipate the color target. In clear contrast, under a high WM load the opposite standard Stroop interference effect was rather found (i.e., slower responses on incongruent than on congruent trials). These findings thus provide further evidence that the availability of working memory is crucial for implementing expectancy-based strategic actions.

Particularly relevant to the present research is a study by Froufe et al. (2009), in which a group of healthy younger participants, and two groups of older adults, one with and one without Alzheimer's dementia (AD), performed a Stroop-priming task very similar to that recently used by Ortells et al. (2017; see also Ortells et al., 2018). The proportion of incongruent trial was much higher (84%) than for the congruent ones (16%); but this time participants did not have to perform a concurrent WM task. Similar to what was found by Ortells et al. (2017; see also Ortells et al., 2018) under low WM load, the younger group in Froufe et al. study (2009) showed a reliable reversed Stroop effect. This ability of young adults to generate expectancy-based strategies has also been reported in other previous studies using similar strategic priming tasks (Daza, Ortells & Fox, 2002; Froufe & Alelú, 2006; Merikle, Joordens & Parallels, 1997; Ortells, Vellido, Daza & Noguera, 2006; Ortells, Daza & Fox, 2003). On the contrary, the group of AD patients showed the opposite Stroop interference effect (i.e., slower responses on incongruent than on congruent trials), which suggests an inability in these patients to generate these expectations. Interestingly, the group of healthy older adults did not show Stroop interference effect, but they showed neither a reliable reversed Stroop, thus suggesting that their expectations were not effective enough to counteract the automatic interference.

Note that the prime-target stimulus onset asynchrony (SOA) interval used by Froufe et al. (2009) in their study (1125 ms) was long enough to develop expectancy-based controlled strategies. However, as previously mentioned, if aging brings an overall decline in processing speed, then this interval may not be always enough for older adults. In support of this, several studies have demonstrated that the ability to suppress the processing of irrelevant information (at least in WM tasks) does not vanish with normal aging, but is delayed. This points to a potential interaction between deficits in inhibitory control and processing speed in older people (e.g., Gazzaley, Clapp, Kelley, et al., 2008; Zanto, Toy, & Gazzaley, 2010; see also Cashdollar et al., 2012).

Based on these considerations, one could argue that the ability to generate expectations could also be delayed in older adults. This could explain the absence of a reliable strategic (reversed Stroop) effect observed by Froufe et al. (2009) in the healthy older group, despite using a seemingly long prime-target SOA. This lack of expectancy-based effects in healthy older adults has also been reported with other semantic priming tasks using relatively long SOAs (i.e., 950 ms; see Langley et al., 2001). Unfortunately, the prime-target SOA was not manipulated in these studies. Alternatively, it is also possible that this lack of strategic indexes a reduction in cognitive control capacities. In any case, both Froufe et al. (2009) and Langley et al. (2001) did point to a potential reduction in WM and/or attentional control in the older group; but did not directly measured any of them, becoming this one of the main goals of our study.

1.1. Current study

The main aim of the present study was to explore if the time needed to implement expectancy-based strategic processes with full efficiency is different in younger and healthy older adults. To this end, participants from both age groups performed different strategic priming tasks, across different experiments, with the purpose to dissociate between priming effects resulting from a controlled (strategic) vs. non-controlled (automatic) processing of critical stimuli (Froufe et al., 2009). This time, however, we used different prime-target SOAs to examine the time course of the strategic processes. In addition, in all our experiments, participants from the two age groups also performed two further tasks to assess their WM and attention control capacities.

2. Experiments 1 and 2

In these experiments we used a similar version of the Stroop-Priming task previously employed by Froufe et al. (2009). This time however, we manipulated different prime-target SOAs in both Experiment 1 (400 vs. 1000 ms-SOA) and Experiment 2 (1000 vs. 2000 ms-SOA) to investigate directly the time course of expectancy-based strategic processes. We included a short prime-target SOA of 400 ms to examine if younger participants show a reversed Stroop (strategic) effect even at that relatively short SOA interval. Using a similar Stroop-Priming task, previous research has reported strategic effects by young adults at relatively short SOAs of 300-400 ms (e.g., Merikle & Joordens, 1997).

On the other extreme, we decided to include a long SOA of 2000 ms (instead of 1125 ms as in Froufe et al., 2009) to give older adults enough time to fully implement controlled strategies if that was the problem. However, the control deficits affecting older adults may not be solely linked to poor processing speed. Some authors have suggested that they may also stem from difficulties maintaining relevant information in WM. For example, expectancy effects in younger adults usually increase with the SOA, but this is not always the case for the older ones. In some priming studies where the prime stimulus does not remain on screen during the interstimulus interval, older adults display a decline in expectancy effects when the SOA increased (e.g., Balota, Black, & Cheney, 1992). A possible interpretation of all these findings is that that older and younger individuals may differ in both the speed needed to implement strategies and in the capacity to maintain relevant information in WM. Including a SOA of 2000 ms will allow testing for both possibilities.

All participants in our experiments also completed (a) the Change Localization task (Johnson, McMahon, Robinson, et al., 2013; Ortells et al., 2018), and (b) a version of the Antisaccade task (Hutchison, 2007; see also, Kane et al., 2001; Unsworth et al., 2004). In the Change Localization task, a sample array containing four colored circles is followed by a test array. This one is identical to the sample array except for one of the four circles presented in a different color. The task is to report the location of the change. The simplicity of this task is in sharp contrast with other more conventional WM span tasks (e.g., Unsworth, Redick, Heitz, Broadway, & Engle, 2009) providing additional advantages. For example, it is very short -between 8 and 10 minutes-, there is no time pressure, no task switching, and there is no need for background knowledge (e.g., vocabulary or math facts) to perform it. For all these reasons, this task is especially well fit to assess WM in older people and in some clinical populations (e.g., Johnson et al., 2013). The fact that chance is 25% rather than 50% also minimizes guessing effects and increases measurement reliability (e.g., Johnson et al., 2013). Importantly, despite its simplicity, its validity is comparable to other more complex measures of WM capacity (e.g., Operation Span task), correlating strongly with general measures of higher cognitive abilities (including fluid intelligence) and attention control in both healthy adults and clinical populations (e.g., people with schizophrenia) (e.g., Cowan, Elliot, Saults, et al., 2005; Fukuda, Vogel, Mayr, & Awh, 2010; Johnson et al., 2013; Shipstead, Harrison, & Engle, 2015).

In the Antisaccade task, participants have to identify a letter target briefly presented at the left or right of fixation. The target is preceded by an abrupt-onset cue appearing either on the same (prosaccade block), or on the opposite side of fixation (antisaccade block). In the prosaccade trials, participants benefit from the appearance of the cue, which automatically oriented attention towards the target location. Unlike the prosaccade trials, in the antisaccade trials, participants have look away from the flashed cue to be able to identify the target on the opposite visual field before it disappeared. This ability to reorient from the cue to the target location seems to be dependent on WMC. Previous work with the antisaccade task has reported differences in groups supposedly varying in WMC, such as schizophrenics or patients with lesions in the prefrontal cortex when compared to healthy controls (e.g., Fukushima, Fukushima, Chiba, et al., 1988); older compared to younger adults (e.g., De Jong, 2001), or even between younger adults varying in WMC (e.g., Hutchison, 2007; Kane et al., 2001; Ortells et al., 2016; Unsworth et al., 2004).

The inclusion of a prosaccade condition in our task, which is more dependent on automatic orienting of attention (thus requiring less executive control and WMC), would allow to assess the differential performance between the prosaccade and antisaccade conditions, as an additional index of attentional control. If older adults have mainly a general decline in speed, then responses should be slower in both prosaccade and antisaccade trials. Conversely, if they have also a decreased attentional control capacity then their performance could be much worse on the antisaccade than on prosaccade trials (i.e., a reliable interaction between Age Group and Saccade Condition -antisaccade vs. prosaccade).

Lastly, older adults in the two Experiments were also pre-screened to rule out cognitive impairment. More detailed information about these tests can be found in the next section.

2.1. Materials and Method

2.1.1. Participants

Fifty-two (26 young and 26 older adults) and fifty-two (26 young and 26 older adults) native Spanish speakers with normal or corrected-to-normal vision participated in Experiments 1 and 2, respectively. These sample sizes were similar to that used by previous studies addressing strategic priming (e.g., Froufe et al., 2009; n = 27; Ortells et al., 2017; n = 26). The younger groups were undergraduate students from the University of Almería [Experiment 1: mean age = 21.2; SD = 3.7; range = 18-32; 15 females; Experiment 2: mean age = 22.3; SD = 2.7; range = 18-29; 14 females] who received course credits for their participation. Participants in the older groups were healthy volunteers recruited through the 'University for the Older People' Learning Program developed by the University of Almería [Experiment 1: mean age = 70.5; SD = 4.2; range = 65-78; 14 females; Experiment 2: mean age = 70; SD = 2.7; range = 65-75; 14 females]. All the experiments of the present research were conducted in compliance with the Helsinki Declaration, and with the ethical protocols and recommendations of the "Code of Good Practices in Research", "Commission on Bioethics in Research from the University of Almería". Participants also signed informed consents before their inclusion, with the protocol being approved by the "Bioethics Committee in Human Research" from the University of Almería.

The older participants were prescreened to ensure that they were healthy with no history of neurological, psychiatric or vascular disease, showed no symptoms of depression, nor were taking any psychoactive drugs or medication for high blood pressure. These tests were taken at the beginning of each experimental session and consisted of: (a) the 35-point Lobo's Mini-Examen Cognoscitivo (MEC; Lobo, Saz, Marcos, et al., 1999), a validated Spanish version in the elderly population of Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), used to rule out cognitive impairment or dementia (norm score > 24); (b) the Spanish version (Martínez, Onís, Dueñas, et al., 2002) of the Yesavage abbreviated questionnaire (GDS; Yesavage, Brink, Rose, & Lum, 1983), employed to test for depression (norm score < 5); (c) the Lawton and Brody Instrumental Activities Of Daily Living Scale (IADL; Lawton and Brody, 1969), validated to Spanish (Vergara, Bilbao, Orive, Garcia-Gutierrez, Navarro, & Quintana, 2012), to measure the degree of autonomy of the person in different daily activities crucial for independent living (norm score > 7). None of the older adults were excluded from the experiments, since all scored within two standard deviations of the norm on each of the above tests (see Table 1).

Table 1. Screening scores for the older participants in Experiments 1 to 4.

	Experiment 1	Experiment 2	Experiment 3	Experiment 4
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
MEC	32.62 (1.55)	32.96 (1.61)	33.54 (1.07)	33.35 (0.94)
GDS	0.69 (1.01)	0.58 (0.99)	0.65 (0.85)	0.69 (0.84)
IADL	7.88 (0.33)	7.92 (0.39)	7.92 (0.39)	7.81 (0.49)

2.1.2. Apparatus and Stimuli

The experiments were run on a PC using E-Prime software v2.0 (Psychology Software Tools, Pittsburgh, PA). Stimuli were displayed on a 17-inch CRT monitor at a viewing distance of approximately 60cm. Responses were collected using a standard keyboard.

The Change Localization task trials consisted of four colored circles subtending about 0.96º horizontally and 0.96º vertically. The four colors were randomly selected from a set of nine different colors with the following red, green, and blue (RGB) values: orange (255, 113, 0), yellow (255, 255, 0), magenta (255, 0, 255), red (255, 0, 0), white (255, 255, 255), blue (0, 0, 255), black (0, 0, 0), cyan (0, 255, 255), and green (0, 255, 0). The circles were displayed forming a circumference. The distance between fixation and the nearest and farthest stimuli subtended 3.36º and 6.24º, respectively. All stimuli were displayed against a grey background (60, 60, 50).

In the Antisaccade task, the target stimulus consisted of the letters "O" or "Q" (in Courier new font size 22) subtending about 0.43º horizontally and 0.86º vertically. They were displayed in white against a black background at a distance of 3° to the left or right of fixation (+). The pattern mask following the target offset consisted of the characters "###" (in Arial font size 22) over an area of 0.86º vertically and.43º horizontally.

In the Stroop-Priming task, the prime stimuli were two color words (RED or GREEN) in Courier new font size 22 written in white, with each letter occupying an area of about 0.35º wide and 0.52º high. The target was a rectangle presented in either red (255, 0, 0) or green (0, 255, 0) at fixation, subtending 7.39º horizontally and 2.6º vertically. All stimuli were presented against a black background.

2.1.3. Procedure

In both experiments participants from the two age groups did the Change Localization and the Antisaccade tasks (the order of both tasks was counterbalanced across participants) before performing the Stroop-Priming task. No effects involving task order approached significance in neither Experiment.

Change-Localization task. Each trial of this task began with a 1000 ms central fixation cross (+), which remained on the screen throughout the trial. The fixation was followed by a sample array presented for 150 ms consisting of four circles each one in a different color. After a 900 ms blank screen, a test array appeared, identical to the sample array except for one of the four items which was in a changed color. The task was to indicate the location of the change using the computer mouse. Each participant completed 12 practice trials followed by 64 experimental trials divided in two consecutive blocks (32 trials each) with time for a break between blocks.

Antisaccade task. Trials began with a white fixation cross (+) presented on a black background for a random duration between 500 and 1500 ms. A white asterisk (*) then appeared randomly 3.8° to either the left or right of fixation for 200 ms, followed by a 100 ms blank interval. A letter target (O vs. Q) then appeared on either the same side of the asterisk (prosaccade block) or the opposite one (antisaccade block). The target was displayed for 100 ms and was immediately followed by a pattern mask (###) of 5000 ms duration until response. Participants had to press either the '1' or the '2' keys on the computer keyboard to indicate the identity of the target, with key-target allocations being counterbalanced between participants. Participants completed two consecutive blocks of 64 trials/block (16 practice followed by 48 experimental trials), one for the antisaccade and other for the prosaccade block, with the order of blocks counterbalanced across participants. The block order did not reach significance in neither Experiment.

Stroop-Priming task. Each experimental trial began with a central fixation cross (+) presented for 500 ms, followed by the prime word "VERDE" (GREEN) or "ROJO" (RED) presented in white letters for 200 ms. The prime display offset was followed by blank screen for either 200, 800, or 1800 ms (depending on the prime-target SOA manipulation). The target was a colored rectangle in either green or red appearing at fixation. This remained on the screen 2000 ms or until response, whichever happened first (Figure 1). The participants responded to the color (red or green) of the rectangle by pressing the keys '1' or '2' on the computer keyboard. Both keys were labeled RED and GREEN (with red and green stickers, respectively), with the location of the label counterbalanced between participants. Incorrect responses were followed by a 500-ms feedback emoticon (sad face). A 500 ms blank inter-trial interval was presented before the beginning of the next trial. The prime-target pairings were congruent (i.e., GREEN-green) on 20% of the trials and incongruent (i.e., GREEN-red) on the remaining 80%. Before the beginning of the experiment, participants from both age groups were explicitly informed about the differential proportion of congruent and incongruent prime-target pairings, and were actively encouraged to capitalize on the predictive information provided by the prime word to optimize their performance. Thus, they were told that given a particular prime word (e., RED), they should expect that the forthcoming color target would be the color not named by the prime (e.g., green), as incongruent prime-target pairs were much more frequent than congruent pairs.

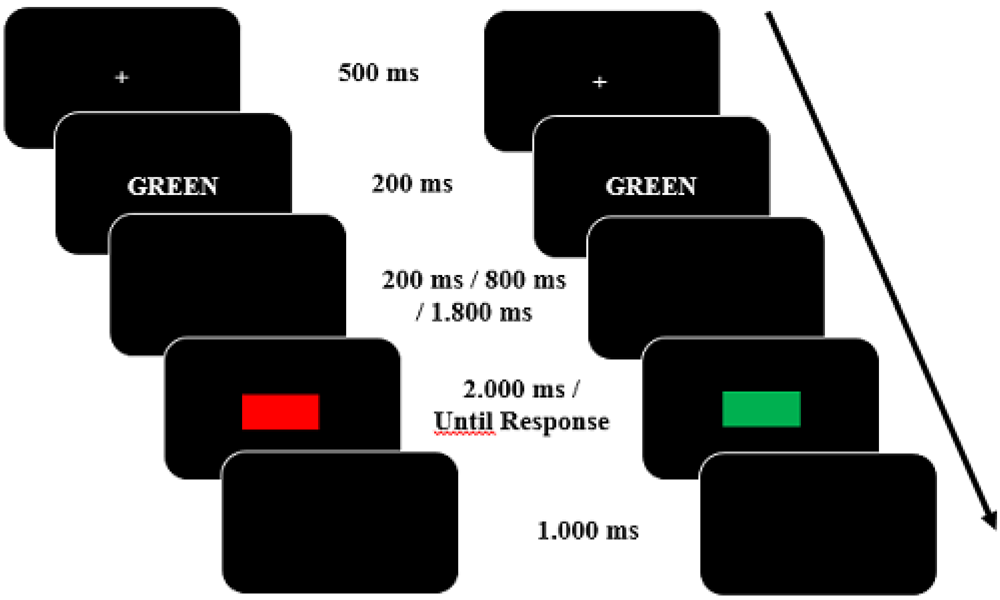


Figure 1. Stroop-Priming task. Examples of incongruent (left) and congruent (right) trials used in Experiments 1 and 2.

There were 40 practice trials (20 for each prime-target SOA condition) followed by 120 experimental ones divided in two blocks: 60 trials for each prime-target SOA condition (Experiment 1: 400 and 1000 ms; Experiment 2: 1000 and 2000 ms), with the order of the blocks counterbalanced across participants. Within each SOA block, there were 48 incongruent trials (80%) and 12 congruent trials (20%), and the target (colored rectangle) was displayed in red or green the same number of trials. The participants initiated each prime-target block by pressing the space bar on the computer keyboard. Once a SOA block was initiated it ran to completion, so that the participants could rest only between blocks. Because the order of SOA blocks did not interact with any other variable in our Experiments, the data are collapsed across SOA order in the Results and Discussion section.

2.2. Results and Discussion

WM Capacity and Attention Control tasks. To quantify WM storage Capacity (WMC) using the Change Localization task, a variant of the Pashler/Cowan K equation was used, where *K* represented how many items have been stored in WM (Cowan et al., 2005). Given that each trial contains a change, there is no potential for false alarms. As a result, *K* was calculated by multiplying each participant proportion of correct responses by four (the number of items in the memory array).

Table 2 presents descriptive statistics for young and older participants in both experiments for the Change Localization and the Antisaccade tasks. Independent-samples t-tests were used to examine whether there were significant differences in performance between younger and older participants for each task. As it can be seen in this Table, younger adults showed a significantly higher WM storage capacity than older adults in both Experiments 1 and 2. The younger group also responded reliably faster and more accurate than the older group in both the antisaccade and prosaccade trials.

Table 2. Comparisons between younger and older adults in Experiments 1 and 2.

	Younger mean (SD)	**Older mean (SD)**	**Group differences**	**Effect Size *d***
Experiment 1				
Age	21.2 (3.7)	70.5 (4.2)	t (50) = 44.4	12.5
WMC	3.25 (.35)	2.05 (.44)	t (50) = 10.8	**3.02**
Antisaccade				
RT (ms)	727 (259.6)	1352 (537.2)	$t\ (36)^a = 5.34$	1.48
AC (%)	.78 (.11)	.59 (.10)	t (50) = 6.7	1.81
Prosaccade				
RT (ms)	579 (144.1)	1044 (323.8)	$t\ (35)^a = 6.7$	1.85
AC (%)	.88 (.08)	.74 (.10)	t (50) = 5.6	1.55
Experiment 2				
Age	22.3 (2.7)	69.6 (2.7)	t (50) = 63.4	17.5
WMC	3.17 (.42)	2.27 (.57)	t (50) = 6.4	**1.80**
Antisaccade				
RT (ms)	610 (148.5)	1245 (552.8)	$t\ (29)^a = 5.7$	1.57
AC (%)	.84 (.10)	.61 (.12)	t (50) = 7.7	2.10
Prosaccade				
RT (ms)	528 (132.3)	955 (290.5)	$t\ (35)^a = 6.8$	1.90
AC (%)	.92 (.06)	.75 (.13)	$t\ (36)^a = 5.8$	1.70

All p values < .0001
[a] Correction of *df*s for unequal variances

Participants' performance in the Change Localization and Antisaccade tasks was also assessed by correlation analyses, producing similar results for both experiments. Namely, WM Capacity and participants' age were highly correlated [Experiment 1: r = -.86, p < .001; Experiment 2: r = -.70, p < .001], showing that increases in age are associated with a decline in WM Capacity. Participants' WMC also correlated with their performance in both the antisaccade [Experiment 1 = RTs: r = -.69; AC %: r = .65;

Experiment 2 = RTs: $r = -.57$; AC %: $r = .77$] and prosaccade trials [Experiment 1 = RTs: $r = -.72$; AC %: $r = .55$; Experiment 2 = RTs: $r = -.49$; AC %: $r = .72$], as well as with the difference between antisaccade and prosaccade conditions [Experiment 1: RTs: $r = -.45$, $p = .001$; AC %: $r = -.31$, $p = .024$; Experiment 2: RTs: $r = -.39$, $p = .004$; AC %: $r = -.32$, $p = .02$]. This latter finding suggests that the reduced WMC showed by older adults in the two experiments (as compared with younger participants) seems to be associated with two main causes. First, a slower processing-speed, demonstrated by increased reaction times in all conditions, including the prosaccade. And second, a decreased capacity for attentional control, as revealed by a disproportionate deterioration of performance in the antisaccade trials -compared to the prosaccade ones- in the older group.

These impressions were further confirmed using a mixed analysis of variance (ANOVA) in which Age (younger vs. older) was treated as a between-participants factor, and Saccade Type (antisaccade vs. prosaccade) as the within-participants variable. As expected, both Age [Experiment 1 [RTs: F (1, 50) = 36.5, $p < 0.001$, $\eta^2 = 0.42$; Accuracy: F (1, 50) = 48.5, $p < 0.001$, $\eta^2 = 0.49$; Experiment 2 [RTs: F (1, 50) = 47.1, $p < 0.001$, $\eta^2 = 0.48$; Accuracy: F (1, 50) = 53.2, $p < 0.001$, $\eta^2 = 0.52$], and Saccade Type were significant [Experiment 1 [RTs: F (1, 50) = 45.5, $p < 0.001$, $\eta^2 = 0.48$; Accuracy: F (1, 50) = 101.8, $p < 0.001$, $\eta^2 = 0.67$; Experiment 2 [RTs: F (1, 50) = 15.4, $p < 0.001$, $\eta^2 = 0.24$; Accuracy: F (1, 50) = 107.6, $p < 0.001$, $\eta^2 = 0.68$], and more interestingly, so it was the interaction between these two variables in both Experiment 1 [RTs: F (1, 50) = 5.6, $p = 0.022$, $\eta^2 = 0.10$; Accuracy: F (1, 50) = 3.4, $p = 0.07$, $\eta^2 = 0.06$] and Experiment 2 [RTs: F (1, 50) = 4.8, $p = 0.03$, $\eta^2 = 0.09$; Accuracy: F (1, 50) = 9.02, $p = 0.04$, $\eta^2 = 0.15$].

Stroop-Priming task. Trials containing an incorrect response (Experiment 1 = 1.4%; Experiment 2 = 1.45%), or those with reaction times (RTs) faster than 200 ms or falling more than 2.5 standard deviations from the overall mean RT (Experiment 1= 1.1%; Experiment 2 = 1.9%) were removed from analyses.

Mean correct RTs and error rates were computed for each participant in the two age groups as a function of Congruency and SOA. Results were analyzed with a 2 (Congruency: congruent, incongruent) x 2 (SOA: -Experiment 1: 400, 1000, -Experiment 2: 1000, 2000) x 2 (Age Group: younger, older) mixed ANOVA for each Experiment, with Congruency and SOA manipulated within participant and Age between groups (see Table 3; values in brackets are Standard Deviations).

Table 3. Responses in the Stroop-Priming task for Experiments 1 and 2.

		Prime-target Congruency			
		Younger		**Older**	
		Congruent	**Incongruent**	**Congruent**	**Incongruent**
Exp 1	400-ms	527 (101.1)	562 (97.3)	784 (181.5)	826 (197.4)
		1.1 (2.7)	1.4 (1.7)	1.7 (2.9)	2.4 (3.1)
	1000-ms	579 (172.9)	543 (133.8)	778 (176.2)	780 (181.1)
		1.1 (2.3)	1.1 (2.3)	1.2 (2.9)	1.2 (2.9)
Exp 2	1000-ms	553 (151.1)	514 (122.7)	720 (164.3)	726 (161.8)
		1.5 (2.9)	1.4 (1.9)	1.5 (2.9)	1.6 (2.3)
	2000-ms	554 (139.7)	513 (119.1)	751 (140.7)	711 (128.6)
		1.4 (2.1)	1.2 (2.1)	1.5 (2.9)	1.4 (1.7)

Error rates showed no significant effect in either Experiment (all *p*s > .24). The RTs revealed a main effect of Age Group in both Experiment 1 [F (1, 50) = 33.3, p < 0.001, η^2 = 0.40], and Experiment 2 [F (1, 50) = 26.3, p < 0.001, η^2 = 0.34], where older participants were slower (Experiment 1 = 792 ms; Experiment 2 = 727 ms) than the younger ones (Experiment 1 = 553 ms; Experiment 2 = 533). The interaction between SOA and Congruency was also significant in the two experiments [Experiment 1= F (1,

50) = 58.2, $p < 0.001$, $\eta^2 = 0.54$; Experiment 2 = F (1, 50) = 5.01, $p = 0.03$, $\eta^2 = 0.09$], and even more relevant was the three-way significant interaction between SOA, prime-target Congruency, and Age Group [Experiment 1 = F (1, 50) = 4.35, $p = 0.04$, $\eta^2 = 0.08$; Experiment 2 = F (1, 50) = 4.20, $p = 0.046$, $\eta^2 = 0.08$]. Further analyses revealed a very different Stroop-Priming pattern as a function of prime-target SOA for the two age groups in each experiment (Figure 2).

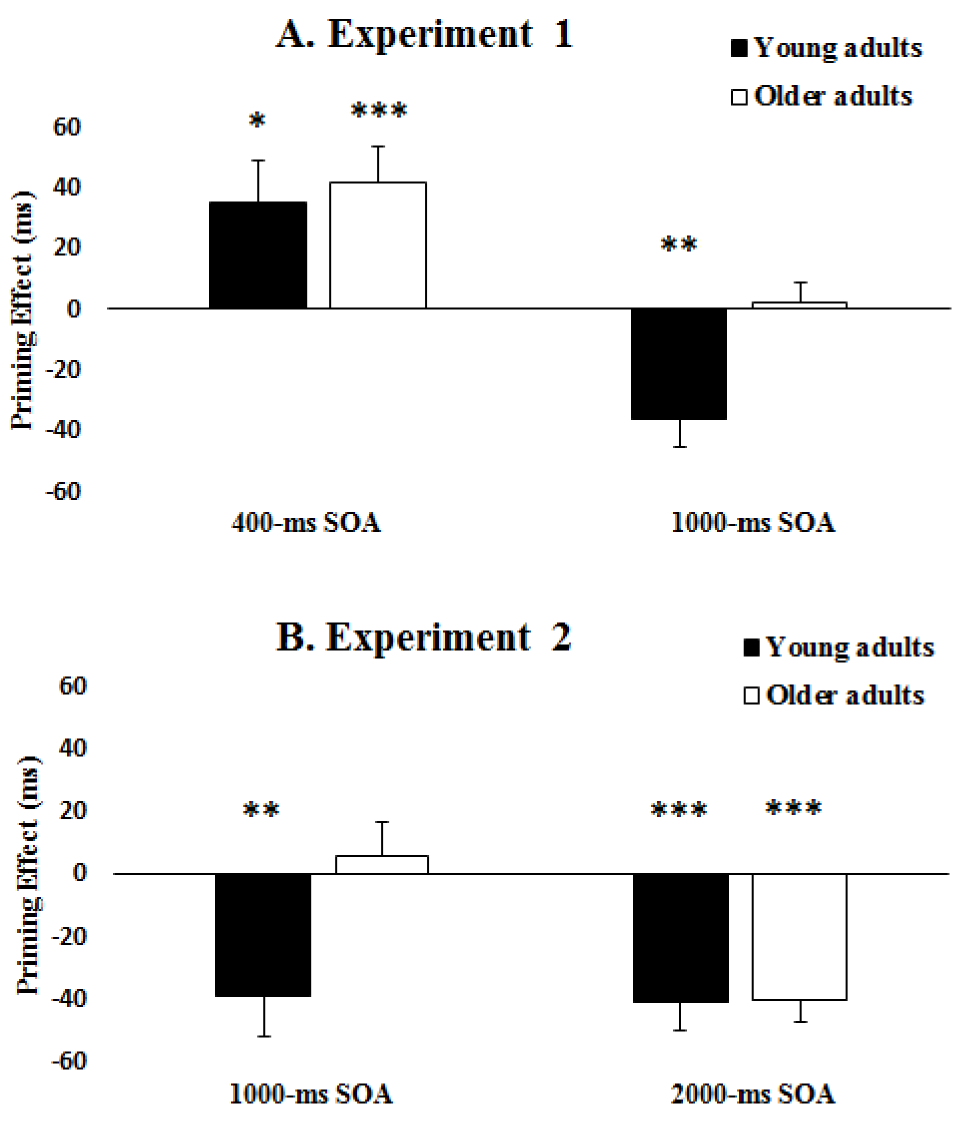


Figure 2. Stroop-Priming effects in Experiments 1 and 2.

In Experiment 1 (400 and 1000 SOA), the younger group showed the opposite Stroop-Priming pattern for each SOA, (Congruency x SOA interaction, [F (1, 25) = 34.01, *p* < 0.001, η^2 = 0.58]). Namely, we observed a standard Stroop interference at 400-ms SOA (-35 ms; F (1, 25) = 5.9, p = 0.02, η^2 = 0.19), and a reversed (strategic) Stroop at the longer 1000-ms SOA (+36 ms; F (1, 25) = 9.46, p = 0.005, η^2 = 0.28). The Congruency x SOA interaction was also evident in the older group (F (1, 25) = 25.1, p < 0.001, η^2 = 0.50), presenting standard Stroop interference at 400ms SOA (-42 ms; F (1, 25) = 23.5, p < 0.001, η^2 = 0.49). However, unlike the younger group, neither standard nor reversed strategic effects were observed at the longer 1000ms SOA (-2 ms; F < 1). This finding closely replicates the absence of reversed Stroop reported by Froufe et al. (2009) with healthy older people under very similar task conditions.

In Experiment 2 (1000 and 2000 SOA), the youngest exhibited strategic reversed Stroop in both 1000 ms (+39 ms; F (1, 25) = 9.4, p = 0.005, η^2 = 0.27) and 2000 ms SOA (+41 ms; F (1, 25) = 22.1, p = 0.001, η^2 = 0.47). In contrast, in the older group we found a reliable Congruency x SOA interaction (F (1, 25) = 14.3, p = 0.001, η^2 = 0.36). At the SOA of 1000 ms there was no reliable effect of any kind (-6 ms; F < 1), replicating what found in Experiment 1. But at the longest 2000 ms SOA, they showed reliable strategic effects of a similar magnitude to those found in the younger group (+40 ms; F (1, 25) = 32.4, p < 0.001, η^2 = 0.56).

The lack of a reliable strategic effect (reversed Stroop) at the SOA of 1000 ms in both Experiments 1 and 2 closely replicates the findings reported by Froufe et al. (2009) with healthy older people using very similar task conditions (i.e., SOA = 1150 ms). These results do not necessarily imply that all the older participants in our experiments were unable to show strategic effect at the SOA of 1000-ms. It is possible that some older adults can implement predictive strategies better and/or faster than others. Indeed, in a series of further correlation analyses for the entire sample of participants we found that the amount of strategic Stroop-priming (i.e., congruent minus incongruent) at the 1000-

ms SOA condition was negatively correlated with age in both Experiment 1 ($r = -.36$, $p < .007$) and Experiment 2 ($r = -.37$, $p < .006$). Even more interesting, the strategic priming at 1000-ms SOA also positively correlated with their WMC scores. This correlation reached statistical significance in Experiment 2 ($r = .34$, $p < .014$), but not in Experiment 1 ($r = .19$, $p > .18$). Still, these observations are consistent with other studies linking WM resources with the development of predictive controlled strategies (e.g., Heyman et al., 2014; Hutchison et al., 2014; Ortells et al., 2017; 2018).

The consistent and reliable reversed Stroop showed by older participants at the longest 2000-ms SOA in Experiment 2, clearly contrast with previous reports finding a drop in expectancy-based priming for older adults, at least when the prime stimulus did not remain on the screen during the interstimulus interval (e.g., Balota et al., 1992). The results of Experiment 2 thus suggest that older individuals do not necessarily find it more difficult to maintain the relevant information in their WM, at least under relatively simple tasks as the one used here.

3. Experiment 3

In Experiments 1 and 2, we found that, compared to younger participants, older adults not only had lower WM capacity and Attention Control, but also needed more time to efficiently implement expectancy-based strategies. In the present study, we wanted to replicate the differential time-course of strategic processes associated with age using a semantic priming task. One of the advantages of this task is that we can include a greater stimulus set, also requiring higher conceptual level (semantic) of representation than the word color Stroop task. To this aim, we used pictorial stimuli previously used in our lab (e.g., Ortells et al., 2003; Ortells et al., 2006), which have been shown to produce qualitatively different (opposite) semantic priming effects depending on whether the processing of the prime stimuli is strategic (conscious) or not (automatic).

Participants made a semantic judgment task (animal vs. inanimate object) about a picture target preceded by a picture prime. On 80% of the trials (unrelated condition) the prime and target pictures belong to different semantic categories (e.g., DOG – fork; SPOON – cat), whereas on the remaining 20% of the trials (related condition) they are made of highly associated members from the same category (e.g., DOG – cat; SPOON – fork). Participants were again strongly encouraged to use the predictive information provided by the prime picture to improve their categorization performance. Thus, given a prime picture (e.g., a dog), they should expect that the upcoming target would belong to the opposite semantic category (i.e., an object), as the unrelated trials were much more frequent (80%) than the related trials (see also Neely, 1977, for a similar procedure). To investigate the time-course of congruency priming effects, the prime-target SOA was manipulated at two levels: 400 and 1000 ms, as in Experiment 1.

3.1. Materials and Method

3.1.1. Participants

Twenty-six younger and 26 older adults participated. All of them were native Spanish speakers and had self-reported normal or corrected-to-normal vision. The younger participants were undergraduate students from the University of Almería [Age = 20.6; SD = 2.5; Range = 18-30; 14 females) who participated in the study in exchange by course credits. Older participants (age = 70.6; SD = 4.7; range = 64-81; 15 females) were healthy volunteers recruited through the 'University for the Older People' Learning Program from the University of Almería, following the same protocol as described in the Experiments 1 and 2.

3.1.2. Stimuli and Procedure

Before performing the Congruency-priming task, participants from the two age groups performed the WM (Change Localization) and Attention Control (Antisaccade) tasks used in Experiments 1 and 2, with the order of tasks being again counterbalanced across participants (as in Experiments 1 and 2, there was no significant effect involving task order).

The picture stimuli were line drawings of 8 animals and 8 inanimate objects taken from the gray scale shaded images set by Snodgrass and Vanderwart (1980). They were displayed on a white background, with their dimensions ranging from 1.92° to 3.36° (height), and from 1.92° to 5.76° (width). For each participant and block of trials, each picture appeared five times as a prime and five times as a target stimulus. Each prime was paired with five different target pictures: one was a strongly associated co-exemplar (and highly similar in terms of feature overlap; see below), and four times were pictures from the opposite category.

All the semantically related pictures were also rated by participants in a previous similarity evaluation study as being highly similar in terms of both functional and visuals features. In that study, 80 picture pairs (40 animals and 40 inanimate objects) taken from the Snodgrass and Vanderwart (1980)' stimulus set, were presented to a different group of 100 undergraduate students from the University of Almeria. Participants had to rate both the functional and visual similarity of each picture pair ("In terms of features in common, how functionally and visually similar are the stimuli that these pictures refer to?") on 7-point scales (1= not at all similar; 7 = highly similar). Only those pairs from each category with rating scores higher than 5 points on the two 7-points scales were used for the congruency priming experiment (see Appendix A).

Each trial in the Congruency-Priming task began with a central fixation (a black cross) presented on a white background for a random duration between 500 and 1500 ms. A prime picture then appeared in the center of the screen for 200 ms, followed by a blank screen for either 200 ms or 800 ms (depending on the SOA condition). This was followed by a central target that remained on the screen 2000 ms or until response (Figure 3). Participants indicated the semantic category (animal vs. inanimate object) of the target by pressing the '1' and the '2' keys on the computer keyboard, with key-category allocations being counterbalanced between participants. A 500-ms feedback emoticon (sad face) was presented following an incorrect response. A 500 ms inter-trial interval elapsed before the start of the next congruency-priming trial. The prime and target pictures belonged to different semantic categories (unrelated condition) on 80% of the trials, and they were semantically related co-exemplars (related condition) on 20% of the trials. As in the previous experiments, participants were explicitly informed about the differential proportion of related and unrelated prime-target pairings trials and were encouraged to use this for their own benefit.

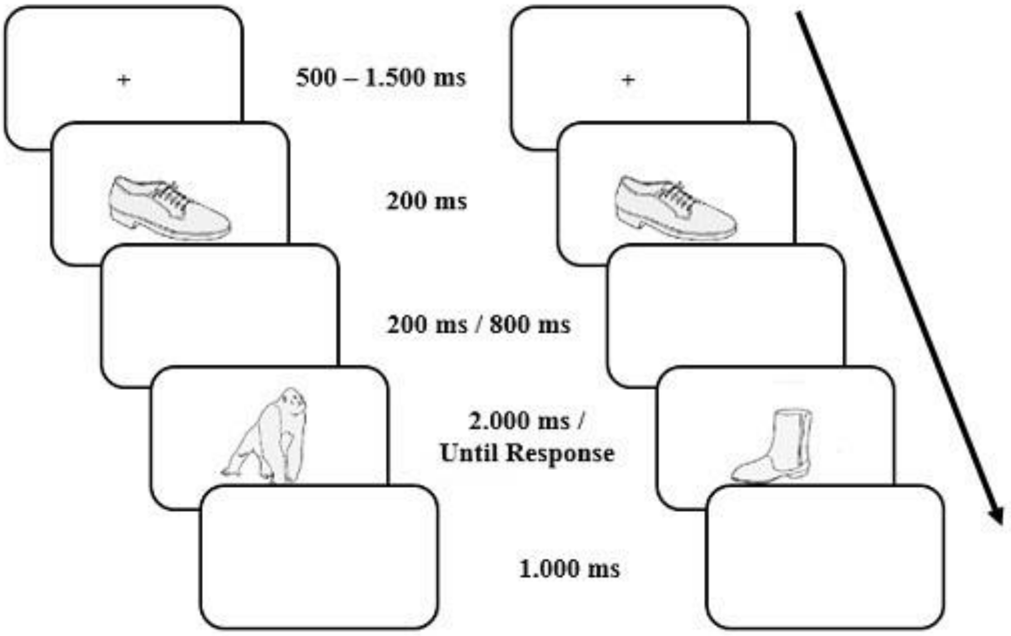


Figure 3. Congruency-Priming task. Sequence of events of an incongruent (left) and congruent (right) trial in the Congruency-priming task used in Experiments 3 and 4.

Each participant took part in a single session (lasting about 20 min) consisting of 40 practice trials (20 for each SOA condition) followed by 160 experimental trials consisting of two consecutive blocks of 80 trials, one block for each SOA condition (400 ms vs. 1000 ms). The order of the two blocks was counter-balanced across participants (there was no significant effect involving SOA order). From the 80 experimental trials of each block, 64 were unrelated (80%) and 16 (20%) were related, and within each of these two trial-sets, the target picture belonged to either “animals” or “inanimate objects” category on the same number of trials.

3.2. Results and Discussion

WM Capacity and Attention Control tasks. Descriptive statistics and comparisons between younger and older adults on WM storage capacity (Change Localization K-score), response speed (RTs) and accuracy (%) in the Attention Control task (antisaccade and prosaccade blocks) are presented in Table 4.

Table 4. Comparisons between younger and older adults.

	Younger Mean (SD)	**Older Mean** (SD)	**Group differences***	**Effect Size d**
Age	20.6 (2.5)	70.6 (4.7)	t (38)[a] = 48.04	13.3
WMC	3.24 (.38)	2.05 (.47)	t (50) = 10.1	2.80
Antisaccade				
RT (ms)	622 (140.1)	1327 (553.2)	t (29)[a] = 6.4	1.75
AC (%)	.80 (.90)	.56 (.09)	t (50) = 9.5	2.70
Prosaccade				
RT (ms)	499 (93.6)	1023 (373.5)	t (28)[a] = 6.9	1.92
AC (%)	.91 (.08)	.72 (.10)	t (50) = 7.0	2.10

*All *p* values < .0001 (Student's t-test)
SD, Standard Deviations
[a] Correction of *df*s for unequal variances

The differences found between younger and older adults were very similar to those in the previous experiments. Compared to their younger counterparts, older participants showed lower WM Capacity and responded slower, and less accurate, on both the antisaccade and prosaccade trials. As in Experiments 1 and 2, WMC and participants' age were highly correlated (r = - .83, p < .001), again indicative of an age-related decline in WM Capacity. WMC scores also correlated with performance in the antisaccade [RTs: r = - .68; AC %: r = .82] and prosaccade blocks [r = - .69; AC %: r = .74], and also with the differences between the antisaccade and prosaccade conditions (RTs: r = - .47, p < .001; AC %: r = - .33, p = .02). As in Experiments 1 and 2, the results were further analyzed with a mixed ANOVA with Age as a between-participants factor and Saccade Type (antisaccade vs. prosaccade trials) as repeated measures. As previously found, there were reliable differences due to Age [RTs: F (1, 50) = 45.3, p < 0.001, η^2 = 0.47; Accuracy: F (1, 50) = 76.9, p < 0.001, η^2 = 0.61], and Saccade Type [RTs: F (1, 50) = 59.5, p < 0.001, η^2 = 0.54; Accuracy: F (1, 50) = 156.2, p < 0.001, η^2 = 0.76]. But more interestingly, there was a reliable interaction between these two variables in both RTs (F (1, 50) = 10.75, p = 0.003, η^2 = 0.18) and Accuracy (F (1, 50) = 6.5, p = 0.014, η^2 = 0.12). These results reinforce the idea that a reduction in WMC in older adults would be associated not only with a general response slowing, but also with a decreased capacity for attentional control.

Congruency-Priming task. For the analysis of responses in the Congruency-Priming task, we excluded trials with target responses incorrect (2.45%), and those with RTs faster than 200 ms, or falling more than 2.5 standard deviations from the overall mean RT (2.38 %). Mean correct RT and error rates were computed for each participant in the two age groups as a function of Prime-Target Relatedness (related, unrelated) and SOA (400 ms, 1000 ms). These were further submitted to two separate 2 x 2 x 2 ANOVAs (different for RTs and error rates), with Relatedness and SOA as within participant manipulation, and Age (younger, older) as a between group factor (see Table 5).

Table 5. Results of the Congruency-Priming task for both age groups.

	Prime-target Relatedness			
	Younger		**Older**	
	Related	Unrelated	Related	Unrelated
400-ms	535 (70.8)	549 (80.9)	745 (207.1)	778 (174.1)
	2.0 (2.8)	2.85 (2.5)	2.5 (3.4)	3.1 (3.5)
1000-ms	568 (94.5)	533 (94.1)	777 (208.6)	772 (180.5)
	2.4 (3.5)	2.2 (2.2)	2.5 (3.9)	2.1 (3.6)

No effect was significant in the analysis of the error rates (all ps > .17). Conversely, ANOVA of RT data revealed a main effect of Age (F (1, 50) = 31.04, p < 0.001, η^2 = 0.38), such that older participants responded again slower to the targets (768 ms) than the younger adults (546 ms). Prime-Target Relatedness interacted with both SOA (F (1, 50) = 19.4, p < 0.001, η^2 = 0.28), and Age (F (1, 50) = 5.13, p = 0.028, η^2 =

0.09). Further analyses of this later interaction revealed a very different priming pattern as a function of Age (Figure 4). The younger adults showed a reliable relatedness x SOA interaction, (F (1, 25) = 25.9, p < 0.001, η^2 = 0.51), due to a facilitatory priming effect at the shortest 400-ms SOA (+14 ms; F (1, 25) = 5.3, p = 0.03, η^2 = 0.17), and an opposite (strategic) priming effect at 1000-ms SOA (-35 ms; F (1, 25) = 15.8, p = 0.001, η^2 = 0.39). In clear contrast, the older group presented a facilitatory priming at the shortest 400-ms SOA (+34 ms; F (1, 25) = 5.1, p = 0.03, η^2 = 0.17), but a lack of reversed (strategic) priming at 1000-ms SOA (-5 ms; F < 1), with a reliable Relatedness x SOA interaction in this Age group (F (1, 25) = 4.96, p = 0.03, η^2 = 0.17).

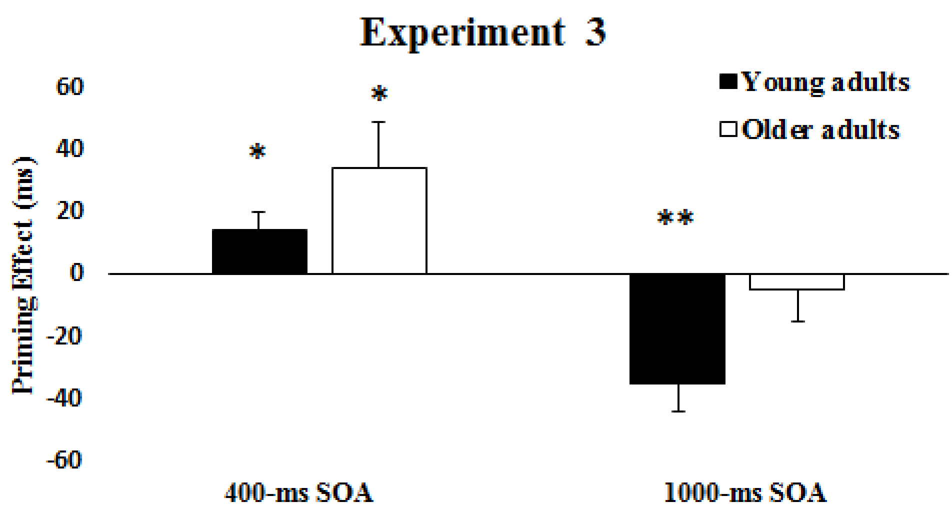


Figure 4. Congruency Priming effects in Experiment 3.

The pattern across SOAs showed by older participants with this priming task, is consistent with what was found in Experiment 1 using a similar prime-target SOA interval with a different type of task (Stroop). Whereas younger adults are able to efficiently develop attentional strategies at SOA intervals on the range of 1000 ms, or even less (more than half of younger adults showed strategic priming effects in the Congruency-Priming task even in the shorter 400-ms SOA interval), the older group do not seem to be able to do the same within that interval. According to our previous results with the Stroop task, they seem to need longer for an efficient implementation of expectancy-based strategic processes.

As argued before (see Discussion section of Experiments 1 and 2), we do not discard the possibility that the older adults with a greater WMC could implement predictive strategies more effectively than others. Yet, the correlation between participants' WMC and strategic priming at 1000-ms SOA did not reach statistical significance (r = .21, p > .126), as had occurred in Experiment 1.

4. Experiment 4

This experiment had two main goals. First, to see if the expectancy-based strategic effecs found with a Stroop priming task at the longest 2000-ms SOA in older participants can also be found with other tasks, such as the congruency priming task used in Experiment 3. In this task the prime picture was also presented for a limited period of time (200 ms), being absent for the remaining SOA interval, as occurred in the Stroop-Priming task used in Experiments 1 and 2.

In addition, it has been argued that strategy-dependent processes may require some amount of practice until they can be implemented (e.g., Ortells et al., 2003; Logan & Zbrodoff, 1992; Thompson-Schill, Kurt & Gabrieli, 1998). A second goal of this experiment was to investigate whether the strategic processing of goal-relevant information could be differentially modulated by task practice in older vs. younger adults. Previous work examining age and practice on cognitive performance have produced somewhat mixed findings. Some studies report that older adults have difficulties automatizing newly learned skills (e.g., Rogers, 1992; Rogers & Fisk, 1991). Others, however, have found very similar practice effects in older and younger adults in different cognitive control tasks, such as task switching (Kramer, Hahn & Gopher, 1999) or Stroop interference (Davidson, Zacks & Williams, 2003). Yet, given that older adults generally show a reduced WMC and a slower processing speed than younger adults, it is possible that they also need more practice to be able to build these controlled strategies.

To test for that, here we used the same priming procedure used in Experiment 3 with two main differences: (a) the SOA remained fixed at 2000 ms; and (b) both young and older participants performed four consecutive blocks of trials. If the development of predictive strategies based on stimulus redundancy requires different amount of practice for young and older participants, then we expect to obtain a three-way interaction between Practice, Priming, and Age Group.

4.1. Method

4.1.1. Participants

Twenty-six younger and 26 older adults participated in Experiment 4. All of them were native Spanish speakers self-reporting normal or corrected-to-normal vision. The younger participants were undergraduate students from the University of Almería (age = 22.1; SD = 4.2; range = 19-35; 15 females) who participated in the study in exchange by course credits. Older participants (age = 68.5; SD = 4.4; range = 64-81; 15 females) were healthy volunteers recruited through the same system described earlier.

4.1.2. Stimuli and Procedure

These were similar to those used in Experiment 3, except that in the priming task (a) the animate and inanimate stimuli presented as primes were never presented as targets or vice versa; (b) the 200-ms prime picture was always followed by a blank screen of 1800 ms, such that the prime-target SOA remained fixed at 2000 ms; and (c) the task practice was manipulated, with participants from both age groups performing 4 consecutive blocks of experimental trials (40 trials per block). As in Experiment 3, within each block, the prime and target pictures belonged to different semantic categories on 80% of the trials (32), and they were semantically related co-exemplars on the 20% of the trials (8). Instructions emphasized the generation of category-based expectations as in previous experiments.

4.2. Results and Discussion

WM Capacity and Attention Control tasks. Descriptive statistics for performance by both age groups in Change Localization and Antisaccade tasks are presented in Table 6, as well as comparisons between younger and older adults on WM storage capacity (Change Localization K-score) and response speed (RTs) and accuracy (%) in the Attention Control task (antisaccade and prosaccade blocks).

Table 6. Comparisons between younger and older adults in Experiment 4.

	Younger Mean	**Older Mean**	**Group differences***	**Effect Size d**
Age	22.1 (4.2)	68.5 (4.4)	t (50) = 38.9	11.0
WMC	2.9 (.38)	2.3 (.55)	t (44)[a] = 4.5	1.30
Antisaccade				
RT (ms)	582 (119.1)	1085 (515.4)	t (28)[a] = 4.8	1.34
AC (%)	.81 (.09)	.58 (.10)	t (50) = 8.7	2.40
Prosaccade				
RT (ms)	520 (118.5)	809 (290.3)	t (33)[a] = 4.71	1.30
AC (%)	.89 (.07)	.72 (.12)	t (41)[a] = 7.1	1.97

*All *p* values < .0001 (Student's t-test)
Values in brackets are Standard Deviations.
[a] Correction of *df*s for unequal variances

As in our previous experiments, WMC scores correlated again with age (r = -.56, p < .001), and with participants' performance in the antisaccade [RTs: r = - .46; AC %: r

= .79] and prosaccade trials [r = - .48; AC %: r = .74], as well as with the differences in performance between the both conditions (RTs: r = - .33, p = .02; AC %: r = - .36, p = .009), suggesting again a reduced capacity for attention control in older people. This conclusion is strengthened by results of further ANOVAs with Age (younger vs. older) and Saccade Type (antisaccade vs. prosaccade trials) as between- and within-participants variables, respectively. The main effects of Age [RTs: F (1, 50) = 28.4, p < 0.001, η^2 = 0.33; Accuracy: F (1, 50) = 71.6, p < 0.001, η^2 = 0.59] and Saccade Type were reliable again [RTs: F (1, 50) = 29.7, p < 0.001, η^2 = 0.37; Accuracy: F (1, 50) = 143.8, p < 0.001, η^2 = 0.74], as well as the interaction between these two factors, in both RTs (F (1, 50) = 11.82, p = 0.001, η^2 = 0.19) and Accuracy (F (1, 50) = 6.7, p = 0.012, η^2 = 0.12).

Congruency-Priming task. Trials containing an incorrect response (2.17% of trials), or with RTs faster than 200 ms or falling more than 2.5 standard deviations from the overall mean RT (2.10% of trials) were removed from analyses. Mean correct RT and error rates were computed for each participant in the two age groups as a function of task Practice (Trial Blocks 1-4), and Prime-Target Relatedness (Related, Unrelated). Resulting values were submitted to two different 4 x 2 x 2 ANOVAs, with task Practice and Prime-Target Relatedness as within participant variables, and Age (younger, older) as a between participants factor.

The ANOVA on error rates showed no significant effects (all ps > .28). The RT ANOVA revealed a main effect of Age (F (1, 50) = 29.2, p > 0.001, η^2 = 0.37), as older adults were slower (694 ms) than younger adults (536 ms). We also found an overall effect of reversed priming (F (1, 50) = 37.8, p > 0.001, η^2 = 0.43), because of faster responses to incongruent (590 ms) than congruent pairs (635 ms). Yet, this variable did not interact either with Practice or Age. Both younger and older participants showed very similar, and reliable, reversed priming effects, reaching significance from the first practice block for both age groups. Mean correct reaction times (in milliseconds) and error percentages (in %) in the Congruency-Priming task are presented in Table 7 (see also Figure 5) as a function of Prime-Target Relatedness (Related vs. Unrelated), and Task Practice (Trial Blocks 1, 2, 3, and 4) across age groups (young vs. older participants).

Table 7. Responses in the Congruency-Priming task for each block.

	Prime-Target Relatedness			
	Younger		**Older**	
	Related	Unrelated	Related	Unrelated
Block 1	564 (117.8)	519 (92.9)	726 (180.3)	686 (132.3)
	2.6 (4.8)	2 (2.8)	2.8 (5.1)	2.1 (3.1)
Block 2	565 (128.2)	526 (86.1)	723 (151.8)	678 (125.2)
	2.4 (4.5)	2.2 (2.3)	2.8 (6.3)	2 (3.5)
Block 3	552 (94.9)	516 (88.2)	711 (127.1)	660 (106.5)
	2.2 (5.7)	2.2 (2.9)	2.2 (4.4)	1.9 (2.4)
Block 4	536 (95.9)	514 (87.3)	701 (139.8)	667 (106.7)
	2 (5.7)	1.7 (1.7)	2.1 (4.1)	1.6 (2.3)

Values in brackets are Standard Deviations.

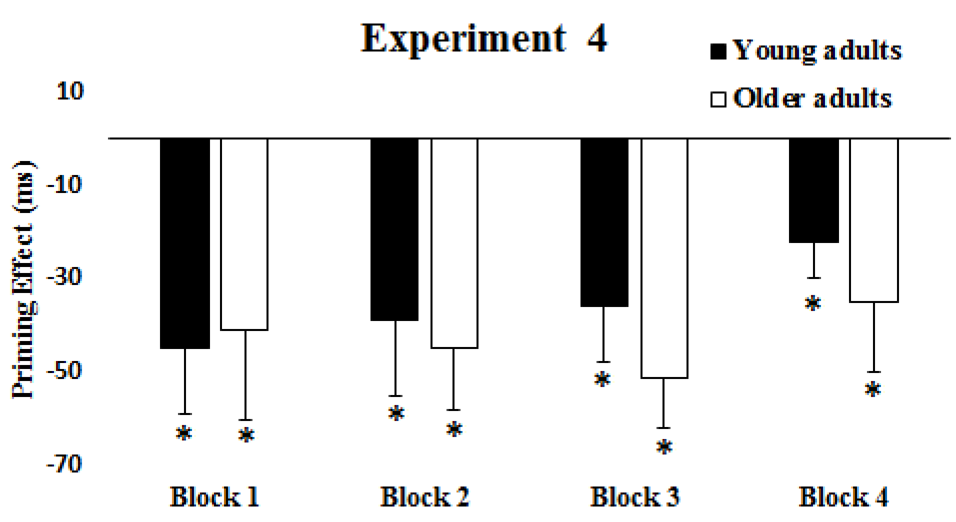


Figure 5. Congruency Priming effects across Trial Blocks in Experiment 4.

These results are consistent with those found in Experiment 2 using a different task, demonstrating once again that older adults, when given enough time, are able to implement controlled strategies as efficiently as younger adults do. Together, the findings of Experiments 2 and 4 suggest that older adults are able to maintain the relevant task information in their WM.

5. General Discussion

Cognitive impairment associated with normal aging has an impact in multiple domains, including selective attention, working memory, and episodic memory. Most of the deterioration seems to be rather specific of tasks involving controlled (top-down) processing (e.g., Langley, Fuentes, et al., 2001). This seems to be the case in those attention and memory tasks in which some irrelevant information interferes with target processing (arriving from internal or external sources) thus requiring some level of executive control to counteract it. Thus, it has been found that the presence of distracting information negatively impact task performance in older adults much more than in younger individuals (e.g., Anderson et al., 2011; De Fockert et al., 2009; Gazzaley et al., 2008; Mayas et al., 2012). Interestingly, some recent research has suggested that in older adults, the ability to inhibit or supress irrelevant information could also be delayed in time (e.g., Cashdollar et al., 2012; Gazzaley et al., 2008; Zanto et al., 2010).

The main goal of the present research was to investigate if the ability to develop task based expectancies is also delayed in normal aging. To this end, we conducted a series of four experiments where younger and older adults performed different strategic priming tasks. A common factor in these tasks was that the way prime information is used (strategic or controlled, vs. non-strategic or automatic) allows the measure of priming effects in opposite directions. To explore the time course of these effects, the SOA was manipulated across experiments and thus achieve a range of intervals, which included

400, 1000 and 2000 ms.

To further understand if these age differences were associated to changes in working memory capacity and attention control, both younger and older participants in our experiments also performed a Change Localization task (to assess WMC), and a version of the Antisaccade task that included both antisaccade and prosaccade trial blocks (to assess attention control).

This research strategy has produced a wealth of results. Firstly, relative to younger individuals, older adults responded consistently slower (and less accurate) in all the tasks. This result is consistent with a large body of evidence showing a generalized decline in processing speed with normal aging (e.g., Salthouse, 1996; 2000). A second relevant finding was a reduction in WMC in older adults found in all our experiments. Their performance in the Change Localization task was always worse than with younger participants. These results replicate the pattern found in other similar visual WM tasks, such as the Change Detection task (e.g., Cashdollar et al., 2012).

An additional important finding was that performance in the WMC task (*k* scores) negatively correlated not only with the age or the overall speed in the Antisaccade task, but also with their differential performance between the antisaccade and prosaccade blocks. Thus, the decreased WMC likely resulting of aging seems to be associated not only with an overall processing speed decline, but also with a reduced capacity for attention control in older adults. This idea is further supported by evidence in all our experiments of older adults presenting greater deterioration of responses (both latency and accuracy) in the more control demanding antisaccade than in the prosaccade condition (see Tables 2, 4, and 6).

These findings are consistent with previous research showing that individuals with a lower WM Capacity are also impaired on several attention tasks, such as the Stroop or the antisaccade task, which require participants to maintain the relevant information in WM while performing an ongoing task (e.g., Hutchison, 2007; Kane et al., 2001; Kane & Engle, 2003). Our results are also compatible with the executive attention theory of working memory developed by Engle and colleagues (e.g., Engle & Kane, 2004). In that theory, inter-individual differences in WMC would mainly reflect variations in a domain-general attention control ability, necessary to sustain the task goal and constrain the focus of attention to relevant target in the presence of distraction.

Particularly relevant were the results from our priming tasks showing a delay in the development of expectancies in older adults. Younger participants showed strategic effects already at 1000 ms SOA (with Stroop in experiments 1 and 2, with congruency priming in Experiment 3). But this was not the case with older participants, as they consistently failed to show reversed strategic priming during the same interval and tasks. These results replicate those found by Froufe et al. (2009) in a similar strategic Stroop-like task with a prime-target SOA of 1125 ms. Other semantic priming studies using a similar SOAs (e.g., 950 ms) have also reported problems in Alzheimer's Dementia and healthy older adults when having to generate attentional expectations for semantically related information (e.g., Langley, Fuentes, et al., 2001). One could therefore conclude that controlled strategic processing is impaired with normal aging.

Braver and colleagues have in fact suggested that one of the fundamental mechanisms that leads to age-related cognitive changes is a deficit in the ability to process contextual information for a proactive mode of control. These authors have developed the dual-mechanisms control (DMC) model to explain cognitive deficits in older adults and other clinical populations (e.g., schizophrenia). The model assumes that goal directed behavior could be the result of two different modes of cognitive control: proactive and reactive (e.g., Braver et al., 2001; Braver & Barch, 2002; see Braver, 2012, for a review).

Proactive control would reflect a preparatory and resource demanding type of control in which a predictive cue (or context) is used by individuals to prepare a specific response to a future target. This control mode requires active maintenance of the goal-relevant information in an accessible state (in Working Memory) to efficiently focus attention on that information while ignoring competing distractors. In contrast to proactive control, the reactive form of control does not require a continuous effort or monitoring, but instead involves using a target stimulus to automatically retrieve appropriate actions from long-term memory. By using different tasks and experimental procedures (e.g., the AX-Continuous Performance Test, AX-CPT) to assess the DMC theory, Braver et al. have reported evidence that relative to younger individuals, healthy older adults would show a reduced tendency to use proactive control, but an increased tendency to use reactive control (e.g., Braver, 2012; Braver et al., 2007).

On the other hand, as noted in the introduction, previous work has found that in younger adults expectancy effects are usally increased with the SOA, but they seem to decrease in older adults (e.g., Balota, Black, & Cheney, 1992; Experiments 1 and 3), when the prime appears briefly on the screen and is not available during the interstimulus interval. That drop in expectancy effects could be due to difficutlies in the older group to maintain the relevant information in WM.

Note that in our priming tasks the prime stimulus did not remain on the screen during the whole SOA interval and, instead, was always presented for only 200 ms followed by a blank screen. If older participants in our experiments find it difficult to maintain information about the prime in WM compared to younger ones, then they may still show reduced strategic effects when giving them extra time (2000 ms) to complete their strategies.

But this was clearly not the case in either Experiment 2 or Experiment 4. When the prime-target SOA was lengthened to 2000 ms, older adults could strategically use the information provided by the prime stimulus to anticipate the target response. They could hold this information in WM despite the prime stimulus disappearing after a short exposure until the target onset. Thus, our older participants responded reliably faster to incongruent than to congruent targets on both the Stroop task (Experiment 2) and the Congruency-priming task (Experiment 4). These strategic priming effects were similar in magnitude to those showed by the younger participants and were also unaffected by task practice. These results are in clear contrast to those reported previously by others (e.g., Balota et al., 1992) and the simplicity of our tasks might be the reason. Future research might be needed to investigate: a) how changes in WM load impact time course of expectancy generation in older adults, and b) how the perceptual availability of prime information during this period of time may reduce this load.

The present findings replicate and extend the results from other previous studies in showing that not only the ability to inhibit or disengage from irrelevant information, but also the ability to efficiently implement controlled facilitatory strategies (i.e., expectancy generation) would be delayed in time, rather than abolished in normal aging. An interesting issue for future research would be to compare strategic priming effects at longer SOA intervals (e.g., 2000 ms) in healthy older adults and those with Alzheimer's dementia (AD). This would allow us to determine whether the deficits observed in the patient population are also due to a delay in the implementation of strategies (as observed with older adults) or instead, they are unable to generate predictive expectations even at intervals of 2000 ms or beyond.

Author Contributions

Conceptualization: Carmen Noguera, Juan J. Ortells, Paloma Marí-Beffa

Formal analysis: Sergio Fernández, Juan J. Ortells

Funding acquisition: Juan J. Ortells

Investigation: Sergio Fernández, Dolores Álvarez, Encarna Carmona,

Methodology: Carmen Noguera, Juan J. Ortells

Writing – original draft: Carmen Noguera, Dolores Álvarez, Encarna Carmona

Writing – review & editing: Juan J. Ortells, Paloma Marí-Beffa

6. References

Aguirre, E., Hoare, Z., Spector, A., Woods, R. T., & Orrell, M. (2014). The effects of a Cognitive Stimulation Therapy [CST] programme for people with dementia on family caregivers' health. *BMC geriatrics*, *14*, 31. doi:10.1186/1471-2318-14-31

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

Balota, D. A., Black, S. R., & Cheney, M. (1992). Automatic and attentional priming in young and older adults: Reevaluation of the two-process model. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(2), 485-502. doi: 10.1037/0096-1523.18.2.485

Braver, T. S. (2012). The variable nature of cognitive control: a dual mechanisms framework. *Trends Cogn. Sci.* 16, 106–113. doi: 10.1016/j.tics.2011.12.010

Braver, T. S., & Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neuroscience & Biobehavioral Reviews*, *26*(7), 809-817. doi: 10.1016/S0149-7634(02)00067-2.

Braver, T. S., Barch, D. M., Keys, B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., Janowsky, J. S., Taylor, S. F., Yesavage, J. A., Mumenthaler, M. S., Jagust, W. J., & Reed, B. R. (2001). Context processing in older adults: evidence for a theory relating cognitive control to neurobiology in healthy aging. *J. Exp. Psychol. Gen.* 130,746–763. doi: 10.1037//0096-3445.130.4.746

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). "Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control," in *Variation in working memory,* eds. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, and J. N. Towse (New York, NY: Oxford University Press), 76-106.

Burke, D. M., White, H., & Díaz, D. L. (1987). Semantic priming in young and older adults: Evidence for age constancy in automatic and attentional processes. *J Exp Psychol Hum Percept Perform. 13*: 79-88. doi: 10.1037/0096-1523.13.1.79.

Butler, K. M., Zacks, R. T., & Henderson, J. M. (1999). Suppression of reflexive saccades in younger and older adults: age comparisons on an antisaccade task. *Mem. Cognit. 27*(4), 584-591

Cashdollar, N., Fukuda, K., Bocklage, A., Aurtenetxe, S., Vogel, E. K., & Gazzaley, A. (2012). Prolonged disengagement from attentional capture in normal aging. *Psychology and aging, 28*(1), 77-86.

Chiarello, C., Church, K. L., & Hoyer, W. J. (1985). Automatic and controlled semantic priming: Accuracy, response bias, and aging. *J Gerontol. 40*: 593-600. doi: 10.1093/geronj/40.5.593.

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

Craik, F. I. M., & Salthouse, T. A. (Eds.). (2000). The handbook of aging and cognition (2nd ed.). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Davidson, D. J., Zacks, R. T., & Williams, C. C. (2003). Stroop interference, Practice, and Aging. *Aging Neuropsychol Cogn. 10*: 85-98. doi: 10.1076/anec.10.2.85.14463.

Daza, M. T., Ortells, J. J., & Fox, E. (2002). Perception without awareness: Further evidence from a Stroop priming task. *Percept Psychophys.* 64, 1316-1324. 64: 1316. doi:10.3758/BF03194774

De Fockert, J. W. (2005). Keeping priorities: the role of working memory and selective attention in cognitive aging. *Sci. Aging Knowledge Environ*. 44, pe34.

De Fockert, J., Ramchurn, A., Van Velzen, J., Bergström, Z., & Bunce, D. (2009). Behavioural and ERP evidence of increased interference in old age. *Brain Res. 1282*, 67–73.

De Jong, R. (2001). Adult age differences in goal activation and goal maintenance. *Eur J Cogn Psychol, 13*: 71-89. doi: 10.1080/09541440042000223

Engle, R. W., and Kane, M. J. (2004). "Executive attention, working memory capacity, and a two-factor theory of cognitive control," in *The psychology of learning and motivation,* ed. B. Ross (New York, NY: Elsevier), 145-199.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state." A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*(3), 189–198

Froufe, M., & Alelú, R. (2006). Función ejecutiva y actuación estratégica: Efectos de las instrucciones, la edad, la AIE y algunas patologías. II Congreso Regional de la SIP. La Habana (Cuba).

Froufe, M., Cruz, I., & Sierra, B. (2009). (dis)Función ejecutiva en personas mayores con y sin Alzheimer: Actuación estratégica basada en expectativas. *Psicológica*, *30*, 119-135.

Fukuda, K., Vogel, E., Mayr, U., & Awh, E. (2010). Quantity, not quality: the relationship between fluid intelligence and working memory capacity. *Psychon. Bull. Rev.* 17, 673–679. doi: 10.3758/17.5.673

Fukushima, J., Fukushima, K., Chiba, T., Tanaka, S., Yamashita, I., & Kato, M. (1988). Disturbances of voluntary control of saccadic eye movements in schizophrenic patients. *Biol Psychiatry, 23*(7), 670- 677. doi: 10.1016/0006-3223(88)90050-9

Gazzaley, A., Clapp, W., Kelley, J., McEvoy, K., Knight, R. T., & D'Esposito, M. (2008). Age-related top-down suppression deficit in the early stages of cortical visual memory processing. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(35), 13122-6.

Gazzaley, A. (2012). "Top-down modulation deficit in the aging brain: An emerging theory of cognitive aging". In *Principles of Frontal Lobe Function (*2nd edn), ed. D. T. Stuss and R. T. Knight (New York: Oxford University Press), 593–608.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The Psychology of Learning and Motivation, Vol. 22* (pp. 193-225). New York: Academic Press.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention & Performance, XVII, Cognitive Regulation of Performance: Interaction of Theory and Application* (pp. 653-675). Cambridge, MA: MIT Press.

Henry, J. D., & Crawford, J. R. (2004). A meta-analytic review of verbal fluency performance following focal cortical lesions. *Neuropsychology*, *18*: 284 –295. doi: 10.1037/0894-4105.18.2.284.

Heyman, T., Van Rensbergen, B., Storms G., Hutchison, K. A., & De Deyne, S. (2014). The influence of Working Memory Load on Semantic Priming. *J. Exp. Psychol. Learn. 41*, 911–920. doi:10.1037/xlm0000050

Hutchison, K. A. (2007). Attentional control and the relatedness proportion effect in semantic priming. *J. Exp. Psychol. Learn.* 33(4), 645–662. doi: 10.1037/0278-7393.33.4.645

Hutchison, K. A., Heap, S. J., Neely, J. H., & Thomas, M. A. (2014). Attentional control and asymmetric associative priming. *J. Exp. Psychol. Learn.* 40, 844-856. doi:10.1037/a0035781

Johnson, M. K., McMahon, R. P., Robinson, B. M., Harvey, A. N., Hahn, B., Leonard, C.

J., Luck, S. J., & Gold, J. M. (2013). The relationship between working memory capacity and broad measures of cognitive ability in healthy adults and people with schizophrenia. *Neuropsychology* 27, 220–229. doi: 10.1037/a0032060

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

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General*, *132*(1), 47-70. doi: 10.1037/0096-3445.132.1.47

Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: Explorations of executive control processes in the task-switching paradigm. *Acta Psychol. 101*: 339-378. doi: 10.1016/S0001-6918(99)00011-6.

Langley, L. K., Fuentes, L. J., Hochhalter, A. K., Brandt, J., & Overmier, J. B. (2001). Inhibition of return in aging and Alzheimer's disease: performance as a function of task demands and stimulus timing. *J Clin Exp Neuropsychol*, *23*(4), 431-446.

Lawton, M. P., & Brody, E. M. (1969). Assessment of older people: self-maintaining and instrumental activities of daily living. *Gerontologist*, *9*(3), 179-186.

Levitt T., Fugelsang, J., & Crossley, M. (2006). Processing Speed, Attentional Capacity, and Age-Related Memory Change. *Experimental Aging Research, 32*(3), 263-295. doi: 10.1080/03610730600699118

Lobo, A., Saz, P., Marcos, G., Día, J. L., De la Cámara, C., Ventura, T., Morales Asín, F., Fernando Pascual, L., Montañés, J. A., & Aznar, S. (1999). Revalidation and standardization of the cognition mini-exam (first Spanish version of the Mini-Mental Status Examination) in the general geriatric population. *Medicina Clínica,* *112*(20), 767–774.

Logan, G. D., & Zbrodoff, N. J. (1992). Constraints on strategy construction in a speeded discrimination task. *J Exp Psychol Hum Percept Perform. 8*: 502-520. doi: 10.1037/0096-1523.8.4.502.

Lustig, C., Hasher, L., & Zacks, R. T. (2007). Inhibitory deficit theory: Recent developments in a "new view" In D. S. Gorfein & C. M. MacLeod (Eds.), *Inhibition in cognition* (pp. 145-162). Washington, DC, US: American Psychological Association. doi: 10.1037/11587-008

Marí-Beffa, P., Hayer, A. E., Machado, L., & Hindle, J. V. (2005). Lack of inhibition in Parkinson's disease: evidence from a lexical decision task. *Neuropsychologia, 43*(4), 638-646. doi: 10.1016/j.neuropsychologia.2004.07.006.

Martínez, J., Onís, M., Dueñas, R., Colomer, C., Aguado, C., & Luque, R. (2002). Versión española del cuestionario de Yesavage abreviado (GDS) para despistaje de depresión en mayores de 65 años: adaptación y validación**.** *Medifam, 12*(10), 620-630.

Mayas, J., Fuentes, L. J., & Ballesteros, S. (2012). Stroop interference and negative priming (NP) suppression in normal aging. *Archives of Gerontology and Geriatrics, 54*(2), 333-338. doi: 10.1016/j.archger.2010.12.012.

Merikle, P. M., & Joordens, S. (1997). Parallels between perception without attention and perception without awareness. *Conscious. Cogn*, *6*, 219-236. doi:10.1006/ccog.1997.0310

Mummery, C. J., Shallice, T., & Price, C. J. (1999). Dual-process model in semantic priming: A functional imaging perspective. *Neuroimage, 9*: 516-525. doi: 10.1006/nimg.1999.0434.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106*(3), 226-254. doi: 10.1037/0096-3445.106.3.226

Ortells, J. J., Álvarez, D., Noguera, C., Carmona, E., & De Fockert, J. W. (2017). The influence of working memory load on expectancy-based strategic processes in the stroop-priming task. *Front. Psychol.* 8:129. doi: 10.3389/fpsyg.2017.00129

Ortells, J. J., Daza, M. T., & Fox, E. (2003). Semantic activation in the absence of perceptual awareness. *Perception and Psychophysics, 65*, 1307–1317.

Ortells, J. J., De Fockert, J. W., Romera, N., & Fernández, S. (2018). Expectancy-Based Strategic Processes Are Influenced by Spatial Working Memory Load and Individual Differences in Working Memory Capacity. *Frontiers in psychology*, *9*, 1239. doi:10.3389/fpsyg.2018.01239

Ortells, J. J., Noguera, C., Álvarez, D., Carmona, E., & Houghton, G. (2016). Individual differences in working memory capacity modulates semantic negative priming from single prime words. *Front. Psychol*, *7*, 1-14. doi: 10.3389/fpsyg.2016.01286

Ortells, J. J., Vellido, C., Daza, M. T., & Noguera, C. (2006). Semantic priming effects with and without perceptual awareness. *Psicológica: International Journal of Methodology and Experimental Psychology, 27*, 225–242.

Rogers, W. A. (1992). Age differences in visual search: Target and distractor learning. *Psychol Aging. 7*: 526-535. doi: 10.1037/0882-7974.7.4.526.

Rogers, W. A., & Fisk, A. D. (1991). Age-related differences in the maintenance and modification of automatic processes: Arithmetic Stroop interference. *Hum Factors. 33*: 45-56. doi: 10.1177/001872089103300104.

Rossell, S. L., Price, C. J., & Noble, A. C. (2003). The anatomy and time course of semantic priming investigated by fMRI and ERPs. *Neuropsychologia, 41*: 550-564.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103*(3), 403-428. doi: 10.1037/0033-295X.103.3.403

Salthouse, T. A. (2000). Aging and measures of processing speed. *Biological Psychology, 54*, 35-54. doi: 10.1016/S0301-0511(00)00052-1.

Shipstead, Z., Harrison, T. L., & Engle, R. W. (2015). Working memory capacity and the scope and control of attention. *Atten. Percept. Psychophys.* 77, 1863–1880. doi: 10.3758/s13414-015-0899-0

Shivde, G., & Thompson-Schill, S. L. (2004). Dissociating semantic and phonological maintenance using fMRI. *Cogn Affect Behav Neurosci. 4*: 10-19. doi: 10.3758/CABN.4.1.10.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity. J Exp Psychol Hum Learn, 6(2), 174-215.

Thompson-Schill, S. L., Kurtz, K. J., & Gabrieli, J. D. E. (1998). Effects of semantic and associative relatedness on automatic priming. *J Mem Lang. 38*: 440-458. doi: 10.1006/jmla.1997.2559.

Unsworth N., Redick, T. S., Heitz, R. P., Broadway, J. M., & Engle, R. W. (2009). Complex working memory span tasks and higher-order cognition: a latent-variable analysis of the relationship between processing and storage. *Memory, 17*(6), 635-654. doi: 10.1080/09658210902998047

Unsworth, N., Schrock, J. C., & Engle, R. W. (2004). Working memory capacity and the antisaccade task: Individual differences in voluntary saccade control. *J Exp Psychol Learn Mem Cogn. 30*:1302–1321. doi: 10.1037/0278-7393.30.6.1302.

Vergara, I., Bilbao, A., Orive, M., Garcia-Gutierrez, S., Navarro, G., & Quintana, J. M.

(2012). Validation of the Spanish version of the Lawton IADL Scale for its application in elderly people. *Health and quality of life outcomes*, *10,* 130. doi: 10.1186/1477-7525-10-130

Yesavage, J. A., Brink, T. L., Rose, T. L., Lum, O., Huang, V., Adey, M., & Leirer, V. O. (1982). Development and validation of a geriatric depression screening scale: A preliminary report. *Journal of Psychiatric Research*, *17*(1), 37-49. doi: 10.1016/0022-3956(82)90033-4.

West, R., & Alain, C. (2000). Age-related decline in inhibitory control contributes to the increased Stroop effect observed in older adults. *Psychophysiology*, *37*(2), 179–189. doi: 10.1111/ 1469-8986.3720179

Zanto, T. P., & Gazzaley, A. (2014). "Attention and Ageing" in *The Oxford Handbook of Attention,* eds. A. C. Nobre, and S. Kastner (New York, NY: Oxford University Press), 927-971. doi: 10.1093/oxfordhb/9780199675111.013.02

Zanto, T. P., Toy, B., & Gazzaley, A. (2010). Delays in neural processing during working memory encoding in normal aging. *Neuropsychologia*, *48*(1), 13-25.

7. Appendix A.

List of prime-target pairs used in Experiments 3 and 4. Mean (SD) functional and visual similarity rates in a rating similarity pilot study (1= not at all similar; 7 = highly similar), for animal and inanimate-object pictures (and their English translations), presented as semantically related prime-target pairs.

Prime	Target	Functional Similarity	Visual Similarity
Gato (cat)	Perro (dog)	5.75 (1.16)	5.44 (1.12)
Gorila (gorilla)	Mono (monkey)	6.21 (0.94)	5.10 (1.39)
Oveja (sheep)	Cabra (goat)	5.39 (1.07)	5.14 (1.19)
Tigre (tiger)	León (lion)	5.89 (1.03)	5.12 (1.24)
Tornillo (bolt)	Tuerca (screw)	6.38 (0.96)	5.66 (0.99)
Cuchara (spoon)	Tenedor (fork)	6.06 (1.14)	5.23 (1.34)
Taza (cup)	Vaso (glass)	6.58 (0.71)	5.02 (1.61)
Bota (boot)	Zapato (shoe)	6.77 (0.48)	5.01(1.53)

V

Estudio Experimental III

Estudio 3. Working memory capacity modulates expectancy-based strategic processing: Behavioral and electrophysiological evidence[3]

[3]Manuscript published as:

Fernández, S., Ortells, J. J., Kiefer, M., Noguera, C., & De Fockert, J. W. (2021). Working memory capacity modulates expectancy-based strategic processing: Behavioral and electrophysiological evidence. *Biological Psychology, 159,* 108023. doi: 10.1016/j.biopsycho.2021.108023

Working memory capacity modulates expectancy-based strategic processing: Behavioral and electrophysiological evidence

Sergio Fernández[1], Juan José Ortells[14], Markus Kiefer[2], Carmen Noguera[14], & Jan W. De Fockert[3]

[1] Department of Psychology, University of Almería, Almería, Spain

[2] Department of Psychiatry, Ulm University, Ulm, Germany

[3] Department of Psychology, Goldsmiths, University of London, London, UK

[4] CEINSA, Health Research Center, University of Almería, Spain

Abstract

The present research measured participants' event-related brain activity while they performed a Stroop-priming task that induced the implementation of expectancy-based strategic processes. Participants identified a colored (red vs. green) target patch preceded by a prime word (GREEN or RED), with incongruent prime-target pairings being more frequent (75%) than congruent pairs (25%). The prime-target stimulus onset asynchrony (SOA) was manipulated at two levels: 300 vs. 700 ms. Participants also performed a change localization task to assess their working memory capacity (WMC). At the 300 ms SOA, all participants presented a Stroop-priming congruency effect (slower responses on incongruent than on congruent trials) and an increased N2 amplitude in incongruent trials, irrespective of their WMC. At the 700-ms SOA, the lower-WMC group showed again a larger negative-going waveform to incongruent targets, whereas the higher-WMC group exhibited a reversed Stroop-priming congruency effect (faster responses to incongruent targets) and the N2 component was absent.

Keywords: Stroop priming effects; expectancy-based strategic processes; SOA intervals; individual differences in working memory capacity; N2 ERP component

1. Introduction

Working memory (WM) is the cognitive system that allows us to actively retain and manipulate a limited amount of internal information (e.g., Baddeley, 1986). WM function is not only important for storage and manipulation of information but also supports attentional selection: WM maintains the goal-directed focus on the relevant aspects of the environment, while actively blocking the processing of irrelevant or distracting information (e.g., Gazzaley & Nobre, 2012; Kane, Bleckley, Conway & Engle, 2001; Lavie, Hirst, De Fockert & Viding, 2004).

A line of investigation that provides direct evidence for a close association between WM and selective attention uses a methodological strategy based on "extreme-groups", in which WM capacities of a large sample of participants are first assessed by means of several WM tasks. Participants showing higher and lower scores on those tasks (e.g., first vs. fourth quartiles) are then required to perform selective attention tasks. For instance, when participants have to name the ink color of a color word in a conventional Stroop task, individuals with a high WM capacity (WMC) are usually more effective at selectively attending to the relevant ink color and at suppressing the influence of the irrelevant name of the color word, compared to low-WMC participants. Similar differences between high-WMC and low-WMC individuals have been reported in other selective attention tasks (e.g., Ahmed & De Fockert, 2012; Conway, Tuholski, Shisler & Engle, 1999; Kane & Engle, 2003; Kiefer, Ahlegian & Spitzer, 2005; Megías, Ortells, Noguera, Carmona & Marí-Beffa, 2020; Ortells, Noguera, Álvarez, Carmona & Houghton, 2016; see also Wiemers & Redick, 2018).

In a similar vein, studies on cognitive ageing have shown that older adults, who often perform worse than younger individuals on WM tasks (e.g., Gazzaley, 2012; Noguera, Fernández, Álvarez, Carmona, Marí-Beffa, & Ortells, 2019), tend to be more vulnerable to (and need more time to block) the influence of competing distractors in selective attention tasks, thus showing a similar pattern to that observed in younger adults with lower WMC (Gazzaley, 2012; Gazzaley, Clapp, Kelley, McEvoy, Knight & D'Esposito, 2008; Jost, Bryck, Vogel & Mayr, 2011; see also Noguera et al., 2019).

Another line of evidence supporting a role of WM in selective attention comes from studies that use a dual task paradigm, in which a WM task is combined with a selective attention task (e.g., Stroop) to measure the distractor interference in a context of varying memory load (e.g., retaining series of random vs. ordered digits). The usual finding is that distractor effects on the attention task, in terms of increased response latency and/or reduced accuracy, are greater under high compared to low WM load (e.g., De Fockert, Mizon & D'Ubaldo, 2010; De Fockert, Rees, Frith & Lavie, 2001; Lavie & De Fockert, 2005; see De Fockert, 2013, for a review).

Although much less investigated, there also is evidence that a reduction in the availability of WM resources, as a consequence of either cognitive ageing, having low WMC, or performing a concurrent task demanding a high load, could negatively affect facilitatory strategic processing in priming tasks. Semantic priming is said to occur when responses to a target stimulus (e.g., chair) are faster (and more accurate) when it has been preceded by a semantically related prime (e.g., table) rather than an unrelated prime (e.g., lion). These priming effects have been argued to be the result of at least two kinds of forward-acting prospective mechanisms: automatic spreading preactivation of the target representation, and controlled strategies such as expectancy generation (McNamara, 2005; Neely, 1991; for a retrospective strategic mechanism that begin to operate after the target appears, see Neely & Keefe, 1989). Expectancy generation is described as slow, effortful, and under conscious control and involves using the prime on a given trial to develop expectancy for specifically related targets during the interval between prime and target onset. Facilitation in target identification occurs if the target is included among the generated expectancy set (see Becker, 1980; Neely, 1977; 1991; Posner & Snyder, 1975, for more detailed descriptions of expectancy generation).

Some recent studies have demonstrated that under conditions that encourage the use of expectancy-based controlled strategies (i.e., a high proportion of related pairs), priming effects were greatly reduced (or even eliminated) for participants with low WMC, or under high WM load (e.g., Heyman, Van Rensbergen, Storms, Hutchison & Deyne, 2014; Hutchison, Heap, Neely & Thomas, 2014). However, as these studies used a conventional facilitatory priming paradigm, in which both controlled and automatic priming processes converge with regard to their beneficial effects on target processing (i.e., faster responses on related than on unrelated trials), the above results cannot be unequivocally interpreted in terms of a decreased strategic processing. When both types of processes contribute to performance in the same direction (i.e., facilitating), it is difficult to know whether the reduced priming effects under high load conditions, or in low-WMC individuals, are really due to a less efficient use of expectancy-based strategies (but see Hutchison, 2007). Alternatively, based on several previous demonstrations that supposedly automatic priming effects (e.g., induced by subliminally present stimuli) can be modulated by attentional influences (e.g., Kiefer & Brendel, 2006; Kiefer & Martens, 2010), it is not implausible that a low WMC could also lead to a reduction of the automatic processing of the prime stimulus.

In order to overcome this potential limitation, some other studies have used alternative priming paradigms, in which strategic vs. non-strategic (automatic) prime processing can lead to qualitatively different behavioral effects (i.e., priming effects in opposite directions; e.g., Merikle & Joordens, 1997; Noguera et al., 2019; Ortells, Álvarez, Noguera, Carmona, and De Fockert, 2017; Ortells, Daza, & Fox, 2003).

An illustrative example is the Stroop-priming task developed by Merikle and colleagues to demonstrate that predictive strategies based on stimulus redundancy only occurs when observers are consciously aware that the prime identity (e.g., Merikle & Cheesman, 1987; Merikle & Daneman, 1998; Merikle, Joordens, & Stolz, 1995; Merikle & Joordens, 1997; see also Daza, Ortells, & Fox, 2002). They used a two-color sequential variant of the Stroop task, in which two color words -RED or GREEN- are used to prime responses to two target colors -also red or green-, and the incongruent prime-target pairings are much more frequent (80% of the trials) than congruent pairings (20%). The differential proportion of congruent vs. incongruent trials induces participants to strategically utilize the predictive information provided by the primes to maximize performance. Since only two colors are used and incongruent prime-target pairings occurred on most of the trials, the best prediction that could be made concerning the target was that it would be the color *not named* by the prime (cf. Merikle & Cheesman, 1987; see also Merikle & Joordens, 1997). Such a predictive strategy had allowed participants to anticipate the target correctly on 80% of the trials (having only led to incorrect anticipations on 20% of trials), so participants' responses could be faster (and/or more accurate) on incongruent than on congruent trials.

This strategic reversal of the Stroop congruency effect is in fact, the kind of result pattern that is observed with this Stroop priming task when the prime is clearly visible (i.e., presented for a long duration and/or unmasked), such that it can be consciously identified (e.g., Merikle & Cheesman, 1987; Merikle & Daneman, 1998; Merikle & Joordens, 1997; Merikle, Joordens, & Stolz, 1995), and the prime-target stimulus onset asynchrony (SOA) is long enough (e.g., 500 ms or longer) to allow the implementation of predictive strategies (e.g., Daza, Ortells & Fox, 2002; Froufe, Cruz, & Sierra, 2009; see also Noguera et al., 2019).[1]

On the contrary, under task conditions that impede or make difficult the strategic processing of the prime, such as presenting it below the threshold of awareness, and/or using a short prime-target SOA (e.g., 300 ms or less), participants' performance is similar to that observed when congruent and incongruent trials are equally probable (i.e., 50/50); namely, a standard Stroop congruency effect is rather found, with faster responses on congruent than on incongruent trials (e.g., Daza, Ortells & Fox, 2002; Merikle & Cheesman, 1987; Merikle & Joordens, 1997). [2]

This Stroop-priming task (with congruent to incongruent ratio (C/I) = 20/80), in combination with a concurrent verbal working memory task that demanded either a high or a low load, was recently used by Ortells et al. (2017). In order to maximize the implementation of predictive strategies in the Stroop priming task, the prime word was always presented for 100 ms and unmasked (thus always being clearly visible) and relatively long prime-target SOA of 1000 ms was used (see also Froufe et al., 2009; Noguera et al., 2019). The prime word was preceded by a sequence of either five different random digits (high load) or five repetitions of the same digit (low load), which the participants were required to memorize. After two, three, or four Stroop priming trials, participants had to decide whether or not a single probe digit was a part of the previously memorized digit-set. The key finding was a reliable interaction between prime-target congruency and WM load. Reversed (strategic) Stroop effects were found under low WM load, whereas (non-strategic) Stroop congruency effects were observed under high WM load. These findings provide further evidence that a reduction in the availability of WM resources by engaging WM in an additional task of high load can lead to less efficient strategic processing of task-relevant information. Non-strategic, automatic processing prevails under such high WM load conditions.

These effects of WM load on expectancy-based strategic processing were replicated in a further study by Ortells, De Fockert, Romera, and Fernández (2018) with a non-verbal (spatial) WM tasks. This suggests that the effects of WM load on strategic prime processing are not domain-specific, but rather domain-general (e.g., shared attentional control resources).

A similar dependence of expectancy-based strategies on WM resources has been recently observed in a study comparing Stroop-priming effects in younger and older adults (Noguera et al., 2019): A strategic reversed Stroop effect at long SOAs (e.g., 1000 ms) was only observed in younger adults, but not in older adults (which showed lower WMC). These findings suggest that expectancy-based strategies can only be efficiently implemented if WMC is available to appropriately process the strategically relevant information.

1.1. Current study

The present research had two main aims. Firstly, we wanted to further investigate whether the implementation of controlled attentional strategies, like expectancy generation, was sensitive to individual differences in WMC.

Secondly, as far as we know, no previous study has explored whether individual differences in WM capacity can modulate electrophysiological correlates of strategic priming. Previous research examining a possible dependence of expectancy-based strategic processing on the availability of WM resources has exclusively based on behavioral measures of performance. Thus, we set up to track the time course of the neuro-cognitive mechanisms underlying the interaction between WMC and strategic attentional processing using event-related potential (ERP) recordings.

To this end, we used a Stroop-priming task similar to that of Ortells and colleagues (2017; 2018; Noguera et al., 2019), such that incongruent prime-target pairings were much more frequent (75%) than congruent pairings (25%). Rather than combining the Stroop-priming task with a concurrent WM task, this time a sample of younger adults performed the single Stroop priming task under two prime-target SOAs of 300 ms and 700 ms, which were presented in two different trial blocks counterbalanced across participants. In most of previous studies reporting qualitatively different priming effects as a function of strategic vs. non-strategic prime processing, the main factors (e.g., prime-mask SOA; prime-target SOA; WM load) have been manipulated either (a) across different participants, or (b) across different blocks (e.g., Daza et al., 2002; Merikle & Joordens, 1997; Noguera et al., 2019; Ortells et al., 2003; see also Hutchison et al., 2014; Ortells et al., 2017; 2018). Block-wise (or even between-subject) manipulation of SOA has the advantage of fostering expectancy-based processes because participants can establish expectancy about occurrence of a particular target type more easily than with randomized presentation of SOA. Accordingly, in the present study we manipulated the prime-target SOA in a blocked design.

To assess WMC, participants performed the Visual Change Localization task as used previously (Ortells et al., 2018; Noguera et al., 2019). This task is much simpler than other complex span tasks often used to assess WMC (e.g., Operation or Symmetry Span tasks), as it is shorter (less than 10 minutes), and does not require task switching. Despite its simplicity, performance in the Visual Change Localization task has shown strong correlations with broader measures of higher cognitive abilities and attentional control capacities (e.g., Johnson et al., 2013; Noguera et al., 2019; Castillo Escamilla, Fernández Castro, Baliyan, Ortells-Pareja, Ortells, & Cimadevilla, 2020).

Based on previous findings showing consistent strategic effects with this kind of priming tasks at relatively long SOAs and/or in participants with a higher WMC (e.g., Froufe et al., 2009; Noguera et al, 2019; Ortells et al., 2018), we expected to find a reliable three-way interaction between Congruency, prime-target SOA, and WMC. To the extent that a relatively short SOA of 300 ms will impede the efficient implementation of expectancy-based strategies, we predict that participants, irrespective of their WMC, will show faster responses on congruent relative to incongruent trials, thus revealing non-strategic processing of the prime at the 300-ms SOA. At the longer 700-ms SOA, however, we expect to find a reversed (strategic) Stroop priming effect in participants with higher WMC (faster responses on the more frequent incongruent trials), whereas low-WMC individuals could show a Stroop-priming interference effect (or reduced reversed Stroop compared to high-WMC individuals).

In ERP recordings, the N2 ERP component typically indexes attentional conflict processing (e.g., during an incongruent trial in a Stroop task). This negative deflection has a fronto-central scalp distribution and peaks around 200-350 ms after target stimulus presentation (e.g., Donohue, Appelbaum, McKay & Woldorff, 2016; Jongen & Jonkman, 2011; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004; Tillman & Wiens, 2011; see Folstein & Van Petten, 2008, for a review). The amplitude of the N2 component has been found to be more negative in incongruent Stroop trials compared to congruent trials (e.g., Clayson & Larson, 2011; Wendt & Luna-Rodríguez, 2009). The N2 modulations have also been observed in other different sequential priming paradigms, such as response-cueing tasks inducing different response expectations (i.e., differential probability of incongruent and congruent trials; see for example, Gajewski, Stoerig & Falkenstein, 2008) and visuo-motor response priming (Kiefer, Liegel, Zovko & Wentura, 2017; Martens, Ansorge & Kiefer, 2011). Other studies using a negative priming paradigm, have also reported an enhanced N2 amplitude when participants respond to a probe target that was presented as an ignored distractor in a preceding prime display. This negative-going waveform in the N200 time window has been interpreted as evidence for attentional inhibition mechanisms (e.g., Frings & Groh-Bordin, 2007; Gibbons, 2006; Hinojosa, Pozo, Méndez-Bértolo, & Luna, 2009).

To the extent that a prime-target SOA of 300 ms impedes (or makes more difficult) an efficient development of expectancy-based strategies in our Stroop-priming task, thus leading to a congruency effect (slower responses to incongruent than to congruent targets), it would be plausible to find a more negative N2 component in incongruent compared to congruent trials for all our participants, irrespective of their WMC. On the contrary, at the SOA of 700 ms, a differential ERP pattern for participants with lower vs. higher WMC should be observed. Whereas individuals with lower WMC would again show an enlarged N2 component in incongruent trials similar to that found at the shorter 300-ms SOA, the difference in amplitude of N2 between incongruent and congruent conditions should be significantly reduced (or even eliminated) in higher WMC individuals. By means of expectancy generation, high WMC individuals should not experience a cognitive conflict in incongruent trials, as expressed by putatively reversed behavioral Stroop effects at the 700-ms SOA.

2. Materials and Methods

2.1. Participants

Seventy-four right-handed undergraduate students (59 women) from the University of Almeria (age range = 18 - 40 years; *M* = 21.49, *SD* = 4.03) received course credits for their participation in the study. All participants were native Spanish speakers with normal or corrected-to-normal vision. This sample size was greater than that used by previous studies investigating the influence of either aging or adult differences in WMC on expectancy-based strategies with this Stroop-priming task (e.g., Froufe et al., 2009; *n* = 67; Ortells et al., 2018; *n* = 44; Noguera et al., 2019; Exp 1 and 2, *n* = 52). The experiment was conducted in compliance with the Declaration of Helsinki, and with the ethical protocols and recommendations of the "Code of Good Practices in Research", "Commission of Bioethics in Investigations from the University of Almeria". Participants were informed of the details of the experiment and signed an informed consent before their inclusion, with the protocol being approved by the Bioethics Committee in Human Research from the University of Almeria.

2.2. Stimuli and Apparatus

The experiment was run on a PC using E-prime software v2.0 (Psychology Software Tools, Pittsburgh, PA). The stimuli were presented on a 17-inch CRT monitor (screen refresh rate: 16.67 ms) at a viewing distance of approximately 60 cm, and the responses were collected using mouse and joystick.

In the Change Localization task, four colored circles about 0.96º horizontally and 0,96º vertically were presented on a grey (RGB values 60, 60, 50) background screen. The four circles were randomly selected from a set of nine colors with the following RGB values: Black (0, 0, 0), Blue (0, 0, 255), Cyan (0, 255, 255), Green (0, 255, 0), Magenta (255, 0, 255), Orange (255, 113, 0), Red (255, 0, 0), Yellow (255, 255, 0) and White (255, 255, 255). The colors of the four circles were not repeated on the same screen and each one appeared randomly in one quadrant of the screen with a minimum and maximum distance respective to the central fixation point of 3.36º and 4.8º visual angle, respectively.

In the Stroop-priming task, the prime stimulus was either the word RED or GREEN (with font Courier New to size 22) written in white, whose letters occupied an approximate area of about 0.35º visual angle in width and of about 0.52º visual angle in height. The target stimulus was a rectangular patch presented in either red (255, 0, 0) or green (0, 255, 0) at fixation (7.39º horizontally and 2.6º vertically). All stimuli were presented on a black background (0, 0, 0).

2.3. Design and Procedure

Participants attended a single experimental session lasting about 55-60 minutes. Each participant first completed the Change Localization Task (e.g., Noguera et al., 2019; Ortells et al., 2018; see also Johnson et al., 2013), which allowed to assess their WMC. In this task, each trial started with a fixation point (+) in the center of the screen that remained on the screen until the end of the trial. After 1,000 ms, a sample array displaying four color circles (each circle colored in a different color) was presented for 100 ms. After a 900 ms black screen, a test array appeared, which was similar to the previous sample array except that one of the four circles had changed its color, and participants had to indicate the location of the change using the mouse (see for example Ortells et al., 2018, Figure 1, for a similar version of the task). Participants performed 12 practice trials followed by two experimental blocks of 32 trials per block, with a break interval between them. A variant of the Pashler/Cowan K equation (e.g., Cowan et al., 2005) was used to evaluate participants' WMC. As each stimulus array contained four circles and each test array always contained a circle that changed color, the proportion of correct responses from each participant was multiplied by four to calculate their WMC (*K* score). After completing the change localization task, each participant performed the Stroop-priming task (see Figure 1).

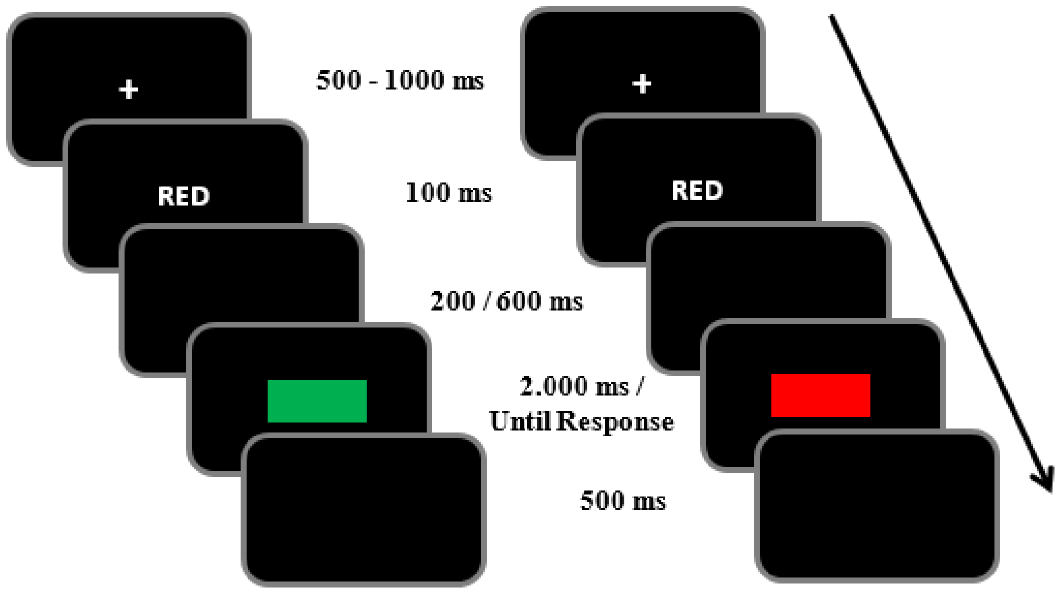


Figure 1. Examples of incongruent **(left)** and congruent **(right)** trials in the Stroop-priming task.

Each experimental trial of the Stroop-priming task started with a central fixation point (variable duration between 500-1000 ms) followed by a prime word in Spanish [‘VERDE’ (GREEN) or ‘ROJO’ (RED)] in white letters displayed for 100 ms. After the prime word offset, a blank screen was presented for either 200 or 600 ms (thus resulting in a prime-target Stimulus Onset Asynchrony –SOA- interval of either 300 or 700 ms). Thereafter, a target stimulus (a central rectangle in either red or green) was shown, which remained on the screen until the response was given. Participants responded to the rectangle color by pressing one of the two buttons of a joystick with the index fingers of their two hands (hand counterbalanced across participants). The prime and target stimuli referred to either the same color (congruent trials) or different colors (incongruent trials) on 25% and 75% of the trials, respectively. At the beginning of the experiment, participants received information about the differential proportion of congruent and incongruent pairs, and were actively encouraged to strategically use that information to improve their performance in the task. Participants performed 24 practice trials followed by two experimental blocks (144 trials per block), one block for each SOA condition (300 and 700 ms), with the order of the two blocks being counterbalanced across participants. Each SOA block was divided into three blocks of 48 trials each (12 congruent trials and 36 incongruent trials), with breaks between them where participants could rest and move.

2.4. EEG recording and analysis

The participants were seated in a comfortable chair in a dimly lit, electrically shielded room. Scalp voltages were continuously recorded from 29 active electrodes mounted in a cap (actiCAP, Brain Products, Munich, Germany) arranged according to the international 10–10 system. An electrode between Fpz and Fz was connected to the ground, and an electrode between Fz and Cz was used as recording reference. Vertical eye movements were monitored with supra- and infraorbital electrodes. Two additional electrodes were attached over the left and right mastoids. ERP data were off-line re-referenced to averaged mastoids. All EEG electrode impedances were maintained below 5 kΩ. Brain electrical signals were digitized with a sampling rate of 250 Hz (0.1–70 Hz band-pass, 50 Hz notch filter) by an AC-coupled amplifier (Brain Amp, Brain Products, Munich, Germany). After recording, EEG data was digitally band-pass filtered (high cutoff: 25 Hz, 24 dB/octave attenuation; low cutoff: .2 Hz, 12 dB/octave attenuation), and segmented from 100 ms pre-target onset to 1000 ms post-target onset. The EEG was corrected for ocular/blink artifacts using independent component analysis (ICA; Makeig, Bell, Jung, Ghahremani, & Sejnowski, 1997). Remaining ocular and muscular artifacts were automatically rejected in any EEG channel (maximum amplitude in the recording epoch ±100 μV; maximum difference between two consecutive sampling points 50 μV; maximum difference of two values in the epoch 200 μV; lowest allowed activity-change 0.5 μV in successive intervals of 100 ms) and, corresponding EEG segments were excluded from averaging. EEG data were corrected to a 100 ms baseline prior to the onset of the target (the last 100 ms of the time interval of the empty screen). Finally, electrodes were re-referenced to averaged mastoids. Artifact-free EEG segments to trials with correct responses were averaged separately for the four combinations of SOA and congruency conditions (with the mean percentage of EEG analyzable epochs per condition given in parentheses): 300-ms SOA (94% and 94.4% for congruent and incongruent conditions, respectively); 700-ms SOA (93.5% and 94.5% for congruent and incongruent trials, respectively).

Nine electrodes of fronto-central scalp regions (electrode sites: F3/F4, FC1/FC2, Fz, FCz, Cz, C3/C4), in which the N2 ERP component is usually largest (Donohue et al., 2016; Jongen et al. 2011; Tillman & Wiens, 2011; see Folstein & Van Petten, 2008, for a review), were selected for statistical analyses. Based on the theoretical expectations formulated in the introduction, we chose the time window of 190-290 ms post-target onset (encompassing the N200 component) for statistical analysis of the ERP data (the exact position and extension of that time window was based on visual inspection; see also Footnote 4). Mean amplitudes in the 190-290 ms post-target time range were computed for each of those electrodes. A repeated measures 2 x 2 x 3 x 3 ANOVA was performed on that time window (no reliable differences were noticeable when comparing the pattern of prime-locked ERP effects associated to the different conditions), treating congruency (congruent, incongruent), prime-target SOA (300, 700 ms), laterality (left, mid, right) and caudality (frontal, fronto-central, central) as within-participant factors (p level of .05). The Geisser and Greenhouse (1959) correction was applied to all repeated measures with more than one degree of freedom, when appropriate.

3. Results

3.1. Behavioral Results

Trials containing an incorrect response (3.3%) or those with reaction times (RTs) faster than 200 ms or more than 2.5 standard deviations from the overall mean RT (1.8%) were removed from analyses. For the analysis of responses in the Stroop-priming task, mean RTs of correct responses and error rates (ER) were entered into two 2 x 2 Analyses of Variance (ANOVAs) with prime-target SOA (300 and 700 ms) and prime-target congruency (congruent and incongruent) as within-participant factors. Mean correct RTs and ER as a function congruency and SOA conditions are depicted in Table 1.

The ANOVA on ERs showed no significant effects [all *F*s < 1]. The ANOVA on RTs showed a significant main effect of congruency [F (1, 73) = 29.87, p < 0.001, η^2 = 0.29], with slower responses on incongruent (450 ms) than on congruent trials (438 ms) (i.e., a standard Stroop congruency effect). In addition, congruency interacted with prime-target SOA [F (1, 73) = 37.7, p < 0.001, η^2 = 0.34]. A further analysis of this interaction (see Table 1) showed a reliable Stroop congruency effect at 300-ms SOA [-22 ms; t (74) = 8.74, p < 0.001, d = 0.37], with this congruency effect being nonsignificant at the longer 700-ms SOA [-2 ms; t < 1].

Table 1. Mean (SD) correct reaction times (ms) and error percentages (in %) for congruent and incongruent trials in the Stroop-priming task, at 300-ms SOA and 700-ms SOA.

	Congruent	**Incongruent**	**Stroop effect**
300-ms SOA	430 (59.7)	453 (61)	- 22 *
	3.0 (4)	3.2 (2.8)	
700-ms SOA	445 (64.5)	447 (63.4)	- 2
	3.6 (3.7)	3.5 (2.8)	

In order to test whether the strategic use of congruency proportion in the Stroop-priming task was modulated by individual differences in WMC, we conducted an analysis of covariance (ANCOVA) treating prime-target SOA and congruency as within-participants factors, and WMC as a continuous covariate (for similar analyses, see Hutchison, 2007; Ortells et al., 2018; Richmond et al., 2015). The results showed again a main effect of prime-target congruency [F (1, 72) = 19.34, $p < 0.001$, $\eta^2 = 0.21$], which interacted with WMC [F (1, 72) = 13.35, $p = 0.001$, $\eta^2 = 0.16$] and SOA [F (1, 72) = 4.48, $p = 0.038$, $\eta^2 = 0.06$], and most importantly, there was a significant three-way interaction between SOA, Congruency, and WMC [F (1, 72) = 8.95, $p = 0.004$, $\eta^2 = 0.11$].

To decompose this latter interaction, we analyzed the Congruency x WMC interaction separately for the 300-ms and 700-ms SOA conditions (see Figure 2). At the 300-ms SOA condition, no reliable congruency x WMC interaction was found [F (1, 72) = 1.26, $p > 0.266$]. Hence, participants consistently responded slower on incongruent than on congruent trials (i.e., a standard Stroop congruency effect) regardless of their WM capacity. In clear contrast, at the longer 700-ms SOA condition, there was a reliable crossover interaction between congruency and WMC [F (1, 72) = 21.57, $p < 0.001$, η^2 = 0.23], which shows that only participants with higher WMC were able to use an efficient strategic of congruency proportions, giving rise to a reversed strategic Stroop effect (see Table 2 for descriptive statistics; see also Figure 3[3]). In fact, at the SOA of 700 ms, there was a reliable negative correlation between participants' WMC and the congruency effect [r = -.48, $p < 0.001$].[4]

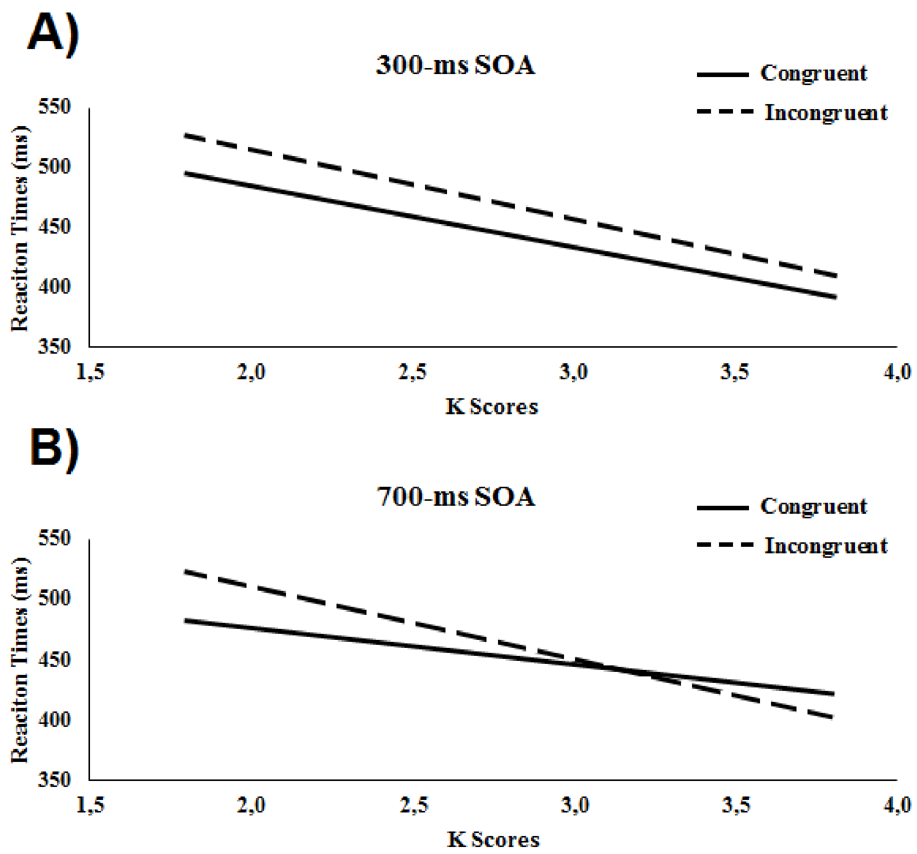


Figure 2. Participants' response time (ms) for congruent and incongruent conditions in the Stroop-priming task as a function of WMC (K) scores under **(A)** 300-ms and **(B)** 700-ms SOA conditions.

Table 2. Descriptive statistics for the Change Localization task and the Stroop-priming effects (incongruent minus congruent; in milliseconds) for each SOA-condition in the Stroop-priming task (300 ms and 700 ms).

	Change Localization Task			Stroop-priming Task					
				300-ms SOA			**700-ms SOA**		
	K Mean (SD)	**Skew**	**Kurtosis**	**Stroop effect (SD)**	**Skew**	**Kurtosis**	**Stroop effect (SD)**	**Skew**	**Kurtosis**
Overall Sample	3.08 (0.41)	-0.48	0.23	- 22.54 (22.18)	0.65	0.87	- 2.10 (25.89)	0.25	0.86
Low-WMC Group	2.71 (0.34)	-0.65	0.28	- 29.37 (27.54)	0.57	-0.39	- 14.79 (26.29)	0.90	0.27
Medium-WMC Group	3.04 (0.18)	-1.02	0.63	- 19.61 (21.78)	0.03	0.60	- 6.74 (18.49)	-0.10	0.16
High-WMC Group	3.48 (0.21)	-0.76	0.63	- 18.52 (14.41)	0.20	0.44	+ 15.05 (22.89)	-0.26	-0.46

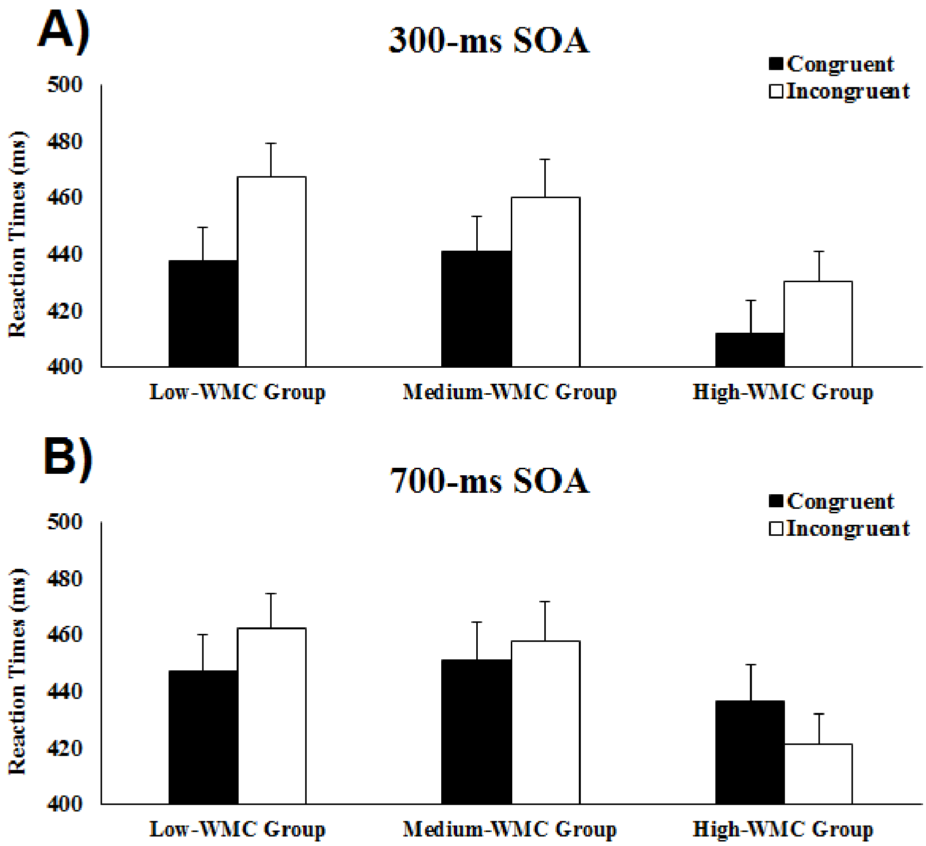


Figure 3. Mean reaction times (and standard error of the mean) for congruent and incongruent prime-target pairs as a function of SOA condition (A: 300-ms SOA; B:700-ms SOA) and WMC group (low-, medium-, and high-WMC).

3.2. Electrophysiological Results

The ANOVA on the 190-290 post-target epoch (N2) showed significant main effects of caudality [F (1, 72) = 25.87, p < 0.001, η^2 = 0.26] and laterality [F (1, 72) = 11.33, p < 0.001, η^2 = 0.13]. The voltages were collapsed across the nine fronto-central electrode sites as neither of both interacted with either congruency or prime-target SOA. The main effect of congruency was significant [F (1, 73) = 9.51, p = 0.003, η^2 = 0.12], with the ERPs in incongruent trials being more negative than congruent trials (i.e., an enlarged N2 component in incongruent trials). The interaction between congruency and SOA was also significant [F (1, 73) = 13.92, p = 0.001, η^2 = 0.16]: At the 300 ms SOA, N2 amplitude was reliably more negative for incongruent than for congruent trials [-0.71

μV; *t* (73) = 4.36, $p < 0.001$, $d = 0.33$]. However, this was not the case at the 700 ms SOA, in which the voltage difference between the two-congruency conditions was not significant [-0.05 μV; $t < 1$; see Figure 4].

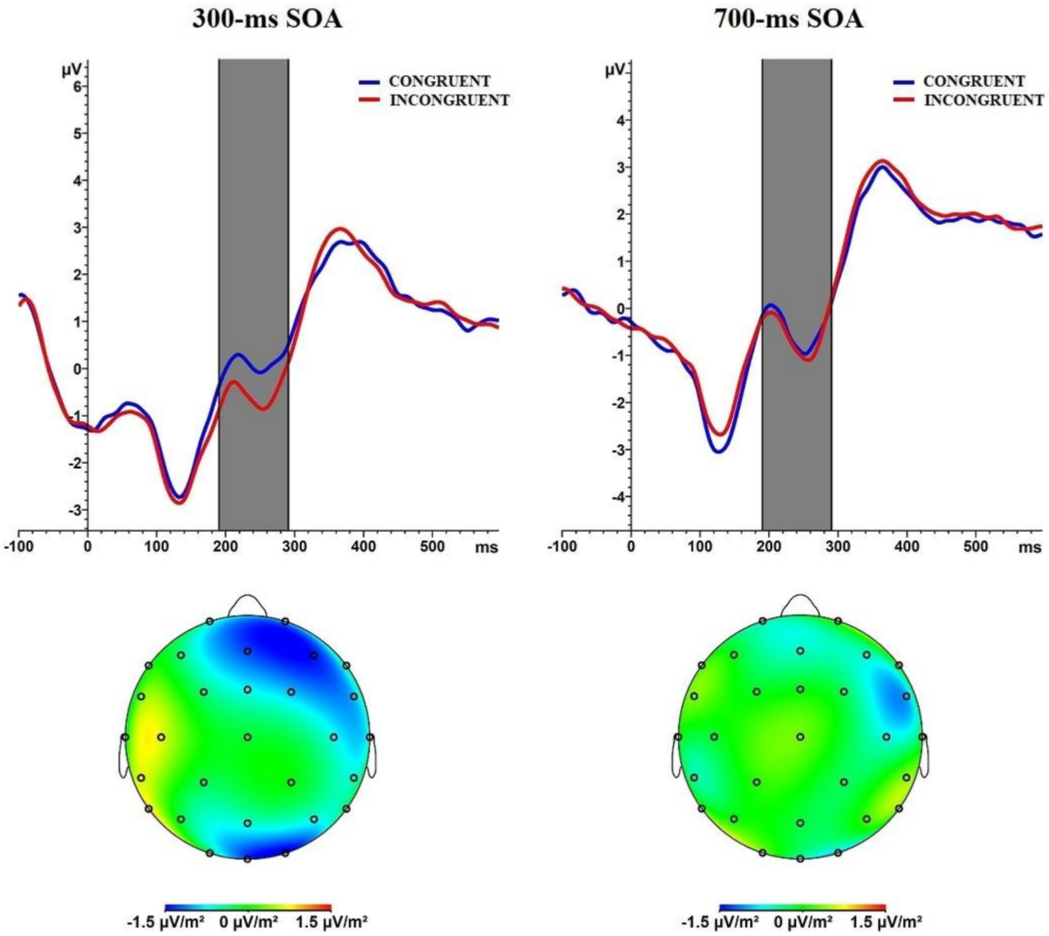


Figure 4. Grand-averaged voltage data (collapsed across fronto-central electrode sites) in the two SOA conditions (**A:** 300 ms, **B:** 700 ms) as a function of prime-target congruency (**blue**: congruent, **red**: incongruent). The analyzed epoch lasted from 100 ms before the target onset to 600 ms post-target. Negative potentials are plotted downwards. Vertical gray shadings above the X-axes indicate the 190-290 ms and the topographic voltage maps across the 29 electrode sites, displaying the N2 conflict effects, coded in color, averaged in the same time window (incongruent minus congruent conditions).

We conducted again an ANCOVA, using WMC as a continuous covariate variable and prime-target SOA and congruency as within-participants factors. This analysis showed an interaction between SOA and Congruency [F (1, 72) = 4.39, $p = 0.04$, η^2 =

0.06] and, as also found in the previous analysis, a significant three-way interaction between SOA, Congruency, and WMC [F (1, 72) = 6.9, p = 0.011, η^2 = 0.09].

At the 300-ms SOA condition, no reliable congruency x WMC interaction was found [F (1, 72) = 0.68, p > 0.41]: Participants consistently showed a higher negative amplitude on incongruent than on congruent trials lower on incongruent than on congruent trials (i.e., a N2 component) regardless of their WM capacity (see Figure 5A). In contrast, at the longer 700-ms SOA condition, there was a crossover interaction between congruency and WMC [F (1, 72) = 5.31, p = 0.024, η^2 = 0.07], such that a higher WMC was associated with a smaller negative amplitude (or a higher positive amplitude on incongruent trials) whereas lower-WMC participants showed a greater negativity in incongruent trials as at the shorter 300-ms SOA (see Figure 5B). In addition, at the longer SOA of 700 ms, there was a reliable correlation between participants' WMC and the congruency effect [r = .26, p = 0.024].[5]

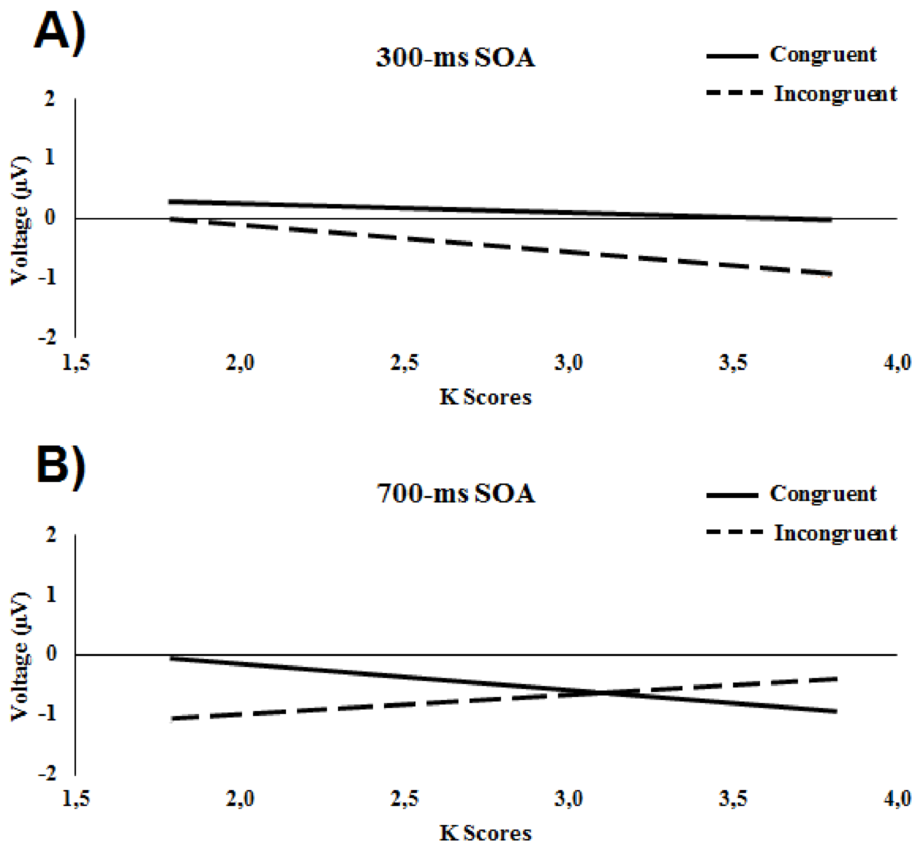


Figure 5. Participants' voltage (µV) for congruent and incongruent conditions in the Stroop-priming task as a function of WMC (K) scores under **(A)** 300-ms and **(B)** 700-ms SOA conditions in the 190-290 ms window.

4. Discussion

Although WM and selective attention have traditionally been considered to be separated cognitive concepts, evidence from different lines of research has been accumulated in support of close link between these two constructs (e.g., De Fockert, 2013; Gazzaley, 2012; Kiyonaga & Egner, 2014; Zanto & Gazzaley, 2014). Numerous studies have consistently demonstrated that a reduction in the availability of WM resources, as consequence of either cognitive ageing, having lower WMC, or imposing a high load in a concurrent memory task, is associated with a worse performing in different kinds of selective attention tasks. The usual finding is a reduced ability to efficiently inhibit or suppress the processing of competing, but task-irrelevant distractors.

More recently, evidence has been reported about variations in WM control resources may also affect forward-acting controlled attention strategies like expectancy generation. Under conditions that encourage the use of predictive strategies in different kind of cued-priming tasks (i.e., a differential proportion of related and unrelated prime-target pairings), controlled (strategic) priming effects are significantly reduced (or even reversed) for individuals with a lower-WMC (or older people), or when participants perform a concurrent WM task demanding a high load (e.g., Froufe et al., 2009; Heyman et al., 2014; Hutchison et al., 2014; Noguera et al., 2019; Ortells et al., 2018).

To our knowledge, however, no attempt has been made so far to explore whether electrophysiological (ERP) correlates of strategic (vs. non-strategic) priming effects could also be modulated by variations in WMC. This was the main goal of the present research. More concretely, we aimed to investigate whether the development of expectancy-based strategic processes could show a differential time-course in lower-WMC vs. higher-WMC individuals. Accordingly, participants' brain related-activity (ERP) was registered while they performed two consecutive trial blocks of a Stroop-priming task with a higher proportion of incongruent (75%) than of congruent trials (25%). The two trial blocks were identical except in the prime-target SOA (300 ms vs. 700 ms). The inclusion of both relatively short (300 ms) and longer (700 ms) SOA intervals in this kind of Stroop priming task had previously demonstrated to be effective to induce to find qualitatively different behavioral effects (i.e., Stroop priming effects in opposite directions) resulting from a strategic vs. non-strategic (automatic) processing of the prime stimulus (e.g., Daza et al., 2002; Noguera et al., 2019; Ortells et al., 2003). Previously to the Stroop priming task, all participants performed a Visual Change Localization task to assess their WMC (e.g., Castillo et al., 2020; Noguera et al., 2019; Ortells et al., 2018).

There were several relevant findings in our study. Firstly, the behavioral results showed a reliable three-way interaction between Congruency, prime-target SOA, and WMC, which replicates and extends the findings reported by other recent studies using similar strategic priming tasks (e.g., Ortells et al., 2018). Namely, under a relatively short prime-target SOA of 300 ms, which did not appear to be long enough to allow efficient strategic processing of the prime stimulus, all our participants, irrespective of their WMC, responded reliably slower to the incongruent compared to the congruent trials, despite they knew the former trials were much more frequent than the latter ones. Such a kind of non-strategic effect has been observed (i) in both younger and older adults at similar short SOA intervals (e.g., Noguera et al., 2019); (ii) in elderly populations with Alzheimer dementia even a much longer SOAs (e.g., Froufe et al., 2009); (iii) when the prime stimulus is briefly presented and immediately postmasked to impede its conscious identification (e.g., Daza et al., 2002; Merikle & Joordens, 1997); or (iv) when participants are required to perform a concurrent memory task demanding a high load (e.g., Ortells et al., 2017; 2018).

On the contrary, when the prime-target SOA was lengthened to 700 ms in our study, participants responded faster to the (more expected) incongruent targets than to congruent targets. This strategic reversal of the Stroop congruency is the behavioral effect that one usually finds in this Stroop priming paradigm when participants can consciously identify the prime, and the prime-target SOA is enough long to allow them to use the predictive information provided by the prime word to anticipate the target color (e.g., Daza et al., 2002; Froufe et al., 2009; Merikle & Cheesman, 1987; Merikle & Joordens, 1997; Noguera et al., 2019; see also Ortells et al., 2017). The present study replicates and extends those findings in demonstrating that such reversed strategic effect emerged only in participants with higher WMC (i.e., those scoring better in the change localization task), but not in lower WMC individuals, as revealed by a significant interaction between Congruency and WMC at the 700-ms SOA.

Further support of this dependence of strategic processing on WM resources can be found in a recent study by Noguera et al. (2019; Experiments 1-2), who also used the change localization task to assess WMC of both young and healthy older participants. At a prime-target SOA of 400 ms, both age groups responded slower to incongruent than to congruent targets, but at a longer 1000-ms SOA, only the younger participants showed a reversed (strategic) effect in the Stroop priming task. The older group, who scored worse in the WMC task, showed again a non-strategic Stroop congruency effect. The fact that our long prime-target SOA interval was 300 ms shorter than the 1000-ms SOA used by Noguera et al. (2019) could explain why our young participants did not show an overall reversed Stroop, as was the case in Noguera et al.' study. While we cannot completely rule out this possibility, note that the young groups in the experiments by Noguera et al. had scored in the WMC task much better (Exp 1: K = 3,25; Exp 2: K = 3,18) than our young participants (K = 3,08). These differences in WMC scores can also explain why Ortells et al. (2018) found a strategic effect in the low WM load condition by the overall sample of participants only in Experiment 2 (+ 21 ms), but a non-significant Stroop congruency (- 4 ms) in Experiment 1, despite the same Stroop priming task and prime-target SOA (1000 ms) were used in the two experiments. Interestingly, whereas participants in Experiment 2 had a relatively high mean K score (3,28), as in Noguera et al.' study, the overall participants' K score in Experiment 1 by Ortells et al (2018) was clearly lower (3,09), a WMC score very similar to that found in our study.

The inability of low-WMC participants to show a reversed Stroop effect at the longer 700-ms SOA, resembles the absence of strategic priming effects showed by older individuals in several prior studies using similar priming tasks (e.g., Froufe et al., 2009;

Noguera et al., 2019). In order to account for impaired cognitive control shown by older adults and several clinical populations (e.g., schizophrenia patients), Braver and colleagues have proposed that goal directed behavior would be the result of a dual-mechanisms cognitive control (DMC): proactive and reactive control (e.g., Braver et al., 2001; Braver, Burgess, and Gray, 2007; see Braver, 2012, for a review). Proactive control reflects an effortful (resource demanding) and preparatory mode of control, which involves maintaining goal-relevant contextual information in an accessible state and using predictive cues to prepare a specific response to an upcoming target. In contrast, the reactive control does not require continuous monitoring (and maintenance) of contextual cues, but instead depends on the target information to automatically retrieve the appropriate actions from long-term memory. By using different cue-probe tasks (e.g., the AX-Continuous Performance Test, AX-CPT), numerous studies have reported evidence that older adults, as well as younger adults with low WMC, are less likely to efficiently use a proactive cognitive control mode than young adults high in WMC (e.g., Braver et al., 2007; Redick, 2014; Redick and Engle, 2011; Richmond et al., 2015; Wiemers and Redick, 2018).

The proactive control involved in maintaining an expected response in a cue-probe task (AX-CPT) in the DMC model, corresponds closely to the forward-acting attention strategy (expectancy generation) invoked to explain controlled semantic priming. This prospective expectancy mechanism is assumed to be under conscious control, effortful, relatively slow, and involves using the prime to develop an expectancy for specific related targets during the SOA interval between prime and target onset in a priming task (Becker, 1980; Neely, 1977; Posner and Snyder, 1975; for a review see Neely, 1991). Note on this respect that the differences in performance showed by high- vs. low-WMC individuals, are mainly observed in controlled priming effects which depend on prospective (or proactive) expectancy mechanisms, but not in priming effects resulting from a non-strategic (automatic) prime processing (e.g., Heyman et al., 2014; Hutchison, 2007; Hutchison et al., 2014; Neely, 1991).

These lines of argument could be used to explain why our high-WMC vs. low-WMC participants showed a different (opposite) priming pattern at 700-ms SOA, but not at the shorter 300-ms SOA. To the extent that the later SOA interval would impede an adequate implementation of prospective (or proactive) controlled strategies in our study, we would expect to find a fairly similar non-strategic Stroop-priming effect irrespective of participants' WMC. We indeed found this result pattern, as all our participants responded consistently slower to the incongruent than to congruent targets, despite foreknowing the former were much more frequent than the later ones.

On the contrary, when the prime-target SOA was lengthened to 700 ms, thus making more probable that participants could rely on expectancy-based proactive control strategies (i.e., when environmental cues are helpful), it is not unreasonable that only participants with a high-WMC, but not those with lower-WMC, showed a reliable reversal of Stroop priming effect. Note in fact, that the size of this strategic priming at the longer 700-ms SOA reliably correlated with participants' scores in the change localization task.

Similar differences between high- vs. low-WMC individuals in the use of predictive strategies to guide response selection to subsequent targets have been observed with other cued attention paradigms, as the antisaccade task (e.g., Kane, Bleckley, Conway, & Engel, 2001; Ortells et al., 2016; Noguera et al., 2019; Unsworth, Schrock, & Engle, 2004).

In either case, the fact that our participants with a lower-WMC showed no evidence for expectancy use at the longer 700-ms SOA, responding slower to the incongruent than to congruent trials, does not necessarily demonstrate that they mainly relied on reactive (rather than proactive) control strategies. Our study does not allow to determine whether low-WMC individuals are indeed unable to implement expectancy-based strategies that would overcome automatized response tendencies, or rather they can generate expectancies, but these could take longer than in high-WMC individuals. The current design is unable to distinguish between these two possibilities, which could be addressed by future experiments specifically designed to examine them. Yet, the results of some recent studies in our labs suggest that a reduced WM capacity, resulting for example from aging, would mainly affect the instantiation (time course) of predictive strategies. For example, Noguera et al. (2019) found healthy older people were unable to show strategic priming effects (e.g., a reversed Stroop) at a relatively long SOA of 1000 ms. However, they showed strategic priming effects of a comparable magnitude to those by young adults, when the prime-target SOA was lengthened to 2000 ms.

Regarding our ERP findings, they are clearly consistent with the behavioral results. At the shorter SOA of 300 ms, in which our participants consistently responded slower on incongruent than on congruent trials (i.e., standard Stroop congruency effect; see Figure 2A), we found a negative deflection at fronto-central electrode sites in the time window between 190-290 ms (see Figure 4). This ERP modulation (N2) is typically assumed to index attentional conflict processing, as their amplitude is more negative in conflicting (e.g., an incongruent Stroop trial) as compared to non-conflict conditions in the attention task (e.g., Clayson & Larson, 2011; Donohue et al., 2016; Ridderinkhof et al., 2004; see Folstein & Van Petten, 2008, for a review).

Although the N2 component (and some other late ERP components, such as N450; see for example Larson, Kaufman, & Perlstein, 2009; Kałamała et al., 2020) is usually found in ERP studies using a conventional Stroop task where both irrelevant (e.g., word) and irrelevant (color ink) stimulus features are simultaneously presented, some previous work has reported similar N2 modulations using sequential variants of Stroop-like tasks (e.g., Gajewski, Stoerig, & Falkenstein, 2008). Congruency effects on the N2 have been also observed during visuo-motor priming paradigms, suggesting that this ERP components indexes resolution of response conflicts (Kiefer, Liegel, Zovko & Wentura, 2017; Martens, Ansorge & Kiefer, 2011). To the extent that showing slower RTs to an incongruent target at 300-ms SOA would reflect a non-strategic processing of the prime word in our Stroop priming task, we expect to find a fairly similar N2 modulation in all our participants, irrespective of their WMC. Our results are clearly consistent with these predictions, as revealed by the lack of a reliable interaction between congruency and WMC ($F < 1$) at this shorter SOA. Thus, both low- and high-WMC participants showed a greater N2 amplitude on incongruent than on congruent trials (see Figure 4).

At the longer 700-ms SOA, however, the observed ERP pattern was reliably affected by individual differences in WMC. Thus, participants with a lower WMC showed again an enlarged N2 component in incongruent trials, as under the shorter 300-ms SOA. This supposedly non-strategic ERP pattern was comparable with the behavioral Stroop congruency effect at the corresponding SOAs. In clear contrast, the N2 component was completely absent in participants with a higher WMC, with similar amplitude for both incongruent and congruent trials. The elimination of the N2 effect at 700-ms SOA in participants with high WMC seems to confirm that, after a longer SOA interval, they were able to strategically process the prime and prepare to respond to the opposite color, thus counteracting the supposedly automatic interference effect.

5. Limitations and future directions

The elimination of the N2 ERP component (which was associated to a reversed behavioral Stroop congruency) observed at the 700ms-SOA in higher WMC participants was assumed to reflect a more efficient implementation of expectancy-based strategies by these individuals.

Note however that the participants in our study were informed about the greater proportion of incongruent relative to congruent prime-target pairings, and actively encouraged for using predictive strategies (e.g., preparing to respond to the opposite-incongruent color to that of the prime word) to improve their performance. Consequently, it is not implausible that high- and low-WMC groups showed some differential EEG effects during preparation preceding the target onset (i.e., prime-locked ERP activity registered in the interval between the color prime word and the target), particularly at the longest 700 ms-SOA. For example, given that participants responded with different hands to the two targets, it remains possible that they begin to prepare a concrete response (e.g., a right-hand response to a red target) on presentation of the opposite prime color word (GREEN). If so, we could see an increased frontal negativity prior to the target onset at the longest 700-ms SOA, particularly in higher WMC participants, which might even be lateralized to the contralateral side (lateralized readiness potential; e.g., C3 for a right-hand response). To test such hypothesis, we conducted further analyses in different time windows preceding the target onset (e.g., from -400 to -200 ms; from -200 ms to 0 ms), treating WMC as a continuous covariate. Yet, no reliable effect related to WMC was found, thus suggesting that a similar preparatory EEG activity (e.g., response preparation on presentation of the prime word) for both higher-WMC and lower-WMC individuals. Whether individual differences in WMC could modulate some prime-locked ERP activity during the SOA period at prime-target SOA intervals longer than those used in the present study, it remains an open issue for future research.

The use of relatively longer prime-target SOAs in the Stroop priming task could also allow us to distinguish between WMC effects on the formation/generation of expectations and effects on the strategic use/exploitation of the expectations to maximize performance. The current task design is not capable of disentangling between these two possibilities. Some prior work on normal aging has reported that not only the ability to inhibit irrelevant information, but also de ability to implement forward-acting control strategies (i.e., expectancy generation) would be delayed in time, rather than abolished (e.g., Noguera et al., 2019; Gazzaley et al., 2008). An interesting issue to be addressed by future research is whether low-WMC individuals could be able to efficiently generate predictive expectations and counteract the automatic (Stroop congruency) effects in our task when the prime-target SOA is lengthened (e.g., at 1000 ms or longer).

It should be noted that WMC was a measured (i.e., performance in the Change Localization task), rather than manipulated, variable. The differences observed in the Stroop priming task as a function of WMC, could at least partly reflect other potential differences between participants (e.g., motivational factors, perceptual ability, speed of processing, etc.). If, for example, prospective controlled mechanisms such as expectancy generation are assumed to depend on the ability to quickly recognize primes, high-WMC individuals could be better able to quickly recognize the prime words, allowing for a greater contextual influence from the primes in the priming task (see Hutchison et al., 2014, for a similar line of argument). Participants with a higher-WMC showed, in fact, decreased reaction times in all experimental conditions (see Figures 2 and 3), as revealed by a reliable negative correlation between participants' scores in the Change Localization test and their overall mean RTs (averaged across congruency and SOA conditions) in the Stroop priming task [r = -.35, p = 0.002]. We did not register, however, additional measurements from our participants that would allow us to determine whether low- and high-WMC participants in our study did also differ in other processes, as for example, motivation, or processing-speed. Further studies aimed to provide more direct evidence on the role of WMC on strategic (vs. non-strategic) prime processing, could examine variations in Stroop priming effects across short and longer SOAs, while directly manipulating working memory load.

6. Conclusions

Overall, the present results replicate and extend some prior demonstrations that reduced availability of WM resources (i.e., having lower WMC) not only affects the ability to inhibit irrelevant information in selective attention tasks, but it also leads to less efficient strategic processing of goal-relevant information (e.g., Heyman et al., 2014; Hutchison et al., 2014; Ortells et al., 2017; 2018; see also Noguera et al., 2019).

The Stroop priming paradigm used in the present research had consistently demonstrated to be effective to show qualitatively different (i.e., opposite) behavioral effects resulting from a strategic vs. non-strategic prime processing (e.g., Daza et al., 2002; Merikle & Cheesman, 1987; Merikle & Joordens, 1997; Noguera et al., 2019; Ortells et al., 2017; 2018). Yet, to our knowledge, this is the first time that a Stroop priming paradigm is used in an EEG study in an attempt to determine whether a differential electrophysiological (ERP) pattern can also be observed depending on the way (i.e., strategic vs. non-strategic) the prime stimulus is processed.

A second, and even more relevant contribution of the current study is that it provides the first evidence of a fairly different ERP pattern of the N2 ERP component reflecting resolution of response conflict in a Stroop-priming task as a function of individual differences in WMC. Whether a similar ERP modulation could be observed when participants perform a concurrent WM task of high vs. low load, remains an interesting matter for future research.

Acknowledgements

This research was supported by Grant PSI2017-83135-P from the Spanish Ministry of Economy and Competitiveness. Correspondence concerning this article should be addressed to either Sergio Fernández (sfg354@ual.es) or Juan José Ortells (jortells@ual.es).

7. References

Ahmed, L., & De Fockert, J. W. (2012). Focusing on attention: the effects of working memory capacity and load on selective attention. *PLoS One,* 7:e43101. doi: 10.1371/journal.pone.0043101

Atkinson, R. C. y Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. En K. W. Spence & J. T. Spence, *The psychology of learning and motivation: II.* Academic Press. doi: 10.1016/S0079-7421(08)60422-3

Baddeley, A. D. (1986). *Working memory*. Oxford: Clarendon Press.

Becker, C. A. (1980). Semantic context effects in visual word recognition: an analysis of semantic strategies. *Memory & cognition*, *8*(6), 493–512. doi: 10.3758/bf03213769

Braver, T. S. (2012). The variable nature of cognitive control: a dual mechanisms framework. *Trends Cogn. Sci., 16,* 106–113. doi: 10.1016/j.tics.2011.12.010

Braver, T. S., Barch, D. M., Keys, B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., et al. (2001). Context processing in older adults: evidence for a theory relating cognitive control to neurobiology in healthy aging. *J. Exp. Psychol. Gen., 130,* 746–763. doi: 10.1037//0096-3445.130.4.746

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). "Explaining the many varieties of working memory variation: dual mechanisms of cognitive control," in Variation in Working Memory, eds A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (New York, NY: Oxford University Press), 76–106.

Castillo Escamilla, J., Fernández Castro, J. J., Baliyan, S., Ortells-Pareja, J. J., Ortells Rodríguez, J. J., & Cimadevilla, J. M. (2020). Allocentric Spatial Memory Performance in a Virtual Reality-Based Task is Conditioned by Visuospatial

Working Memory Capacity. *Brain sciences*, *10*(8), 552. doi: 10.3390/brainsci10080552

Clayson, P. E., & Larson, M. J. (2011). Conflict adaptation and sequential trial effects: Support for the conflict monitoring theory. *Neuropsychologia, 49,* 1953–1961.

Conway, A. R., Tuholski, S. W., Shisler, R. J., & Engle, R. W. (1999). The effect of memory load on negative priming: An individual differences investigation. *Mem. Cognition, 27*, 1042-1050. doi: 10.3758/BF03201233

Cowan, N., Elliott, E. M., Saults, J. S., Morey, C. C., Mattox, S., Hismjatullina, A., et al. (2005). On the capacity of attention: its estimation and its role in working memory and cognitive aptitudes. *Cogn. Psychol., 51*, 42–100. doi: 10.1016/j.cogpsych.2004.12.001

Daza, M. T., Ortells, J. J., & Fox, E. (2002). Perception without awareness: further evidence from a Stroop priming task. *Percept. Psychophys., 64*, 1316–1324. doi: 10.3758/BF03194774

De Fockert, J. W. (2013). Beyond perceptual load and dilution: A review of the role of working memory in selective attention. *Front. Psychol.*, *4*, 1-11. doi: 10.3389/fpsyg.2013.00287

De Fockert, J. W., Mizon, G. A., & D'Ubaldo, M. (2010). No negative priming without cognitive control. *J. Exp. Psychol. Human, 36,* 1333-1341. doi: 10.1037/a0020404

De Fockert, J.W., Rees, G., Frith, C. D., & Lavie, N. (2001). The role of working memory in visual selective attention. *Science*, *291*, 1803–1806.

Donohue, S. E., Appelbaum, L. G., McKay, C. C., & Woldorff, M. G. (2016). The neural dynamics of stimulus and response conflict processing as a function of response complexity and task demands. *Neuropsychologia*, *84,* 14–28. doi:10.1016/j.neuropsychologia.2016.01.035

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: a review. *Psychophysiology*, *45*, 152–170. doi:10.1111/j.1469-8986.2007.00602.x

Frings, C., & Groh-Bordin, C. (2007). Electrophysiological correlates of visual identity negative priming. *Brain research*, *1176*, 82–91. doi: 10.1016/j.brainres.2007.07.093

Froufe, M., Cruz, I., & Sierra, B. (2009). (dis)Función ejecutiva en personas mayores con y sin Alzheimer: actuación estratégica basada en expectativas. *Psicológica, 30*, 119–135.

Gajewski, P. D., Stoerig, P., & Falkenstein, M. (2008). ERP--correlates of response selection in a response conflict paradigm. *Brain research*, *1189*, 127–134. doi: 10.1016/j.brainres.2007.10.076

Gazzaley, A. (2012). “Top-down modulation deficit in the aging brain: an emerging theory of cognitive aging,” in *Principles of Frontal Lobe Function*, 2nd Edn, eds D. T. Stuss and R. T. Knight (New York, NY: Oxford University Press), 593–608.

Gazzaley, A., Clapp, W., Kelley, J., McEvoy, K., Knight, R. T., & D’Esposito, M. (2008). Age-related top-down suppression deficit in the early stages of cortical visual memory processing. *P. Natl. Acad. Sci. USA, 105,* 13122–13126. doi:10.1073/pnas.0806074105

Gazzaley, A., & Nobre, A. C. (2012). Top-down modulation: bridging selective attention and working memory. *Trends Cogn. Sci., 16,* 129–135. doi: 10.1016/j.tics.2011.11.014

Geisser, S., & Greenhouse, S. (1959). On methods in the analysis of profile data. *Psychometrica*, *24*, 95–112.

Gibbons, H. (2006). An event-related potential investigation of varieties of negative priming. *Journal of Psychophysiology, 20*(3), 170–185. doi: 10.1027/0269-8803.20.3.170

Glaser, M. O., & Glaser, W. R. (1982). Time course analysis of the Stroop phenomenon. *Journal of experimental psychology. Human perception and performance*, *8*(6), 875–894. doi: 10.1037//0096-1523.8.6.875

Heyman, T., Van Rensbergen, B., Storms G., Hutchison, K. A., & De Deyne, S. (2014). The influence of Working Memory Load on Semantic Priming. *J. Exp. Psychol. Learn., 41*, 911–920. doi:10.1037/xlm0000050

Hinojosa, J.A., Pozo, M.A., Méndez-Bértolo, C., & Luna, D. (2009). Event-related potential correlates of visual identity negative priming unbiased by trial-by-trial effects. *Brain and Cognition*, *69*, 531–537

Hutchison, K. A. (2007). Attentional control and the relatedness proportion effect in semantic priming. *J. Exp. Psychol. Learn. Mem. Cogn*., *33*,645–662.doi: 10.1037/0278-7393.33.4.645

Hutchison, K. A., Heap, S. J., Neely, J. H., & Thomas, M. A. (2014). Attentional control and asymmetric associative priming. *J. Exp. Psychol. Learn., 40*, 844-856. doi:10.1037/a0035781

Johnson, M. K., McMahon, R. P., Robinson, B. M., Harvey, A. N., Hahn, B., Leonard, C. J., et al. (2013). The relationship between working memory capacity and broad measures of cognitive ability in healthy adults and people with schizophrenia. *Neuropsychology*, *27*, 220–229. doi: 10.1037/a0032060

Jongen, E. M., & Jonkman L. M. (2011). Effects of concurrent working memory load on distractor and conflict processing in a name-face Stroop task. *Psychophysiology*, *48*, 31-43. doi:10.1111/j.1469-8986.2010.01037.x

Jost, K., Bryck, R. L., Vogel, E. K., & Mayr, U. (2011). Are old adults just like low working memory young adults? Filtering efficiency and age differences in visual working memory. *Cereb. Cortex*, *21*, 1147–1154. doi:10.1093/cercor/bhq185

Kałamała, P., Ociepka, M., & Chuderski, A. (2020). ERP evidence for rapid within-trial adaptation of cognitive control during conflict resolution. *Cortex*, *131*, 151-163.

Kane, M. J., Bleckley, M. K., Conway, A. R., and Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *J. Exp. Psychol. Gen. 130*, 169-183. doi: 10.1037/0096-3445.130.2.169

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: the contributions of goal neglect, response competition, and task set to Stroop interference. *J. Exp. Psychol. Gen.*, *132*, 47–70. doi: 10.1037/0096-3445.132.1.47

Kiefer, M., Ahlegian, M., & Spitzer, M. (2005). Working memory capacity, indirect semantic priming and Stroop interference: Pattern of interindividual prefrontal performance differences in healthy volunteers. *Neuropsychology*, *19*, 332-344.

Kiefer, M., & Brendel, D. (2006). Attentional modulation of unconscious 'automatic' processes: Evidence from event-related potentials in a masked priming paradigm. *J. Cogn. Neurosci.*, *18*, 184-198.

Kiefer , M., Liegel, N., Zovko, M., & Wentura, D. (2017). Mechanisms of masked evaluative priming: Task sets modulate behavioral and electrophysiological priming for picture and words differentially. *Social Cognitive and Affective Neuroscience*, *12*(4), 596-608.

Kiefer, M., & Martens, U. (2010). Attentional sensitization of unconscious cognition: Task sets modulate subsequent masked semantic priming. *J. Exp. Psychol. Gen.*, *139*, 464-489.

Kiyonaga, A. & Egner, T. (2014). The Working Memory Stroop Effect: When Internal Representations Clash With External Stimuli. *Psychol. Sci., 25,* 1619-1629.

Larson, M. J., Kaufman, D. A., & Perlstein, W. M. (2009). Conflict adaptation and cognitive control adjustments following traumatic brain injury. *Journal of the International Neuropsychological Society: JINS*, *15*(6), 927–937. doi: 10.1017/S1355617709990701

Lavie, N., & De Fockert, J. W. (2005). The role of working memory in attentional capture. *Psychon. Bull. Rev., 12*, 669–674. doi: 10.3758/BF03196756

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load Theory of Selective Attention and Cognitive Control. *J. Exp. Psychol. Gen., 133,* 339-354. doi: 10.1037/0096-3445.133.3.339

Logan, G. D., Zbrodoff, N. J., & Williamson, J. (1984). Strategies in the color-word Stroop task. *Bulletin of the Psychonomic Society, 22*(2), 135–138. doi: 10.3758/BF03333784

Makeig, S., Bell, A. J., Jung, T.-P., Ghahremani, D., & Sejnowski, T. J. (1997). Blind separation of auditory event-related brain responses into independent components. *Proc. Natl. Acad. Sci. USA, 94*, 10979–10984.

Martens, U., Ansorge, U., & Kiefer, M. (2011). Controlling the unconscious: Attentional task sets modulate subliminal semantic and visuo-motor processes differentially. *Psychological Science, 22*(2), 282–291.

McNamara, T. P. (2005). *Essays in cognitive psychology.Semantic priming: Perspectives from memory and word recognition. New York, NY:* Psychology Press. doi: 10.4324/9780203338001

Megías, M., Ortells, J. J., Noguera, C., Carmona, I., & Marí-Beffa, P. (2020). Semantic Negative Priming From an Ignored Single-Prime Depends Critically on Prime-

Mask Inter-Stimulus Interval and Working Memory Capacity. *Frontiers in psychology*, *11*, 1227. doi: 10.3389/fpsyg.2020.01227

Merikle, P. M., & Cheesman, J. (1987). Current status of research on subliminal perception. En M. Wallendorf & P. M. Anderson (Eds.). *Advantages in Consumer Research, Vol. XIV*. Provo, UT: Association for Consumer Research.

Merikle, P. M., & Daneman, M. (1998). Psychological investigations of unconscious perception. *Journal of Consciousness Studies, 5*(1), 5–18.

Merikle, P. M., & Joordens, S. (1997). Parallels between perception without attention and perception without awareness. *Conscious. Cogn., 6*, 219–236. doi: 10.1006/ccog.1997.0310

Merikle, P. M., Joordens, S., & Stolz, J. A. (1995). Measuring the relative magnitude of unconscious influences. *Consciousness and Cognition: An International Journal, 4*(4), 422–439. doi: 10.1006/ccog.1995.1049

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *J Exp Psychol Gen., 106*: 226–254. doi: 10.1037/0096-3445.106.3.226

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. W. Humphreys (Eds.), *Basic progresses in reading - Visual word recognition* (pp. 264–333). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Neely, J. H., & Keefe, D. E. (1989). Semantic priming in the lexical decision task: roles of prospective prime-generated expectancies and retrospective semantic matching. *Journal of experimental psychology. Learning, memory, and cognition*, *15*(6), 1003–1019. doi: 10.1037//0278-7393.15.6.1003

Neely, J. H., & Keefe, D. E. (1989). Semantic context effects in visual word processing: A hybrid prospective/retrospective processing theory. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 24, pp. 207-248). New York: Academic Press.

Noguera, C., Fernández, S., Álvarez, D., Carmona, E., Marí-Beffa, P., & Ortells, J. J. (2019). The implementation of expectancy-based strategic processes is delayed in normal aging. *PloS one*, *14*, e0214322. doi:10.1371/journal.pone.0214322

Ortells, J. J., Álvarez, D., Noguera, C., Carmona, E., & De Fockert, J. W. (2017). The influence of working memory load on expectancy-based strategic processes in the stroop-priming task. *Front. Psychol., 8*:129. doi: 10.3389/fpsyg.2017.00129

Ortells, J. J., Daza, M. T., & Fox, E. (2003). Semantic activation in the absence of perceptual awareness. *Percept. Psychophys., 65,* 1307–1317. doi: 10.3758/BF03194854

Ortells, J. J., De Fockert, J. W., Romera, N., & Fernández, S. (2018). Expectancy-Based Strategic Processes Are Influenced by Spatial Working Memory Load and Individual Differences in Working Memory Capacity. *Front. Psychol., 9*, 1239. doi:10.3389/fpsyg.2018.01239

Ortells, J. J., Noguera, C., Álvarez, D., Carmona, E., & Houghton, G. (2016). Individual differences in working memory capacity modulates semantic negative priming from single prime words. *Front. Psychol., 7*, 1-14. doi: 10.3389/fpsyg.2016.01286

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola Symposium* (pp. 55-85). Hillsdale: Lawrence Erlbaum Associates.

Redick, T. S. (2014). Cognitive control in context: working memory capacity and proactive control. *Acta Psychol., 145*, 1–9. doi: 10.1016/j.actpsy.2013.10.010

Redick, T. S., & Engle, R. W. (2011). Integrating working memory capacity and context-processing views of cognitive control. *The Quarterly Journal of Experimental Psychology*, *64*(6), 1048–1055. doi: 10.1080/17470218.2011.577226

Richmond, L. L., Redick, T. S., & Braver, T. S. (2015). Remembering to prepare: the benefits (and costs) of high working memory capacity. *J. Exp. Psychol. Learn.*, *41*, 1764–1777. doi: 10.1037/xlm0000122

Ridderinkhof, K. R., Ullsperger, M., Crone, E. A., & Nieuwenhuis, S. (2004). The role of the medial frontal cortex in cognitive control. *Science*, *306*, 443–447.

Tillman, C. M., & Wiens, S. (2011). Behavioural and ERP indices of response conflict in Stroop and flanker tasks. *Psychophysiology*, *48*, 1405-11. doi: 10.1111/j.1469-8986.2011.01203.x

Unsworth, N., Schrock, J. C., and Engle, R. W. (2004). Working memory capacity and the antisaccade task: individual differences in voluntary saccade control. *J. Exp. Psychol. Learn.* 30, 1302–1321. doi: 10.1037/0278-7393.30.6.1302

Wendt, M., & Luna-Rodríguez, A. (2009). Conflict-frequency affects flanker interference: Role of stimulus-ensemble-specific practice and flanker response contingencies. *Exp. Psychol.*, *56*, 206–217.

Wiemers, E. A., & Redick, T. S. (2018). Working memory capacity and intra-individual variability of proactive control. *Acta Psychol.*, *182*, 21–31. doi: 10.3758/s13414-015-089 9-00

Zanto, T. P., & Gazzaley, A. (2014). "Attention and ageing," in *The Oxford Handbook of Attention*, eds A. C. Nobre and S. Kastner (New York, NY: Oxford University Press), 927–971. doi: 10.1093/oxfordhb/9780199675111.013.02

8. Footnotes

Note 1. It should be stressed that only when this Stroop priming task include a much higher proportion of incongruent (e.g., 75-80%) than of congruent prime-target pairings (e.g., 25-20%), one could observe a change in the direction of the difference in performance between incongruent and congruent trials, as a function of the strategic/conscious (reversed Stroop) vs. non-strategic or automatic processing (standard Stroop congruency) of the prime stimulus. By the contrary, when incongruent trials are less frequent (e.g., 20%) than congruent trials, the usual finding is a compatibility effect of a similar (or even greater) magnitude to that observed when congruent and incongruent trials are equally probable (i.e., 50/50). Thus, participants' responses to the target color are faster when it is preceded by the congruent color word than when it is preceded by the incongruent color word (e.g., Logan, Zbrodoff, & Williamson, 1984; Merikle & Cheesman, 1987). But the problem with this latter compatibility effect is that one cannot be sure whether it is mainly the result of either expectancy-based predictive strategies (congruent trials are much more expected than incongruent ones), automatic process (e.g., spreading activation), or a combination of both strategic and automatic influences, as it could be really the case.

Note 2. It is important to note that the interference (incongruent vs. congruent) effect observed in a two-color Stroop priming paradigm under task conditions that preclude a conscious/strategic prime processing, is relatively small (e.g., 15-20 ms or lesser; see for example Daza et al., 2002; Merikle & Cheesman, 1987; Merikle & Joordens, 1997; Merikle, Joordens, & Stolz, 1995). This contrasts with the magnitude of the Stroop interference that usually emerges with conventional or sequential variants of the Stroop task where conflict (incongruent) trials are equally probable, or less frequent than congruent trials (e.g., Glaser & Glaser, 1982; Merikle & Cheesman, 1987).

Note 3. Whereas the ANCOVA analysis considers the full range of WMC scores, for a better visual understanding of that analysis, Figure 3 shows participants divided into high- (k > 3.48), medium- (k < 3.04), and low-WMC (k < 2.71) groups by using a tertile split (see Richmond et al., 2015; Ortells et al., 2018 for a similar approach).

Note 4. To examine whether the observed findings could at least partly be affected by direct trial repetitions, we conducted a further data analysis, in which for each participant, we removed every trial reflecting more than two consecutive direct repetitions from the same condition. The overall mean of trials excluded was relatively low in the two SOA blocks (mean = 12 trials; at about 8,3% of trials), and very similar for all the participants (Min = 6 trials; Max = 16 trials). The results from these re-analyses without trials repetitions produced basically the same result pattern as that found in our original data analyses. Namely, the Congruency x SOA interaction was again significant [F (1, 73) = 38.27, p < 0.001, η^2 = 0.34], as it was the three-way interaction between Congruency, SOA, and WMC as a covariate [F (1, 72) = 9.65, p = 0.003, η^2 = 0.12]. Further analyses of the later interaction revealed again slower responses to incongruent than to congruent targets at the shorter 300-ms SOA, irrespective of participants' WMC. In contrast, at the longer 700-ms SOA, a reliable congruency x WMC was found (F (1, 72) = 21.08, p < 0.001, η^2 = 0.23): Whereas responses from low-WMC participants were again slower to incongruent than to congruent targets, high-WMC individuals showed an opposite priming pattern, with their responses being faster on incongruent than on congruent trials (reversed Stroop).

Note 5. A further visual inspection of ERP-data registered at fronto-central electrode sites (see Figure 4) revealed an additional voltage difference between the two-congruency conditions at a relatively early time window (90-190 ms). This ERP difference emerged at the longer 700-ms, but not at the shorter 300-ms SOA, as revealed by a reliable Congruency x SOA interaction (F (1, 73) = 7.2, p = 0.009, η^2 = 0.09). The results of a further ANCOVA showed a significant three-way interaction between these two later factors and WMC (F (1, 72) = 6.02, p = 0.017, η^2 = 0.08), which revealed that, as occurred in the later post-target epoch associated to the N2 component (190-290 ms), the ERP differences between low-WMC and high-WMC participants emerged mainly at the prime-target SOA which allowed a strategic prime processing (700 ms). Namely, lower-WMC individuals showed a more negative potential in incongruent trials, which resembles the behavioral (i.e., Stroop interference) and ERP effects (e.g., N2) usually found in Stroop conflict conditions. By contrast, individuals with a higher-WMC showed a "reversed" ERP-congruency effects, with a more negative potential to (the less frequent) congruent than to the incongruent targets. These ERP-differences between high- and low-WMC participants could be assumed to provide further evidence for a differential prime processing (strategic vs. non-strategic, respectively) in the Stroop priming task. Yet, this argument should be interpreted with caution. Whereas, overall, our findings are consistent with a supposedly more efficient (and/or faster) implementation of expectancy-based strategies in higher-WMC, relative to lower-WMC individuals, it remains unclear why prime-locked ERP activity was not modulated by WMC in the current study (see General Discussion). An alternative explanation of the ERP differences showed by high-WMC vs. low-WMC participants in an earlier time window (90-190 ms), is that they could reflect differences in sensory evoked ERP components, such as the posterior vision P100 component, an index of stimulus perception and processing (Atkinson et al., 2002; Herrmann; Earls, Curran & Mittal, 2016). But note that the ERP-congruency differences observed in our study were mainly found at fronto-central, but not at more posterior electrode sites (e.g., occipital), where the P100 ERP component is usually observed.

VI

Discusión

La presente tesis doctoral investiga una serie de cuestiones relevantes respecto a la relación entre Memoria de Trabajo (MT) y Atención Selectiva (AS), las cuales son abordadas en tres Estudios Experimentales.

I) Una primera cuestión, a la que tratamos de responder en el Estudio Experimental I, se relaciona con los mecanismos cognitivos responsables de la interferencia que puede observarse en situaciones de tarea dual, cuando el rendimiento en una tarea atencional resulta afectado por la realización concurrente de una tarea de memoria, que demanda una alta carga mental (en comparación a una condición de baja carga). ¿Dicha interferencia se produce porque ambos tipos de tareas comparten un mismo tipo de recursos generales (o inespecíficos) de control atencional, o más bien cuando las tareas comparten recursos de procesamiento más específicos, relacionados con el tipo de representación o información estimular (visual vs. verbal) implicada?

II) Una segunda cuestión relevante, que abordamos en el Estudio Experimental II, es en qué medida la capacidad diferencial de recursos de MT (como la que suele observarse entre adultos jóvenes y mayores), afecta al curso temporal no sólo de los mecanismos de inhibición atencional, sino también al de las estrategias atencionales de carácter facilitatorio (como las basadas en expectativas).

III) Una última cuestión, a la que tratamos de responder en el Estudio Experimental III de la Tesis y que apenas ha sido investigada en la literatura, es si variaciones en la disponibilidad de recursos de control cognitivo (v.g., mayor vs. menor capacidad de MT) inducen modulaciones no sólo a nivel comportamental, sino también en determinados correlatos electrofisiológicos asociados al procesamiento estratégico atencional.

1. Estudio Experimental I

Este estudio tenía dos objetivos fundamentales:

A) Comprobar si la carga de memoria en una tarea de MT espacial (no verbal) afecta a la puesta en marcha de estrategias basadas en expectativas, como se ha observado previamente en una tarea verbal (Ortells y cols., 2017).

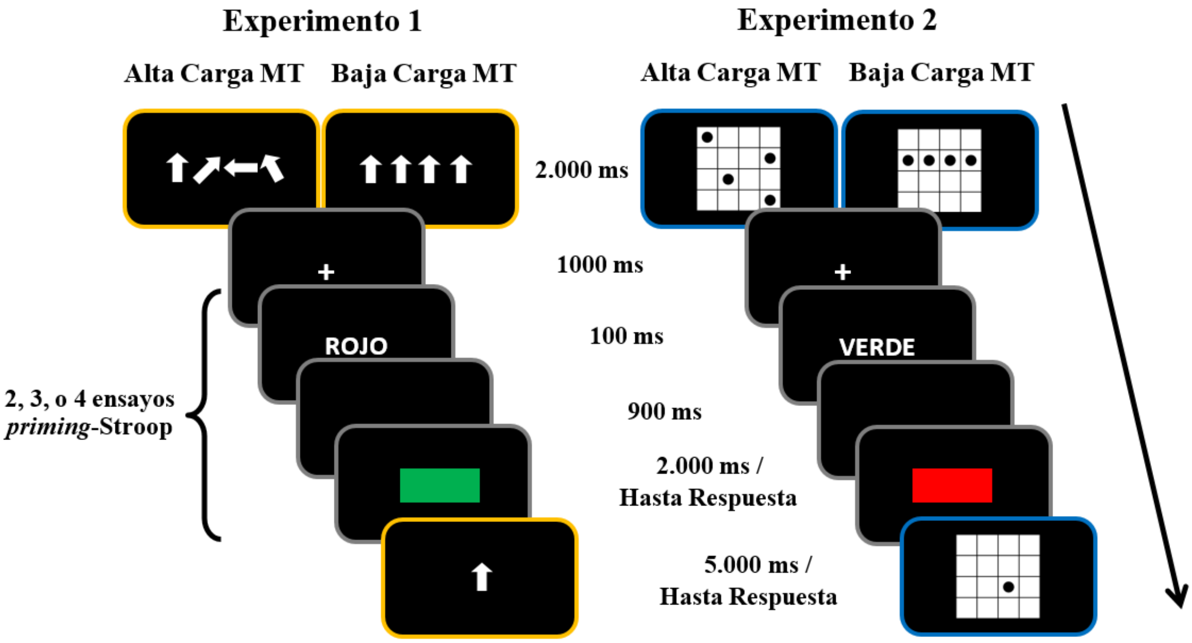
B) Examinar la influencia de las diferencias individuales en capacidad de MT (medida con la tarea de localización del cambio visual; ver Johnson y cols., 2013), en el desarrollo de estrategias atencionales facilitatorias.

En los dos experimentos de esta investigación los participantes realizaban una tarea *priming*-Stroop, compuesta por una mayor proporción de ensayos incongruentes (80%) que congruentes (20%), al mismo tiempo que ejecutaban otra tarea de carga variable de MT de tipo espacial. En el Experimento 1, los participantes debían memorizar conjuntos de cuatro flechas que apuntaban en la misma (carga baja) o en diferentes (carga alta) direcciones, mientras que en el Experimento 2, tenían que retener las localizaciones espaciales de cuatro círculos distribuidos de forma regular (carga baja) o aleatoria (carga alta) en una matriz 4x4 (ver Figura 9).

En ambos estudios, la congruencia *prime*-*target* en la tarea *priming*-Stroop interactuó con el tipo de carga de MT espacial de manera que, en condiciones de alta carga, los participantes no pudieron usar la información predictiva del estímulo *prime* para anticipar la respuesta al color contrario, y mostraron un efecto estándar de interferencia Stroop, independientemente de su capacidad de MT.

Figura 9.

Secuencia de eventos de un ensayo incongruente de la tarea *priming*-Stroop con una alta vs. baja carga de MT espacial a través de cuatro flechas (Experimento 1) o la localización de cuatro círculos en una matriz (Experimento 2).

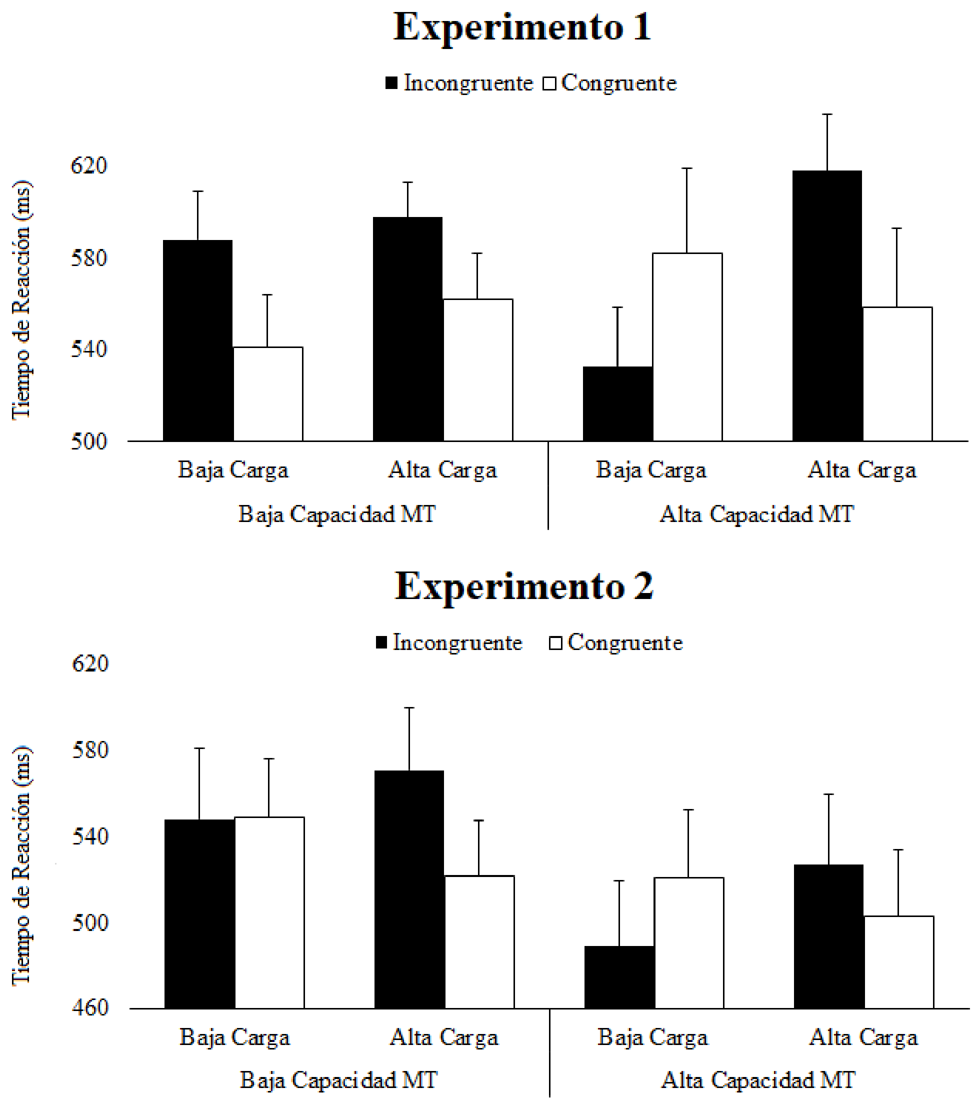


Sin embargo, con una carga baja de memoria espacial, los procesos estratégicos basados en expectativas fueron parcialmente modulados[2] por las diferencias individuales en capacidad de MT. Los participantes con mayor capacidad de MT mostraron una inversión estratégica del efecto Stroop, ya que usaron la información predictiva del *prime* para anticipar su respuesta al *target*. Por el contrario, en aquellos con menor capacidad de MT se observó de nuevo el típico efecto de interferencia Stroop, manifestado en la condición de alta carga de MT (ver Figura 10). Estos resultados son coherentes con los encontrados por Froufe y colaboradores (2009) en personas de mayor (adultos jóvenes) y menor (mayores) capacidad de MT.

[2]Aunque la interacción entre Carga de MT, Congruencia y Capacidad de MT solo fue estadísticamente significativa en el Experimento 1, el patrón de resultados en las distintas condiciones experimentales fue muy similar en ambos estudios.

Figura 10.

Tiempos de reacción en ensayos congruentes e incongruentes en condiciones de baja y alta carga de MT de los grupos de mayor y menor capacidad en el Experimento 1 (arriba) y en el Experimento 2 (abajo).



El patrón de resultados de ambos experimentos demuestra que la implementación de una respuesta estratégica basadas en expectativas, inducida por una mayor proporción de ensayos incongruentes, también se ve afectada por una tarea no verbal de memoria de trabajo. Estos datos extienden y replican los obtenidos por Ortells y colaboradores (2017) con una tarea de carga de MT verbal. Y, además, indican que la interacción entre la MT y procesos atencionales facilitatorios que observamos en la tarea *priming*-Stroop refleja, fundamentalmente, recursos atencionales de carácter general e independientes del tipo de información estimular (verbal vs. visual) de la tarea de memoria.

Aunque algunos estudios previos emplearon también tareas de MT no-verbal, para comprobar su posible influencia en procesos estratégicos facilitatorios (v.g., Heyman y cols., 2014; ver también Kalanthroff y cols., 2015), estas investigaciones incluyeron paradigmas convencionales de *priming* (v.g., con una proporción de ensayos congruentes igual o superior a la de ensayos incongruentes), por lo que los efectos comportamentales inducidos por procesos controlados serían del mismo tipo (v.g., facilitatorios) que los promovidos por procesos automáticos. Por el contrario, en la tarea de *priming* utilizada en nuestra investigación las condiciones de alta y baja carga de MT permitían obtener efectos comportamentales de signo opuesto.

En resumen, y con relación al primer objetivo del Estudio Experimental I, la manipulación de la carga (alta vs. baja) en una tarea concurrente de MT parece afectar no sólo a la capacidad para inhibir o suprimir información distractora (De Fockert y cols., 2010; Lavie y De Fockert, 2005), sino también a la habilidad para implementar adecuadamente estrategias atencionales facilitatorias basadas en expectativas, lo que ocurriría con independencia del tipo de información implicada (visual vs. verbal) en la tarea de carga de MT.

Por otro lado, el hecho de que las diferencias individuales en capacidad de MT sean más determinantes para desarrollar una respuesta estratégica, basada en información previa, podría reflejar diferentes tipos de control cognitivo de los participantes. Precisamente, Braver y colaboradores desarrollaron un modelo de control cognitivo dual (*Dual-mechanisms control* – DMC) que distingue entre control proactivo y control reactivo (Braver y cols., 2001; Braver y cols., 2007; para una revisión, ver Braver, 2012). El control proactivo implica mantener activa información que resulta relevante para focalizar de forma eficiente la atención en un estímulo objetivo y, al mismo tiempo, inhibir potenciales estímulos distractores. Como hemos comprobado, en situaciones que demandan una baja carga de MT, las personas con mayor capacidad de MT utilizan (y, por tanto, mantienen activa) la información predictiva del *prime* para desarrollar una respuesta estratégica antes de que aparezca el *target*. Este tipo de control proactivo podría explicar el (mejor) rendimiento que muestran las personas de mayor capacidad de MT en determinadas situaciones (Redick y Engle, 2011).

El control reactivo, en cambio, se activa automáticamente por el estímulo objetivo, desencadenando un proceso retrospectivo que supone recuperar la información contextual previa de la memoria de largo plazo. Es posible que las personas de baja capacidad hagan uso de este tipo de control para responder en la tarea *priming*-Stroop, ya que muestran una interferencia Stroop típica incluso bajo condiciones de baja carga en tarea de memoria concurrente. En este caso, no usarían la información del *prime* para predecir el estímulo objetivo, sino que responderían a éste ad hoc.

Por tanto, respecto al segundo objetivo, los resultados demuestran que las diferencias individuales en capacidad de MT pueden modular no sólo la acción de procesos atencionales inhibitorios (v.g., Ahmed y De Fockert, 2012; Kane y Engle, 2003), sino también los procesos estratégicos facilitatorios, siendo los participantes con mayor capacidad de MT los únicos que pueden mostrar una inversión estratégica del efecto Stroop, bajo condiciones que permiten la acción de dichas estrategias (v.g., baja carga de MT).

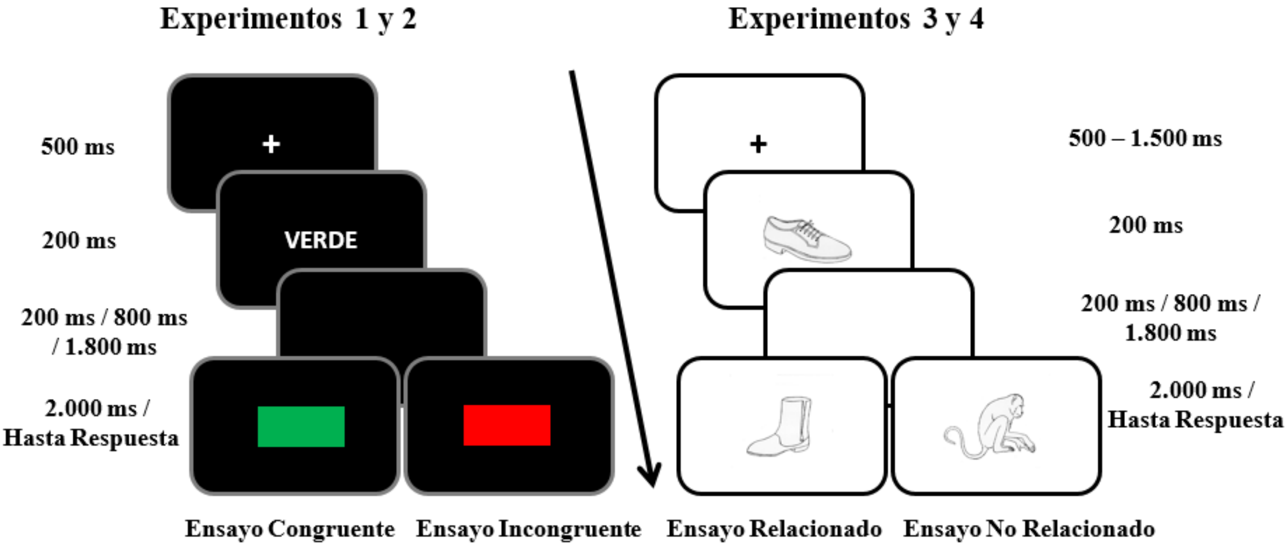
2. Estudio Experimental II

El principal objetivo del segundo estudio de esta Tesis fue investigar si en el envejecimiento normal, además de verse afectada la capacidad para inhibir información irrelevante (De Fockert y cols., 2009; Mayas y cols., 2012), también resulta alterada de algún modo la habilidad para desarrollar estrategias facilitatorias basadas en expectativas, como algunos autores parecen sugerir (v.g., Froufe y cols., 2009). Para ello se comparó el rendimiento de jóvenes y mayores en diferentes tareas de *priming*-Stroop (Experimentos 1 y 2) y *priming* semántico (Experimentos 3 y 4). En ambas tareas se manipuló la duración del SOA *prime-target* a tres niveles (ver Figura 11). Previamente, todos los participantes realizaron además la tarea de localización del cambio visual y la tarea antisacada, para explorar las diferencias asociadas a la edad en capacidad de MT y en el control atencional inhibitorio, respectivamente.

En primer lugar, los resultados indican que los jóvenes son consistentemente más rápidos y cometen menos errores que los mayores en todas las tareas. Y que la capacidad de MT de los participantes correlaciona negativamente con la edad (a mayor edad, menor capacidad de MT) y con la velocidad de respuesta en la tarea antisacada (a menor capacidad, mayor latencia de respuesta). Estos datos sugieren que la reducción de la capacidad de MT asociada a la edad no sólo disminuiría la velocidad de procesamiento, sino también la capacidad de control atencional. Estos hallazgos son compatibles con los observados en estudios previos entre personas de mayor y menor capacidad de MT (Engle y Kane, 2004; Hutchison y cols., 2014; Kane y cols., 2001).

Figura 11.

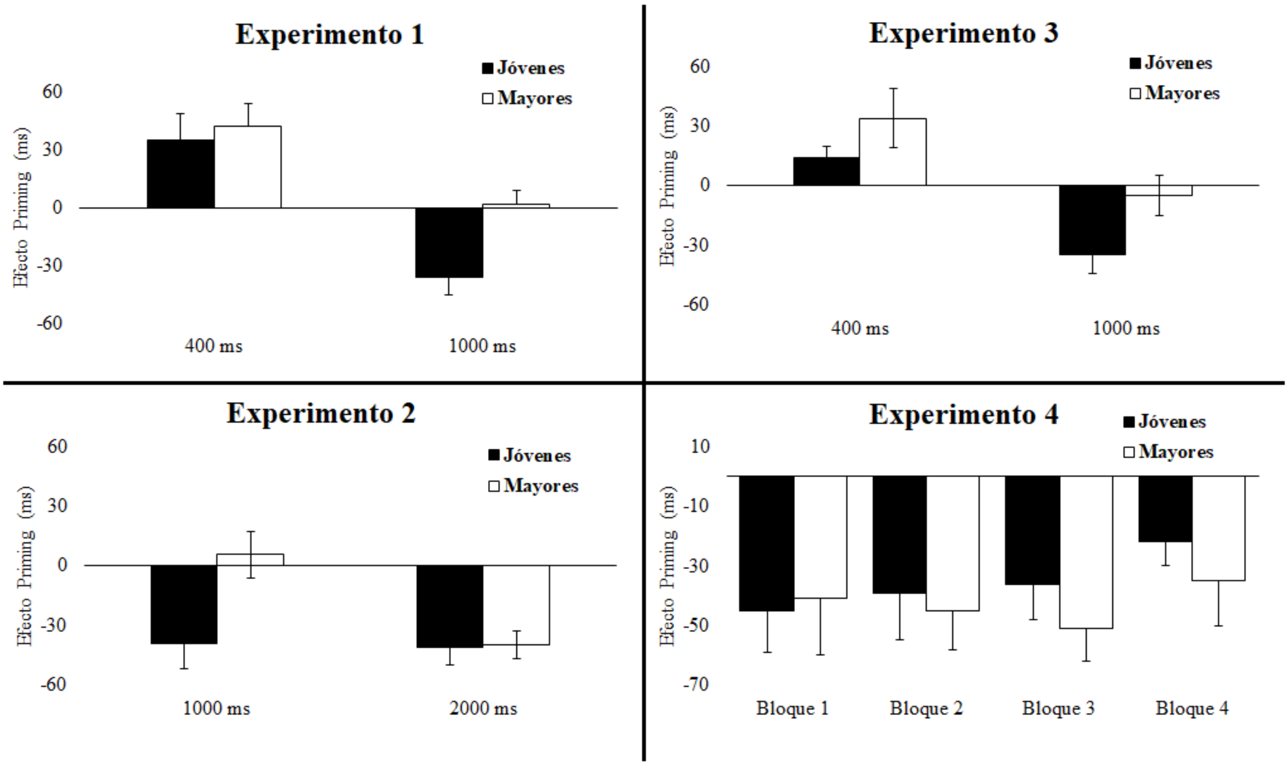
Secuencia de eventos en la tarea *priming*-Stroop (Experimentos 1 y 2) y la tarea de *priming* semántico con imágenes (Experimentos 3 y 4).



En segundo lugar, los mayores también pueden desarrollar expectativas, pero requieren más tiempo que los jóvenes en ambas tareas de *priming*. Los jóvenes realizan un procesamiento estratégico a partir de intervalos de SOA *prime-target* de 1000 ms, mostrando una inversión estratégica de los efectos de *priming* (v.g., menor tiempo de reacción y porcentaje de error en ensayos incongruentes/no-relacionados vs. congruentes/relacionados). Por el contrario, el rendimiento de los mayores sugiere un procesamiento automático de los estímulos en el mismo intervalo temporal de 1000 ms, pues muestran un efecto de facilitación convencional (v.g., respuestas más rápidas y menos errores en ensayos congruentes/relacionados, que incongruentes/no-relacionados; ver Figura 12). Este patrón diferencial es coherente con el observado previamente por Froufe y colaboradores (2009) entre adultos jóvenes y mayores.

Figura 12.

Efectos de *priming* obtenidos a través de los cuatro experimentos en los grupos de jóvenes y mayores en los distintos intervalos temporales empleados.



Sin embargo, con un intervalo de SOA *prime-target* de 2.000 ms, las personas mayores sí son capaces de utilizar estratégicamente la información predictiva del estímulo *prime* y anticipar la respuesta al *target*, mostrando una inversión estratégica del *priming*, similar a la observada en los jóvenes (ver Figura 12, Experimentos 2 y 4).

La interpretación más plausible de estos resultados es que los mayores no muestran una dificultad excepcional para mantener información en la MT, como sugerían estudios previos (Balota y cols., 1992), sino que, al igual que se ha observado en procesos de tipo inhibitorio (v.g., Gazzaley y cols., 2008; Zanto, Toy y Gazzaley, 2010), necesitarían más tiempo, que los jóvenes, para usar con eficacia esa información predictiva e implementar estrategias facilitatorias basadas en expectativas.

El modelo de control cognitivo dual de Braver y colaboradores podría explicar este patrón asumiendo que, incluso las personas con tendencia a mostrar un control de tipo reactivo (v.g., mayores o, en general, aquellas con menor rendimiento en tareas de capacidad de MT; Redick y Engle, 2011), también serían capaces de mantener información previa activa que les fuera útil para una futura respuesta, siempre y cuando dispusieran de tiempo suficiente para ello. Recuérdese que, en nuestro Estudio Experimental 1, el SOA *prime-target* fue de 1000 ms, por lo que es posible que los jóvenes con menor capacidad de MT también hubiesen podido adoptar una estrategia proactiva de haber tenido más tiempo entre la presentación del *prime* y el *target*.

Aunque en nuestro segundo estudio experimental los mayores, con una menor capacidad de MT, ya mostraban un uso eficiente de estrategias en el intervalo de 2000 ms, en las investigaciones sobre el modelo DMC, usualmente utilizando la tarea AX-CPT, suelen emplearse tiempos de demora entre estímulos mucho más largos (> 4000 ms) y hay personas que siguen usando un control reactivo. Sin embargo, encontramos varios aspectos críticos que la diferencian de la tarea *priming*-Stroop de nuestro estudio. Además de contar con más variedad de ensayos (AX, BX, AY y BY; ver Braver y cols., 2005), los participantes deben dar algún tipo de respuesta en los dos ensayos consecutivos que integran cada ensayo experimental (v.g., Braver y cols., 2001: Braver y cols., 2005; Redick y Engle, 2011). Esto podría dificultar que en las tareas del tipo AX-CPT, las personas con una menor capacidad de MT puedan adoptar un modo de control proactivo.

En resumen, los datos de esta serie experimental replican y extienden los hallados por investigaciones anteriores: las personas mayores muestran una demora no solo en su capacidad para inhibir información irrelevante (Cashdollar y cols., 2013; Gazzaley y cols., 2008; Zanto y cols., 2010), sino también para emplear estrategias controladas facilitatorias basadas en expectativas, por lo que necesitan más tiempo para implementarlas de forma similar a la de los jóvenes.

3. Estudio Experimental III

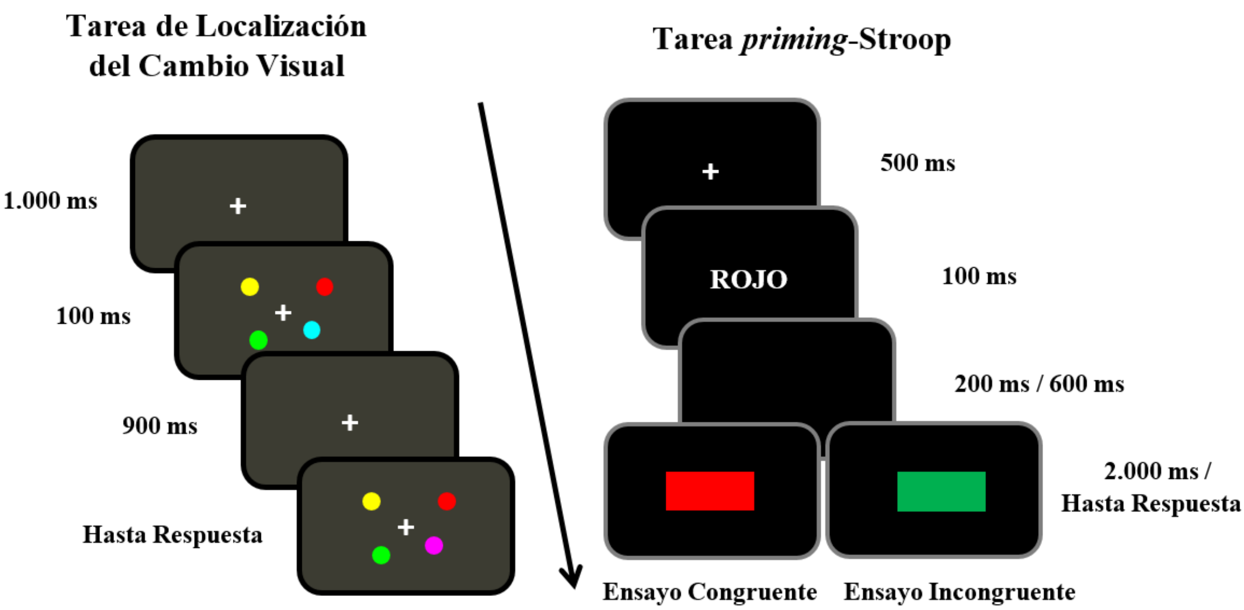
El tercer estudio de la presente Tesis tenía dos objetivos fundamentales:

A) Tratar de replicar y extender los resultados comportamentales de los estudios previos (Noguera y cols., 2019; Ortells y cols., 2018), respecto al papel que la disponibilidad de recursos de MT ejerce sobre el control atencional facilitatorio. Para ello, se empleó la tarea *priming-Stroop* (ver Figura 13) constituida por un 75% de ensayos incongruentes y un 25% de ensayos congruentes. El intervalo de SOA *prime-target* se manipuló a dos niveles (300 vs. 700 ms). La capacidad de MT de los participantes se evaluó a través de la tarea de Localización del Cambio Visual (Ver Figura 13).

B) Explorar los correlatos electrofisiológicos de procesos estratégicos (vs. no estratégicos), y si estos pueden ser también modulados por diferencias individuales en la capacidad de MT.

Figura 13.

Secuencia de eventos de la tarea de Localización del Cambio Visual, para medir capacidad de MT, y de la tarea *priming*-Stroop.



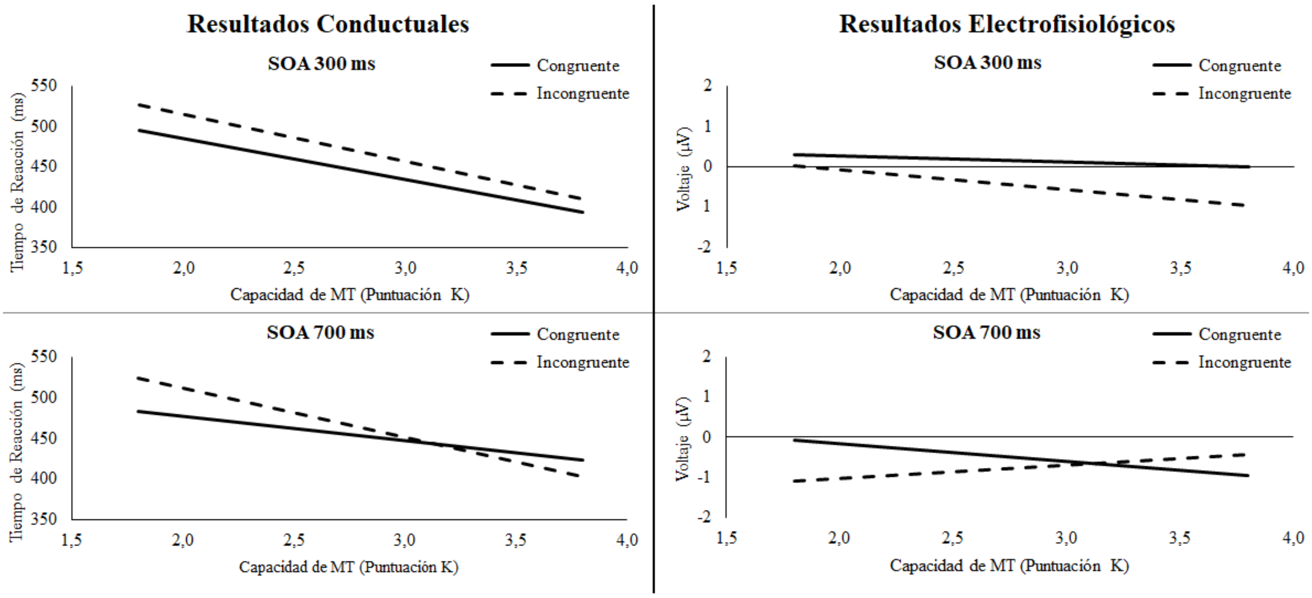
El principal resultado conductual de este estudio fue una triple interacción entre Congruencia, SOA y la capacidad de MT. En el SOA más corto, todos los participantes, con independencia de su capacidad de MT, muestran un efecto estándar de interferencia Stroop, que sugiere la ausencia de un procesamiento estratégico del estímulo *prime*. Sin embargo, en el SOA más largo la capacidad diferencial de MT sí modula la actuación de estrategias basadas en expectativas: de nuevo, las personas de mayor capacidad de MT muestran una inversión estratégica del efecto Stroop, mientras que aquellas con menor capacidad el típico efecto de interferencia Stroop (ver Figura 14, Resultados Conductuales). Estos datos replican y extienden los obtenidos previamente en situaciones de baja carga de MT (Ortells y cols., 2018), y cuando se compara la implementación de estrategias facilitatorias entre personas con mayor y menor capacidad de MT (adultos jóvenes vs. mayores; Noguera y cols., 2019).

Los resultados electrofisiológicos, que constituyen por sí mismos un aspecto novedoso en este tipo de investigaciones, mostraron un patrón muy similar al de los datos comportamentales. En el intervalo de SOA corto, encontramos en todos los participantes un componente N2 fronto-central en la ventana temporal de 190-290 ms (desde la presentación del *target*), independiente de su capacidad de MT. Este componente N2 se suele observar en condiciones de conflicto atencional, como sucede en tareas tipo Stroop, siendo en este caso la amplitud de la onda más negativa (o menos positiva) en situaciones incongruentes, en comparación a las congruentes (e.g., Clayson y Larson, 2011; Donohue y cols, 2016; Ridderinkhof y cols., 2004).

En cambio, cuando se aumenta el intervalo de SOA a 700 ms, el patrón EEG es modulado por las diferencias individuales en capacidad de MT: en aquellos con menor capacidad sigue apareciendo un componente N2, como en el SOA de 300 ms. Por el contrario, en los de mayor capacidad no se encuentra el componente N2. Los ensayos congruentes e incongruentes generan ondas de una misma amplitud (ver Figura 14, Resultados Electrofisiológicos). Estos resultados sugieren que para los participantes con alta capacidad los ensayos incongruentes han dejado de constituir una situación de conflicto, al usar estratégicamente la información sobre el grado de proporción de congruencia *prime-target*.

Figura 14.

Tiempos de reacción (Resultados Conductuales) y de voltaje (Resultados Electrofisiológicos) de los ensayos congruentes e incongruentes, en función de la capacidad de MT en ambos intervalos de SOA (300 y 700 ms).



En conclusión, sistemáticamente encontramos que una disponibilidad limitada de recursos de la MT (v.g., debido a una baja capacidad de MT) parece afectar no solo a la habilidad para inhibir información irrelevante en tareas de atención selectiva, sino también a la capacidad de generar un procesamiento estratégico a partir de información previa (Ortells y cols., 2017; Ortells y cols., 2018; Noguera y cols., 2019). Hasta donde sabemos, este tercer Estudio Experimental constituye la primera investigación publicada que ha empleado el paradigma *priming*-Stroop secuencial en un estudio EEG de potenciales evocados, encontrando evidencias de patrones electrofisiológicos diferentes en función del tipo de proceso usado (v.g., automáticos vs. controlados) y de la capacidad de memoria de trabajo.

4. Limitaciones del Trabajo y Futuras Investigaciones

Las distintas tareas estratégicas empleadas en la presente Tesis dejan patente la diferencia entre actuar bajo procesos de tipo más automático, o de un modo más controlado o voluntario, en función de la capacidad diferencial de MT. Sin embargo, no podemos descartar la contribución adicional de otros factores que también pueden determinar la implementación de uno u otro tipo de proceso, como la motivación (Locke y Braver, 2008), o la velocidad de procesamiento (Neely, 1991). En futuras investigaciones, sería conveniente comprobar si estas u otras variables contribuyen o favorecen la generación de estrategias atencionales facilitatorias, como las basadas en expectativas.

Por otro lado, en el Estudio Experimental III no encontramos actividad electrofisiológica relevante previa a la aparición del *target* como, por ejemplo, la actividad contralateral durante la demora (en inglés, *Contralateral Delay Activity*; CDA), que nos indicaría si las personas con alta capacidad de MT muestran un estado más eficiente de preparación motora, que las personas con menor capacidad. Es posible que este estado se observe en intervalos de demora entre *prime* y *target* superiores al de 700 ms (ver Ikkai y cols., 2010; McCollough y cols., 2007; Vogel y Machizawa, 2004). Además, emplear niveles de SOA *prime-target* más largos también permitiría observar a nivel electrofisiológico si las personas con una menor disponibilidad en recursos de la MT (v.g., debida a una baja capacidad, o al envejecimiento) pueden eliminar también el componente electrofisiológico asociado a conflicto atencional (N2), al ser capaces de implementar estrategias a nivel comportamental, como ya se ha demostrado en otros estudios (Noguera y cols., 2019).

En cuanto a los hallazgos electrofisiológicos asociados a la puesta en marcha de estrategias basadas en expectativas, cabe preguntarse si es posible obtener un patrón similar de resultados manipulando la carga (alta vs. baja) de una tarea de MT concurrente en la tarea *priming*-Stroop, o en otra tarea estratégica alternativa de *priming* semántico que emplee un conjunto estimular más amplio y que demande un procesamiento de la información a nivel de significado.

VII

Conclusiones

A partir de los resultados obtenidos en los tres estudios experimentales que integran la presente Tesis Doctoral, cabe destacar las siguientes contribuciones relevantes:

I) Estudio Experimental I: La carga de MT modula la puesta en marcha de estrategias atencionales facilitatorias en una tarea atencional, con independencia del tipo de información estimular (v.g., verbal vs. visuoespacial) que deben retener y procesar los participantes en la tarea de MT. Esto nos permite concluir que la interacción entre las tareas de Memoría de Trabajo y de Atención Selectiva es de dominio “general” (recursos comunes de control atencional), más que “específico” (v.g., subsistema de procesamiento verbal).

II) Estudio Experimental II: Una menor disponibilidad de recursos cognitivos de la MT (v.g., por baja capacidad de MT, o por la edad), refleja no solo una mayor dificultad para inhibir información irrelevante, sino también una demora en la habilidad para generar procesos controlados facilitatorios, como los basados en expectativas, con independencia del tipo de paradigma de *priming* atencional estratégico empleado (v.g., tarea *priming*-Stroop y *priming* semántico).

III) Estudio Experimental III: La estrecha relación existente entre la Memoria de Trabajo y la Atención Selectiva se observa a nivel comportalmental y electrofisiológico. Influye en el procesamiento facilitatorio atencional de los estímulos, observándose efectos de *priming* de signo opuesto inducidos por procesos automáticos y controlados. Y en el registro del componente N2, asociado a conflicto atencional, que se elimina cuando se hace uso de información predictiva para responder.

Estos hallazgos replican y, sobre todo, extienden los obtenidos previamente en investigaciones comportamentales sobre el procesamiento atencional estratégico. Y, por primera vez, aportan información relevante sobre los correlatos electrofisiológicos asociados al uso de información predictiva útil para la generación de procesos estratégicos basados en expectativas.

VIII

Referencias

Ahmed, L. y De Fockert, J. W. (2012). Focusing on attention: the effects of working memory capacity and load on selective attention. *PLoS ONE, 7,* 1-11 doi: 10.1371/journal.pone.0043101

Atkinson, R. C. y Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. En K. W. Spence & J. T. Spence, *The psychology of learning and motivation: II.* Academic Press. doi: 10.1016/S0079-7421(08)60422-3

Baddeley, A. D. (1986). *Working memory*. Oxford: Clarendon Press.

Baddeley, A. D. (1996). Exploring the central executive. *Quarterly Journal of Experimental Psychology, 49A,* 5-28.

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4,* 417–423.

Baddeley, A. D. y Hitch, G. (1974). Working memory. En G. H. Bower (Ed.), *Psychology of learning and motivation* (Vol. 8, pp. 47–89). New York, NY: Academic Press.

Balota, D. A., Black, S. R. y Cheney, M. (1992). Automatic and attentional priming in young and older adults: Reevaluation of the two-process model. *Journal of Experimental Psychology: Human Perception and Performance, 18*(2), 485-502. doi: 10.1037/0096-1523.18.2.485

Barea Navarro, R. (s.f.). *Manual de Instrumentación Biomédica* (Tema 5: Electroencefalografía). Universidad de Alcalá, Alcalá (España). Recuperado de: http://www.hca.es/huca/web/enfermeria/html/f_archivos/electroencefalografia.pdf

Bermeitinger, C., Frings, C. y Wentura, D. (2008). Reversing the N400: event-related potentials of a negative semantic priming effect. *Neuroreport, 19*(15), 1479–1482. doi: 10.1097/WNR.0b013e32830f4b0b

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

Braver, T. S., Barch, D. M., Keys, B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., Janowsky, J. S., Taylor, S. F., Yesavage, J. A., Mumenthaler, M. S., Jagust, W. J. y Reed, B. R. (2001). Context processing in older adults: evidence for a theory relating cognitive control to neurobiology in healthy aging. *Journal of Experimental Psychology: General*, *130*(4), 746–763.

Braver, T. S., Gray, J. R. y Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. En A. R. A. Conway, C. Jarrold, M. J. Kane (Eds.) & A. Miyake & J. N. Towse (Ed.), *Variation in working memory* (pp. 76–106). Oxford University Press.

Braver, T. S., Satpute, A. B., Rush, B. K., Racine, C. A. y Barch, D. M. (2005). Context processing and context maintenance in healthy aging and early stage dementia of the Alzheimer's type. *Psychology and Aging*, *20*(1), 33–46. doi: 10.1037/0882-7974.20.1.33

Broadbent, D.E. (1958) *Perception and Communication*, Pergamon Press.

Cantor, J. y Engle, R. W. (1993). Working-memory capacity as long-term memory activation: an individual-differences approach. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *19*(5), 1101–1114. doi: 10.1037//0278-7393.19.5.1101

Cantor, J., Engle, R. W. y Hamilton, G. (1991). Short-term memory, working memory, and verbal abilities: How do they relate? *Intelligence*, *15*, 229–246.

Cashdollar, N., Fukuda, K., Bocklage, A., Aurtenetxe, S., Vogel, E. K. y Gazzaley, A. (2013). Prolonged disengagement from attentional capture in normal aging. *Psychology and Aging*, *28*(1), 77–86. doi: 10.1037/a0029899

Castillo Moreno, A. y Paternina-Marín, A. (2006). Redes Atencionales y Sistema Visual Selectivo. *Universitas Psychologica*, *5*(2), 305-326.

Chiappe, D. L. y MacLeod, C. M. (1995). Negative priming is not task bound: a consistent pattern across naming and categorization tasks. *Psychonomic Bulletin and Review*, *2*, 364–369.

Clayson, P. E. y Larson, M. J. (2011). Conflict adaptation and sequential trial effects: Support for the conflict monitoring theory. *Neuropsychologia*, *49*, 1953–1961.

Cohen Kadosh, R., Gevers, W. y Notebaert, W. (2011). Sequential analysis of the numerical Stroop effect reveals response suppression. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(5), 1243-1249. doi: 10.1037/a0023550

Coles, M. G. H. y Rugg, M. D. (1995). *Event-related brain potentials: An introduction.* En M. D. Rugg & M. G. H. Coles (Eds.), *Oxford psychology series, No. 25. Electrophysiology of mind: Event-related brain potentials and cognition* (p. 1–26). Oxford University Press.

Conway, A. R. A. y Engle, R. W. (1994). Working memory and retrieval: A resource-dependent inhibition model. *Journal of Experimental Psychology: General*, *123*, 354–373.

Conway, A. R. A. y Engle, R. W. (1996). Individual differences in working memory capacity: More evidence for a general capacity theory. *Memory*, *4*, 577–590.

Conway, A. R., Tuholski, S. W., Shisler, R. J. y Engle, R. W. (1999). The effect of memory load on negative priming: An individual differences investigation. *Memory & Cognition, 27*, 1042-1050. doi: 10.3758/BF03201233

Crowder, R. G. (1982). The demise of short-term memory. *Acta Psychologica, 50,* 29 1-323.

Daneman, M. y Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19,* 450–466.

Daneman, M. y Carpenter, P. A. (1983). Individual differences in integrating information between and within sentences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *9,* 561–584.

Daneman, M. y Green, I. (1986). Individual differences in comprehending and producing words in context. *Journal of Memory and Language, 25,* 1–18.

Daza, M. T., Ortells, J. J. y Fox, E. (2002). Perception without awareness: Further evidence from a Stroop priming task. *Perception & Psychophysics, 64*, 1316-1324.

De Fockert, J. W. (2013). Beyond perceptual load and dilution: A review of the role of working memory in selective attention. *Frontiers in Psychology*. *4*, 1-11. doi: 10.3389/fpsyg.2013.00287

De Fockert, J. W., Mizon, G. A. y D'Ubaldo, M. (2010). No negative priming without cognitive control. *Journal of Experimental Psychology: Human Perception and Performance, 36,* 1333-1341. doi:10.1037/a0020404

De Fockert, J., Ramchurn, A., Van Velzen, J., Bergström, Z. y Bunce, D. (2009). Behavioural and ERP evidence of increased interference in old age. *Brain Research*, *1282*, 67–73. doi: 10.1016/j.brainres.2009.05.060

De Fockert, J. W., Rees, G., Frith, C. D. y Lavie, N. (2001). The role of working memory in visual selective attention. *Science, 291*, 1803–1806.

Donohue, S. E., Appelbaum, L. G., McKay, C. C. y Woldorff, M. G. (2016). The neural dynamics of stimulus and response conflict processing as a function of response complexity and task demands. *Neuropsychologia*, *84,* 14–28. doi:10.1016/j.neuropsychologia.2016.01.03

Draheim, C., Hicks, K. L. y Engle, R. W. (2016). Combining Reaction Time and Accuracy: The Relationship Between Working Memory Capacity and Task Switching as a Case Example. *Perspectives on psychological science: a journal of the Association for Psychological Science*, *11*(1), 133–155. doi: 10.1177/1745691615596990

Engle, R. W. (2001). *What is working memory capacity?* En H. L. Roediger III, J. S. Nairne, I. Neath, & A. M. Surprenant (Eds.), *Science conference series. The nature of remembering: Essays in honor of Robert G. Crowder* (p. 297–314). American Psychological Association. doi: 10.1037/10394-016

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science, 11*(1), 19–23. doi: 10.1111/1467-8721.00160

Engle, R. W., Cantor, J. y Carullo, J. J. (1992). Individual differences in working memory and comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*(5), 972–992. doi: 10.1037/0278-7393.18.5.972

Engle, R. W., Carullo, J. J. y Collins, K. W. (1991). Individual differences in working memory for comprehension and following directions. *Journal of Educational Research*, *84*, 253-262.

Engle, R. W. y Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. En B. Ross (Ed.), *The psychology of learning and motivation* (pp. 145–199). New York: Academic Press.

Eriksen, C. W. (1995). *The flankers task and response competition: A useful tool for investigating a variety of cognitive problems.* En C. Bundesen & H. Shibuya (Eds.), *Visual Cognition, Vol. 2, Nos. 2 & 3. Visual selective attention* (p. 101–118). Lawrence Erlbaum Associates, Inc.

Eriksen, B. A. y Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a non-search task. *Perception & Psychophysics*, *16*, 143–149.

Fernández, S., Ortells, J. J., Kiefer, M., Noguera, C. y De Fockert, J. W. (2021). Working memory capacity modulates expectancy-based strategic processing: Behavioral and electrophysiological evidence. *Biological Psychology, 159*, Article 108023. doi: 10.1016/j.biopsycho.2021.108023

Folstein, J. R. y Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: a review. *Psychophysiology*, *45*, 152–170. doi:10.1111/j.1469-8986.2007.00602.x

Foreman, N. P., Barraclough, S., Moore, C., Mehta, A. y Madon, M. (1989). High doses of caffeine impair performance of a numerical version of the Stroop task in men. *Pharmacology, Biochemistry and Behavior, 32*(2), 399–403. doi: 10.1016/0091-3057(89)90169-X

Fox, E. (1995). Negative priming from ignored distractors in visual selection: A review. *Psychonomic Bulletin and Review, 2*, 145–173.

Franklin, M. S., Dien, J., Neely, J. H., Huber, E. y Waterson, L. D. (2007). Semantic priming modulates the N400, N300, and N400RP. *Clinical neurophysiology: official journal of the International Federation of Clinical Neurophysiology*, *118*(5), 1053–1068. doi: 10.1016/j.clinph.2007.01.012

Frings, C. y Wentura, D. (2005). Negative priming with masked distractor-only prime trials: awareness moderates negative priming. *Experimental Psychology*, *52*, 131-139.

Froufe, M., Cruz, I. y Sierra, B. (2009). (dis)Función ejecutiva en personas mayores con y sin Alzheimer: Actuación estratégica basada en expectativas. *Psicológica, 30*, 119-135.

Fuentes, L. J. y Tudela, P. (1992). Semantic processing of foveally and parafoveally presented words in a lexical decision task. *Quarterly Journal of Experimental Psychology*, *45A*, 299-322.

Gajewski, P. D., Stoerig, P. y Falkenstein, M. (2008). ERP--correlates of response selection in a response conflict paradigm. *Brain Research*, *1189*, 127–134. doi: 10.1016/j.brainres.2007.10.076

Gazzaley, A. (2012). Top-down modulation deficit in the aging brain: An emerging theory of cognitive aging. En D. T. Stuss and R. T. Knight (Eds.), *Principles of Frontal Lobe Function (*2nd ed.). New York: Oxford University Press, 593–608.

Gazzaley, A., Clapp, W., Kelley, J., McEvoy, K., Knight, R. T. y D'Esposito, M. (2008). Age-related top-down suppression deficit in the early stages of cortical visual memory processing. *Proceedings of the National Academy of Science USA*, *105*, 13122–13126. doi:10.1073/pnas.0806074105

Gazzaley, A. y Nobre, A. C. (2012). Top-down modulation: Bridging selective attention and working memory. *Trends in Cognitive Sciences,* 16, 129-135. doi: 10.1016/j.tics.2011.11.014

Harrison, T. L., Shipstead, Z., Hicks, K. L., Hambrick, D. Z., Redick, T. S. y Engle, R. W. (2013). Working memory training may increase working memory capacity but not fluid intelligence. *Psychological Science*, *24*, 2409–2419.

Hart, S. J., Green, S. R., Casp, M. y Belger, A. (2010). Emotional priming effects during Stroop task performance. *NeuroImage*, *49*(3), 2662–2670. doi: 10.1016/j.neuroimage.2009.10.076

Hasher, L., Zacks, R. T. y May, C. P. (1999). Inhibitory control, circadian arousal, and age. En D. Gopher & A. Koriat (Eds.), *Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application* (pp. 653–675). The MIT Press.

Heyman, T., Van Rensbergen, B., Storms G., Hutchison, K. A. y De Deyne, S. (2014). The influence of Working Memory Load on Semantic Priming. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *41*, 911–920. doi:10.1037/xlm0000050

Hill, H., Ott, F. y Weisbrod, M. (2005). SOA-dependent N400 and P300 semantic priming effects using pseudoword primes and a delayed lexical decision. *International journal of psychophysiology: official journal of the International Organization of Psychophysiology*, *56*(3), 209–221. doi: 10.1016/j.ijpsycho.2004.12.004

Hutchison, K. A., Heap, S. J., Neely, J. H. y Thomas, M. A. (2014). Attentional control and asymmetric associative priming. *Journal of Experimental Psychology: Learning, Memory and Cognition, 40,* 844-856. doi:10.1037/a0035781

Ikkai, A., McCollough, A. W. y Vogel, E. K. (2010). Contralateral delay activity provides a neural measure of the number of representations in visual working memory. *Journal of Neurophysiology*, *103*(4), 1963–1968. doi. 10.1152/jn.00978.2009

Johnson, M. K., McMahon, R. P., Robinson, B. M., Harvey, A. N., Hahn, B., Leonard, C. J., Luck, S. J. y Gold, J. M. (2013). The relationship between working memory capacity and broad measures of cognitive ability in healthy adults and people with schizophrenia. *Neuropsychology, 27*, 220–229. doi: 10.1037/a0032060

Jongen, E. M. y Jonkman L. M. (2011). Effects of concurrent working memory load on distractor and conflict processing in a name-face Stroop task. *Psychophysiology, 48*, 31-43. doi:10.1111/j.1469-8986.2010.01037.x

Jost, K., Bryck, R. L., Vogel, E. K. y Mayr, U. (2011). Are old adults just like low working memory young adults? Filtering efficiency and age differences in visual working memory. *Cerebral Cortex, 21*, 1147–1154. doi:10.1093/cercor/bhq185

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice Hall.

Kalanthroff, E., Avnit, A., Henik, A., Davelaar, E. J. y Usher, M. (2015). Stroop proactive control and task conflict are modulated by concurrent working memory load. *Psychonomic Bulletin Review, 22*, 869–875. doi: 10.3758/s13423-014-0735-x

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

Kane, M. J., Conway, A. R. A., Hambrick, D. Z. y Engle, R. W. (2007). Variation in working memory capacity as variation in executive attention and control. En A. R. A. Conway, C. Jarrold, M. J. Kane (Eds.) & A. Miyake & J. N. Towse (Ed.), *Variation in working memory* (pp. 21–46). Oxford University Press.

Kane, M. J. y Engle, R. W. (2003). Working-memory capacity and the control of attention: the contributions of goal neglect, response com- petition, and task set to Stroop interference. *Journal of Experimental Psychology: General*, *132*, 47–70.

Kiefer, M. (2005). Repetition priming modulates category-related effects on event-related potentials: Further evidence for multiple cortical semantic systems. *Journal of Cognitive Neuroscience*, *17*, 199–211.

Kiefer, M. (2012). Executive control over unconscious cognition: attentional sensitization of unconscious information processing. *Frontiers in Human Neuroscience, 6,* 61.

Kiefer, M., Adams, S. y Zovko, M. (2012). Attentional sensitization of unconscious visual processing: Top-down influences on masked priming. *Advances in Cognitive Psychology*, *8*, 50-61.

Kiefer, M. y Martens, U. (2010). Attentional sensitization of unconscious cognition: Task sets modulate subsequent masked semantic priming. *Journal of Experimental Psychology: General, 139*, 464-489.

Kiewra, K. A. y Benton, S. L. (1988). The relationship between information processing ability and notetaking. *Contemporary Educational Psychology*, *13*, 33-44.

Kutas, M. y Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology, 62*, 621–647.

Kyllonen, P. C. y Christal, R. E. (1990). Reasoning ability is (little more than) working memory capacity?! *Intelligence, 14,* 389–433.

Lamers, M. J., Roelofs, A. y Rabeling-Keus, I. M. (2010). Selective Attention And Response Set In The Stroop Task. *Memory & Cognition, 38* (7), 893-904. doi:10.3758/mc.38.7.893.

Langley L. K., Fuentes, L. J., Overmeier, J. B., Bastin de Jong, C. y Prod'Homme, M. (2001). Attention to semantic and spatial information in aging and Alzheimer's disease. *Psicológica, 22*, 293-323.

Lavie, N. (2001). The role of capacity limits in selective attention: Behavioral evidence and implications for neural activity. En J. Braun & C. Koch (Eds.), *Visual attention and cortical circuits* (pp. 49–68). Cambridge, MA: MIT Press.

Lavie, N. y De Fockert, J. W. (2005). The role of working memory in attentional capture. *Psychonomic Bulletin & Review, 12*, 669–674.

Lavie, N., Hirst, A., de Fockert, J. W. y Viding, E. (2004). Load Theory of Selective Attention and Cognitive Control. *Journal of Experimental Psychology: General, 133*, 339-354. doi: 10.1037/0096-3445.133.3.339

Locke, H. S. y Braver, T. S. (2008). Motivational influences on cognitive control: behavior, brain activation, and individual differences. *Cognitive, affective & behavioral neuroscience, 8*(1), 99–112. doi: 10.3758/cabn.8.1.99

Lu, C. H. y Proctor, R. W. (1994). Processing of an irrelevant location dimension as a function of the relevant stimulus dimension. *Journal of Experimental Psychology: Human Perception and Performance, 20*(2), 286–298. doi: 10.1037/0096-1523.20.2.286

Lu, C. H. y Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review, 2*(2), 174–207. doi: 10.3758/BF03210959

Luck, S. J. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: MIT Press.

Lustig, C., Hasher, L. y Zacks, R. T. (2007). Inhibitory deficit theory: Recent developments in a "new view" En D. S. Gorfein & C. M. MacLeod

(Eds.), *Inhibition in cognition* (pp. 145–162). American Psychological Association. doi: 10.1037/11587-008

Martens, U., Ansorge, U. y Kiefer, M. (2011). Controlling the unconscious: Attentional task sets modulate subliminal semantic and visuo-motor processes differentially. *Psychological Science*, *22*, 282–291.

May, C. P., Kane, M. J. y Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin, 118*, 35-54.

Mayas, J., Fuentes, L. J. y Ballesteros, S. (2012). Stroop interference and negative priming (NP) suppression in normal aging. *Archives of gerontology and geriatrics*, *54*(2), 333–338. doi: 10.1016/j.archger.2010.12.012

McCollough, A. W., Machizawa, M. G. y Vogel, E. K. (2007). Electrophysiological measures of maintaining representations in visual working memory. *Cortex; a journal devoted to the study of the nervous system and behavior*, *43*(1), 77–94. doi: 10.1016/s0010-9452(08)70447-7

Meier, B. P. y Robinson, M. D. (2004). Why the sunny side is up: association between affect and vertical position. *Psychological Science*, *15*(4), 243–247. doi: 10.1111/j.0956-7976.2004.00659.x

Merikle, P. M. y Cheesman, J. (1987). Current status of research on subliminal perception. En M. Wallendorf & P. M. Anderson (Eds.). *Advantages in Consumer Research, Vol. XIV.* Provo, UT: Association for Consumer Research.

Merikle, P. M. y Joordens, S. (1997). Parallels between perception without attention and perception without awareness. *Consciousness and Cognition, 6*, 219-236.

Merikle, P. M., Joordens, S. y Stolz, J. A. (1995). Measuring the relative magnitude of unconscious influences. *Consciousness and Cognition: An International Journal*, *4*(4), 422–439. doi: 10.1006/ccog.1995.1049

Milliken, B., Joordens, S., Merikle, P. M. y Seiffert, A. E. (1998). Selective attention: a reevaluation of the implications of negative priming. *Psychological Review*, *105*(2), 203–229. doi: 10.1037/0033-295x.105.2.203

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General*, *106*: 226–254. doi: 10.1037/0096-3445.106.3.226

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. En D. Besner & G. W. Humphreys (Eds.), *Basic progresses in reading - Visual word recognition* (pp. 264–333). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Neely, J. H., Keefe, D. E. y Ross, K. L. (1989). Semantic priming in the lexical decision task: Roles of propective prime-generated expectancies and retrospective semantic matching. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*, 1003–1019. doi:10.1037/0278-7393.15.6.1003

Neill, W. T., Valdes, L. A., Terry, K. M. y Gorfein, D. S. (1992). Persistence of negative priming: II. Evidence for episodic trace retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*(5), 993–1000. doi: 10.1037/0278-7393.18.5.993

Noguera, C., Álvarez, D., Carmona, E. y Parra, L. (2015). Temperament and negative semantic priming in children 7 to 12 years old. *Child Neuropsychology*, *21*, 302–313. doi: 10.1080/09297049.2014.913558

Noguera, C., Fernández, S., Álvarez, D., Carmona, E., Marí-Beffa, P. y Ortells, J. J. (2019). The implementation of expectancy-based strategic processes is delayed in normal aging. *PloS one*, *14*(3), e0214322. doi: 10.1371/journal.pone.0214322

Noguera, C., Ortells, J. J., Abad, M. J. F., Carmona, E. y Daza, M. T. (2007). Semantic priming effects from single words in a lexical decision task. *Acta Psychologica*, 125, 175–202. doi: 10.1016/j.actpsy.2006.07.007

Ortells, J. J., Álvarez, D., Noguera, C., Carmona, E. y De Fockert, J. W. (2017). The Influence of Working Memory Load on Expectancy-Based Strategic Processes in the Stroop-Priming Task. *Frontiers in Psychology, 8*, 1-8. doi: 10.3389/fpsyg.2017.00129

Ortells, J. J., Daza, M. T. y Fox, E. (2003). Semantic activation in the absence of perceptual awareness. *Perception and Psychophysics*, *65*, 1307–1317. doi: 10.3758/BF03194854

Ortells, J. J., De Fockert, J. W., Romera, N. y Fernández, S. (2018). Expectancy-Based Strategic Processes Are Influenced by Spatial Working Memory Load and Individual Differences in Working Memory Capacity. *Frontiers in Psychology, 9*, 1239. doi:10.3389/fpsyg.2018.01239

Ortells, J. J., Frings, C. y Plaza-Ayllon, V. (2012). Influence of spatial attention on conscious and unconscious word priming. *Consciousness and cognition*, *21*(1), 117–138. doi: 10.1016/j.concog.2011.10.012

Ortells, J. J., Kiefer M., Castillo A., Megías M. y Morillas A. (2016). The semantic origin of unconscious priming: Behavioral and event-related potential evidence during category congruency priming from strongly and weakly related masked words. *Cognition*, *146*, 143–57

Ortells, J. J., Marí-Beffa, P. y Plaza-Ayllón, V. (2013). Unconscious congruency priming from unpracticed words is modulated by prime-target semantic relatedness. *Journal of Experimental Psychology: Learning, Memory and Cognition, 39*, 394–413.

Ortells, J. J., Noguera, C., Álvarez, D., Carmona, E. y Houghton, G. (2016). Individual differences in working memory capacity modulates semantic negative priming from single prime words. *Frontiers in Psychology,* 7, 1-14. doi: 10.3389/fpsyg.2016.01286

Parasuraman, R. (1984). Sustained attention in detection and discrimination. En R. Parasuraman y D. R. Davies (Eds.), *Varieties of Attention* (pp. 243-271). Orlando, FL: Academic Press.

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., Jr, Miller, G. A., Ritter, W., Ruchkin, D. S., Rugg, M. D. y Taylor, M. J. (2000). Guidelines for using human event–related potentials to study cognition: recording standards and publication criteria. *Psychophysiology, 37; 127 – 52.*

Posner, M. I. y Snyder, C. R. R. (1975). Attention and cognitive control. En R. L. Solso (Ed.), *Information processing and cognition: The Loyola Symposium* (pp. 55-85). Hillsdale: Lawrence Erlbaum Associates.

Qi, S., Zeng, Q., Luo, Y., Duan, H., Ding, C., Hu, W. y Li, H. (2014). Impact of working memory load on cognitive control in trait anxiety: an ERP study. *PloS One, 9*(11), e111791. doi: 10.1371/journal.pone.0111791

Redick, T. S. y Engle, R. W. (2011). Integrating working memory capacity and context-processing views of cognitive control. *Quarterly Journal of Experimental Psychology*, *64*(6), 1048–1055. doi: 10.1080/17470218.2011.577226

Ridderinkhof, K. R., Ullsperger, M., Crone, E. A. y Nieuwenhuis, S. (2004). The role of the medial frontal cortex in cognitive control. *Science, 306*, 443–447.

Shor, R. E., Hatch, R. P., Hudson, I. J., Landrigan, D. T. y Shaffer, H. J. (1972). Effect of practice on a Stroop-like spatial directions task. *Journal of Experimental Psychology, 94*, 168-172.

Spronk, M. y Jonkman, L. M. (2012). Electrophysiological evidence for different effects of working memory load on interference control in adolescents than adults. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *83*(1), 24–35. doi: 10.1016/j.ijpsycho.2011.09.019

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662.

Tillman, C. M. y Wiens, S. (2011). Behavioural and ERP indices of response conflict in Stroop and flanker tasks. *Psychophysiology, 48,* 1405-11. doi: 10.1111/j.1469-8986.2011.01203.x

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology, 37A*, 571–590.

Tsuchida, Y., Katayama, J. y Murohashi, H. (2012). Working memory capacity affects the interference control of distractors at auditory gating. *Neuroscience Letters*, *516*(1), 62–66. doi: 10.1016/j.neulet.2012.03.057

Vogel, E. K. y Machizawa, M. G. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature*, *428*(6984), 748–751. doi: 10.1038/nature02447

Wendt, M. y Luna-Rodríguez, A. (2009). Conflict-frequency affects flanker interference: Role of stimulus-ensemble-specific practice and flanker response contingencies. *Experimental Psychology, 56*, 206–217.

White, B. W. (1969). Interference in identifying attributes and attribute names. *Perception & Psychophysics, 6,* 166-168.

Wolach, A. H., McHale, M. A. y Tarlea, A. (2004). Numerical stroop effect. *Perceptual and Motor Skills*, *98*(1), 67–77. doi: 10.2466/pms.98.1.67-77

Woodman G. F. (2010). A brief introduction to the use of event-related potentials in studies of perception and attention. *Attention, Perception & Psychophysics, 72*(8), 2031–2046. doi: 10.3758/APP.72.8.2031

Zanto, T. P. y Gazzaley, A. (2014). Attention and ageing. En A. C. Nobre & S. Kastner (Eds.), *The Oxford handbook of attention* (pp. 927–971). Oxford University Press.

Zanto, T. P., Toy, B. y Gazzaley, A. (2010). Delays in neural processing during working memory encoding in normal aging. *Neuropsychologia*, *48*(1), 13-25.

Zhao, Y., Tang, D., Hu, L., Zhang, L., Hitchman, G., Wang, L. y Chen, A. (2014). Concurrent working memory task decreases the Stroop interference effect as indexed by the decreased theta oscillations. *Neuroscience*, *262*, 92–106. doi: 10.1016/j.neuroscience.2013.12.052