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Envejecimiento cognitivo: Efectos del entrenamiento con videojuegos en la memoria de trabajo viso-espacial de mayores sanos

PILAR TORIL BARRERA

Licenciada en Psicología

Programa de Doctorado en "Envejecimiento y Enfermedades Neurodegenerativas" con Mención de Calidad (Ref. MCD 2003-00411)

DEPARTAMENTO DE PSICOLOGÍA BÁSICA II

FACULTAD DE PSICOLOGÍA

UNIVERSIDAD NACIONAL DE EDUCACIÓN A DISTANCIA

Directora

Dra. Soledad Ballesteros Jiménez

Codirectores

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Dra. Soledad Ballesteros Jiménez

Catedrática de Psicología Básica

Departamento de Psicología Básica II, UNED

Codirectores

Dr. José Manuel Reales Avilés

Profesor Titular, Departamento de Metodología, UNED

Dra. Julia Mayas Arellano

Profesora, Departamento de Psicología Básica II, UNED

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5. OBJETIVOS DE LA TESIS DOCTORAL

Esta Tesis Doctoral pretende responder algunos interrogantes realizando una serie de aportaciones a la literatura científica existente en el área de estudio de la memoria de trabajo y entrenamiento de mayores con videojuegos. La Tesis se divide en 8 Capítulos.

En el Capítulo 1, se realiza una breve exposición y revisión del envejecimiento, de los principales cambios cognitivos que se producen cuando envejecemos y de la memoria como uno de los procesos cognitivos que más se deteriora con la edad. El último punto de este Capítulo está dedicado a la memoria de trabajo, que es uno de los tipos de memoria más afectados en el envejecimiento, y que constituye el tema central de esta Tesis Doctoral. El principal objetivo de esta parte de la investigación ha sido estudiar el efecto de los dibujos en blanco y negro, fotografías en color, y de la edad en la memoria de trabajo viso-espacial de los mayores sanos.

El Capítulo 2 se dedica al tema de la plasticidad cerebral en el cerebro humano y en el envejecimiento, y su implicación en el entrenamiento con videojuegos en mayores. Posteriormente, se explican las ventajas del uso de los entrenamientos con videojuegos y los efectos de este tipo de intervenciones en las funciones cognitivas de los mayores sanos.

En el Capítulo 3 se presenta un estudio donde investigamos la memoria explícita e implícita en jóvenes y mayores. Este estudio muestra cómo la memoria explícita está deteriorada en mayores sanos mientras la memoria implícita permanece intacta. Dicho estudio está publicado en *Psicothema* en el año 2012.

En el Capítulo 4 se presentan los resultados de un estudio donde investigamos la memoria de trabajo viso-espacial. Debido a que la memoria de trabajo es uno de los procesos cognitivos que más se deterioran en el envejecimiento, fue interesante incluir en esta Tesis

Doctoral un estudio donde se investigara este proceso cognitivo. Este estudio se realizó con jóvenes y mayores sanos. El objetivo fue comprobar el efecto que tenían los dibujos en blanco y negro comparados con fotografías en color en adultos jóvenes y mayores en una tarea informatizada de memoria de trabajo viso-espacial.

En el Capítulo 5, se presenta la publicación de un estudio meta-analítico realizado para comprobar la eficacia de los entrenamientos con videojuegos en mayores sanos. Este meta-análisis constituye una buena revisión bibliográfica de la literatura existente sobre entrenamiento con videojuegos y mayores sanos. Además pretende aportar resultados claros acerca de la efectividad de los entrenamientos con videojuegos en mayores sanos, ya que la literatura en este área ha mostrado resultados discrepantes. Este estudio está publicado en la revista *Psychology and Aging,* en el año 2014.

En el Capítulo 6, se presenta el último estudio de esta Tesis Doctoral. Este estudio longitudinal consistió en un entrenamiento cognitivo con videojuegos, y el objetivo fue investigar la eficacia de dicho entrenamiento en la memoria de trabajo viso-espacial de los mayores sanos y su transferencia a otros tipos de memoria. Este estudio tuvo como objetivo aportar nuevos datos al debate existente en la literatura científica, donde unos investigadores encuentran mejoras después del entrenamiento en la memoria de trabajo, y otros no. Este estudio está enviado a una revista con índice de impacto para su revisión.

En el Capítulo 7 presenta la discusión general y conclusiones de los resultados obtenidos en los estudios que forman esta Tesis Doctoral en castellano.

Finalmente, en el Capítulo 8 se presenta un resumen de la Tesis Doctoral en inglés.

"La ciencia será siempre una búsqueda, jamás un descubrimiento real. Es un viaje, nunca una llegada"

Karl Popper

6. CAPÍTULO 1. MEMORIA Y ENVEJECIMIENTO

6.1. EL ENVEJECIMIENTO

Durante las últimas décadas se han producido cambios demográficos en las sociedades de los países desarrollados debidos a los avances médicos y mejoras en las condiciones de vida de la población. Estos factores hacen que haya aumentado la esperanza de vida y que el envejecimiento de la población sea objeto de atención y de estudio por parte de los investigadores. Precisamente este fenómeno del envejecimiento de la población se postula como uno de los mayores logros de la humanidad, pero a la vez constituye un desafío muy importante al que tienen que enfrentarse gobiernos e instituciones. Así, las sociedades tienen que dedicar más recursos para atender las necesidades crecientes de la población de mayor edad. Por ejemplo, España es uno de los países que más recursos debe invertir ya que las previsiones de la ONU lo sitúan como el país occidental más envejecido del mundo en el año 2050. Las estimaciones realizadas muestran que en esa fecha el 44% de los españoles tendrán 60 años o más. Además, se prevé que la población de los mayores de 80 años sea la que más crezca.

El envejecimiento es un fenómeno natural, continuo y universal que afecta a todos los seres vivos, aunque no de la misma manera ni con la misma intensidad (Fleischman & Gabrieli, 1998; Nilsson, 2003). En la actualidad se consideran dos formas de envejecimiento, el normal y el patológico. El envejecimiento normal cursa sin patología biológica o mental (Baltes & Baltes, 1990). Este tipo de envejecimiento es el que aparece mayoritariamente en los mayores. Por el contrario, el envejecimiento patológico se produce cuando los mayores presentan enfermedades físicas y mentales que les impide realizar actividades de la vida diaria y llevar una vida independiente. Debemos entender el envejecimiento como algo positivo ya que la mayoría de las personas presentan un envejecimiento normal caracterizado por la pérdida de la función muscular y de la agudeza de los órganos de los sentidos junto con un enlentecimiento de los procesos mentales. Solamente un pequeño porcentaje de la población mayor presenta envejecimiento patológico.

En la literatura científica se han propuesto una serie de factores que pueden promover tanto la salud del mayor como un adecuado funcionamiento cognitivo durante el envejecimiento, propiciando una mejor calidad de vida. Entre estos factores destacan el estado de la salud, el ejercicio físico, el nivel de educación y las actividades intelectuales, incluyendo el entrenamiento cognitivo, que se tratará detalladamente en el Capítulo 2.

6.1.1. El estado de salud

Parece que el estado de la salud correlaciona con el funcionamiento cognitivo en el proceso de envejecimiento (Garfein & Herzog, 1995). Algunos estudios han encontrado que la ausencia de enfermedades crónicas reducen el riesgo de deterioro cognitivo (Schaie, 1994). Por otro lado, la agudeza sensorial puede mediar en los cambios cognitivos que están relacionados con la edad (Marsiske, Klumb, & Baltes, 1997). Los resultados de otros estudios basados en datos clínicos muestran que una presión arterial elevada correlaciona con una peor ejecución en tareas cognitivas (Launer, Masaki, Petrovich, Foley, & Havlik, 1995). La obesidad es otro factor que influye en la ejecución de tareas cognitivas en los mayores. Los estudios muestran una correlación negativa entre obesidad y actuación en pruebas cognitivas (Elias, Elias, Sullivan, Wolf, & D Agostino, 2005; Jeong, Nam, Son, Son, & Cho, 2005; Hassing, Dahl, Pedersen, & Johansson, 2010). Además, la diabetes, que en ocasiones es consecuencia de la obesidad, es otra enfermedad que afecta a las funciones cognitivas de los mayores. Existe una asociación importante entre la diabetes, el deterioro cognitivo leve y demencia (Arvanitakis, Wilson, Bienias, Evans, & Bennet, 2004; Awad, Gagnon, & Messier, 2004). Concretamente, Biessels, Vander Heide, Kamal, Bleys y Gispen (2002) encontraron déficits en memoria, aprendizaje y resolución de problemas en los mayores diabéticos. Otros estudios (Nilsson & Whalin, 2009; Redondo, Reales, & Ballesteros, 2010) han encontrado déficits en la memoria explícita de mayores diabéticos manteniéndose intacta la memoria implícita.

6.1.2. Ejercicio físico

Los beneficios atribuidos a la actividad física son numerosos y bien conocidos. El ejercicio físico se ha asociado con menor incidencia de trastornos crónicos como enfermedades coronarias (Powell, Thompson, Caspersen, & Kendrick, 1987), diabetes tipo 2 (Kriska, Blair, & Pereira, 1994), obesidad (Blair & Brodney, 1999) y presión arterial alta (Blair, Goodyear, Gibbons, & Cooper, 1984). Algunos investigadores sugieren que el ejercicio físico puede mejorar la salud y la plasticidad cerebral a lo largo del ciclo vital, pero especialmente en el proceso de envejecimiento (Cotman & Berchtold, 2002) y puede ser una medida preventiva contra el deterioro cognitivo en los mayores (Erikson & Kramer, 2009). Algunos estudios longitudinales han estudiado a los mayores sanos que realizaban ejercicio físico, y el riesgo de padecer deterioro cognitivo. En este sentido, Podewils et al. (2005) encontraron una relación inversa entre la actividad física y el riesgo de padecer demencia. Larson, Wang y Bowen (2006) encontraron que las personas que realizaban ejercicio físico tres veces por semana o más, tenían menos riesgo de padecer demencia que aquellos que realizaban menos ejercicio. En otra investigación, Colcombe et al. (2006) estudiaron los cambios que se producían en el volumen cerebral de 2 grupos de mayores después de un entrenamiento físico. Un grupo realizó 6 meses de ejercicios aeróbico (caminar 45 minutos 3 días a la semana) y el otro grupo realizó ejercicios de estiramiento y tonificación (no aeróbico). Los resultados mostraron que el volumen cerebral aumentó en los mayores sanos que realizaron ejercicio físico aeróbico respecto a los que realizaron ejercicios de estiramiento y tonificación. Como era de esperar, no hubo cambios en el volumen cerebral del grupo de jóvenes. En otro reciente estudio, Voelcker-

Rehage, Godde y Staudinger (2011) asignaron a los mayores a tres grupos: 1) con ejercicio aeróbico; 2) con ejercicios de coordinación y 3) estiramiento como condiciones de control. Los resultados para el grupo aeróbico muestran que en los mayores hubo una actividad cerebral más eficiente después del entrenamiento aeróbico que el entrenamiento en las condiciones de control. Voss et al. (2010) examinaron el impacto del ejercicio físico en las conexiones cerebrales. Los participantes de este estudio se entrenaron caminando 3 veces por semana, en sesiones de 40 minutos durante un año. Los resultados mostraron que el ejercicio físico produjo efectos positivos en la conectividad de las redes neurales, que a menudo están afectadas en el proceso de envejecimiento. En otro estudio, Correa, Leite, Nicolasi, Hauser y Nappi (2001) encontraron que el ejercicio físico y el estilo de vida saludable parecen influir de manera positiva en la actuación cognitiva de los mayores. Además, recientes revisiones realizadas en este tema muestran los efectos beneficiosos del ejercicio físico en la cognición y cerebro de los mayores (Kraft, 2012; Voelcker-Rehage & Niemann, 2013).

6.1.3. Nivel educativo

Las personas con mayor nivel educativo parece que realizan mejor las pruebas cognitivas (Zec, 1995; Osorio, Fay, Pouthas, & Ballesteros, 2010). Osorio, Ballesteros, Fay y Pouthas (2009) realizaron un estudio conductual y electroencefalográfico de recuerdo de inicios de palabras. El objetivo de esta investigación fue estudiar los correlatos neurales de la memoria episódica mediante una prueba de recuerdo de inicios de palabras en un grupo de mayores sanos, con una media de edad de 64 años y con un elevado nivel educativo. Los resultados de este grupo de mayores se compararon con los de un grupo de jóvenes, con una media de edad de 25 años. Los resultados conductuales mostraron que los dos grupos actuaron de manera similar en la prueba de memoria explícita. Sin embargo, los resultados de potenciales evocados mostraron cambios en la actividad cerebral relacionados con la edad.

Otros estudios con neuroimagen (Daselaar & Cabeza, 2005; Haut et al., 2005) también han encontrado cambios en la actividad cerebral asociados a la edad. En este sentido, Cabeza (2002) demostró que sujetos con alto nivel educativo muestran una reducción de la asimetría cerebral frontal. Los mayores necesitan mayor cantidad de tejido cerebral frontal para compensar ese déficit normal asociado a la edad. Esta compensación les permite rendir como los sujetos más jóvenes. Manly, Schupf, Tang y Stern (2005) encontraron una fuerte influencia del nivel educativo en las medidas cognitivas en los mayores.

6.1.4. Actividades cognitivamente estimulantes

La implicación en actividades cognitivamente estimulantes se ha relacionado con menor riesgo de padecer demencia, y por eso, la estimulación cognitiva se ha estudiado como una opción de tratamiento no farmacológico para reducir el riesgo de padecer deterioro cognitivo (Wilson, Bennet, Bienias, Mendes de León, Morris, & Evans, 2003). Los estudios realizados con mayores utilizando entrenamiento cognitivo concluyen que este tipo de intervenciones protegen contra el envejecimiento patológico y producen efectos positivos en actividades de la vida diaria (Valenzuela & Sachdev, 2009). Además, el hecho de involucrarse en actividades de lectura, realización de puzles, juegos, y otros hobbies al menos seis horas por semana reduce el riesgo de padecer demencia (Hughes, Chang, Vander, & Ganduli, 2010). Investigadores como Wilson et al. (2003) mostraron que los ancianos sin demencia que participan con frecuencia en actividades cognitivamente estimulantes presentan niveles más bajos de deterioro cognitivo y tienen menor riesgo de padecer la enfermedad de Alzheimer. En otro estudio (Wilson et al., 2002) también se observó que la frecuencia de leer el periódico, revistas o libros estaba asociada a una reducción del riesgo de padecer demencia en un 33%. En la misma línea, Fabrigoule et al. (1995) observaron que actividades como viajar, realizar trabajos complejos y tejer estaba asociado con un bajo riesgo de demencia.

6.2. CAMBIOS EN LOS PROCESOS COGNITIVOS ASOCIADOS A LA EDAD

A medida que envejecemos las funciones psicológicas muestran un enlentecimiento, y, en ocasiones, un deterioro de procesos como la atención, velocidad de procesamiento, memoria de trabajo y memoria episódica (LaVoie & Light, 1994; Park, Polk, Mikels, Taylor, & Marshuetz, 2001). Sin embargo, no todos los procesos cognitivos se deterioran con la edad, ya que el conocimiento del mundo, conocimiento semántico, memoria autobiográfica y el *priming* de repetición, como medida de memoria implícita, apenas están afectados con la edad (Ballesteros & Reales, 2004; Ballesteros, Reales, Mayas, & Heller, 2008; Toril, Mayas, Reales, & Ballesteros, 2012).

La memoria permite almacenar, organizar, codificar y retener información, de manera que después pueda ser recuperada. Los mayores tienen dificultades para evocar recuerdos almacenados en la memoria y para reconocer objetos y lugares familiares. Esta queja es debida a que la memoria es uno de los procesos que más se deterioran en el envejecimiento. Este proceso no es unitario. Existen varios tipos de memoria y no todos los tipos de memoria se deterioran de la misma manera durante el envejecimiento (Baddeley, 1990; Gabrieli, 1998; Henson, 2003; Squire, 1992; Squire & Zola-Morgan, 1998). Una de las clasificaciones de memoria más aceptadas distingue entre memoria implícita y memoria explícita (Squire, 1987; Tulving, 1983). La memoria explícita supone la recuperación intencional y consciente de la información previamente almacenada. Este tipo de memoria se evalúa con pruebas de recuerdo (libre o señalado) y de reconocimiento “antiguo-nuevo” (LaVoie & Light, 1994; Verhaeghen, & Salthouse, 1997). Los diferentes estudios que han evaluado este tipo de memoria en los mayores mostraron que éstos suelen actuar peor que los jóvenes en pruebas de recuerdo libre (LaVoie & Light, 1994; Verhaeghen & Salthouse, 1997) que en las pruebas de reconocimiento.

Además, algunos estudios han encontrado que a veces, el reconocimiento es similar en jóvenes y en mayores (Osorio et al., 2009; Sebastián, Reales, & Ballesteros, 2011).

La memoria implícita es un tipo de memoria cuyo contenido se recupera de manera inconsciente o no voluntaria. Se evalúa mediante pruebas indirectas, es decir, pruebas en las que las instrucciones no hacen mención a la recuperación voluntaria de la información previamente almacenada. La forma habitual de mostrar la existencia de este tipo de memoria es comprobando la existencia de *priming* (mejora en la ejecución de los sujetos en medidas de tiempo de respuesta o precisión para los estímulos presentados previamente comparándolos con los estímulos nuevos). Hay importantes disociaciones entre estos dos tipos de memoria con la edad. Frente al deterioro que presenta la memoria explícita con la edad, sobre todo cuando se evalúa con pruebas de recuerdo, numerosos estudios han mostrado que la memoria implícita apenas se deteriora con la edad (Osorio et al., 2010; Ballesteros, González, Mayas, García, & Reales, 2009; Ballesteros & Reales, 2004; Fleischman & Gabrieli, 1998; LaVoie & Light, 1994; Mitchell, 1989).

Las causas fundamentales que explican el deterioro de la memoria y de otros procesos cognitivos en los mayores son las siguientes. La primera es la *hipótesis de la causa común* que considera que el deterioro cognitivo está causado por un único mecanismo común, que implica que los efectos negativos del envejecimiento, tanto cognitivos como sensoriales pueden reflejar una pérdida global de las funciones cerebrales, que aumentaría con la edad. En esta línea, podemos encontrar la disminución en la velocidad de procesamiento como un factor general que explicaría el deterioro cognitivo asociado a la edad (Kail & Salthouse, 1994). En segundo lugar, el deterioro cognitivo en los mayores se explicaría por problemas asociados a mecanismos cognitivos específicos. En este sentido, existe evidencia de que las funciones ejecutivas, relacionadas con procesos como la memoria de trabajo, la inhibición y la flexibilidad mental, se deterioran con la edad (Park, 2000). Las funciones ejecutivas intervienen en procesos cognitivos como la codificación, razonamiento, y en muchas tareas de la vida diaria que requieren el aprendizaje o respuestas a nuevas informaciones. Dentro de estas funciones está la memoria de trabajo. Existe consenso en la comunidad científica acerca del deterioro de la memoria de trabajo con la edad (Bopp & Verhaeghen, 2005; Johnson, 2003; Park, Lautenschlanger, Hedden, Davidson, Smith, & Smith, 2002; Park & Reuther-Lorenz, 2009).

Puesto que el objetivo central de esta Tesis Doctoral es investigar los efectos de la edad y del entrenamiento con videojuegos en la memoria de trabajo de los mayores, en los siguientes apartados de esta Tesis Doctoral se abordará con más detalle la memoria de trabajo.

6.3. MEMORIA DE TRABAJO

6.3.1. Concepto

El concepto de memoria de trabajo ha cambiado significativamente ya que pacientes con alteraciones en la memoria a corto plazo tenían un funcionamiento normal de la memoria a largo plazo. Uno de los casos más conocidos es el del paciente K.F (Warrington & Shallice, 1969). El hecho de que este tipo de pacientes pudieran aprender información nueva a pesar de mostrar alteraciones en la memoria a corto plazo, sugirió que la memoria a corto plazo y la memoria de trabajo no podían ser lo mismo. En general, hablamos de memoria a corto plazo para referirnos al sistema que se ocupa del almacenamiento de información en situaciones en que las tareas no compiten por recursos cognitivos (Savage, Lavers, & Pillay, 2007), mientras que nos referimos a memoria de trabajo como aquella ocupada del almacenamiento y procesamiento de un estímulo (Baddeley, 1986; Just & Carpenter, 1992).

En 1974, Baddeley y Hitch utilizaron el término “*working memory*” (memoria de trabajo) para referirse a un sistema capaz de retener y manipular temporalmente la información mientras participa en tareas cognitivas como el aprendizaje, recuperación, comprensión y razonamiento. Por tanto, se considera que “*working memory*” involucra almacenamiento y manipulación mental de la información.

6.3.2. El modelo teórico de Memoria de Trabajo de Baddeley

De acuerdo con este modelo, la memoria de trabajo es un sistema de capacidad limitada que tiene funciones de almacenamiento y control del procesamiento. Está compuesto por el *ejecutivo central* que supervisa y coordina las actividades llevadas a cabo por los dos sistemas subsidiarios: la *agenda viso-espacial* y el *bucle fonológico* (Baddeley & Logie, 1999). El *ejecutivo central* trabaja como una estructura supervisora que selecciona estrategias y coordina actividades para procesar los estímulos que se almacenaron previamente en los sistemas subsidiarios.

Figura 1. Modelo de memoria de trabajo de Baddeley (2000).

Probablemente el *bucle fonológico* sea el componente más ampliamente estudiado del modelo de Baddeley y Hitch (1974; 2000). El *bucle fonológico* es el responsable del almacenamiento de la información auditiva-verbal, y puede mantenerla durante 2 segundos. El *bucle fonológico* desempeña un papel fundamental en el aprendizaje de la lectura (Jorn, 1983) y en la adquisición del lenguaje. El *bucle fonológico* se dividió en un almacenamiento pasivo de información fonológica, y en el proceso de control articulatorio que consiste en el proceso de “repaso” que permite refrescar la información y evitar el decaimiento de la huella de la memoria.

La *agenda viso-espacial* se encarga del procesamiento y almacenamiento de imágenes mentales y de la información visual y espacial. Los dos sistemas subsidiarios, que al principio fueron concebidos como unitarios, fueron ampliados con posterioridad (Baddeley, 1986; Baddeley, & Larsen, 2007). La *agenda viso-espacial* también se dividió en dos: el almacén visual que se encarga del almacenamiento pasivo de la información visual percibida o generada internamente, y el segundo, que se encarga de la codificación, mantenimiento y repaso activo de secuencias espaciales o movimientos percibidos.

6.3.3. La memoria de trabajo viso-espacial

Uno de los estudios que componen esta Tesis Doctoral (Capítulo 4) investiga cómo el cerebro humano percibe y codifica información recibida de manera visual y espacial. Por tanto, es relevante dedicar un apartado específico a este componente del modelo de memoria de trabajo de Baddeley.

Como se ha descrito anteriormente, la memoria de trabajo visual es un subsistema que permite el mantenimiento temporal de la información visual (por ejemplo, color y forma) mientras que la memoria de trabajo espacial está encargada del mantenimiento temporal de la información espacial. Sin embargo, a pesar de la evidencia empírica (Andrade, Kemps, Werniers, May, & Szmalec, 2002; Hartley, Speer, Jonides, Reuter-Lorenz, & Smith, 2001; Logie & Marchetti, 1991) y neuropsicológica (Farah, Hammond, Levine, & Calvanio, 1988; Luzzatti, Vecchi, Agazzi, Cesa-Bianchi, & Vergani, 1998) que existe para considerar la existencia de la separación de la memoria de trabajo visual y espacial, aún se cuestiona que puedan ser independientes. Parece que no está claro cuando la memoria de trabajo visual necesita recursos de la memoria de trabajo espacial para guardar información de los objetos. Algunos investigadores (Luck & Vogel, 1997) argumentan que la memoria de trabajo visual almacena información codificada como representaciones de objetos integrados. En este caso, la memoria para determinadas características (la forma y el color) y la memoria que se utiliza para ver cómo esas características son organizadas como un objeto, son una sola memoria, y la misma. Por el contrario, otros investigadores (Wheeler & Treisman, 2002) argumentan que la memoria de trabajo visual almacena características de los objetos en almacenes de memoria específicos y requiere de la memoria de trabajo espacial y de la atención para mantener estas características organizadas como representaciones de objetos integradas en la memoria. En este caso, la memoria para las características de los objetos y la memoria para la organización de esas características, se apoya en mecanismos separados (memoria de trabajo visual y espacial).

Las investigaciones realizadas en memoria de trabajo viso-espacial durante el ciclo vital han mostrado que los mayores realizan peor las tareas que implican este proceso cognitivo (Park et al., 2002). Sin embargo, a pesar de la extensa literatura existente en este tema, memoria de trabajo, el componente viso-espacial ha sido menos estudiado que el componente verbal (Cornoldi & Vecchi, 2000; Logie, 1995). Por esta razón, el segundo estudio de esta Tesis Doctoral tuvo como objetivo investigar la influencia del tipo de dibujo y la edad en una tarea de memoria de trabajo viso-espacial usando "*jigsaw puzzle task*", una herramienta muy útil para investigar la memoria de trabajo viso-espacial en mayores (Vecchi & Richardson, 2000). Este estudio se muestra en el Capítulo 4 de esta Tesis Doctoral.

7. CAPÍTULO 2. PLASTICIDAD Y ENTRENAMIENTO CON VIDEOJUEGOS

7.1. PLASTICIDAD CEREBRAL

El deterioro de las funciones cognitivas que se produce con la edad impide a muchos mayores poder llevar una vida independiente. Precisamente, esta falta de independencia es uno de los miedos a los que se enfrentan los mayores. Basándose en este hecho, la pregunta que se plantea, es si es posible minimizar o paliar los efectos del envejecimiento en las funciones cognitivas de los mayores. En primer lugar, para mejorar las funciones cognitivas, el cerebro tiene que tener "plasticidad", es decir, la habilidad para cambiar su estructura o función en respuesta a algún tipo de estimulación externa. La plasticidad está relacionada con la gran flexibilidad que encontramos en los mamíferos, en general, y más concretamente en el ser humano.

7.1.1. Plasticidad en el cerebro humano

En algunos estudios que comentamos a continuación, se demuestra que podríamos esperar cambios en los cerebros humanos adultos como el resultado de un entrenamiento. Por ejemplo, en la adquisición y el mantenimiento de la habilidad musical. Elbert, Pantev, Wienbruch, Rockstroh y Taub (1995) usaron magneto-encefalografía (MEG) para investigar las representaciones somato-sensoriales de la zona de la mano en los músicos, especialmente, los violinistas. Recordemos que los violinistas usan la mano derecha para manejar el arco y la mano izquierda para las cuerdas. Estimular los dedos con un dispositivo controlado demostró que las respuestas en el hemisferio derecho de los músicos eran más grandes que las observadas en los que no eran músicos. Estos hallazgos sugieren que un área cortical más grande se dedica a representar las sensaciones de los dedos de los músicos.

En los estudios de Sadato et al. (1996) encontramos más evidencia a favor de que el cerebro humano es plástico. En este estudio (Sadato et al., 1996) se utilizó tomografía por emisión de positrones (PET) para medir el flujo sanguíneo en la corteza visual durante una tarea de discriminación en personas ciegas y videntes. Encontraron que en los ciegos el flujo sanguíneo aumentaba en la corteza visual, la cual responde solo a estimulación visual, mientras que en los videntes el flujo sanguíneo disminuía durante la realización de la tarea. En otro estudio, Kauffman, Theoret y Pascual Leone (2002) estudiaron los efectos de la plasticidad en videntes, a los que se les tapó los ojos, y en sujetos videntes, a los que no se les tapó los ojos. Los participantes recibieron un entrenamiento intensivo en lectura de Braille. Los resultados mostraron que los sujetos a los que se tapaba los ojos discriminaban mejor las letras Braille que los participantes a los que no se les tapaba los ojos. Los hallazgos de estos estudios muestran que en el cerebro adulto normal, el entrenamiento puede inducir cambios relativamente rápidos en la organización de la corteza cerebral, lo que indica cierta plasticidad para adquirir y retener nueva información y diferentes habilidades.

7.1.2. Plasticidad y envejecimiento

En el proceso de envejecimiento normal el cerebro experimenta algunos cambios. Por ejemplo, los surcos se hacen más pronunciados, se produce pérdida de células en algunas zonas y encogimiento del tejido cerebral (Haug & Eggers, 1991). Además, el envejecimiento da lugar a menores concentraciones de neurotransmisores, especialmente la dopamina, implicada en el funcionamiento de los lóbulos frontales, y de la acetilcolina, que es importante en la memoria y el aprendizaje (Woodruff-Pak, 1997). Además, unas zonas cerebrales envejecen más que otras. Raz (2000) sugirió que tanto los estudios *post mortem* como las imágenes en vivo mostraban que las zonas con mayor atrofia eran el hipocampo, la corteza pre-frontal dorso-lateral y algunas zonas del cerebelo. Sin embargo, no todo es negativo, ya que el cerebro envejecido puede poner en marcha procesos compensatorios para paliar o minimizar los cambios que se producen a nivel cerebral, lo que le permite paliar el deterioro cognitivo. Así, estudios de neuroimagen han mostrado que el cerebro tiene la capacidad de aumentar la amplitud de su función con la edad. Es decir, el cerebro responde a los cambios aumentando su actividad o reactivando zonas cerebrales adicionales para procesar la información (Dennis & Cabeza, 2008; Park & Reuter Lorenz, 2009).

La investigación apoya que el ejercicio y el entrenamiento se asocia con un aumento en el volumen del cerebro, así como las respuestas funcionales en regiones selectivas como la corteza frontal y parietal (Colcombe & Kramer, 2003). En el área de neuroquímica, Valenzuela et al. (2003) investigaron la actividad de los neurotransmisores en mayores que habían sido entrenados usando el método Loci. Los resultados mostraron una mejora en memoria y en la actividad neuroquímica de los mayores. Por tanto, parece evidente que la experiencia y el entrenamiento son efectivos para favorecer la plasticidad cerebral. Específicamente, el ejercicio físico y el entrenamiento cognitivo parecen tener impacto en estructuras cerebrales. Concretamente, el ejercicio y el entrenamiento se asocian con aumentos en el volumen cerebral, así como las respuestas funcionales en regiones selectivas como las cortezas frontal y parietal (Colcombe & Kramer, 2003; Colcombe et al., 2006; Goh & Park, 2009). Por tanto, atendiendo a los resultados de los estudios en este área, parece que el cerebro humano muestra cierta plasticidad, ya que es capaz de responder a estimulación externa. Puesto que esta Tesis Doctoral pretende dar respuesta a algunos interrogantes planteados respecto a si el entrenamiento cognitivo con videojuegos es efectivo o no para mejorar y/o mantener las funciones cognitivas de los mayores, en el siguiente punto abordaremos el impacto de los videojuegos en el entrenamiento cognitivo de los mayores.

7.2. ENTRENAMIENTO CON VIDEOJUEGOS

7.2.1. El fenómeno de los videojuegos en los mayores

Recientemente, los videojuegos han alcanzado gran popularidad principalmente en los jóvenes pero también entre los mayores. Un estudio realizado en Estados Unidos, en Mayo de 2009 por *Entertainment Software Association*, mostró que el 63% de los americanos habían jugado con videojuegos en los últimos 6 meses. De hecho, los mayores de 65 años jugaron más que cualquier otro grupo de edad. Actualmente, los mayores están muy concienciados con el uso de las nuevas tecnologías, en general, y con los videojuegos, en particular, como una herramienta útil para reducir el riesgo de padecer deterioro cognitivo. En este sentido, la industria dedicada a la creación de videojuegos desempeña un papel importante en la implementación de nuevos videojuegos que sean atractivos para los mayores y que sean útiles como instrumento para reducir el riesgo de padecer algún tipo de deterioro.

7.2.2. El uso de los videojuegos y sus ventajas

Actualmente hay mucho interés en el uso de los videojuegos como herramienta para mejorar ciertas habilidades cognitivas en mayores (Anguera et al., 2013; Ballesteros et al., 2014). Además, el uso de videojuegos para intentar mejorar ciertos procesos cognitivos en los mayores tiene algunas ventajas sobre los entrenamientos cognitivos tradicionales: 1) Los videojuegos son relativamente más baratos que poner en práctica un programa de entrenamiento cognitivo tradicional donde es necesario más tiempo, y más recursos para entrenar a los mayores; 2) Los videojuegos suelen ser más entretenidos y divertidos para los mayores que los entrenamientos tradicionales de papel y lápiz (Zelinski & Reyes, 2009) ya que éstos incluyen imágenes en movimiento, sonidos y retroalimentación inmediata de cómo se ha realizado el juego; 3) El uso de los videojuegos puede ayudar a mantener niveles aceptables de bienestar general en los mayores ya que los jugadores regulares y ocasionales de videojuegos muestran niveles más altos de bienestar social y menos depresión que los no jugadores (Allaire, McLaughlin, Trujillo, Whitlock, & Laporte, 2013).

7.2.3. Los primeros entrenamientos con videojuegos

El uso de videojuegos como herramienta de entrenamiento en los mayores sanos es relativamente reciente. Los primeros estudios que encontramos datan de 1986. Por tanto, comparando este campo con otras intervenciones en mayores, se trata de un ámbito de estudio reciente. Desafortunadamente, la investigación realizada sobre la eficacia de los videojuegos ha proporcionado resultados mixtos, ya que mientras unos estudios encuentran resultados que avalan la eficacia de los videojuegos para mejorar algunas funciones cognitivas en mayores (Anguera et al., 2013; Belchior, 2008) otros estudios no encuentran efecto del entrenamiento con videojuegos en los procesos cognitivos de los mayores (Boot et al., 2013; Owen et al., 2010). Una de las causas por las que las diferentes intervenciones con videojuegos en mayores aportan resultados diferentes, en ocasiones contradictorios, es la gran variabilidad de intervenciones que se realizan. Es decir, se utilizan diferentes tipos de videojuegos, se realizan entrenamientos con diferente número de videojuegos, se evalúan diferentes procesos cognitivos, se usan diferentes pruebas para evaluar esos procesos cognitivos, las características de los participantes, como la edad varían entre los estudios, y la duración del entrenamiento es variable (efecto de la dosis). Todas estas variables son muy importantes a la hora de diseñar un programa de entrenamiento con videojuegos. En el apartado siguiente se exponen detalladamente estas variables.

Los primeros estudios de entrenamiento con videojuegos mostraron mejoras en tiempo de reacción (Clark, Lamphear, & Riddick, 1987; Dustman, Emmmerson, Steinhaus, Shearer, & Dustman, 1992; Goldstein, 1997) en inteligencia (Drew & Waters, 1986) en atención (Belchior, 2008), etc. Sin embargo, otros estudios no encontraron transferencia a otros procesos cognitivos después del entrenamiento (Ackerman, Kanfer, & Calderwood, 2010; Boot et al., 2013). Precisamente encontrar transferencia a otros procesos cognitivos no entrenados después del entrenamiento es uno de los aspectos más debatido y controvertido en la literatura científica relacionada con el entrenamiento con videojuegos en mayores sanos.

7.2.4. Efectos del entrenamiento con videojuegos en mayores

La gran controversia existente en este ámbito de estudio ha dado lugar en los últimos años a la realización de nuevos estudios que han aportado a este tema novedosos resultados pero poco consenso. Los resultados han variado mucho entre los estudios. La duración del entrenamiento es una de las posibles causas de la diferencia de resultados en las diferentes intervenciones. Algunos estudios realizan entrenamientos largos, que en principio pueden hacernos pensar que son más efectivos. Sin embargo, la realidad es que estos entrenamientos largos acaban cansando y aburriendo a los mayores que los realizan. En dos meta-análisis recientes se muestra que los programas de entrenamiento cortos son más efectivos que largos (Lampit, Hallock, & Valenzuela, 2014; Toril, Reales, & Ballesteros, 2014). Otra variable que puede influir es la edad de los participantes en el estudio, el número y el tipo de videojuego empleado en el entrenamiento.

Basak, Boot, Voss y Kramer (2008) entrenaron a mayores sanos con un rango de edad de 63 a 75 años con un videojuego de acción y estrategia "*Rise of Nations"* durante 4-5 semanas, con una frecuencia de 3 veces por semana. Los resultados mostraron que el grupo que entrenó con videojuego mejoró en memoria, funciones ejecutivas y habilidades viso-espaciales. En otro estudio, Anguera et al. (2013) utilizaron un videojuego diseñado específicamente para entrenar a mayores, "*Neuroracer*". La duración del entrenamiento fue de 4 semanas, y los resultados fueron positivos. El grupo entrenado mejoró en los procesos cognitivos evaluados y los beneficios del entrenamiento se transfirieron a otras habilidades no entrenadas. Este resultado es importante, ya que la mayoría de los estudios no encuentran transferencia a otras habilidades no entrenadas. Stern et al. (2011) entrenaron con "*Space Fortress*" a mayores sanos durante 12 semanas (36 horas). Los resultados mostraron mejora en funciones ejecutivas. Belchior (2008) entrenó a los mayores durante 2-3 semanas y encontró mejoras en velocidad de procesamiento. Ballesteros et al. (2014) encontraron mejoras después del entrenamiento en tiempo de reacción, atención, memoria de reconocimiento visual y en bienestar social.

Sin embargo, otros estudios recientes no han encontrado efectos positivos del entrenamiento con videojuegos. Por ejemplo, Ackerman et al. (2010) entrenaron a mayores de 50 a 71 años de edad con *"Big Brain Academy"* 5 veces por semana durante 4 semanas pero no encontraron mejoras después del entrenamiento. Boot et al. (2013) tampoco encontraron mejoras en las funciones cognitivas evaluadas después del entrenamiento con *"Mario Kart"* ni después de entrenar a los mayores con *"Brain Age"*. Maillot, Perrot y Hartley (2012) entrenaron a mayores de 65 a 75 años de edad con *"Nintendo Wii"* durante 12 semanas. Los resultados mostraron mejoras del grupo entrenado en medidas físicas y velocidad de procesamiento pero no en habilidades viso-espaciales, como habían encontrado Basak et al. (2008).

De los resultados de estos estudios podemos extraer escasas conclusiones respecto a la eficacia de los videojuegos en las funciones cognitivas de los mayores. El único consenso que parece existir entre los estudios es que el tiempo de reacción y la atención si mejoran después del entrenamiento con videojuegos. Por esta razón, Kueider, Parisi, Gross y Rebok, (2012) realizaron una revisión sistemática para investigar la eficacia de los videojuegos en los mayores. En este estudio se incluyeron ocho intervenciones con videojuegos. Los resultados mostraron que el entrenamiento con videojuegos tiene efectos positivos en tiempo de reacción y la velocidad de procesamiento; y son menos efectivos para mejorar las funciones ejecutivas. Puesto que esta revisión sistemática incluyó sólo ocho estudios de entrenamiento con videojuegos, las conclusiones fueron limitadas. Por esta razón, y debido a los resultados mixtos existentes en la literatura científica, creímos necesario realizar un estudio meta-analítico más completo para intentar extraer conclusiones válidas acerca de la efectividad de los entrenamientos con videojuegos en mayores. Este estudio meta-analítico es uno de los artículos que componen esta Tesis Doctoral (Toril et al., 2014). Ver Capítulo 5.

7.3. ENTRENAMIENTO DE LA MEMORIA DE TRABAJO

La memoria de trabajo es un proceso cognitivo de importancia vital para poder llevar una vida independiente. Como ya se ha visto en el Capítulo 1 de esta Tesis Doctoral, este tipo de memoria se deteriora con la edad (Bopp & Verhaeghen, 2005; Park et al., 2002; Park & Reuther-Lorenz, 2009) y está formada por varios componentes. Aunque han sido numerosos los estudios realizados sobre el ejecutivo central y el bucle fonológico, muy pocos estudios han evaluado los efectos del entrenamiento de la memoria de trabajo viso-espacial en los mayores (Cornoldi & Vecchi, 2000; Logie, 1995). Recientemente, algunos estudios han investigado posibles efectos del entrenamiento en memoria de trabajo (Boot, Blakely, & Simons, 2011; Dahlin, Bäckman, Nely, & Nyberg, 2008; Klingberg, 2010; Morrison & Chein, 2011; Perrig, Hollenstein, & Oelhafen, 2009; Shipstead, Redick, & Engle, 2010; Takeuchi, Taki, & Kawashima, 2010). Sin embargo, los resultados son mixtos, ya que unos estudios encontraron efectos positivos del entrenamiento (Morrison & Chein, 2011) mientras otros estudios no encontraron que el entrenamiento de la memoria de trabajo fuera efectivo (Shipstead et al., 2010).

Karbach y Verhaeghen (2014) en un meta-análisis reciente, examinaron los efectos del entrenamiento en funciones ejecutivas y memoria de trabajo en mayores. Estos investigadores sugieren que variables como el tipo de entrenamiento, intensidad, y duración del mismo podrían explicar los resultados contradictorios encontrados en los distintos estudios.

Además, sus resultados mostraron que la memoria de trabajo y las funciones ejecutivas mejoraron significativamente después del entrenamiento.

En un estudio reciente con videojuegos realizado en nuestro laboratorio (Ballesteros et al., 2014) investigamos los efectos de 20 sesiones de 1 hora de entrenamiento con videojuegos en funciones cognitivas que se deterioran en el envejecimiento y en una prueba de bienestar subjetivo. En este estudio participaron dos grupos, el experimental, que recibió el entrenamiento y el control, que se reunió con los experimentadores varias veces durante la duración del estudio. Los resultados mostraron mejoras significativas en el grupo entrenado en velocidad de procesamiento, atención, memoria de reconocimiento visual y en bienestar social. Sin embargo, la memoria de trabajo viso-espacial y las funciones ejecutivas no mejoraron después del entrenamiento. En el grupo control no se produjo ningún cambio. Sin embargo, las mejoras observadas en el grupo experimental desaparecen en la evaluación de seguimiento (tres meses), lo que sugiere la necesidad de realizar alguna sesión de recuerdo para conservar los efectos beneficiosos encontrados inmediatamente después de haber finalizado el entrenamiento.

Considerando los resultados de este estudio y conociendo la importancia de la memoria de trabajo para los mayores, el interés en las posibles mejoras de este proceso cognitivo después del entrenamiento es un tema importante en la investigación en el área de envejecimiento. Por esta razón, y siendo consciente del debate abierto relacionado con los efectos del entrenamiento en la memoria de trabajo, en general, y con videojuegos, en particular, realizamos el estudio final de esta Tesis Doctoral.

Este último estudio se diseñó teniendo en cuenta los resultados de nuestro estudio de meta-análisis (Toril et al., 2014). Por esta razón preparamos un entrenamiento de 15 sesiones, con 6 videojuegos de "no action" centrados en entrenar la memoria de trabajo. Nuestras hipótesis fueron: 1) el entrenamiento con videojuegos mejorará la memoria de trabajo de los entrenados; y 2) se producirá transferencia a la memoria episódica, y 3) los efectos del entrenamiento se mantendrán 3 meses después de haber finalizado el entrenamiento. Este estudio se presenta en el Capítulo 6 de esta Tesis Doctoral.

8. CAPÍTULO 3. EL ENVEJECIMIENTO AFECTA A LAS PRUEBAS DE COMPLECIÓN DE RAICES Y RECONOCIMIENTO PERO NO A LA GENERACIÓN DE CATEGORÍAS

Toril, P., Mayas, J., Reales, J.M., & Ballesteros, S. (2012). El envejecimiento afecta a las pruebas de compleción de raíces y reconocimiento pero no a la generación de categorías, *Psicothema, 24,* 345-351

Abstract

In this study, we investigated the effect of aging in two implicit memory tasks, *word-stem completion* and *category generation,* and in explicit recognition. We compared the performance of young and older adults on these implicit memory tasks with those of explicit recognition. We expected better performance of young than older adults in the explicit memory task and similar priming in both implicit memory tasks. The results showed that young adults performed better than older adults in the recognition task. Moreover, both age groups showed priming in the implicit memory tasks although priming was greater in young adults compared to older adults in the word-stem completion memory task while both age groups showed similar level of priming in the category generation task. The present results showed dissociations as a function of age not only between the explicit and the implicit tasks but also between the implicit tasks.

Key words: Ageing, category generation, implicit memory, explicit memory, recognition, word-stem completion

En este estudio investigamos el efecto de la edad en dos tareas de memoria implícita, la prueba de *compleción de raíces* y la de *generación de categorías*, y comparamos la actuación de jóvenes y mayores en estas pruebas con la actuación en una prueba de memoria explícita (reconocimiento "antiguo-nuevo"). Nuestra predicción fue que los jóvenes actuarían mejor que los mayores en la prueba de reconocimiento, mientras que ambos grupos mostrarían efectos de *priming* similar en ambas pruebas de memoria implícita. Los resultados mostraron: (a) en los dos grupos de edad hubo *priming* en ambas tareas de memoria implícita; (b) los jóvenes mostraron más *priming* que los mayores en la tarea de compleción de raíces, mientras el *priming* fue similar en ambos grupos en la tarea de generación de categorías; y (c) los jóvenes actuaron mejor que los mayores en la prueba de memoria explícita. Estos resultados, no solo mostraron disociación entre las tareas de memoria implícita y explícita, sino también entre dos tareas de memoria implícita.

Key words: Envejecimiento, *priming*, compleción de raíces, generación de categorías, reconocimiento

8.1. INTRODUCCIÓN

El envejecimiento es un proceso complejo que afecta a todos los seres vivos aunque no lo hace con la misma intensidad (Fleischman y Gabrieli, 1998; Nilsson, 2003; Park, Polk, Mikels, Taylor y Marshuetz, 2001). A medida que las personas envejecen las funciones psicológicas muestran un enlentecimiento y, a veces, un deterioro pronunciado como ocurre en la atención selectiva, la velocidad de procesamiento, la memoria de trabajo y la memoria episódica (La Voie y Light, 1994; Park et al., 2001). Sin embargo, no todas las funciones psicológicas se deterioran con la edad. El conocimiento semántico, el conocimiento del mundo y el *priming* de repetición, como medida de la memoria implícita, se mantienen intactas con la edad (Ballesteros y Reales, 2004; Ballesteros, Reales, Mayas, y Heller, 2008).

La memoria es uno de los procesos que se deterioran en el envejecimiento. Este proceso permite almacenar información y retenerla a veces durante toda la vida. Sin embargo, la memoria no es un proceso unitario. La literatura ha mostrado que no todos los tipos de memoria se deterioran con la misma intensidad en el envejecimiento (Baddeley, 1990; Gabrieli, 1998; Henson, 2003; Schacter, 1987; Squire, 1992; Squire y Zola-Morgan, 1988).

Una de las clasificaciones de la memoria más aceptadas distingue entre memoria explícita y memoria implícita (Squire, 1987; Tulving, 1983). La memoria explícita es un tipo de memoria que supone la recuperación intencional y consciente de la experiencia previa. Este tipo de memoria se evalúa principalmente mediante pruebas directas de recuerdo (libre o señalado) y de reconocimiento "antiguo-nuevo" (La Voie y Light, 1994; Verhaeghen y Salthouse, 1997). La memoria implícita, por el contrario, es un tipo de memoria cuyo contenido puede recuperarse de forma inconsciente y que se evalúa mediante pruebas indirectas; esto es, mediante pruebas en las que las instrucciones no hacen mención a la recuperación voluntaria de la información previamente almacenada. La memoria implícita se evalúa normalmente comprobando la existencia de *priming*. El *priming* se define como una mejora en la ejecución de los sujetos, ya sea en medidas de tiempo de respuesta o de precisión, para los estímulos presentados previamente en comparación con estímulos no presentados o nuevos. Se han encontrado importantes disociaciones con la edad entre ambos tipos de pruebas (Ballesteros y Reales, 2004; Fleischman, 2007; Mitchell y Bruss, 2003; Schacter, 1987). Numerosos estudios han mostrado que las personas mayores suelen actuar peor que los jóvenes cuando la memoria episódica o explícita se evalúa con pruebas de recuerdo libre (La Voie y Light, 1994; Verhaeghen y Salthouse, 1997) y, en menor medida cuando se evalúa con pruebas de reconocimiento. Incluso se ha encontrado que en ocasiones la memoria de reconocimiento es similar en jóvenes y mayores (e.i., Osorio, Ballesteros, Fay, y Pouthas, 2009; Sebastián, Reales, y Ballesteros, en prensa). Frente al declive que suele experimentar la memoria explícita, sobre todo cuando se evalúa con pruebas de recuerdo libre, un gran número de estudios han mostrado que la memoria implícita de las personas mayores apenas se deteriora con la edad (e.i., Osorio, Fay, Pouthas, y Ballesteros, 2010; Ballesteros, González, Mayas, García y Reales, 2009; Ballesteros y Reales, 2004; Fleischman y Gabrieli, 1998; La Voie y Light, 1994; Mitchell, 1989).

La literatura ha distinguido, entre otros, dos tipos de *priming*, el perceptivo y el conceptual. El primero se evalúa con pruebas implícitas en las que el procesamiento está determinado por las propiedades físicas de los estímulos, mientras que el segundo está relacionado con el procesamiento semántico (Ballesteros, 2010). El *priming* perceptivo se conceptualiza como pre-semántico porque parece que en él no influye el significado siendo, sin embargo, muy sensible a los cambios físicos de los estímulos entre la fase de estudio y la de prueba (Roediger y Blaxton, 1987). El *priming* conceptual, por el contrario, estaría relacionado con operaciones de codificación semántica, siendo menos sensible a los cambios en las propiedades perceptivas de los estímulos (Schacter, 1990). Aunque existe consenso sobre la existencia de disociaciones entre tareas implícitas y explícitas en el envejecimiento, existen bastantes discrepancias en lo que respecta a si existen o no disociaciones en función de la edad entre tareas de *priming* perceptivo y tareas de *priming* conceptual. Mientras algunas investigaciones apuntan a un deterioro en el componente perceptivo (Abbenhuis, Raaijmakers y Van Woerden, 1990; Small, Hultsch y Masson, 1995) otras lo han encontrado en el componente conceptual (Jeliric, Craik y Moscovitch, 1996; Maki y Knopman, 1996, Maki, Zonderman y Weingartner, 1999).

El objetivo de este estudio es comprobar si dos tareas de memoria implícita que exigen producción o generación pero que difieren en el tipo de procesamiento (perceptivo-conceptual *vs.* únicamente conceptual) se encuentran preservadas en el envejecimiento, y su posible disociación con una prueba de reconocimiento explícito "antiguo-nuevo". Para comprobar las posibles disociaciones en función de la edad hemos utilizado dos tareas de memoria implícita, la prueba de generación de ejemplares de categorías, con un elevado componente conceptual, y la prueba de compleción de raíces, considerada por algunos investigadores como una prueba mixta con componentes perceptivos y conceptuales (Daselaar, Veltman, Rombouts, Raaijmakers y Jonker, 2005; Osorio et al., 2010; Mitchell y Bruss, 2003). Para evaluar la memoria explícita hemos utilizado una prueba de reconocimiento "antiguo-nuevo". Basándonos en los resultados de algunos estudios previos que han encontrado una memoria explícita deteriorada en mayores, esperamos que la actuación de los jóvenes en este tipo de pruebas sea mejor que la de los mayores. Aunque esta predicción no resulta novedosa, las puntuaciones de reconocimiento obtenidas en nuestro estudio nos permitirán realizar las comparaciones pertinentes entre tareas explícitas e implícitas.

8.2. MÉTODO

8.2.1. Participantes

En este estudio participaron 20 adultos mayores sanos y 20 adultos jóvenes. El grupo de mayores estaba formado por 15 mujeres y 5 hombres con edades comprendidas entre los 65 años y los 75 años ($\overline{X} = 71,8; S_X = 5,6$). El grupo de jóvenes lo formaron 11 mujeres y 9 hombres con edades comprendidas entre los 25 y los 35 años ($\overline{X} = 33,1; S_X = 1,5$). Las desviaciones típicas de ambos grupos resultaron significativamente diferentes según la prueba de Levene [F (1, 38) = 29,77, p < 0,0001], mostrando el grupo de mayores una variabilidad más elevada. Todos los participantes tenían visión normal o corregida a normal y completaron una serie de pruebas psicológicas antes de realizar las tareas experimentales de memoria implícita y explícita. Entre estas pruebas se incluía el Mini Examen Cognoscitivo (MMSE, Folstein, Folstein y McHugh, 1975) con el fin de descartar a los participantes con deterioro cognitivo. El punto de corte utilizado fue de 24 puntos. La capacidad verbal se evaluó con la Prueba de Información del Weschler (Weschler, 2001) y con una prueba de lectura consistente en leer el párrafo de un texto. Además, los participantes en este estudio realizaron la prueba manipulativa de Cubos del Weschler (Weschler, 2001). Antes de comenzar el estudio los participantes firmaron un consentimiento informado. El estudio se realizó cumpliendo las normas éticas vigentes contenidas en la Declaración de Helsinki de 1964. La Tabla 1 presenta las puntuaciones de ambos grupos en las pruebas psicológicas.

Tabla 1. Puntuaciones medias y desviaciones típicas (SD) de jóvenes y mayores en las pruebas neuropsicológicas

	Grupo de jóvenes (n=20)		**Grupo de mayores (n=20)**	
	Media	**SD**	**Media**	**SD**
Edad	33,10	1,5	71,8	5,6
Minimental	---	---	25,2	1,4
Prueba de información[*,1]	16,3	0,8	11,7	0,97
Prueba de cubos[*,2]	15,25	0,96	7,8	0,89

Nota: *p < 0,05, T para muestras independientes; 1 prueba perteneciente al WAIS verbal, 2 prueba perteneciente al WAIS manipulativo.

8.2.2. Instrumentos

Prueba de compleción de raíces y tarea de reconocimiento. Los estímulos fueron 120 palabras, todas ellas sustantivos, seleccionadas a partir del Diccionario de Frecuencias Lingüísticas del castellano (Alameda y Cuetos, 1995). Las palabras se distribuyeron aleatoriamente en 4 listas de 30 palabras cada una con características similares en cuanto a la longitud $(\overline{X} = 2{,}8;\ S_X = 0{,}56)$, medida en sílabas, y la frecuencia de uso $(\overline{X} = 106;\ S_X = 56{,}8)$. Dos de las listas se utilizaron en la prueba de compleción de raíces y las otras dos en la prueba de reconocimiento. Las raíces tenían una media de 3,8 posibilidades de compleción evaluadas mediante su búsqueda en el diccionario. En ambas tareas las listas de palabras fueron contrabalanceadas de manera que tuvieran la misma probabilidad de ocurrencia en las distintas condiciones experimentales.

Prueba de generación de ejemplares de categorías. Los estímulos consistieron en 60 palabras pertenecientes a 6 categorías diferentes distribuidas en dos listas con 3 categorías cada una (lista A y lista B). La lista A estaba formada por 30 palabras que pertenecían a 3 categorías diferentes (10 árboles, 10 animales y 10 plantas). En la lista B aparecían 30 palabras correspondientes a las otras 3 categorías (10 verduras, 10 frutas y 10 de ropa). Estas palabras también fueron seleccionadas a partir del Diccionario de Frecuencias Lingüísticas del castellano (Alameda y Cuetos, 1995). Las dos listas tenían una frecuencia de uso $(\overline{X} = 100; S_x = 12,7)$ y longitud $(\overline{X} = 3; S_x = 0,79)$ similares, y se contrabalancearon para los distintos participantes. En la Tabla 2 se presentan ejemplos de las palabras utilizadas en las tres tareas.

Tabla 2. Ejemplos de palabras utilizadas en las tres tareas de memoria

	Tarea	
Generación de categorías	**Compleción de raíces**	**Reconocimiento**
Gato (140)	Comida (134)	Pantalla (142)
Sombrero (88)	Famoso (83)	Escala (88)
Gallina (37	Campana (34)	Capitán (34)

Nota: entre paréntesis aparecen las frecuencias de uso.

8.2.3. Diseño experimental y procedimiento

El diseño general consistió en un diseño factorial mixto 2 (Grupo: jóvenes y mayores) x 2 (Tipo de Estudio: estudiado y no estudiado) x 3 (Prueba: compleción de raíces, generación de ejemplares y reconocimiento). Grupo fue el factor intersujetos mientras que los dos últimos factores fueron intrasujetos. Los participantes realizaron las tareas de manera individual. Las dos tareas de memoria implícita se contrabalancearon en función de los participantes y siempre precedieron a la prueba de memoria explícita para evitar la contaminación de la memoria implícita por el uso de estrategias explícitas.

Memoria Implícita: Prueba de compleción de raíces de palabras

Fase de estudio. En esta fase se presentaron a cada participante 30 palabras procedentes de las listas utilizadas en esta prueba. Estas palabras se presentaron aleatoriamente, escritas en minúscula, con formato Arial 44 en negro sobre fondo blanco y centradas en la pantalla del ordenador de 11.6", que distaba aproximadamente 50 cm del participante. Cada palabra se presentó durante 1 segundo. La tarea de los participantes consistió en leer en voz alta cada una de las palabras presentadas.

Fase de prueba. En esta fase los participantes realizaron la tarea de compleción de raíces de palabras. Se presentaron en papel 30 raíces de palabras consistentes en las tres primeras letras de una palabra. Quince raíces pertenecían a palabras que habían sido presentadas en la fase de estudio y otras quince raíces eran nuevas (pertenecían a palabras no estudiadas previamente). La tarea consistió en completar cada raíz presentada con la primera palabra que les viniera a la mente.

Memoria implícita: Tarea de generación de ejemplares de categorías

Fase de estudio. En esta fase se presentaron a cada participante 30 palabras pertenecientes a la lista A ó B. Las palabras se presentaron en ordenador con formato e intervalos idénticos a los de la fase de estudio de la prueba de compleción de raíces. La tarea consistió en leer en voz alta cada palabra presentada.

Fase de prueba. En esta fase se presentó a cada participante un folio con el nombre de 6 categorías (3 estudiadas y 3 no estudiadas) y se les pidió que escribiesen todos los nombres de los ejemplares de cada categoría que les vinieran a la mente.

Memoria explícita: Prueba de reconocimiento

Fase de estudio. Se pidió a los participantes que leyeran una serie de quince palabras procedentes de las dos listas utilizadas para esta prueba. Las palabras se presentaron en ordenador con formato e intervalos idénticos a los de la fase de estudio de las pruebas de memoria implícita.

Fase de prueba. Después de 5 minutos cada participante realizó la prueba de reconocimiento. En esta fase, se presentó a cada participante un folio con quince palabras nuevas entremezcladas con quince palabras presentadas previamente durante la fase de estudio y se le pidió que marcara qué palabras reconocía de la fase de estudio anterior (antiguas) y qué palabras no se habían presentado antes.

8.3. ANÁLISIS DE DATOS

La puntuación en la prueba de *compleción de raíces* se calculó como la diferencia entre la proporción de raíces completadas con palabras que coincidían con las previamente presentadas en la fase de estudio (aciertos) y la proporción de raíces completadas con palabras que coincidían con el grupo de palabras no estudiadas (línea base).

La puntuación en la tarea de *generación de categorías* se calculó como la proporción de palabras generadas que pertenecían a la lista estudiada (aciertos) y se comparó con la proporción de palabras generadas que no pertenecían a la lista estudiada (línea base).

La puntuación en la prueba de *reconocimiento* se obtuvo como la diferencia entre el número de aciertos y el de falsas alarmas de la matriz de confusión. Además, la actuación en la prueba de reconocimiento se evaluó mediante el índice de sensibilidad *d´* y de sesgo *c* de la Teoría de Detección de Señales, TDS (Macmillan, 2005) utilizando el programa TDS_EXPERT (Reales y Ballesteros, 2000).

8.4. RESULTADOS

Para analizar los datos se realizó un MANOVA 2x2 mixto con dos factores, Grupo (jóvenes *vs* mayores) como factor intersujetos y Tipo de Estudio (estudiado *vs* no estudiado) como factor intrasujetos, con dos variables dependientes: proporción de compleción de raíces y proporción de compleción de categorías. Se encontraron diferencias significativas en el contraste multivariado para el factor principal Grupo [Λ de Wilks $= 0{,}475$, $F(2, 37) = 20{,}4$, $p < 0{,}0001$], así como para el factor Tipo de Estudio [Λ de Wilks = 0,082, $F(2, 37) = 206{,}8$, $p < 0{,}0001$] y la interacción doble entre Grupo y Tipo de Estudio [Λ de Wilks = 0,741, $F(2, 37) = 6{,}46$, $p = 0{,}004$]. Tal y como recomiendan Page, Brauer y MacKinon (2003), la significatividad del análisis multivariado nos permite realizar e informar de los ANOVAs univariados para cada variable independientemente. Al incluir un factor intrasujeto se utilizará la corrección de Greenhouse-Geisser para todos los análisis univariados.

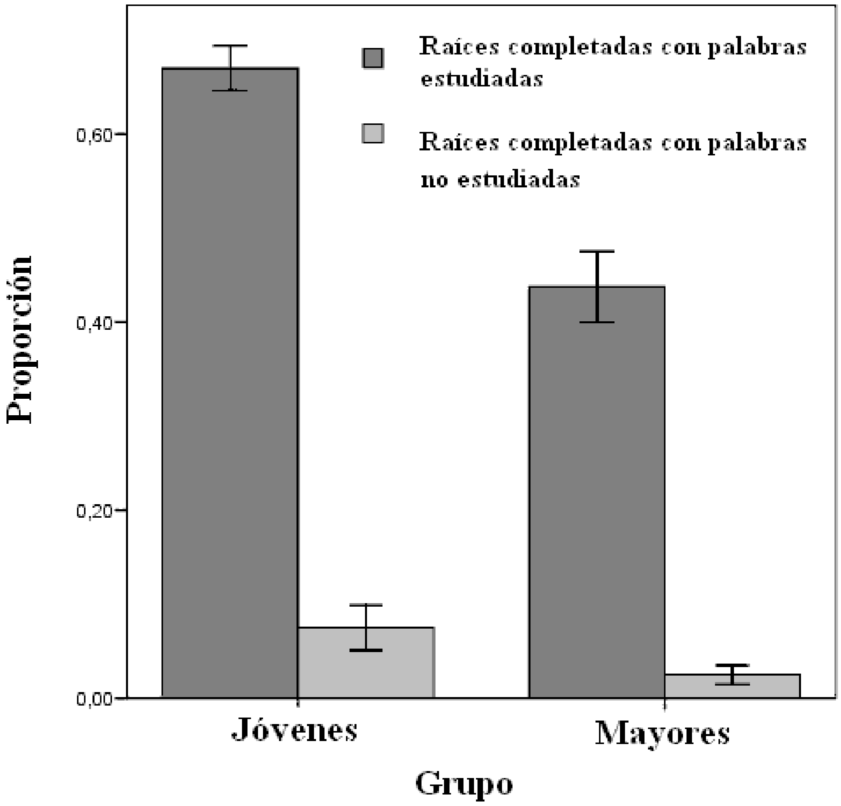
8.4.1. Compleción de raíces

El ANOVA univariado para la proporción de raíces correctamente completadas mostró que el factor Tipo de Estudio resultó altamente significativo [$F(1, 38) = 378{,}57$, $MC_e = 5{,}07$, $p < 0{,}0001, \eta_p^2 = 0{,}909$, *potencia* = 1]. La media de palabras completadas con raíces estudiadas ($\overline{X} = 0{,}55; S_X = 0{,}18$) fue superior a la media obtenida en la línea base ($\overline{X} = 0{,}05; S_X = 0{,}08$). El factor Grupo también resultó estadísticamente significativo [$F(1, 38) = 30{,}20$, $MC_e = 0{,}39$, $p < 0{,}0001, \eta_p^2 = 0{,}443$, *potencia* = 0,93]. Los jóvenes completaron más raíces que los mayores ($\overline{X} = 0{,}67; S_X = 0{,}10$ y $\overline{X} = 0{,}43; S_X = 0{,}16$ respectivamente). Finalmente, la interacción Grupo x Tipo de Estudio también resultó estadísticamente significativa [$F(1, 38) = 12{,}42$, $MC_e = 0{,}16$, $p < 0{,}0001, \eta_p^2 = 0{,}246$, *potencia* = 1]. El estudio de esta interacción (véase Figura 1) mostró que aunque ambos grupos obtuvieron *priming* (la diferencia entre las proporciones de raíces completadas con palabras estudiadas y con palabras pertenecientes a la línea base), la magnitud del mismo fue mayor en el grupo de jóvenes (0,60) que en el grupo de mayores (0,41). Estos datos se muestran en la Tabla 3.

Se calculó el *priming* relativo en la prueba de compleción de raíces aplicando la siguiente fórmula (Snodgrass, 1989; Snodgrass y Feenan, 1990):

$$PR = \frac{A - B}{1 - B}$$

siendo A, la proporción de raíces completadas con palabras estudiadas y B, la proporción de raíces completadas con palabras no estudiadas. Esta medida expresa las puntuaciones de *priming* absoluto (A-B) en relación a la diferencia entre el nivel de la línea base y el máximo posible (1-B). Con los valores obtenidos a partir de la fórmula anterior se realizó un ANOVA de un factor (Grupo) con dos niveles. Este análisis confirmó los resultados anteriores al mostrar la existencia de diferencias significativas entre jóvenes y mayores [$F(1, 38) = 20,38$, $MC_e = 0,46$, $p < 0,00$, $\eta_p^2 = 0,349$, *potencia* = 0,993]. Véase Figura 1.



Barras de error +/- 1 ET

Figura 1. Interacción en la prueba de compleción de raíces de palabras entre Grupo (jóvenes *vs* mayores) y Tipo de Estudio (estudiado *vs* no estudiado); ET (Error Típico).

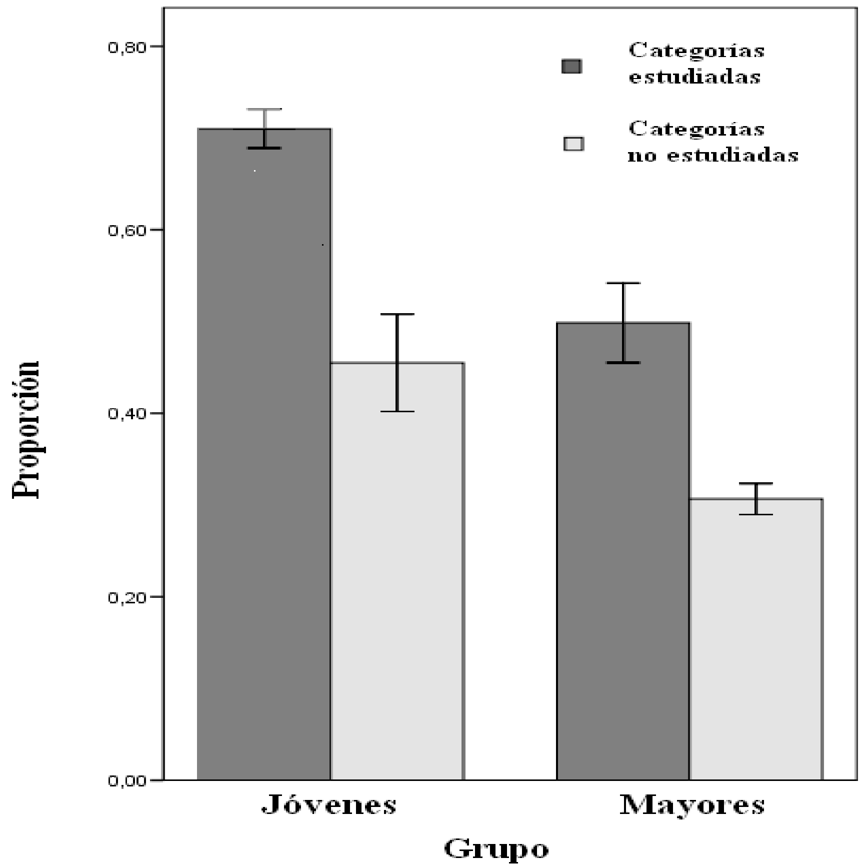
8.4.2. Generación de ejemplares de categorías

El ANOVA univariado para la proporción de categorías completadas mostró que el factor principal Tipo de Estudio resultó estadísticamente significativo [$F(1, 38) = 59,93$, $MC_e = 0,017$, $p < 0,001$, $\eta_p^2 = 0,612$, *potencia* = 1]. La proporción media de palabras generadas a partir de categorías estudiadas fue mayor $(\overline{X} = 0{,}6; S_X = 0{,}18)$ que la proporción de palabras generadas a partir de categorías no estudiadas $(\overline{X} = 0{,}38; S_X = 0{,}18)$. El factor principal Grupo también resultó significativo [$F(1, 38) = 17{,}143$, $MC_e = 0{,}03$, $p < 0{,}001$, $\eta_p^2 = 0{,}311$, *potencia* = 0,981]. Los mayores generaron menos ejemplares $(\overline{X} = 0{,}49; S_X = 0{,}19)$ que los jóvenes $(\overline{X} = 0{,}71; S_X = 0{,}96)$. Sin embargo, la interacción Grupo x Tipo de Estudio no resultó estadísticamente significativa ($p > 0{,}05$). En ambos grupos, el *priming* fue similar (0,26 y 0,19 para jóvenes y mayores respectivamente). Ver la Tabla 3 y Figura 2.

Tabla 3. Puntuaciones medias de grupos de jóvenes y mayores en las pruebas de memoria implícita y explícita

	Grupo de jóvenes (n=20)		**Grupo de mayores (n=20)**	
Tareas de Memoria Implícita	**Proporción**	**SD**	**Proporción**	**SD**
Raíces completadas (p. estudiadas)	0,67	0,10	0,43	0,16
Raíces completadas (p. no estudiadas)	0,07	0,10	0,02	0,04
Priming (raíces)	0,60	--	0,41	--
Categorías generadas (p. estudiadas)	0,71	0,96	0,49	0,19
Categorías generadas (p. no estudiadas)	0,45	0,23	0,30	0,76
Priming (categorías)	0,26	--	0,19	--
Tarea de Memoria Explícita	**Media**	**SD**	**Media**	**SD**
Aciertos – Falsas Alarmas	13,4	3,20	9,75	2,59
d' promediada	2,63	0,245	1,77	0,18
Criterio (*c*)	0,079	0,122	0,224	0,09

Nota: SD (desviación típica)



Barras de error +/- 1 ET

Figura 2. Proporción media de categorías estudiadas y no estudiadas (línea base) en el grupo de jóvenes y de mayores. ET (Error Típico).

Para confirmar que estos resultados no se debieron a las puntuaciones superiores de los jóvenes, se calculó el *priming* relativo (PR) y con los resultados que se obtuvieron se realizó un ANOVA de un factor intersujetos (Grupo) con dos niveles. Los resultados mostraron que no había diferencias significativas entre jóvenes y mayores [$F(1, 39) = 1{,}09$, $MC_e = 0{,}07$, $p = 0{,}30$, *potencia* = 0,17]. Por tanto, aunque los resultados del primer análisis mostraban que los jóvenes produjeron más palabras pertenecientes a las categorías presentadas en la fase de estudio que los mayores, los resultados de este análisis indican que el *priming* relativo fue similar en ambos grupos de edad.

8.4.3. Memoria explícita

Se calcularon los valores del índice de sensibilidad *d´* y del sesgo *c* de la TDS para ambos grupos de edad (ver Figura 3). El supuesto de homocedasticidad se comprobó mediante la prueba de Levene, no resultando significativo en ninguna de las variables dependientes [F (1, 38) = 0,772, $p > 0,05$ y F(1, 38) = 2,250, $p > 0,05$, para *d´* y *c*, respectivamente]. Se realizó un ANOVA intersujetos para el factor Grupo con dos niveles. Los resultados mostraron diferencias significativas entre ambos grupos en *d´* [F(1, 38) = 8,420, MC_e = 6,2, p < 0,01, η_p^2 = 0,181, *potencia* = 0,80], pero no en el índice *c* de sesgo de respuesta F(1, 38) = 1,219, MC_e = 0,34, p = 0,27]. Ver Tabla 3 y Figura 3.

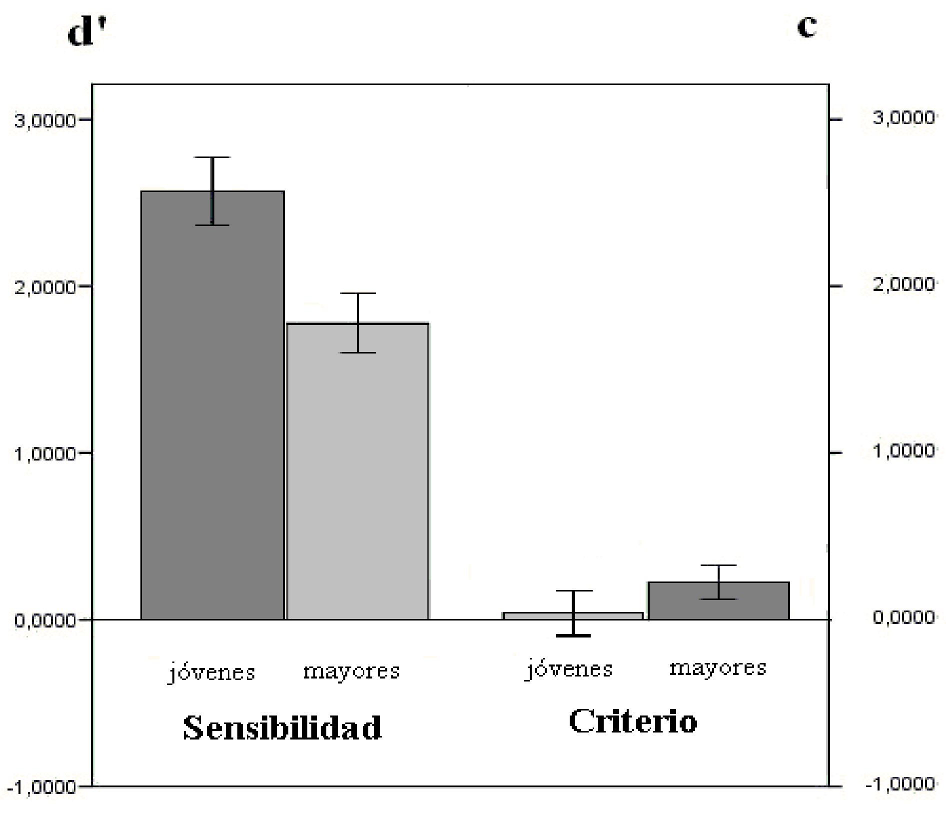


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Figura 3. Puntuaciones medias de ambos grupos (jóvenes y mayores) en los índices de sensibilidad d´ y criterio c.

Para evaluar si los resultados eran robustos, repetimos el análisis anterior utilizando medidas no paramétricas de sensibilidad [Aciertos (A) - Falsas Alarmas (FA)]. Se realizó un ANOVA univariado con el factor Grupo con dos niveles utilizando la medida A – FA como variable dependiente. El supuesto de homocedasticidad mediante la prueba de Levene resultó no significativo [$F(1, 38) = 3{,}50$, $p > 0{,}05$], lo que garantiza el supuesto de homocedasticidad de varianzas. El efecto principal del factor Grupo resultó estadísticamente significativo [$F(1, 38) = 15{,}69$, $MC_e = 133{,}25$, $p < 0{,}01$, $\eta_p^2 = 0{,}292$, *potencia* = 0,971]. Los jóvenes reconocieron más palabras ($\overline{X} = 13{,}4; S_X = 3{,}20$) que los mayores ($\overline{X} = 9{,}75; S_X = 2{,}59$), lo que sugiere que la memoria explícita se deteriora con la edad, tanto utilizando una medida paramétrica de sensibilidad como una prueba no paramétrica.

8.5. DISCUSIÓN Y CONCLUSIONES

Los principales resultados de este estudio fueron tres: (1) los mayores actuaron peor que los jóvenes en la prueba de reconocimiento; (2) ambos grupos mostraron el mismo *priming* cuando la memoria implícita se evaluó con la prueba de *generación de categorías* pero no cuando se evaluó con la prueba de *compleción de raíces*; y (3) encontramos una disociación en función de la edad entre las tareas *de generación de categorías* y de memoria de reconocimiento cuando se utilizó la medida de *priming* relativo. La edad afectó negativamente a la tarea de reconocimiento explícito pero no a la de *generación de categorías*. Sin embargo, las tareas de *compleción de raíces* y de reconocimiento mostraron el mismo patrón de resultados en ambos grupos de edad. Los dos grupos actuaron de manera similar en una prueba implícita, la prueba de *generación de categorías*, mientras que los jóvenes mostraron un *priming* superior al de los mayores en la prueba de *compleción de raíces*. En consecuencia, podemos afirmar que la edad tuvo un efecto diferente sobre las dos tareas implícitas, afectando a la tarea de *compleción de raíces* pero no a la de *generación de categorías*. Los resultados de la prueba de reconocimiento son consistentes con los de la literatura que han mostrado el efecto negativo del envejecimiento sobre la memoria explícita (ver Ballesteros y Reales, 2004; La Voie y Light, 1994; Redondo et al., 2010; Verhaeghen y Salthouse, 1997). En el caso de la tarea implícita de compleción de raíces, los resultados obtenidos están en la línea de otros estudios que han utilizado esta misma tarea (Osorio et al., 2010) y que han encontrado *priming* tanto en jóvenes como en mayores. En este estudio, ambos grupos mostraron facilitación pero el tamaño del *priming* fue superior en los jóvenes que en los mayores, tanto en puntuaciones directas como en puntuaciones relativas. Nuestros resultados concuerdan con los de otros investigadores que han encontrado un efecto de *priming* menor en los mayores que los jóvenes (e.g., Abbenhuis et al., 1990; Chiarello y Hoyer, 1988; Daselaar et al., 2005; Hultsch, Masson y Small, 1995; Small et al., 1995). Daselaar y colaboradores (2005) encontraron que en la prueba de compleción de raíces, los dos componentes que se asume subyacen a su ejecución, el perceptivo y el conceptual, se encuentran afectados en el grupo de mayores. Small et al. (1995) también encontraron un rendimiento superior en los jóvenes en esta prueba, mientras jóvenes y mayores actuaron de manera similar en una tarea conceptual. Es interesante señalar que hemos encontrado un *priming* similar en ambos grupos en la prueba conceptual de generación de categorías con puntuaciones de *priming* relativo. Estos resultados refuerzan las conclusiones de otros estudios que han encontrado que el *priming* conceptual se mantiene con la edad (v.g., Light y Albertson, 1989; Isingrini, Vazou y Leroy, 1995). Isingrini y colaboradores (1995) compararon el efecto de la edad en una prueba de generación de categorías con la actuación en una prueba de memoria explícita y encontraron deterioro de la memoria explícita con el aumento de la edad mientras que la memoria implícita conceptual se mantenía, lo que sugiere que la memoria implícita conceptual y la memoria explícita pueden estar mediadas por sistemas de memoria diferentes.

Desde el enfoque de los sistemas de memoria (Squire, 1992; Tulving y Schacter, 1990), las disociaciones entre medidas de memoria son el reflejo de las operaciones de distintos sistemas cerebrales con un desarrollo evolutivo diferente. El sistema de memoria episódica contiene experiencias personales localizadas en el lugar y en el tiempo, se desarrolla lentamente en la niñez, llega a su punto máximo en la juventud y se deteriora con el envejecimiento. Este sistema depende del lóbulo temporal medio y del hipocampo y las técnicas de imágenes han mostrado activación en estas áreas cerebrales cuando se recupera información de forma voluntaria (Davachi y Dobbins, 2008). Asimismo, lesiones en estas estructuras cerebrales producen amnesia. Por su parte, el sistema de memoria procedimental y de representación perceptual no requiere la recuperación voluntaria de sus contenidos y suelen mantenerse relativamente estables con la edad (Ballesteros y Reales, 2004; Osorio et al., 2010; para revisiones, ver también Fleischman, 2007; Fleischman y Gabrieli, 1998). Frente a los defensores de los sistemas de memoria, el enfoque de procesamiento explica las disociaciones encontradas entre diferentes pruebas de memoria recurriendo a la relación entre los procesos de codificación y recuperación de la información (Roediger y Blaxton, 1987; Roediger, Buckner y McDermott, 1999). Los resultados del presente estudio son congruentes con la existencia de sistemas de memoria diferentes implicados en pruebas de memoria implícita y explícita, pero sugieren además que también dentro de los mismos sistemas podrían existir disociaciones en función de la edad. Es posible que los componentes perceptivo-conceptuales asociados a las pruebas implícitas no sigan el mismo curso evolutivo (Billingsley, Smith y McAndrews, 2002), y/o que unas tareas implícitas sean más sensibles que otras a la hora de detectar los pequeños cambios que se producen durante el envejecimiento en este sistema de memoria (ver Mitchell y Bruss, 2003), de manera similar a como ocurre con las pruebas de recuerdo vs reconocimiento en la memoria explícita.

9. CAPÍTULO 4. EFFECTS OF AGE AND TYPE OF PICTURE ON VISUOSPATIAL WORKING MEMORY ASSESSED WITH A COMPUTERIZED JIGSAW-PUZZLE TASK

Toril, P., Reales, J.M., Mayas, J., & Ballesteros, S. (*Submitted*). Effects of age and type of picture on visuospatial working memory assessed with a computerized jigsaw-puzzle task

Abstract

In two experiments, we investigated the effect of colour in a computerized version of the jigsaw puzzle task. In Experiment 1, 25 older adults and 25 young adults were presented with two types of puzzles, colour and black-and-white, varying in difficulty from 4 to 9 pieces. We hypothesized that both groups would perform the task better with colour than with black-and-white jigsaws. The results showed that young adults performed better than older adults in both conditions. Contrary to our expectation, the older group performed the task better with the black-and-white stimuli, while the younger adults performed better with the colour ones. In Experiment 2, 20 older adults and 20 young adults were presented with the same puzzles and they had to identify the stimuli as fast and accurately as possible. The results showed that the older group identified the black-and-white pictures faster than those presented in colour, while the younger adults identified the two types of stimuli similarly. These results suggest that older adults are less likely to inhibit irrelevant colour information in working memory. Additionally, the two age groups could use different cognitive strategies to solve the task.

Keywords: young adults, older adults, object recognition, visuospatial working memory, jigsaw puzzle task

9.1. INTRODUCTION

Working memory (WM) allows the temporary storage and manipulation of the information required to perform complex cognitive tasks (Baddeley, 1992). WM is central to many cognitive functions, including concentration, problem solving, and impulse control. However, this cognitive function shows a significant decline with age (e.g., Bopp & Verhaeghen, 2005; Johnson, 2003; Park, Lautenschlanger, Hedden, Davidson, Smith, & Smith, 2002).

WM is a multicomponent system (Baddeley & Logie, 1999) conceptualized as a mental workspace consisting of activated representations that are available for manipulation in a temporary buffer during cognitive processing (Baddeley, 1986). The specialized components include a central executive that coordinates and regulates information coming from domain-specific slave systems that store verbal (the phonological loop) and visuospatial (the visuospatial sketchpad) material. The visuospatial system is assumed to maintain visuospatial information temporarily and it can be distinguished from verbal working memory. Visual WM is a subsystem that enables the temporary maintenance of visual information (e.g., colour and shape), while spatial working memory is in charge of the temporary maintenance of spatial information (e.g., location and direction). Despite the empirical (e.g., Andrade, Kemps, Werniers, May, & Szmalec, 2002; Hartley, Speer, Jonides, Reuter-Lorenz, & Smith, 2001; Logie & Marchetti, 1991) and neuropsychological (e.g., Farah, Hammond, Levine, & Calvanio, 1988; Luzzatti, Vecchi, Agazzi, Cesa-Bianchi, & Vergani, 1998) evidence for the separation of visual and spatial representations in WM, it is unclear under what conditions visual WM requires resources from spatial WM in order to retain object information. Some researchers argue that visual WM stores information coded as integrated object representations (Luck & Vogel, 1997). In this case, memory for features (e.g., circle and yellow) and memory for how features are organized as an object would be one and the same. By contrast, other researchers argue that visual WM stores values of features from different dimensions in separate feature-specific memory stores, and requires spatial WM and attention to keep those features organized as integrated object representations in memory (Wheeler & Treisman, 2002). In this case, memory for features and memory for feature organization would be supported by separate mechanisms (visual and spatial WM).

Empirical studies investigating visuospatial WM across the lifespan have suggested that older adults show a reduction in performance in tasks that demand this cognitive resource (Park, et al., 2002). Compared to young adults, older adults are impaired in tasks that require the temporary storage and active manipulation of visuospatial as opposed to verbal information (e.g., Jenkins, Myerson, Joerding, & Hale, 2000; Vecchi & Cornoldi, 1999; Park et al., 2002). Despite the huge literature on WM, the visuospatial component has been the least studied WM component (e.g., Cornoldi & Vecchi, 2000; Logie, 1995).

In the present study, we investigated the influence of type of picture (colour pictures and line drawings) on the visuospatial WM of young and older adults using a computerized jigsaw puzzle task, a useful tool for investigating visuospatial WM in older adults (Vecchi & Richardson, 2000).

The human visual system recognizes objects, using as input several stimulus dimensions such as colour, shape, and orientation (e.g., Bramao, Reis, Peterson, & Faísca, 2011; Humphreys, Goodale, Jakobson, & Servos, 1994; Price & Humphreys, 1989; Therriault, Yaxley, & Zwaan, 2009). However, how these features are processed is still an open question (Bramao, Faisca, Reis, & Peterson, 2010).

Object recognition depends not only on the amount of information stored in memory, but also on the ability to bind visual features. Recent studies have investigated whether this binding ability changes as a function of age. An age-related binding deficit might explain the decline in performance observed in visual working memory across the lifespan. However, it is not clear that this deficit occurs in visual working memory. Some studies (Brockmole, Parra, Della Sala, & Logie, 2008; Parra, Abrahams, Logie, & Della Sala, 2009) have shown that binding between surface features such as colour and shape seems to be unaffected in normal aging. However, other studies have shown that children and older adults have more binding deficits than young adults (Cowan, Naveh-Benjamin, & Saults, 2006; Brockmole and Logie, 2013; Mitchell, Johnson, Raye, Mather, & D´Esposito, 2000). Brown and Brockmole (2010) suggested that specific age-related binding deficits could occur under high attentional load conditions. Consequently, greater age-related binding deficits would be found in tasks that require active manipulation of information (Craik & Anderson, 1999; Kester, Benjamin, Castel, & Craik, 2002).

The influence of colour as a stimulus dimension on object recognition has been the subject of several studies (e.g., Tanaka, Weiskopf, & Williams, 2001; Price & Humphreys, 1989). For example, Tanaka et al. (2001) reported that objects represented by colour and shape might show a recognition advantage over objects represented only by shape under conditions where access to edge information is limited. Price and Humphreys (1989) demonstrated that brightness and texture gradients (photographic details) affect object recognition and naming. For example, incongruent colour objects disrupted naming accuracy, while there were advantages due to congruent colour objects and photographic details on responses to objects from both structurally similar and structurally dissimilar sets. In addition, their results suggest that surface details can affect object recognition and naming. Congruent coloured objects are recognized faster than monochrome objects, and colour does not affect categorical judgments (Naor-Raz, Tarr, & Kersten, 2003) but does facilitate object naming (Davidoff & Ostergaard, 1988). Other researchers have suggested that edge-based representations are crucial for object recognition (Biederman & Ju, 1988; see Sanocki, Bowyer, Heath, & Sarkar, 1998). Despite the number of studies conducted on this subject, there is no agreement on the role of colour in object recognition. For this reason, Bramao et al. (2011) conducted a meta-analysis with participants aged 18 to 60 years in order to understand the role of colour information. The results of this meta-analysis showed a moderate effect of colour on object recognition ($d = 0.28$) and suggested that colour diagnosticity (degree to which a particular object is associated with a specific colour) influences object recognition.

A relevant question addressed in the present study is how participants recognize fragmented pictures and integrate the fragments to solve puzzles. To perform the task, the perceiver needs to integrate the different parts of the picture and must keep this information active in visuospatial WM. Some theories of visual object recognition argue that an image is necessarily organized into parts and that these parts are matched to structured representations of parts in long-term memory (e.g., Marr & Nishihara, 1978; Biederman, 1988). By contrast, other theories suggest that object identification does not rely on previously stored representations of parts of the object and their spatial relations, but relies on viewpoint-dependent information about smaller aggregates of visual characteristics (e.g., Lowe, 1985; Tarr & Pinker, 1989; Ullman, 1989).

In the present study, we investigated the effect of type of stimulus (black-and-white line drawings and colour pictures) on the active visuospatial WM of young and older adults, assessed with a computerized jigsaw puzzle task. We hypothesized that: (1) young adults would perform better than older adults irrespective of the type of puzzle; (2) both age groups would perform better with puzzles presented in colour than in black and white because colour provides additional information that could help them to recognize the object and to solve the task; and (3) older adults would benefit more than younger adults when the puzzle pieces were presented in colour than in black and white.

In summary, Experiment 1 investigated whether young adults would outperform older adults in a computerized version of the jigsaw puzzle task using colour and black-and-white stimuli to assess visuospatial WM. The results show that the older group performed the task better with the black-and-white stimuli, while the younger adults performed better with the colour ones. Based on these results, in Experiment 2, different groups of young and older adults performed a speeded identification task to investigate whether the two age groups would identify black-and-white and colour fragmented pictures similarly.

9.2. EXPERIMENT 1

9.2.1. Method

Participants

The participants in this experiment were 25 young adults (mean age = 31.60 years; *SD* = 11.22; age range, 20-45) and 25 older adults (mean age = 72.00 years; *SD* = 6.43; age range, 65-85). The young participants were undergraduate students who received course credits for their participation. Older participants were recruited from a local community centre for older adults. All the older participants had a Mini-Mental State Examination (MMSE, Folstein, Folstein, & McHugh, 1975) score > 26 (maximum score 30) and had normal or corrected-to-normal vision.

All participants signed an informed consent form for participation in the study, which was approved by the Ethical Review Board of the Universidad Nacional de Educación a Distancia. The experiments were conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki as revised in October 2008. The demographic characteristics and test scores are displayed in Table 1 (top).

Table 1. Demographic data and test scores of Experiments 1 and 2.

Characteristics	**Older adults**	**Young adults**		
	Mean (*SD*)	**Mean (*SD*)**	***t*- test**	***p***
		EXPERIMENT 1		
Age (Years)	72.00 (6.43)	31.60 (11.22)	15.61	0.00
Education (Years)	14.68 (2.01)	15.84 (1.40)	-2.36	0.02
MMSE	28.76 (0.83)	--------		
		EXPERIMENT 2		
Age (Years)	71.40 (5.48)	31.90 (4.33)	25.26	0.00
Education (Years)	13.50 (2.09)	16.55 (0.99)	-5.88	0.00
MMSE	28.35 (1.08)	---------		

Note. MMSE, Mini Mental State Examination (*SD* in parentheses).

The *t*-test showed significant differences between groups ($p < 0.01$) in educational level. To control this difference statistically, we performed an ANCOVA on our results using educational level as a co-variable. However, the assumption of homogeneity of regression slopes was violated in both experiments (*ps* < 0.01). The ANCOVA is not justifiable if this assumption is not fulfilled. For this reason, we performed the results of the ANOVAs without educational level as co-variable.

Materials and Stimuli

The jigsaw puzzle task was originally developed to assess active visuospatial abilities in older adults (Vecchi & Richardson, 2000). In our computerized task, participants were asked to solve jigsaw puzzles consisting of four, six or nine pieces presented at the centre of the computer screen. Each piece was numbered and the participants were given a prepared response sheet and instructions to write down the numbers corresponding to the pieces in their correct spatial positions. The task was programmed with E-prime version 2.0 (Psychology Software Tools Inc., Pittsburgh, PA, USA).

The black-and-white jigsaws were prepared using 15 pictures selected from the Snodgrass and Vanderwart (1980) picture set with a mean familiarity of 4.3 (*SD* = 0.26) and a visual complexity mean of 2.4 (*SD* = 0.32). A further 15 pictures were selected from a colour picture set (Moreno & Montoro, 2012) with a mean familiarity of 4.3 (*SD* = 0.15) and a visual complexity mean of 2.3 (*SD* = 0.30). *T*-tests showed that the two picture sets did not differ significantly in familiarity or in visual complexity (*ps* > 0.05) according to the information provided in the original articles from which the drawings (Snodgrass & Vanderwart, 1980) and the colour pictures (Moreno & Montoro, 2012) were extracted. Furthermore, we asked 13 young adults (mean age = 23.92 years, *SD* = 5.26) and 16 older adults (mean age = 70.13, *SD* = 5.39) to evaluate the complexity of both picture sets following the standard procedure provided by Snodgrass and Vanderwart (1980). The complexity mean for the younger group was 2.33 (*SD* = 0.46) and for the older group it was 1.99 (*SD* = 0.48), while the complexity mean was 2.19 (*SD* = 0.43) for the colour stimuli and 2.13 (*SD* = 0.59) for the black-and-white stimuli. A 2 (group: older *vs.* younger adults) x 2 (type of stimuli: colour *vs.* black-and-white drawings) mixed analysis of variance (ANOVA) with group as the between-subjects factor and type of picture as the within-subjects factor was conducted on the mean complexity scores corresponding to each type of stimulus in young and older adults. The analysis showed that neither the main effect of group [F (1, 27) =3.72, MSE=1.69 p > 0.05, $\eta^2_{partial}$=0.12] nor the type of stimulus [$F(1,27) = 0.75, MSE = 0.07\ p > 0.05, \eta^2_{partial} = 0.03$] were statistically significant. The type of stimulus x group interaction was not statistically significant (p > 0.05). These results indicate that both age groups judged that the colour pictures and line drawings were similar in complexity.

The pictures pertained to 3 different categories (living objects, clothes and objects) with 5 pictures each for each type of jigsaw (colour and black-and-white). Pictures were fragmented into 4, 6 and 9 pieces to produce 45 different puzzles. The pictures were enlarged to fit an area of 12 cm x 12 cm and divided into four pieces of 6 cm x 6 cm, six pieces of 6 cm x 4 cm, or nine pieces of 3 cm x 3 cm. There were three different counterbalanced orders and the pictures under each condition were randomly presented. Each participant was presented with a total of 15 puzzles of 4, 6 and 9 pieces. Figure 1 shows examples of colour and black-and-white puzzles of 4, 6 and 9 pieces.

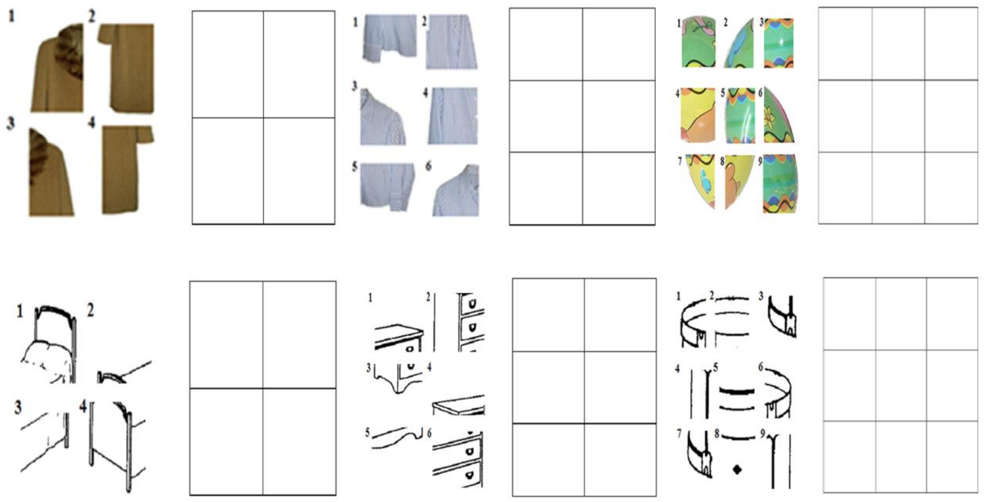

Figure 1. Examples of puzzles containing four, six and nine pieces. Top: color jigsaw puzzles; bottom: black-and-white jigsaw puzzles.

Participants had to write down on an answer sheet the number of each piece in the correct spatial location. The response sheets contained grids of the same size as the original pictures and were divided into the appropriate number of squares (4, 6 and 9). Two practice puzzles were presented at the beginning of the experimental session, but these results were not included in the analysis.

Procedure

Participants were tested individually in a quiet room. They were seated in front of the computer screen at a distance of approximately 50 cm. Colour conditions were counterbalanced across participants. A trial began with the presentation of a fixation cross at the centre of the computer screen for 500 milliseconds followed by the presentation of the pieces of a puzzle for 90 seconds. Each fragment of the puzzle had a number in the upper left corner. Participants were asked to write down the appropriate numbers in the correct spatial locations of the response sheet. They were allowed to correct their responses within a time limit of 90 seconds. Performance was assessed in terms of the number of correctly solved puzzles at each complexity level (4, 6 and 9 pieces) under each colour condition. The entire experimental session lasted approximately 40 minutes.

9.2.2. Results and discussion

A 2 (Group: older *vs*. younger adults) x 2 (Type of puzzle: colour *vs*. black-and-white) x 3 (Level of fragmentation: 4, 6, 9 pieces) mixed analysis of variance (ANOVA) was conducted on the proportion of correctly solved puzzles at each level of fragmentation. Group was the between-subjects variable while Type of puzzle and Level of fragmentation were the within-subjects variables. The analysis showed that the main effect of Group was statistically significant $[F(1,48) = 74.31, MSE = 13.95, p < 0.05, \eta^2_{partial} = 0.60]$. Young adults performed significantly better (mean = 0.77; *SD* = 0.15) than older adults (mean = 0.34; *SD* = 0.15). The main effect of Level of fragmentation (4, 6 and 9 pieces) was also statistically significant $[F(2,48) = 146.89, MSE = 6.76, p < 0.05, \eta^2_{partial} = 0.20]$, showing that performance deteriorated as a function of Level of fragmentation. Puzzles fragmented into 4 pieces (mean = 0.79; *SD* = 0.10) were easier to solve than those fragmented into 6 pieces (mean = 0.59; *SD* = 0.15), and the most difficult puzzles were those fragmented into 9 pieces (mean = 0.27; *SD* = 0.15). The main effect of Type of puzzle (Colour *vs*. Black-and-White) was not significant ($p > 0.05$). The mean for black-and-white puzzles was 0.55 (*SD* = 0.01) and for colour puzzles it was 0.56 (*SD* = 0.01). The two-way Type of puzzle x Group interaction was statistically significant [$F(1, 48) = 14.87$, $MSE = 0.55$, $p < 0.05$, $\eta^2_{partial} = 0.23$]. Simple effects analysis of this interaction shows that the older group performed better with the black-and-white puzzles (mean = 0.38; *SD* = 0.20) than with the colour puzzles (mean = 0.30; *SD* = 0.15), while the opposite occurred with the young adults, who performed better with the colour (mean = 0.82; *SD* = 0.15) than with the black-and-white puzzles (mean = 0.72; *SD* = 0.20). The two-way Type of puzzle x Level of fragmentation interaction was also significant [$F(2, 48) = 5.72, MSE = 0.17, p < 0.05, \eta^2_{partial} = 0.10$]. The analysis of this interaction indicates that performance with puzzles of 4 and 6 pieces did not differ whatever the Type of puzzle [$F(1,49) = 1.28$, $MSE = 0.06$, $p > 0.05$, $\eta^2_{partial} = 0.26$], but with puzzles of 9 pieces, performance differed significantly as a function of the puzzle type [$F(1, 49) = 10.16, MSE = 0.28, p = 0.002$]. This interaction indicates that at the most difficult level, colour made the task easier. Finally, the Level of fragmentation x Group interaction was also significant [$F(2, 48) = 12.33, MSE = 0.56, p < .05, \eta^2_{partial} = 0.20$], suggesting that the performance of the older group differed as a function of fragmentation from level 4 to level 9 (*ps* < 0.001). By contrast, young adults performed marginally better with puzzles of 4 and 6 pieces ($p = 0.09$), and significantly worse with puzzles of 9 pieces ($p < 0.001$). No other interaction was significant. Figure 2 shows the proportions of puzzles solved correctly under the two colour conditions by age group and level of fragmentation.

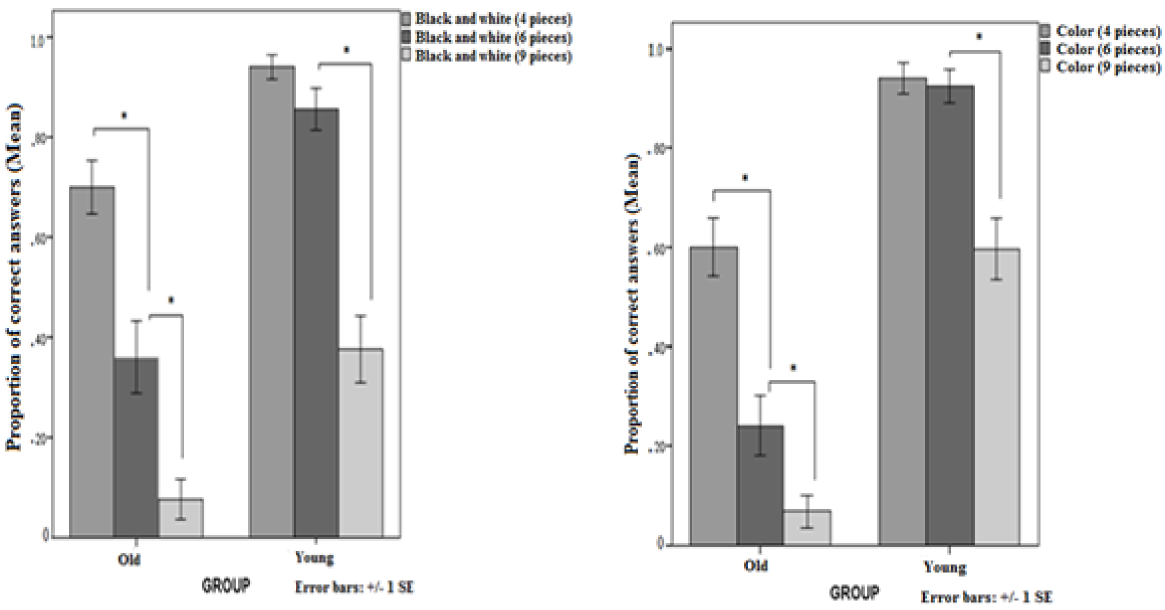

Figure 2. Proportions of puzzles correctly solved by young and older adults Experiment 1). The left panel shows the performance with the black-and-white pictures and the right panel the performance with the color puzzles. Error bars indicate the error in the reported measurement.

This experiment investigated age-related differences in visuospatial working memory assessed with black-and-white and colour jigsaw puzzles varying in difficulty. The main findings were: (1) the younger group performed better than the older group with both types of puzzles; (2) in both age groups, performance deteriorated as the level of fragmentation increased; (3) older adults performed better with the black-and-white jigsaws than with the colour jigsaws, while the opposite occurred with young adults. Interestingly, young adults performed similarly with the puzzles of 4 and 6 pieces (i.e. when the task was easier), but at the most difficult level (9 pieces) they performed significantly better when the puzzles were presented in colour. Our results are in line with those of Richardson and Vecchi (2002) who found that young adults solved the jigsaw puzzle task better than older adults. These results suggest a significant decline in visuospatial performance with age.

We also hypothesized that both groups would perform better with colour than with black-and-white stimuli. This prediction was confirmed in the young group but not in the older group. This result suggests that colour information only plays a role under certain circumstances. For example, Price and Humphrey (1989) showed that surface dimensions became more informative when objects needed to be disambiguated. However, Ostergaard and Davidoff (1985) explored the effects of colour on object naming and recognition and obtained conflicting patterns; colour pictures were named faster than black-and-white pictures, but this effect did not carry over to an object recognition task, suggesting that colour facilitates object naming but does not affect object recognition.

Another explanation of our findings with the older group might be a different pattern for inhibition processes (e.g., Bowles & Salthouse, 2003; Hasher and Zacks, 1988; Persad, Abeles, Zacks, & Denburg, 2002). It is well established that inhibition exerts control over the content of WM by helping to prevent irrelevant or no longer relevant stimuli from saturating WM capacity (e.g., Hasher & Zacks, 1988; Zacks & Hasher, 1994). Moreover, age-related differences in the selection of the best strategy may result from a decrease in processing resources (Bouazzaoui et al., 2010), which may lead older adults to select the best strategy less often than young adults.

In summary, the results of Experiment 1 show that older adults did not benefit from colour as young adults did. We conducted Experiment 2 to investigate whether the results of the older adults were due to an identification or recognition limitation of the stimuli presented in the puzzles. If older adult perform better with black-and-white puzzles than with colour puzzles, then they should identify this type of fragmented picture faster and/or more accurately than colour pictures.

9.3. EXPERIMENT 2

The aim of this experiment was to investigate whether young and older adults identify fragmented black-and-white and colour pictures differently. Based on the results of Experiment 1, we thought that the better performance of older adults with black-and-white than with colour puzzles might be due to faster and/or more accurate identification of black-and-white stimuli. The main result of Experiment 1 (the interaction between Group and Type of puzzle) could be explained by the fact that older adults identify or recognize stimuli faster when they are in black and white, while younger adults perform better with coloured objects.

9.3.1. Method

Participants

Forty new volunteers participated in this experiment. Twenty were young adults and 20 were older adults recruited from a local community centre for older adults. The older group completed the MMSE with a cut-off score of 26. All of the participants had normal or corrected-to-normal vision, and all signed an informed consent form. Demographic data are shown in Table 4.1 (bottom).

Materials and procedure

The materials and their display on the computer screen were identical to those used in Experiment 1 but the participants performed a speeded identification task. Participants were tested individually in a quiet room. They were seated in front of a computer at a distance of approximately 50 cm from the screen. Each trial began with the presentation of a fixation cross at the centre of the screen for 500 ms followed by the presentation of a puzzle that appeared at the centre of the screen until response. Participants had to press the space bar as soon as they identified the picture shown in the puzzle. Identification times for correct responses to the 4, 6 and 9 piece puzzles, as well as the proportion of correct pictures identified under the two colour conditions, were recorded as dependent variables in the analyses.

9.3.2. Results and discussion

An ANOVA was conducted on identification times (in seconds) corresponding to the correct responses with 2 (Group: older *vs* younger adults) x 2 (Type of puzzle: colour *vs* black-and-white) x 3 (Level of fragmentation: 4, 6, 9 pieces) mixed analysis of variance (ANOVA). Group was the between-subjects variable while Type of puzzle and Level of fragmentation were manipulated as within-subjects variables. The analysis showed that the main effect of Group was statistically significant [$F(1, 38) = 121.67$, $MSE = 1358.93$, $p < 0.001$, $\eta^2_{partial} = 0.76$], suggesting that young adults identified pictures faster (mean = 0.98; *SD* = 1.34) than older adults (mean = 5.73; *SD* = 1.34). The main effect of Level of fragmentation (4, 6 and 9 pieces) was also statistically significant [$F(2, 38) = 17.79$, $MSE = 76.86$, $p < 0.001$, $\eta^2_{partial} = 0.31$]. Identification time was slower as a function of Level of fragmentation (level 4, mean = 2.61, *SD* = 1.11; level 6, mean = 2.98, *SD* = 0.93; level 9, mean = 4.47, *SD* = 1.60). The main effect of Type of puzzle was also significant [$F(1,38) = 12.55$, $MSE = 33.95$, $p < 0.001$, $\eta^2_{partial} = 0.24$]. Black-and-white pictures were identified faster (mean = 2.98, *SD* = 0.98) than colour pictures (mean = 3.73, *SD* = 1.11). The Type of jigsaw x Group interaction was also statistically significant [$F(1, 38) = 18.70, MSE = 50.57, p < .001, \eta^2_{Partial} = 0.33$]. The simple effects analysis showed that there were significant differences between Colour and Black-and-white puzzles in the older group ($p < 0.001$) but not in the younger group ($p > 0.05$).The Level of fragmentation x Group interaction was significant [$F(2, 76) = 9.37$, $MSE = 40.48$, $p < 0.001$, $\eta^2_{partial} = 0.19$], suggesting that for the older group, there was no difference between levels of fragmentation 4 and 6 ($p > 0.05$), but level 9 was significantly more difficult ($p < 0.05$), while the young adults performed similarly at all levels of fragmentation.

No other interaction achieved statistical significance (all *ps* > 0.05). Figure 3 shows the mean identification times of young and older adults for the two types of puzzle and levels of fragmentation.

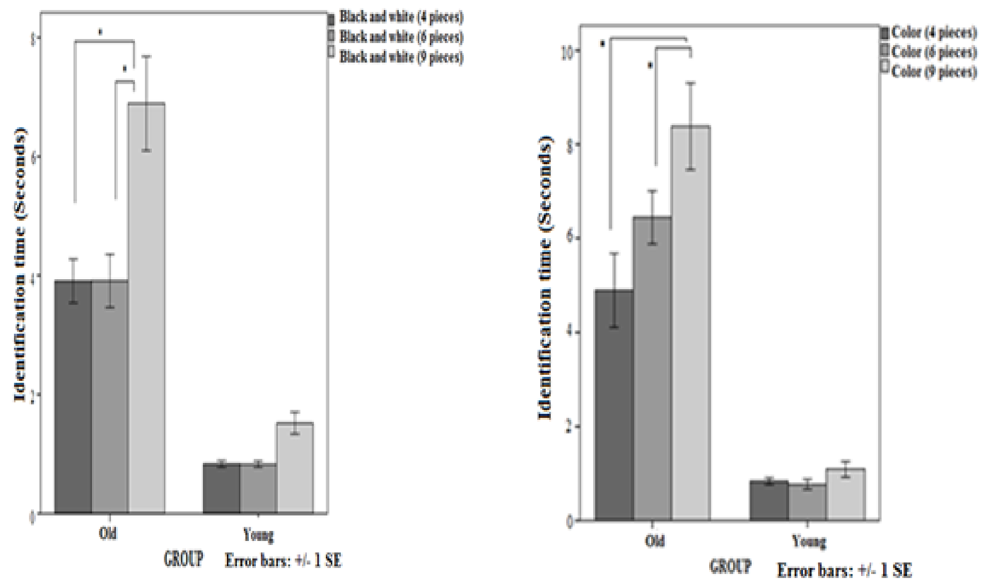

Figure 3. Mean identification times corresponding to young and older adults in Experiment 2. The left panel shows the performance with black-and-white puzzles and the right panel the performance with color puzzles. Error bars indicate the error in the reported measurement.

Another ANOVA was conducted on the proportion of correct identification with 2 (Group: older *vs*. younger adults) x 2 (Type of puzzle: colour *vs*. black-and-white) x 3 (Level of fragmentation: 4, 6, 9 pieces) with Group manipulated between subjects, while Type of puzzle and Level of fragmentation were manipulated within subjects.

This analysis showed that the main effect of Group was statistically significant $[F(1,38) = 21.58, MSE = 0.50, p < .001, \eta^2_{Partial} = 0.36]$, suggesting that the young adults performed better (mean = 0.94, *SD* = 0.04) than the older adults (mean = 0.85, *SD* = 0.04).

The main effect of Level of fragmentation was also statistically significant $[F(2,76) = 3.16, MSE = 0.06, p = 0.048, \eta^2_{Partial} = 0.07]$, showing that there were significant differences in the proportion of correct identifications between the three levels of fragmentation (level 4, $\text{mean} = 0.92, SD = 0.04$; level 6, $\text{mean} = 0.91, SD = 0.04$; level 9, $\text{mean} = 0.87, SD = 0.04$). Finally, the main effect of Type of puzzle was significant $[F(1,38) = 14.28, MSE = 0.14, p < 0.001, \eta^2_{Partial} = 0.27]$, showing that the proportion of correct identifications was higher for black-and-white puzzles (mean = 0.92, *SD* = 0.04) than for colour puzzles (mean = 0.87, *SD* = 0.04). The Type of puzzle x Group interaction was statistically significant $[F(1,38) = 25.82, MSE = 0.25, p < 0.001, \eta^2_{Partial} = 0.40]$. The simple effects analysis of this interaction showed that the proportion of correct identifications of black-and-white puzzles was higher than the proportion of correctly identified colour stimuli in the older group ($p < 0.001$) but not in the younger group ($p > 0.05$). No other interaction reached significance (all *ps* > 0.05).

The results of Experiment 2 show that: (1) young adults identified fragmented pictures faster and more accurately than older adults; (2) the time required to identify the pictures increased as a function of the level of fragmentation; (3) older adults identified black-and-white pictures faster and more accurately than colour pictures, while there was no difference in the performance of young adults. These results support our hypothesis. Older adults identified black-and-white pictures not only faster than colour pictures but also more accurately. By contrast, the speed and accuracy of young adults were similar with both types of stimuli. These results suggest that the delay in the perceptual recognition of fragmented colour pictures in older adults could explain the results of Experiment 1.

9.4. GENERAL DISCUSSION

The present study investigated the role of aging and colour in visuospatial WM assessed with a computerized jigsaw puzzle task. Our results show that age affected task performance negatively. Performance of the puzzle task by older adults was poorer than that of young adults, a finding previously reported by Richardson and Vecchi (2002). The present study yielded two main findings. First, older adults performed better with black-and-white puzzles than with colour puzzles, while colour did not influence the performance of young adults (Experiment 1). Second, older adults identified black-and-white pictures faster and more accurately than colour pictures, while the two types of stimuli did not affect the performance of the younger adults, which was significantly faster and more accurate than that of the older adults (Experiment 2). The results support the hypothesis of a limited capacity system that is vulnerable to increasing task complexity and are in accordance with previous literature showing a significant decline in visuospatial abilities with age (see Park et al., 2002). Jenkins et al. (2000) reported a disproportionately greater difficulty in learning visuospatial than verbal materials in older adults compared to young adults. Moreover, Myerson, Hale, Rhee and Jenkins (1999) found evidence for greater age-related impairment of performance on visuospatial than verbal span tasks with age.

Effects of the type of colour puzzle in older and younger adults

To solve the puzzle task successfully, participants need to recognize and integrate the different parts of the picture. Although shape is certainly the primary/main route to object recognition (Tanaka et al., 2001), the literature on this topic suggests that the processes underlying object recognition can use specific colour information (Therriault et al., 2009). Research has shown that objects presented in their typical colour are recognized faster than objects presented in black-and-white or in atypical colours (Humphreys et al., 1994). A recent meta-analytic study (Bramao et al., 2011) reported a moderate effect of colour in object recognition, concluding that the contribution of colour depends on object properties and task conditions.

The recognition of line drawings and photographs may recruit different perceptual and semantic processes (Uttl, Graf, & Santacruz, 2006). Colour information might contribute differently to the recognition of line drawings and photographs. Reis, Faísca, Ingvar and Peterson (2006) investigated whether the surface texture and colour of objects is used to access stored object knowledge in two older groups (illiterates and literates). Their results showed that the illiterate group benefitted from colour information in line drawings and photos, while the literate group benefitted from colour in line drawings but not in photos.

In our task, colour was an irrelevant stimulus feature and could produce interference in older adults. This result might be explained by the idea that aging coincides with a decrease in the effectiveness and efficiency of the ability to control interference. Older adults have more difficulty accessing relevant information in WM and deleting irrelevant information (Zacks & Hasher, 1994). A broader range of information enters WM, cluttering its capacity when inhibitory mechanisms are inefficient. Poor inhibition not only limits but also damages cognitive performance by allowing irrelevant information to intrude and consume storage capacity, and by permitting the use of resources for the processing of irrelevant information (Harnishfeger & Bjorklund, 1993). This is in line with findings of Borella, Carretti and De Beni (2008) that age is negatively associated with WM performance and positively correlated with inhibitory performance. Poor performance in WM tasks is associated with an increase in the number of errors.

The present results might also be explained by the use of different cognitive strategies with age to perform the jigsaw puzzle task. Older adults might use different strategy repertoires. For example, Dunslosky and Hertzog (2001) found that adults over 60 years of age were less likely than young adult to use effective mediators (e.g., generating a sentence or making a mental image) for encoding information and activated different brain networks (Gandini, Lemaire, Anton, & Nazarian, 2008). It could be the case that older adults use fewer strategies than young adults due to a restricted set of strategies at their disposal. Moreover, the decreased processing resources with age might lead older adults to restrict the set of available strategies.

Identification of colour and black-and-white puzzle pictures by young and older adults

In Experiment 2, older adults had to recognize and integrate into an object several pieces of information. Obviously, the primary route in this task was shape, because participants had to re-arrange the elements of the puzzle. Colour could cause interference in older adults when puzzles are presented in colour, and it is possible that colour interfered with object recognition. This pattern of results could be explained by the fact that colour and shape are processed by different modules in the visual cortex (Rentzeperis, Nikolaev, Kiper, & Van Leeuwen, 2014). By contrast, young adults did not show colour interference. It is also possible that reduced inhibition abilities of the older adults made them less able than young adults to suppress interference (Andrés, Van der Linden, & Parmentier, 2004). Another possible explanation is that older and young adults use different cognitive strategies to solve the identification task.

An alternative explanation of the present findings comes from the idea of age-related binding deficits. According to Brown and Brockmole (2010), if the maintenance of feature conjunctions requires attentional resources, memory-binding errors could occur in older adults. They concluded that age-related binding deficits could contribute to a general decline in visual WM under conditions of high attentional load. In the present study, we used the jigsaw puzzle task, a visuospatial WM task. This task requires attention as well as the active manipulation of visual information to mentally reconstruct the picture (Cornoldi & Vecchi, 2003). It is very likely that older adults suffered a binding deficit under high load conditions. However, the present results should be interpreted with caution because the role of attention in feature binding is still open to debate.

9.4.1. Limitations of the present study

It is important to mention that there were educational differences between groups. However, the jigsaw puzzle task is a visuospatial WM task that may not be affected by this variable. Another possible limitation is related to the stimuli used in this study. We selected stimuli from sets of drawings and photos to prepare the puzzles. This could be a potential limitation, although it should be noted that the two picture sets did not differ in familiarity or visual complexity.

9.4.2. Conclusions and future directions

In conclusion, older adults were impaired compared to younger adults in the jigsaw puzzle task, an active visuospatial working memory task. Colour did not help older adults to solve the task but produced interference. In Experiment 1, older adults performed better with black-and-white puzzles than with colour puzzles, while the opposite occurred in young adults. In Experiment 2, older adults identified black-and-white puzzle pictures faster and more accurately than colour ones, while young adults not only identified the stimuli faster and more accurately than older adults, but also their performance with the two types of material was the same. In both experiments, young adults performed the task better than older adults. The findings of Experiment 2 support the results of Experiment 1 and might explain the results obtained in this visuospatial working memory task.

More research is needed using visuospatial WM tasks such as the jigsaw puzzle task to elucidate the role of colour, as well as the processing stage at which colour information modulates fragmented object recognition. Further studies should also investigate the different strategies used by older and young adults that may underlie our results.

10. CAPÍTULO 5. VIDEO GAME TRAINING ENHANCES COGNITION OF OLDER ADULTS: A META-ANALITIC STUDY

Toril, P., Reales, J.M., & Ballesteros, S. (2014), Video Game Training Enhances Cognition of Older adults: A meta-Analytic Study, *Psychology and Aging, 29,* 706-716

Abstract

It has been suggested that video game training enhances cognitive functions in young and older adults. However, effects across studies are mixed. We conducted a meta-analysis to examine the hypothesis that training healthy older adults with video games enhances their cognitive functioning. The studies included in the meta-analysis were video game training interventions with pre-and post-training measures. Twenty experimental studies published between 1986 and 2013, involving 474 trained and 439 healthy older controls, met the inclusion criteria. The results indicate that video game training produces positive effects on several cognitive functions, including reaction time, attention, memory and global cognition. The heterogeneity test showed did not show a significant heterogeneity (I^2 = 20.69 %) but this did not preclude a further examination of moderator variables. The magnitude of this effect was moderated by methodological and personal factors, including the age of the trainees and the duration of the intervention. The findings suggest that cognitive and neural plasticity is maintained to a certain extent in old age. Training older adults with video games enhances several aspects of cognition and might be a valuable intervention for cognitive enhancement.

Keywords: aging, cognitive functions, meta-analysis, moderating factors, video game training

10.1. INTRODUCTION

The proportion of people aged over 65 is increasing worldwide (United Nations, 2010). Given this increasing longevity and the cognitive and physical declines that occur with aging, researchers are investigating ways to promote independent living, delaying cognitive decline as much as possible (for reviews see Hertzog, Kramer, Wilson, & Lindenberger, 2008; Park & Reuter-Lorenz, 2009). To this end, efforts are being made to investigate the potential of new Information and Communication Technologies (ICT) to improve cognitive functioning (Bond, Wolf-Willets, Fiedler, & Burr, 2008) and quality of life in older adults (Ballesteros, Toril, Mayas, Reales, & Waterworth, in press; Leung & Lee, 2005; Peter et al., 2013). The reduction in the number of social relations, the deterioration of physical abilities and the decline of cognitive functioning are important burdens in old age (Meijer, Van Boxtel, Van Gerven, Van Hooren, & Jolles, 2009).

Aging is associated with declines in many cognitive processes. However, current findings from longitudinal studies have found older age a time of decline, stability, and even growth (Baltes & Lindenberger, 1997; Rönnlund, Lövden, & Nilsson, 2008). Specifically, declines occur with age in several processes including, processing speed, attention, executive control, working memory and episodic memory (e.g., Hoyer & Verhaeghen, 2006; Nilsson, 2003; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005; Salthouse, 1996). In contrast, other crystalized cognitive functions as general knowledge, verbal abilities (e.g., Bialystok & Craik, 2006; Hedden & Gabrieli, 2004) and implicit memory (e.g., Ballesteros, Bischof, Goh, & Park, 2013; Ballesteros & Reales, 2004; Mitchell & Bruss, 2003; Wiggs, Weisberg, & Martin, 2006) are mostly preserved or even improve.

A number of recent studies have shown that positive changes in older adults´ cognition can occur after training with video games (Anguera et al., 2013; Buschkuehl et al., 2008; Nouchi et al., 2012). Although findings on this topic are sparse, evidence suggests that the older brain retains considerable plasticity. In other words, it has the ability to increase its capacity in response to experience. The observed increase in neural volume in response to cognitive training is an important indicator of brain change (see Boyke, Driemeyer, Gaser, Büchel, & May, 2009; Park & Bischof, 2013). Encouraged by previous findings showing that cognitive training interventions can improve cognition in healthy older adults (Ball et al., 2002; Basak, Boot, Voss, & Kramer, 2008; Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Willis et al., 2006), there is a growing interest in video game training as an effective way of enhancing important aspects of cognition and neural plasticity in older adults (e.g., Anguera et al., 2013; Boot, Blakely, & Simmons, 2011; Nouchi et al., 2012; Prakash et al., 2012). Cognitive training can be defined as an intervention that provides structured practice on tasks relevant to different aspects of cognitive functioning, such as memory, attention, language, or executive functions. Theoretically, these studies suggest that the older human brain maintains some neural plasticity (e.g., Pascual-Leone, Amedi, Fregni, & Merabet, 2005; Raz et al., 2005) although not to the same degree as young adults (e.g., Bialystok & Craik, 2006; Lee et al., 2008; Li, Brehmer, Shing, Werkle-Bergner, & Lindenberger, 2006).

In our technological society, computer-based training programs and video games have interested researchers as a tool for improving and/or maintaining perceptual and cognitive functions in older adults. However, so far, scientific evidence of the potential of these interventions is mixed, as reviewed below.

10.1.1. Effects of training with video games on cognitive functions in older adults

A video game is an electronic game that involves human interaction with a computer by means of a user interface that generates visual and auditory feedback. Video games can be classified in different non-overlapping categories. The first category is “serious games” (Gopher, Weil, & Bakeret, 1994), primarily designed to convey information or a learning experience of some sort to the game player. A second category comprises “educational games”, such as *Brain Age* and *Brain Training* (McDougall & House, 2012). Video games can also be classified as simple or non-action games and complex games.

The use of video games as a way to enhance cognitive functioning in healthy older adults has an advantage over traditional cognitive training programs in that they are relatively inexpensive, enjoyable and fun (Zelinski & Reyes, 2009). Video games include images, movement, sound and feedback. All these characteristics are more attractive and rewarding than printing materials. Moreover, a recent study (Allaire, Mc Laughlin, Trujillo, Whitlock, & Laporte, 2013) showed that regular and occasional video game players reported significantly higher levels of wellbeing and less depression than non-video game players. For these reasons, video games have been used as a tool for training young and older adults, and are considered to provide a good context for cognitive enrichment (Achtman, Green, & Bavelier, 2008; Green & Bavelier, 2008). Early studies with older adults revealed improvements in several cognitive functions after video game training, including processing speed (Clark, Lamphear, & Riddick, 1987; Dustman, Emmerson, Steinhaus, Shearer, & Dustman, 1992; Goldstein et al., 1997), intelligence (Drew & Waters, 1986), visuo-motor coordination (Drew & Waters, 1986), attention (Belchior, 2008) and global cognitive function (Torres, 2008). However, other studies did not find a significant transfer of training to measures of cognitive and perceptual functioning (e.g., Ackerman, Kanfer, & Calderwood, 2010; Boot et al., 2013; Owen et al., 2010). The transfer of video game training to untrained cognitive functions is critical and has important practical significance.

Recently, Kueider, Parisi, Gross, and Rebok (2012) conducted a systematic review (SR) to examine the effectiveness of computer-based cognitive interventions in cognitively healthy older adults. The SR method attempts to answer a theoretical question by analyzing empirical published studies in the field of interest to obtain a summary of the results in terms of effect size. Meta-analysis, however, provides a better way of analyzing the results of several individual studies. The main advantage of meta-analysis over SR is that it involves statistical tests on individual effect sizes producing, among other things, significance statistics, confidence intervals, and heterogeneity indexes that enhance the information provided by the analysis. For example, Kueider et al. (2012) outlined the difficulties posed by the variability and length of video game interventions in the results obtained. Meta-analysis is thus an appropriate tool to elucidate the conflicting results published so far in this field. The existence of several outcomes and moderator variables in the original studies does not preclude the possibility of conducting a meta-analysis. Borenstein, Hedges, Higging, and Rothstein (2009) suggested that this kind of meta-analysis is feasible although it involves great complexity. The present meta-analytic study is thus intended as a refinement and an extension of the SR conducted by Kueider and colleagues (2012).

One of the main difficulties in obtaining a clear picture of the effects of video game training is the great variability of several key features of the intervention studies, including the type of video game used, the type of cognitive process assessed, the way in which these cognitive processes were evaluated, and personal characteristics of the trainees. Presumably, the mixed results reported in the literature can be attributed to this variability. For example, some studies reported positive results (e.g., Anguera et al., 2013; Goldstein et al., 1997; Torres, 2008), whereas others did not find any cognitive improvement (e.g., Ackerman et al., 2010; Owen et al., 2010). Meta-analysis is a good tool to determine the variables responsible for the discrepancies reported in the intervention studies (Hertzog et al., 2008).

10.1.2. Scope, Aims and Hypotheses of Meta-Analysis

The main aim of this meta-analytic study was to investigate the extent to which cognitive training with video games enhances cognitive functions in healthy older adults. It synthesizes the effect sizes obtained in video game training studies conducted to investigate transfer effects. Furthermore, we were interested to find out which training variables might explain the wide variability of results reported in the literature. We also tried to identify the specific variables involved in the modulation of the effect sizes obtained in the intervention studies. The first step was to review the published literature in order to identify the main variables that modulate the effect. We selected six main variables thought to contribute to the results: (1) the type of video game used; (2) the duration of the training program; (3) the number of games used in the training program; (4) the type of program; (5) the type of control group; and (6) the age of the participants. These variables were coded for each study and introduced as covariates in the analysis. The dependent variables used to compute the effect sizes are known as outcomes. In the literature on video game intervention studies, there are a variety of outcomes related to cognitive processes. We combined the outcomes to compute a single effect size for each study. To examine the effect of the moderator variables, the outcomes were classified into five broad cognitive categories: memory, attention, reaction time, executive functions and global cognitive function.

To code the type of video game used in each study, we attempted to classify them. This was not an easy task as there has been a spectacular development in this field during the last decade. Briefly, the first video games were simple or no-action games (e.g., *Pac-Man* or *Donkey Kong*). Their use as cognitive training tools improved performance on speed of processing tasks but not on executive function or working memory tasks (Clark et al., 1987; Dustman et al., 1992; Goldstein et al., 1997). Later, more complex action games were developed in which planning and strategic factors played a predominant role. Video games such as *Medal of Honor* and *Space Fortress* are classified as complex games that activate many perceptual and cognitive skills. Some studies have used this type of video game in their interventions with older adults (e.g., Basak et al., 2008; Stern et al., 2011). The type of video game used to train older adults is thus an important variable in video game training studies. Zelinski and Reyes (2009) classified video games as simple versus complex. The former does not involve complex cognitive demands, while the latter requires the concurrent recruitment of many perceptual and cognitive skills. We followed this approach when classifying the types of video game used in the intervention studies. Two complementary moderators were also considered in our analysis: duration of training, and number of games used in the intervention. The amount of training, as well as the diversity of skills involved, might also explain some of the variance of the results even when the type of video game is the same. We also included in the meta-analysis other two moderator variables, type of program (commercial video games *versus* "brain training" programs designed specifically to improve cognitive functions) and type of control group (active control group *versus* passive control group). Finally, the age of the participants as a moderator variable is also important as older adults vary considerably in their cognitive abilities and health status. People aged between 60 and 70 might have preserved their functionalities but people older than that might experience the burdens of aging more profoundly.

We hypothesized that there would be an overall cognitive improvement after training, with some variance in the amount of improvement depending on the cognitive processes assessed (outcomes). Moreover, with regard to the combined effect size of the individual studies, we hypothesized that complex games would yield greater improvement than simple games because the former involve a broader range of skills. Our second hypothesis was that there would be a positive relationship between the overall cognitive improvement and the number of training sessions. The third hypothesis was that there would also be a positive relationship between the number of video games the participants were trained to play and improvements in cognition. The fourth hypothesis was that the interaction with the experimenter would be beneficial. We tested this hypothesis by assessing the effect of the type of control group included in the study. The fifth hypothesis was that brain training specifically designed to improve cognition would be more effective than commercial video games. Finally, we hypothesized that cognitive improvements, while remaining significant, would decrease with age. Consequently, the age covariant would have a detrimental effect on cognitive improvement.

10.2. METHOD

10.2.1. Literature Search

A systematic search strategy was used to identify relevant studies to be included in this meta-analysis. The Medline, Psyc-Info and Google Scholar databases were searched to identify relevant studies. Periodic searches of these databases were conducted between 1986 and 2013 using several combinations of the following keywords: “aging”, “older adults”, “video game training”, “memory”, and “cognitive function”. We also performed a manual search and cross-referencing of original articles. We restricted the search to articles written in English. As the video game business developed with the computer industry in the late eighties, the first article found was published in 1986. After reading the articles obtained from the electronic search, we found additional related papers not obtained in the previous step. The titles and abstracts of the original articles were screened for potential inclusion in the study.

10.2.2. Selection criteria

Studies were included if they met the following criteria: 1) they involved only healthy older adults; 2) they reported pre- and post-evaluation results of the same cognitive outcomes; 3) the trained group received only video game training; and 4) the studies reported all the descriptive statistics necessary to compute the *d* effect size index and its confidence interval. The electronic and manual search yielded a total of 60 articles, but only 20 fulfilled the inclusion criteria and were included in the meta-analysis. Figure 1 shows the flow diagram with the search characteristics and the inclusion criteria

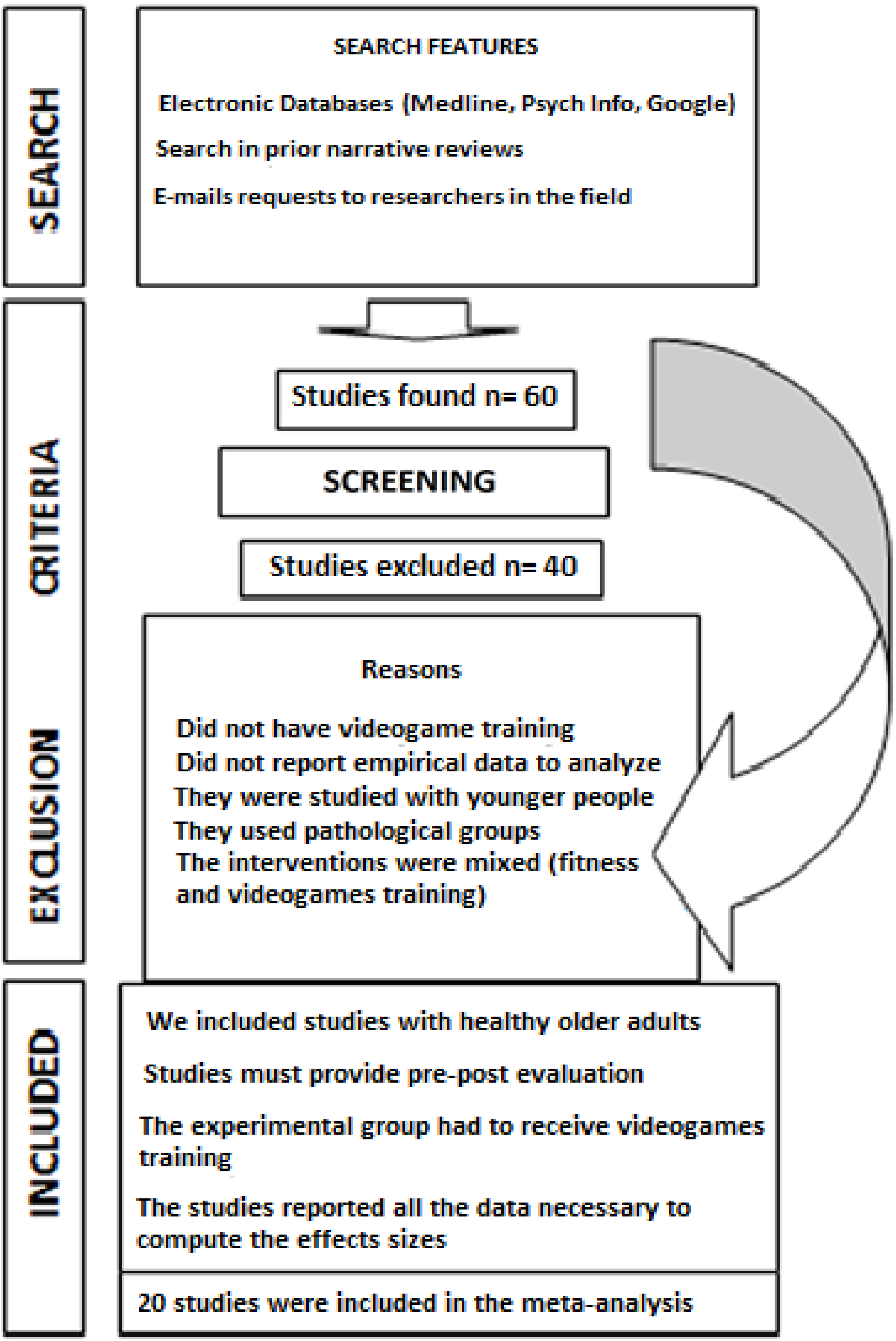

Figure 1. Flow diagram of studies considered and ultimately included in the meta-analysis

Of the 20 articles included in the present study, two (Cassavaugh & Kramer, 2009 and Ackerman et al., 2010) did not include a control group. However, it was possible to compute the effect size indexes corresponding to these two studies using the formula for a pre-post design without a control group (see Equation 1).

$$d = c(n-1)\frac{\bar{Y}_{Pre} - \bar{Y}_{Post}}{S_{Pre}} = \left(1 - \frac{3}{4\,n - 5}\right)\frac{\bar{Y}_{Pre} - \bar{Y}_{Post}}{S_{Pre}}$$

Equation 1

Equation 1 has the *c* term included multiplicatively to correct bias in Cohen's *d* (Hedges & Olkin, 1985; Carlson & Schmidt, 1999), *n* is the number of participants, $\bar{Y}$ is the mean of the dependent variable with the subscript signaling the phase (Pre: pre-test, Post: post-test) and S is the standard deviation of the same dependent variable.

The other 18 studies were coded using Equation 2 (pre-post experimental design with two groups, experimental and control, and a continuous dependent variable).

$$d = \left(1 - \frac{3}{4(n_{Exp} + n_{Cont})}\right)\frac{\left(\bar{Y}_{Pre}^{Exp} - \bar{Y}_{Post}^{Exp}\right) - \left(\bar{Y}_{Pre}^{Cont} - \bar{Y}_{Post}^{Cont}\right)}{\sqrt{\frac{n_{Exp}\left(S_{Pre}^{Exp}\right)^2 + n_{Cont}\left(S_{Pre}^{Cont}\right)^2}{n_{Exp} + n_{Cont} - 2}}}$$

Equation 2

Equation 2 has the same meaning as Equation 1 in the subscripts, superscripts and the symbols used. So, the first multiplicative term between brackets is a bias correction of Cohen´s *d* (Hedges & Olkin, 1985), *n* is the number of participants on each group (signaled by their subscripts) and superscripts *Exp* and *Cont* meaning "Experimental group" and "Control Group" respectively.

Standardized Cohen´s *d* statistics were computed from the pre- and post-intervention means and standard deviations of each group for each outcome variable using the formulas outlined above (Hedges & Olkin, 1985). The characteristics of these studies are presented in Table 1.

Table 1

Characteristics of the studies included in the meta-analysis

STUDY	AGE	Control	N	Video games	Duration (training)	Significant Findings
Ackerman, 2010	50-71	--------------	78	Wii Big Brain Academy	4 weeks: 5x/weeks	No significant transfer of training from Wii practice or reading tasks to measures of cognitive and perceptual speed abilities
Anguera, 2013	M=67	Active /non active	46	Neuroracer	4 weeks	Training enhanced cognitive control in older adults. These benefits were extended to untrained abilities
Basak, 2008	63-75	No contact	39	Rise of Nations	4-5 weeks: 3x/weeks	E.G. improved memory, executive function and visuospatial abilities
Belchior, 2008	67-84	Tetris or no contact	58	UFOV or Medal of Honor	2 weeks: 2-3/week	E.G. improved processing speed more than control group
Boot A, 2013	M=74	No contact	40	Brain Age	12 weeks	Cognitive abilities did not improve
Boot B, 2013	M=74	No contact	34	Mario Kart	12 weeks	Cognitive abilities did not improve
Bozoki, 2013	60-80	Online activities	60	Online video games	6 weeks	Overall analysis did not show transfer effects. The effect sizes were relatively small
Cassavaugh, 2009	M=71.7	-------------	21	Computer training program	2-3 weeks: 8 sessions	E.G. improved Reaction Time
Clark, 1987	57-83	No contact	14	Pac Man or Donkey Kong	7 weeks: 120 min/week	E.G. improved Reaction Time
Drew & Waters, 1986	61-78	Contact	13	Atari Crystal Castle	8 weeks: 12x/week	E.G. improved psychomotor speed and global cognition
Dustman, 1992	62-71	Movie or no contact	60	Breakout, Galaxian Frogger Kaboom, PacMan, …	11 weeks: 3x/week	E.G. improved Reaction Time

Goldstein, 1997	72-85	No contact	22	SuperTetris	5 weeks: 300 min/week	E.G. improved reaction time. E.G. and C.G. also improved executive functions but there were no differences between groups.
Maillot, 2012	65-75	No contact	32	Nintendo Wii	12 weeks	E.G. group improved more than C.G. on measures of physical function, executive control and processing speed functions, but not on visuospatial measures.
McDougall, 2012	M=74	No contact	41	Nintendo Brain Training	6 weeks	E.G. improved in Digit Span Test and other tests
Nouchi, 2012	M=69	Tetris	28	Brain Age	4 weeks	E.G. improved executive functions and processing speed.
Peretz, 2011	60-77	Computer games	121	C. Personal Coach.	12 weeks: 3x/week	E.G. and C.G. improved focused and saturated attention, memory recognition and mental flexibility
Sosa, 2012	M=74	Non active	31	Brain Age	5 weeks: 1/week	E.G. improved syllable (time), arithmetic (time) and Stroop tests
Stern, 2011	M=66	Active or non active control	60	Space Fortress	12 weeks: 36 hours	One measure of executive control showed improvements in E.G.
Torres, 2008	60-86	Muscle relaxation/no contact	43	Super Granny, Zoo Keeper, Penguin Push, Bricks, memory games	8 weeks: 1/week	E.G. showed less cognitive decline than C.G.
Van Muijden, 2012	60-77	Documentary group	72	Anagram, Falling bricks,	7 weeks/ 24.5 hours	Modest support for the potential of video game training to improve cognitive functions in older people

Abbreviations: E.G. Experimental Group; C.G. Control Group; UFOV: Useful Field of View; Control refers to the control group activity

10.2.3. Characteristics of training interventions

As expected, the video games used as training platforms in the 20 studies included in the present investigation differed in several characteristics. It is important to note that none of the video games used in these intervention studies, except those used in Anguera et al.'s (2013) study, were originally designed to improve cognition in older adults. The studies used a wide range of video game genres (see Table 1); some used commercial video games such as *Medal of Honor, Pac Man, Donkey Kong, Tetris, Crystal Castle*, etc., while others used a combination of classic cognitive tasks taken from commercial packages (e.g., *Nintendo Brain Training, Brain Age, Big Brain Academy*, etc.). This implies that the individual studies trained different cognitive processes as an unavoidable consequence. Two other relevant differences were the number of training sessions and the number of video games used in the same intervention study. These two characteristics are likely to affect the intensity of the training program. We coded these characteristics (type of video game, duration or number of training sessions, type of program, type of control group and number of video games included in the training program) as moderator variables.

With regard to the type of video game, these were classified as simple versus complex. A game was coded as complex if it involved multiple cognitive processes and complex cognitive demands. The number of video games was also classified with two categories: few (1 to 6 games) and many (7 to 12 games). Another factor considered in the present study was the duration of the intervention; two levels were selected: short (between 1 and 6 weeks) and long (between 7 and 12 weeks). Type of program was coded with two levels ("brain training" program and video games). The variable type of control group was also coded with two levels (active and passive). The last variable was the age of the participants. Unfortunately, the published studies did not provide consistent information about the age of the participants, some reporting the age range and others the mean age of participants. Consequently, we decided to code age as a categorical variable with two levels: 1) from 60 to 70 years of age, and 2) from 71 to 80 years of age (when the mean age or the half-split range point reported was within these ranges). Finally, we coded the outcome measures of the studies as cognitive processes (reaction time, executive functions, memory, attention and global cognitive functioning) based on the category of tests used at pre-post assessment.

Table 2 displays the moderator variables and their coded levels in the present study.

Table 2 *Variables analyzed*

VARIABLES	LEVELS	
Age of participants	60 to 70 years	71 to 80 years
Training duration	Short (1-6 weeks)	Long (7-12 weeks)
Type of video game	Simple	Complex
Number of games	Few (1 to 6)	Many (7 to 12)
Type of control group	Active	Passive
Type of program	Brain training	Video games

10.2.4. Outcomes

The 20 studies included in this meta-analysis reported multiple outcomes on several cognitive functions that we classified as memory, attention, reaction time, executive functions and overall cognitive function, although not all of them reported the same cognitive functions. Moreover, even when studies assessed the same cognitive functions, they used different tests to evaluate them. The difficulty of comparing different measures of the same cognitive function using different tests was overcome by converting the raw statistics to Cohen's *d* using a common metric for all the outcomes.

To evaluate inter-rater agreement, the first author (P.T.) and the second author (J.M.R) coded the data from the 20 original studies using the same codebook. There was no disagreement regarding the moderator variables (Pearson´s correlation $r = 1$). The level of agreement between the two coders for outcomes (memory, attention, reaction time, global cognitive function and executive functions) was computed as the correlation between the effect sizes (*d*) for the outcomes between the two assessments. The inter-rater correlation for the main outcomes was $r = 0.97$ ($p < 0.001$), indicating that the agreement between the coders was very high, both for moderator and outcome variables.

10.3. META-ANALYTIC PROCEDURE

The analyses were conducted using the Comprehensive Meta-Analysis software (Borenstein et al., 2005). Effect sizes were computed for each individual study and test using Cohen´s *d* for experimental designs with pre-and post-tests and experimental and control groups. As mentioned above, the only exceptions were the studies by Cassavaugh and Kramer (2009) and by Ackerman et al. (2010) in which we used only the treatment group. As all the studies reported data on more than one individual test in the same cognitive area, we computed the mean. The effect size and its standard deviation (SD) for each study and each cognitive function were calculated. Finally, we combined the effect sizes of the same cognitive function in each study to overcome the statistical problem of assigning more weight to studies with more individual outcomes. We used these mean scores for each cognitive function as outcomes instead of raw effect sizes computed for each individual test in each study. Moreover, 5 of the 20 final individual studies included in the meta-analysis had subgroups within the study. In all cases, the subgroups compared the same experimental (trained) group with different control groups. As not all the studies reported data on the same subgroups, we treated each subgroup as a separate study.

Mean effect sizes and confidence intervals were estimated using the fixed effect model. By convention, an absolute effect size of 0.2 or less is considered small, an absolute value between 0.2 and 0.6 is considered moderate, and an estimated value equal to or greater than 0.6 is considered large. A 95% confidence interval was calculated for each effect size to establish whether it was statistically different from zero. We examined the variation in effect sizes between studies using a standardized scale, based on the Q index of homogeneity (Hedges & Olkin, 1985). To estimate the proportion of the observed variance that reflects real differences among studies, we calculated I^2.

Thus, a total of 20 studies contributed data to this meta-analysis, comprising 474 trained older adults and 439 control participants. Full details of all the studies included in this meta-analysis are provided in the References section, marked with an asterisk. A major concern in meta-analytic studies is the existence of publication bias. We used funnel plots to assess the relationship between sample size and effect size (Egger, Davey, Smith, Schneider, & Minder, 1997). As shown below, publication bias does not seem to affect the validity of the overall effect size obtained in the present study.

10.4. RESULTS

10.4.1. Effect size estimates: Mean and test of heterogeneity

An overall effect size was calculated incorporating all effect sizes. The mean effect size was calculated incorporating all effects sizes. The mean effect size was 0.37 (ET = 0.05) with a 95% confidence interval of between 0.26 and 0.48. Effect sizes showed no significant heterogeneity [Q (19) = 23.95, $p > 0.05$, $I^2 = 20.69$ %]. The forest plot is shown in Figure 2.

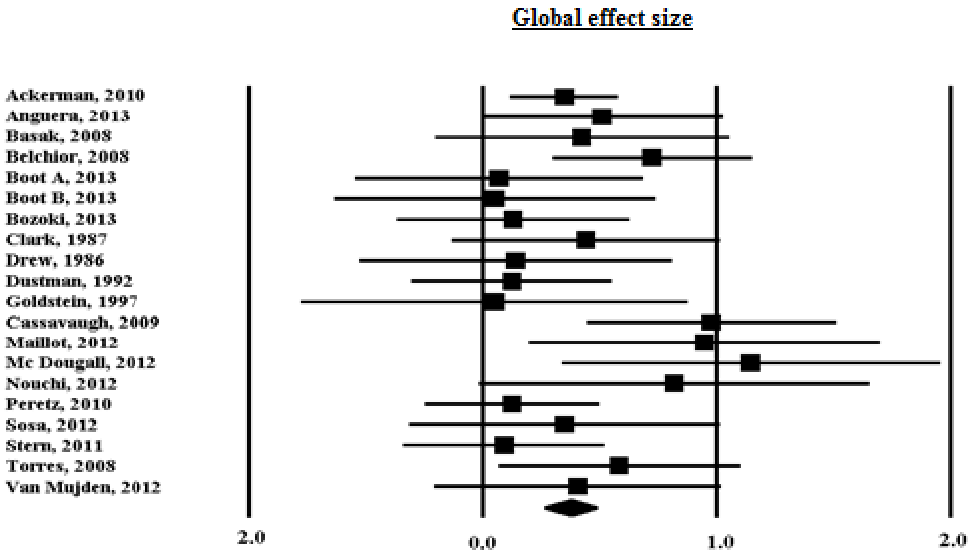

Figure 2. Mean global effect size (*d*) and 95% confidence intervals for the 20 individual studies combining effect sizes within each study. Articles are shown on the left, identified by the first author's name and publication year**.**

Although we obtained a non-significant *p*-value for heterogeneity and did not therefore reject the null hypothesis, we are aware that this result could be due to a low power (Borenstein et al., 2009). For this reason, we calculated the effect of the moderator variables.

Regarding the Type of video game (simple *vs*. complex), the heterogeneity between groups was not significant [Q (1) = 0.55, $p > 0.05$]. The mean effect size for simple video games was 0.42 [CI = (0.25, 0.58), Z = 5.00, $p < 0.01$] and for complex games it was 0.33 [CI = (0.18, 0.48), Z = 4.38, $p < 0.01$].

The second variable was the Duration of training with two levels (short *vs*. long). The heterogeneity between groups was significant [Q (1) = 3.73, $p = 0.05$, $I^2 = 73.19\%$]. The mean effect size for short training was 0.49 [CI = (0.32, 0.67), Z = 5.59, $p < 0.01$] and for long training it was 0.26 [CI = (0.09, 0.43), Z = 3.03, $p < 0.01$].

The third moderator variable analyzed in the present meta-analysis was the Number of video games (few *vs*. many) used in the interventions. The heterogeneity between groups was not significant [Q (1) = 0.37, $p > 0.05$]. The mean effect size for many games was 0.30 [CI = (0.07, 0.54), Z = 2.56, $p < 0.05$] and for few games it was 0.39 [CI = (0.26, 0.51), Z = 6.12, $p < 0.01$].

The fourth variable analyzed was type of program (brain training *vs*. video game). The heterogeneity between groups was not significant [Q (1) = 0.27, $p > 0.05$]. The mean effect size for brain training was 0.34 [CI = (0.17, 0.50), Z = 4.04, $p < 0.01$] and for video games was 0.40 [CI = (0.25, 0.55), Z =5.25, $p < 0.01$].

The next moderator variable analyzed was type of control group (active *vs*. passive). We analyzed this variable in two ways: (1) including all the studies that had a control group, excluding only those without control group (two studies); and (2) analyzing the effect sizes of those studies that used both an active and a passive control group, excluding those studies that had just a passive control or no control group. The results of the first analysis showed that the heterogeneity between groups was not significant [Q (1) = 0.54, $p > 0.05$]. The mean effect size for active control was 0.27 [CI = (0.09, 0.45), Z = 3.03, $p < 0.01$] and for passive control was 0.37 [CI (0.19, 0.55), Z = 4.0, p < 0.01 The results corresponding to the second analysis showed that the heterogeneity between groups was not significant [Q(1) = 0.004, $p > 0.05$]. The mean effect size for active control was 0.36 [CI = (0.06, 0.66), Z = 2.40, p < 0,05] and for passive control 0.37 (CI = (0,07, 0.68), $p < 0.05$]. The difference between active and passive control was not statistically significant but they were significantly different from zero.

Finally, the last moderator variable was age. The heterogeneity of effect sizes for both age groups was highly significant [Q (1) = 4.50, $p < 0.01$, $I^2 = 77.77\%$]. The mean effect size for the 60-70 year-old group was 0.30 [CI = (0.16, 0.44), Z = 4.27, $p < 0.01$] and for the 71-80 year-old group 0.57 [CI = (0.34, 0.79), Z = 4.98, $p < 0.01$]. Table 3 summarizes these results.

Table 3. *Results of the significant moderator variables*

Variable	Level	*d* (ET)	Q	I^2	Z	CI
Age	60-70	0.30 (0.07)	Q(1) = 4,50,p < 0.01	77.77 %	4.27, p < 0.01	[0.16, 0.44]
	71-80	0.57 (0.11)			4.98, p < 0.01	[0.34, 0.79]
Training duration	Short	0.49 (0.08)	Q(1) = 3.73,p = 0.05	73.19 %	5.59, p < 0.01	[0.32, 0.67]
	Long	0.26 (0.08)			3.03, p < 0.01	[0.09, 0.43]
Type of game	Simple	0.42 (0.08)	Q(1) = 0.55, p > 0.05		5.00, p < 0.01	[0.25, 0.58]
	Complex	0.33 (0.07)			4.38, p < 0.01	[0.18, 0.48]
Number of games	Few	0.39 (0.06)	Q(1) = 0.37, p > 0.05		6.12, p < 0.01	[0.26, 0.51]
	Many	0.30 (0.12)			2.56, p < 0.01	[0.07, 0.54]
Type of program	Video games	0.40 (0.07)	Q(1) = 0.27, p > 0.05		5.25, p < 0.01	[0.25, 0.55]
	Brain training	0.34 (0.08)			4.04, p < 0.01	[0.17, 0.50]
Type of control group	Active	0.27 (0.09)	Q(1) = 0.54, p > 0.05		3.03, p < 0.01	[0.09, 0.45]
	Passive	0.37 (0.09)			4.00, p < 0.01	[0.19, 0.55]

To assess the interaction between age and duration of training, we computed the correlation between these two variables. The result showed that the association between these variables was not statistically significant ($r = -0.12, p = 0.60$). This suggests that grouping certain levels of training duration with certain levels of participants´ age did not bias the results obtained in this meta-analysis.

Next, we present the results of the analysis of the combined outcomes for each cognitive function. The heterogeneity between cognitive functions was significant [Q (5) = 13.20, p < 0.05], and we therefore report the analysis using the random effect model for outcomes. We give below the statistics for those cognitive functions that showed a significant treatment effect. The effect size for reaction time [d = 0.63, CI = (0.42, 0.84), Z = 5.93, p < 0.01], memory [d = 0.39, CI = (0.01, 0.64), Z = 3.08, p < 0.05], attention [d = 0.37, CI = (0.17, 0.57), Z = 3.67, p < 0.01], and overall cognitive function [d = 0.38, CI = (0.13, 0.62), Z= 3.07, p < 0.05] were all significant. Only executive functions did not reach statistical significance (p > 0.05). These results are displayed in Table 4.

Table 4. *Effect sizes (d), Z and CI corresponding to each cognitive process (outcomes).*

Outcomes	d (ET)	Z	CI
Memory	0.39 (0.12)	3.08, p < 0.01	[0.01, 0.64]
Attention	0.37 (0.10)	3.67, p < 0.01	[0.17, 0.57]
Reaction Time	0.63 (0.10)	5.93, p < 0.01	[0.42, 0.84]
Cognitive Function	0.38 (0.12)	3.07, p < 0.01	[0.13, 0.62]
Executive Functions	0.16 (0.13)	1.20, p > 0.05	[-0.10, 0.42]

The present results suggest that the effects of the interventions depend on variables such as the age of the participants and the duration (number of sessions) of the intervention. Specifically, this analysis suggests that short interventions (from 1 to 6 weeks) are more effective than long interventions (from 7 to 12 weeks). Furthermore, age has a significant effect, suggesting that the oldest adults (71 to 80 years) benefit more from video game training than younger participants (60-70 years).

10.4.2. Evaluation of publication bias

To evaluate possible publication bias, we performed a funnel plot (see Figure 3). The symmetry of the graph suggests the absence of publication bias. The interpretation of a funnel plot is subjective, so we performed other quantitative tests of publication bias (Begg & Mazumbar, 1994; Egger et al., 1997). First, we applied the Egger test (Egger et al., 1997). This test is an un-weighted regression that takes the precision of each study as the independent variable and effect size as the dependent variable. The Egger test was not significant for the intercept of the regression model [intercept = 0.74; t (8) = 1.03, p = 0.31]. The t-test for the null hypothesis of an intercept equal to zero showed a statistically non-significant result. We can therefore assume that publication bias is not a threat to the validity of the overall effect size. Secondly, we calculated the fail-safe N_{fs} index (Becker, 2005). The result of this analysis suggests that in order to cancel the global mean effect obtained in our meta-analysis (d = 0.37), it would be necessary to have 207 non-published studies with null effects not included in the meta-analysis. These results also suggest that the effect obtained in the present study is not affected by publication bias. Thus, combined results from these methods suggest that the likelihood of publication bias is minimal.

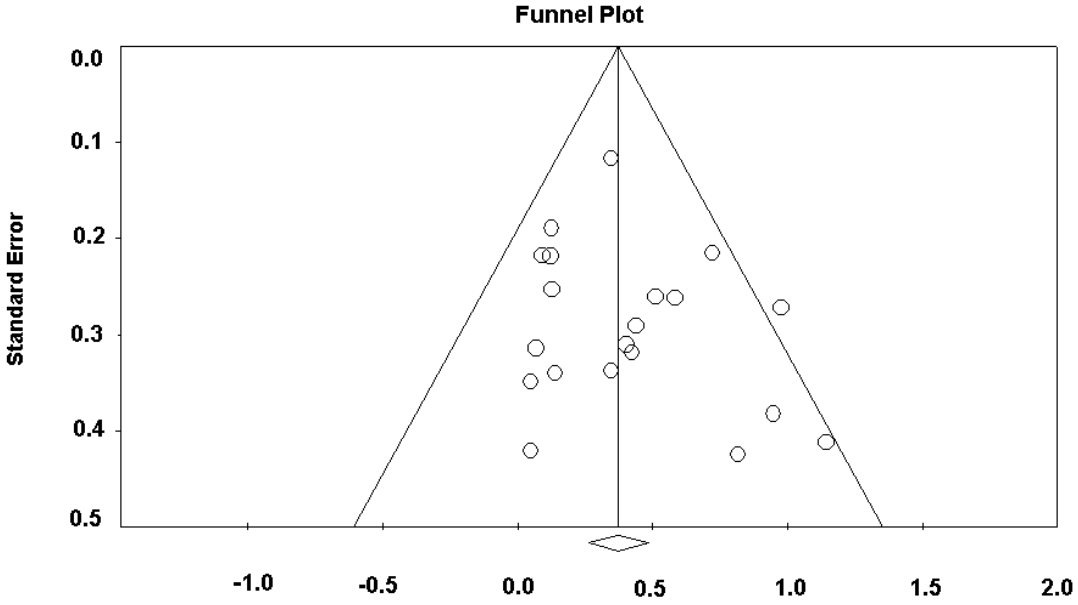

Figure 3. Funnel plot of standard errors and effect sizes *(d)* of the 20 studies of healthy older adults trained with video games included in the meta-analysis.

10.5. DISCUSSION

As far as we know, this is the first meta-analysis of the effects of video game training on improving cognitive functioning in healthy older adults. The present meta-analytic study investigated whether video game training enhances cognitive functions in older adults by re-analyzing individual studies published on this topic since 1986. The overall meta-analysis unambiguously revealed that training older adults with video games improves cognition. The main findings can be summarized as follows: (1) video game training in older adults produces positive effects on several cognitive functions that decline with aging; (2) several methodological and personal factors have moderator effects; (3) among the analyzed variables, the age of the participants and the number of sessions in the training program were significant in modifying the effect size of the interventions. These moderator variables may explain, in part, the variability of the results reported so far in the literature on this topic.

Overall, the results of this meta-analysis confirm our main hypothesis that video game training improves cognitive functioning in older adults. However, the present results do not confirm the specific hypotheses regarding age, duration of training, type of program, number and type of video games. In fact, we predicted greater improvement with longer training interventions, but the results showed that short training is a better option for this type of intervention with older adults. Moreover, cognitive improvements due to video game training increased rather than decreased with age; the oldest adults (71-80 years) improved more after training than younger participants (60-70 years). We also predicted greater cognitive improvements with complex games than with simple games. The results, however, showed no significant differences between simple and complex games. Similar results emerged for the number of video games used in the intervention.

The current results have both theoretical and practical implications. Firstly, duration of training was a significant variable. Our results indicate that the training effects are greater when training is of short duration (1-6 weeks) than when it is long (7-12 weeks). This finding has practical implications as many intervention programs spend a great amount of time training older participants on the assumption that longer training will produce better results. The results of this meta-analysis do not support this assumption. Our own experimental work with senior citizens (Ballesteros et al., 2014; Mayas, Parmentier, Andrés, & Ballesteros, 2014) suggests that long training schedules lead to loss of motivation. Training sessions may be quite exciting at first but older adults get tired and bored in the last sessions. It seems that what motivates older participants to practice the games in the later sessions is not the training *per se* but the affective link or personal relationship established with the experimenter. Moreover, despite evidence suggesting a significant effect size of training on cognitive functioning, older people do not seem to perceive its functionality in their daily life. Apart from the motivational factors outlined above, the present results might be explained in terms of the *Temporal Discounting Hypothesis*. Temporal discounting (Green, Fry, & Myerson, 1994) refers to the phenomenon that future rewards are less valuable than immediate rewards. This temporal discounting is greater in elderly participants whose expected life-time is shorter. This means that the effort put into learning a new task must be balanced with the expected reward of acquiring the new skill. When the time needed to learn and improve in the video game task begins to be relatively long with respect to the expected reward, the motivation to continue training decreases. The reason may be that the anticipated rewards are small compared to the immediate cost of attending the training sessions.

The second significant moderator variable that appeared in our analysis was the age of the trainees. The results suggest that the benefits of training increases as participants get older. This result is relevant for applied purposes and could be explained by the larger training gains in people with lower baseline scores. In other words, the oldest adults (71-80 years) start the training program with lower cognitive functioning scores, but they show greater improvement after training than the younger participants (60-70 years of age). The combination of these two effects may produce a greater effect size in the oldest adults (71-80 years). Our results do not rule out the possibility that the performance of younger participants (60-70 years) may be relatively high at the start of the training program. Notwithstanding, it is worth stressing that while older people may benefit extensively from video game training, they use new technologies and video games in particular less than other members of the population, even when they can obtain a greater benefit.

The results of the current study show that there are no significant differences between few and many video games used in the training phase, although there is a non-significant trend indicating that few games are better than many. In relation to the social interaction between experimenter and trainee that occurs in the experimental group and in the active control group but not in the passive control group, the results suggest a minor, although non-significant beneficial effect on cognition. This effect might be due to motivational factors. This result, however, must be taken with caution due to the small number of studies (five studies) that included passive and active control groups in the same study. Future investigation in this field should include at least these two types of control groups (active and passive) as a better control. It should be noted that the means showed in Table 3 for the variable type of control group correspond to standardized mean differences of the experimental *vs*. active control group and the experimental *vs*. passive control group. This implies that if the active control group had an effect, the computed *d* for the first contrast will be lower than that of the second contrast. The reason is that the performance of the active control group will be closer to the experimental group than to the passive control group. The present results show that there are no significant differences between “brain training” programs and video games. The same happen with type of game. There are no significant differences between simple and complex games, although there is a non-significant trend indicating that simple games produce more benefits than complex games.

So far, we have considered the moderator variables included in the meta-analysis. An important issue, however, is whether the effects of training older people with video games are transferable to untrained tasks. This is the so-called ‘transfer effect’. The question is whether the effects of training with video games transfer to cognitive processes such as memory, attention, executive functions, reaction time and global cognitive function. Excluding executive functions that did not show a significant effect different from zero, effect sizes revealed an interesting pattern in the other cognitive functions. The results of this meta-analytic study suggest that attention is perhaps the cognitive function that improved most following training. This finding is in agreement with the results of a recent study (Mayas et al., 2014). In this study, the trained group, but not the control group, received 20 one-hr training sessions with non-action video games and were evaluated before and after the intervention using a cross-modal visual-auditory oddball task measuring alertness and distraction. The results showed that training reduced distractibility by improving attention filtering (a function that declines with age and is largely dependent on frontal regions) and also improved alertness supported by a larger brain network.

The present study also showed that speed of processing, assessed by reaction time tasks, improved significantly after training. This finding is in line with a recent review (Bavelier, Green, Pouget, & Schrater, 2012). Most video games demand rapid responses and the maintenance in long-term memory of information relevant to the task at hand ready to be used when required. This is reflected in the significant effect of video game training on memory. The significant effect of training on global cognitive function also shows, although to a lesser extent, that some components of training transfer to general cognitive processes as assessed by standardized psychometric intelligence tests.

Interestingly, executive functions did not show a significant effect of training (although there was a trend in this direction). This result is in agreement with the study of Dahlin, Nyberg, Bäckman, and Neely (2008), who found that the transfer of computer training to the updating of information in working memory was limited to young participants. They concluded that older participants have more limited neural plasticity, reducing their ability to generalize an executive skill (information updating). The results of the present meta-analysis are also congruent with those of a study from our laboratory (Ballesteros et al., 2014). A recent meta-analysis conducted with children, young adults, adults, and older adults also yielded negligible effects for executive functions (Powers, Brooks, Aldrich, Palladino, & Alfieri, 2013).

Overall, our results are in line with those of Kueider et al. (2012) who also found that video game training improved reaction time and global cognition but that it was less efficient for improving executive functions. This meta-analysis extends the systematic review carried out by Kueider et al. (2012) by including a greater number of studies. In order to ascertain the consistency of our results, we compared them with those obtained by Kueider and colleagues in the meta-analytic review. The mean effect sizes of both studies are similar. For instance, our mean effect size for reaction time was d = 0.63 versus d = 0.77 reported by Kueider and colleagues. These results suggest that video game training improves memory and other cognitive functions in healthy older adults and have important practical implications. Helping older adults to maintain cognitive health may reduce the risk of dependency. However, the video game industry should create attractive and useful games specifically designed for the elderly, in other words, video games that meet their perceived needs and which may not be the same as those that young people find attractive and engaging.

10.5.1. Future research

More research is needed to study effective ways of maintaining cognition and of improving the quality of life of older adults. The findings regarding the moderating effects of the age of the trainees and the duration of the training program suggest that these factors require further investigation. However, the main issue for future research is how to improve the transfer effects of video games on cognitive functioning in older adults, especially executive functions. A fruitful new approach is the incorporation of neuroimaging data to identify the mental processes that operate in multiple task domains (Anguera et al., 2013; Basak, Voss, Erickson, Boot, & Kramer, 2011; Lustig, Shah, & Reuter Lorenz, 2009; Prakash et al., 2012). These mental processes might be targeted with specific cognitive tasks directed at these processes and evaluating their performance on another task (Dahlin et al., 2008; Persson & Reuter Lorenz, 2008).

10.5.2. Limitations

It is important to stress that publication bias is a potentially serious threat to the validity of the meta-analysis. Publication bias concerns the issue of missing data. However, the statistical analysis suggests that the results of this meta-analysis are reasonably good and that the likelihood of publication bias is minimal.

Finally, it should be noted other possible limitations, including the lack of documented effects on latent factors, which makes it difficult to rule out effects due to specific strategies, the lack of reported effects on abilities related to daily life, and the difficulty to rule out possible effects due to motivational factors rather than neurocognitive plasticity.

10.5.3. Conclusion

In summary, although video game training has positive effects for older adults, the benefits do not transfer to all cognitive functions. Moreover, the positive effects are moderated by personal and methodological factors. For instance, the age of the trainee and the duration of the training program are important factors that have to be considered in this type of intervention and should be the focus of future research. The results of this meta-analytic study suggest neurocognitive plasticity in the aging human brain, as training with video games is found to enhance cognitive performance on several untrained functions.

11. CAPÍTULO 6. VIDEO GAME TRAINING ENHANCES VISUOSPATIAL WORKING MEMORY AND EPISODIC MEMORY IN OLDER ADULTS

Toril, P., Reales, J.M., Mayas, J., & Ballesteros, S. (Submitted). Video game training enhances visuospatial working memory and episodic memory in older adults

Abstract

In this longitudinal intervention study with experimental and control groups, we investigated the effects of video game training on the visuospatial working memory and episodic memory of healthy older adults. Participants were 19 volunteer older adults, who received 15 1-hr video game training sessions with a series of video games selected from a commercial package (*Lumosity*), and a control group of 20 healthy older adults. The results showed that the performance of the trainees improved significantly in all the practiced video games. Most importantly, we found significant enhancements after training in the trained group and no change in the control group in two computerized tasks designed to assess visuospatial working memory, namely the Corsi blocks task and the Jigsaw puzzle task. The episodic memory and short-term memory of the trainees also improved. Gains in some working memory and episodic memory tasks were maintained during a 3-month follow-up period. These results suggest that the aging brain still retains some degree of plasticity, and that video game training might be an effective intervention tool to improve working memory and other cognitive functions in older adults. *Keywords*: Brain plasticity, cognitive aging, episodic memory, training, video games, visuospatial working memory

11.1. INTRODUCTION

Age-related brain changes occurring mainly in the prefrontal cortex and the medial temporal lobe system (including the hippocampus and the cerebellum) are associated with cognitive declines (Raz et al., 2005) in several functions, including processing speed (Salthouse, 1996), peripheral vision (Muiños & Ballesteros, 2014), dynamic visual acuity (Muiños & Ballesteros, 2015), working memory (WM), executive control functioning, and episodic memory (e.g., Baltes & Linderberger, 1997; Hoyer & Verhaeghen, 2006; Nilsson, 2003; Park & Gutchess, 2002; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005). However, other cognitive functions, including implicit memory, verbal abilities and world knowledge, are mostly spared with age (e.g., Ballesteros, Bischof, Goh, & Park, 2013; Ballesteros & Mayas, 2015; Craik & Bialystok, 2006; Mitchell & Bruss, 2003; Osorio, Pouthas, Fay, & Ballesteros, 2010; Park et al., 2002). Experience-related changes induced by the modification of the social environment, physical activity, and cognitive training affect brain structure and function (for a recent review see, Ballesteros, Kraft, Santana, & Tziraki, 2015a). Research on brain plasticity in older adults and its relationship to experiential changes is currently attracting substantial public interest (Raz & Lindenberger, 2013).

Training intervention studies suggest that the older human brain maintains a certain level of neural plasticity (Bialystok & Craik, 2006; Li et al., 2008; Li et al., 2006). Based on this idea, an active line of research concerns ways of maintaining and/or improving cognitive skills (Green & Bavelier, 2003), delaying cognitive and brain declines as much as possible (Hertzog, Kramer, Wilson, & Lindenberger, 2008; Park & Bischof, 2013; Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Park, 2014). The observed increase in neural volume in response to cognitive training is an indicator of brain plasticity (see, Boyke, Driemeyer, Gaser, Büchel, & May, 2009; Park & Bischof, 2013). Based on the assumption that the older brain retains at least some degree of plasticity and still has the capacity to modify its structural and functional patterns to meet new environmental demands, researchers are intensively exploring different types of intervention for older adults.

One of the most popular computerized intervention approaches is training older adults with video games. Some intervention studies have reported improvements in the trained group but not in the control group in several cognitive functions, including processing speed (e.g., Ballesteros et al., 2014; Clark, Lamphear, & Riddick, 1987; Dustman, Emmerson, Steinhaus, Shearer, & Dustman, 1992), visuo-motor coordination (Drew & Waters, 1986), attention (e.g., Belchior, 2008; Goldstein et al., 1997; Mayas, Parmentier, Andrés, & Ballesteros, 2014), memory (e.g., Craik et al., 2007; Hampstead et al., 2012; Smith et al., 2009), working memory (e.g., Anguera et al., 2013; Edwards et al., 2005; Erickson et al., 2007), and global cognitive function (Torres, 2008). By contrast, other studies have failed to find any positive effects of training with video games on cognition (e.g., Ackerman, Kanfer, & Calderwood, 2010; Boot et al., 2013; Owen et al., 2010).

Video games are designed with two aims: enjoyment and sustained player engagement (Anguera & Gazzaley, 2015). They can be classified as simple (non-action games) and complex (action games). Complex video games are fast, intense, unpredictable, and require more perceptual and cognitive skills than non-action games (e.g., Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003). Some researchers have used complex video games to train older adults (e.g., Basak, Boot, Voss, & Kramer, 2008; Stern et al., 2011), while others have used non-action games, which seem more appropriate for older adults (e.g., Ballesteros et al., 2014; Torres, 2008; Van Mujden, Band & Hommel, 2012).

An important question in this context is whether training with video games transfers to other untrained cognitive functions. This is a critical issue for its practical significance, but remains debatable. A systematic review conducted to examine the effectiveness of computer-based interventions in cognitively healthy older adults found that video game training improved processing speed and global cognition but was less efficient for improving executive functions (Kueider, Parisi, Gross, & Rebok, 2012). More recently, we conducted a meta-analysis to examine the hypothesis that training older adults with video games enhances their cognitive functioning (Toril, Reales, & Ballesteros, 2014). The studies included in this meta-analysis were 20 experimental video game training interventions with pre- and post-training measures, published between 1986 and 2013. The mean effect size was moderate [0.37 (SE 0.05) with a 95% CI of between 0.26 and 0.48]. The results indicated that training older adults with video games produces moderate positive effects on several cognitive functions (e.g., reaction time, attention, memory and global cognition), but does not improve executive functions. This meta-analytic study (see also Lampit, Hallock, & Valenzuela, 2014) also found that these positive results were moderated by variables such as the age of the trainees and the frequency or length of the training program (the amount of time needed to induce cognitive improvement).

Working memory (WM) is a capacity-limited system that stores and processes information needed for ongoing cognition. This capacity-limited workspace is necessary to keep things in mind while performing complex tasks such as comprehension and reasoning (Baddeley & Hitch, 1974). This key component of cognition, central to many cognitive functions, including concentration, problem solving, and impulse control, declines significantly with age (e.g., Bopp & Verhaeghen, 2005; Park et al., 2002; Park & Reuther-Lorenz, 2009). Many recent reviews and longitudinal computerized cognitive training studies have investigated the effectiveness of computerized training approaches aimed at improving WM (e.g., Boot, Blakely, & Simons, 2011; Dahlin, Bäckman, Nely, & Nyberg, 2009; Klingberg, 2010; Morrison & Chein, 2011; Perrig, Hollenstein, & Oelhafen, 2009; Shipstead, Redick, & Engle, 2010, 2012; Takeuchi, Taki, & Kawashima, 2010). Unfortunately, the results of these studies are at best mixed, with some articles reporting the effectiveness of WM training (e.g., Borella, Carretti, Riboldi, & De Beni, 2010; Klingberg, 2010; Morrison & Chein, 2011), while others concluded that it is ineffective (e.g., Ballesteros et al., 2014; Redick et al., 2013; Shipstead et al., 2010).

Several recent meta-analytic studies (Karbach & Verhaeghen, 2014; Lampit et al., 2014; Toril et al., 2014) have noticed the great variability in the interventions in terms for example of the intensity and duration of the training regimes, whether they are carried out at home or in the presence of the trainer, and the age of the participants. Our meta-analytic study (Toril et al., 2014) showed that a small number of training sessions is more effective than a large number, possibly because older adults get tired and lose motivation after many training sessions. We also found that the benefits of training increased with the age of participants. The lower baseline scores of the older participants can explain this result. Lampit et al. (2014) also found that computerized cognitive training can improve the cognitive performance of healthy older adults, but that its effectiveness varies across domains. They suggested that training more than 3 times per week is ineffective. Karbach and Verhaeghen (2014) examined the effects of executive-function and working-memory training in older adults, suggesting that the inconsistencies of the results were due to differences in the type, intensity, duration of the intervention, and to the methods used to compare different studies. Their results suggest that WM and executive-function training produces significant and large improvements in the performance of the trained tasks and reliable small to medium-sized transfer effects in the process trained, at least in healthy older adults.

A recent randomized controlled trial study conducted to investigate the effects of training older adults with non-action video games on a series of cognitive functions that decline with age and on subjective wellbeing (Ballesteros et al., 2014) found significant improvements in the experimental group after training in processing speed, attention, immediate and delayed visual recognition memory, as well as a tendency to improve in some dimensions (affection and assertiveness) of the wellbeing scale. However, visuospatial WM and executive control did not improve after training. Overall, these pre-/post-training results support the view that training older adults with non-action video games improves some cognitive abilities but not others. Moreover, the assessment conducted after a 3-month no-contact interval showed that the benefits in processing speed, attention and long-term memory vanished and that only the effects on wellbeing were maintained three months later (see Ballesteros et al., 2015b). However, participants in the trained group showed no transfer to either executive control or spatial WM from pre-test to 3-month follow-up. These results suggest that cognitive plasticity can be induced in healthy older adults, but that periodic boosting sessions are needed to maintain the training benefits.

In view of the importance of working memory for the daily life activities of older adults, we designed this longitudinal intervention study taking into account the results of our previous study (Ballesteros et al., 2014, 2015b) and the findings of several recently published meta-analyses (Karbach & Verhaeghen, 2014; Lampit et al., 2014; Toril et al., 2014). The program was composed of 15 one-hour sessions. An important variable is the number of video games included in the training schedule (see Toril et al., 2014), and we therefore selected just 6 non-action video games to train mainly WM. Importantly, all the participants in the experimental group were trained in group sessions at the municipal senior center and in the presence of an experimenter (as recommended by Kelly et al., 2014 and Lampit et al., 2014).

The goal of the present study was to investigate whether cognitively healthy older adults could benefit from training with non-action video games. We addressed two main questions. First, would training older adults with non-action video games improve their visuospatial WM as well as short- and long-term memory? Secondly, would any improvements persist after a 3-month no-contact period? Based on the results of previous studies, we hypothesized that: 1) Video game training would improve the visuospatial WM of older adults; 2) the effects of training would transfer to episodic memory; and 3) memory improvements would persist three months after finishing the training program.

11.2. METHOD

11.2.1. Participants

Forty cognitively healthy volunteer older adults were recruited from a municipal senior center in the Madrid suburbs to participate in this training study. They all had normal or corrected-to-normal vision and hearing. After signing a consent form, participants were randomly assigned either to the trained (experimental) group or to the control group. Participants in both groups regularly attended cultural activities at the senior center (e.g., painting classes, lectures, cultural visits). The control group continued their routine lifestyle activities at the senior center. The study was approved by the Ethics Committee of the Universidad Nacional de Educación a Distancia. The inclusion criteria were to obtain a score of 26 or above on the Mini-Mental State Examination (MMSE; Folstein, 1975) and a normal score on the Information subscale of the WAIS III (Wechsler, 1999). The two groups did not differ in age, years of education, or in the Information subscale and MMSE scores (all *ps* > 0.05). In the experimental group, one participant declined to participate after screening for medical reasons. Thus, 19 participants in the training group and 20 in the control group completed the study. Demographic data for each group are displayed in Table 1.

Table 1. Demographic information for participants in each group

Characteristics	**Experimental Mean (SD)**	**Control Mean (*SD*)**	***p***	***F***
Age (Years)	69.95 (6.73)	73.20 (6.48)	0.13	2.36
Education (Years)	13.37 (3.27)	12.85 (3.36)	0.62	0.23
MMSE	28.31 (1.00)	27.75 (1.48)	0.17	1.92
Information	18.42 (2.61)	16.95 (3.06)	0.11	2.58

Note. Means and Standard deviations (*SD*) by group; MMSE, Minimental State Examination

11.2.2. Study design

The study was a 2 (group: experimental, control) x 3 (session: pre-training, post-training, 3-month follow-up) mixed factorial design. Group was the between-subjects factor and session was the within-subjects factor. To investigate the effectiveness of the intervention to improve and/or maintain both visuospatial WM and short- and long-term memory, participants performed a series of tests and experimental tasks designed to assess these types of memory: digit span forward and backward, Corsi blocks, Jigsaw puzzle task, and immediate and delayed visual episodic memory tasks (Faces I and II, and Family pictures I and II from WMS-III). The Corsi blocks and the Jigsaw puzzle tasks were programmed using E-Prime 2.0 (Psychology Software Tools Inc., Pittsburg, PA, USA). Long-term memory was assessed with tests from the WMS-III (Wechsler, 1997), and the Digit Span tasks were extracted from WAIS III (Wechsler, 1999).

11.2.3. Training Schedule and overview of the training program

Participants assigned to the experimental group completed 15 one-hour training sessions at the community senior center in the presence of the experimenter over a period of 7 to 8 weeks. In each training session, participants played 6 video games twice each. The games were selected from *Lumosity* (http://www.lumosity.com), a web-based cognitive training platform; they were *Speed Match, Memory matrix, Rotation matrix, Face memory, Money comb* and *Lost in migration*. The session score for each participant on each game was calculated as the mean score of the first and second time they played the game. The session reaction time (RT) for each participant on each game was calculated as the mean performance of the first and second time they played the game. The control group did not receive training but met the experimenter periodically (once a month) in the senior center to talk about their activities and other general topics related to aging. The video games used in this study are described below.

Speed Match. In this game, a symbol is displayed on the computer screen, followed immediately by another. The trainee has to decide whether the two symbols are the same, indicating their choice by pressing one of two keys (same, different) as fast as possible.

Memory matrix. A matrix varying in size is displayed in the center of the screen with a pattern of colored squares followed by a blank matrix. The player has to reproduce the pattern by clicking on the squares that were colored.

Rotation matrix. This game is similar to the previous one, except that the matrix is rotated between the coding phase and the response phase. The player has to mentally rotate the encoded matrix, and click on the correct positions of the colored squares.

Face memory. Different faces appear on the screen continuously, one after another, and the player has to decide whether the face on the screen matches the one shown one (1-back), two (2-back), or three (3-back) faces before.

Moneycomb. In this game, a honeycomb appears in the center of screen and a sequence of tokens of different values is presented briefly inside it. The task consists of clicking on the correct tiles of the honeycomb to reveal the tokens in the correct order (from lowest to highest value).

Lost in Migration. In this game, a static flock of birds appears in the center of the screen. The goal is to identify the direction in which the bird in the middle of the flock is flying (right, left, upward, downward) by pressing one of the four arrow keys on the keyboard as fast as possible.

Participants received points based on their performance on each video game. Some of the games also recorded response times. None of the participants in the study reported that they had any previous experience of playing video games.

11.3. ASSESSMENT TASKS AND PROCEDURES

Assessment tasks fell into one of the following three domains: visuospatial working memory, short-term memory and episodic memory.

11.3.1. Viso-spatial working memory tasks

Visuospatial WM (Baddeley & Hitch, 1974) was assessed with the Corsi blocks and the Jigsaw-puzzle task.

Corsi Blocks Task. The original Corsi Blocks task (Milner, 1971) consisted of a set of nine identical blocks (3 x 3 x 3 cm) unevenly positioned on a wooden board (23 x 28 cm). The participant had to point to the blocks in their order of presentation. The length of the sequence increased until recall was no longer correct in terms of order or position (Berch, Krikorian, & Huha, 1998). In this study, we used the same computerized version of the Corsi task as in our previous study (Ballesteros et al., 2014) with four levels of increasing difficulty (2, 3, 4 and 5 cube positions) and 10 trials per level. The stimuli were black squares on a 3 x 3 matrix that appeared one after the other, for one second each. The positions in each sequence were selected randomly, with the restriction that stimuli could not appear in the same position in two consecutive sequences. In each trial, the participant reproduced the previously presented sequence of cubes (the black squares in the 3 x 3 matrix) by writing down their order of presentation on a separate response sheet. To familiarize participants with the task, they performed a practice block of trials. The final score was the proportion of correct sequences obtained at each difficulty level.

Jigsaw-Puzzle Task. The original pencil-and-paper Jigsaw-Puzzle task was developed to assess active visuospatial abilities (Richardson & Vecchi, 2002). We designed a computerized version of this task with puzzles consisting of 4, 6 or 9 pieces. Each piece was numbered and the participant had to write down on a response sheet the number corresponding to the pieces in the correct spatial positions. The stimuli were 15 pictures with similar visual complexity (mean = 2.4, *SD* = 0.32) and familiarity (mean = 4.3, *SD* = 0.26) selected from the Snodgrass and Vanderwart (1980) picture set. Each picture was fragmented into 4, 6 and 9 pieces to produce 45 different puzzles. The pictures were enlarged to fit a 12 cm x 12 cm area and were cut into four 6 cm x 6 cm pieces, six 6 cm x 4 cm pieces, or nine 3 cm x 3 cm pieces using Adobe Photoshop CC (Adobe Systems Software, Ireland Ltd.). We generated three different counterbalanced orders. Different pictures were used at pre-test, post-test and follow-up assessments. Participants were presented with 15 puzzles representing all possible combinations and number of pieces. The response sheets contained grids of the same size as the original pictures with the appropriate number of squares (4, 6, 9 squares). We used 2 puzzles as practice items and their results were not included in the analysis. For each trial, a fragmented picture appeared on the computer screen and the participant wrote down on the response sheet the appropriate numbers to form a spatially correct picture. The jigsaw was presented on the computer screen for 90 seconds. Participants were allowed to correct errors within that time. Performance was assessed in terms of the proportion of correct puzzles per level (4, 6 and 9 pieces).

11.3.2. Short Term memory

Short-term memory was assessed with the Digit Span Test of the WAIS III scale (Wechsler, 1999).

Digit Span Test. This test has two parts: Digit span forward and Digit span backward. For each part, the test administrator says a series of numbers aloud at the rate of one per second. The participant then repeats the numbers in the same order (digit span forward) or in reverse order (digit span backward). Both tests begin with a series of two numbers. For digits forward, the test continues up to a maximum of eight numbers. For digits backward, the test continues up to a maximum of seven numbers. Participants are given two trials at each length and the test continues until the participant fails both trials at one length. In both the forward and the backward task, the score was the maximum number of correctly remembered digits.

11.3.3. Immediate and delayed episodic memory tests

The **Faces and Family pictures** subtests of the Weschler Memory Scale (WMS-III) were used to assess visual episodic memory. For immediate recognition memory, we used Faces I and Family pictures I. Delayed recognition (25 minutes after encoding) was assessed using Faces II and Family pictures II.

11.4. RESULTS

11.4.1. Video Game Practice Effects

Although the main dependent variables of this intervention study were the scores obtained on the memory tests, we also analyzed performance on the video games to evaluate whether the trained participants improved as a consequence of playing the video games. Video game performance showed significant improvements (accuracy and response times) across the 15 training sessions (see Figures 1a and 1b). Figure 1a shows the positive linear trend of the mean number of correct responses as a function of session. Figure 1b presents the mean response times for the video games that recorded response times. The mean scores of each game at the beginning and end of the training period were compared using regression analysis, with Training Session as the predictor variable and Reaction Time (RT) and Game Score as the criterion variables. Performance on all games improved after training. R^2 coefficients were high and accounted for more than 80% of the variance of the model in the 6 games. The ANOVAS for the previous analyses showed that all R^2 coefficients were statistically significant. This means that Training Session was a reliable predictor of Score and RT in the 6 games. Table 2 summarizes the results.

Table 2. Determination coefficients (R^2), F and *p* values for the 6 video games

Video game	*DV*	R^2	R^2 *(corr)*	*F*	*p*
Memory matrix	Score	0.699	0.675	30.14	0.00
Speed match	Score	0.952	0.949	260.64	0.00
	RT	0.951	0.948	254.91	0.00
Lost in migration	Score	0.921	0.914	150.65	0.00
	RT	0.954	0.951	271.49	0.00
Faces	Score	0.896	0.888	112.42	0.00
	RT	0.813	0.798	56.44	0.00
Money comb	Score	0.866	0.856	84.34	0.00
Rotation matrix	Score	0.840	0.828	68.45	0.00

Note. *DV* (Dependent variable); R^2 (Regression coefficient); R^2corr (corrected regression coefficient); *F* (*F* values of ANOVAs); *p* (*p* values)

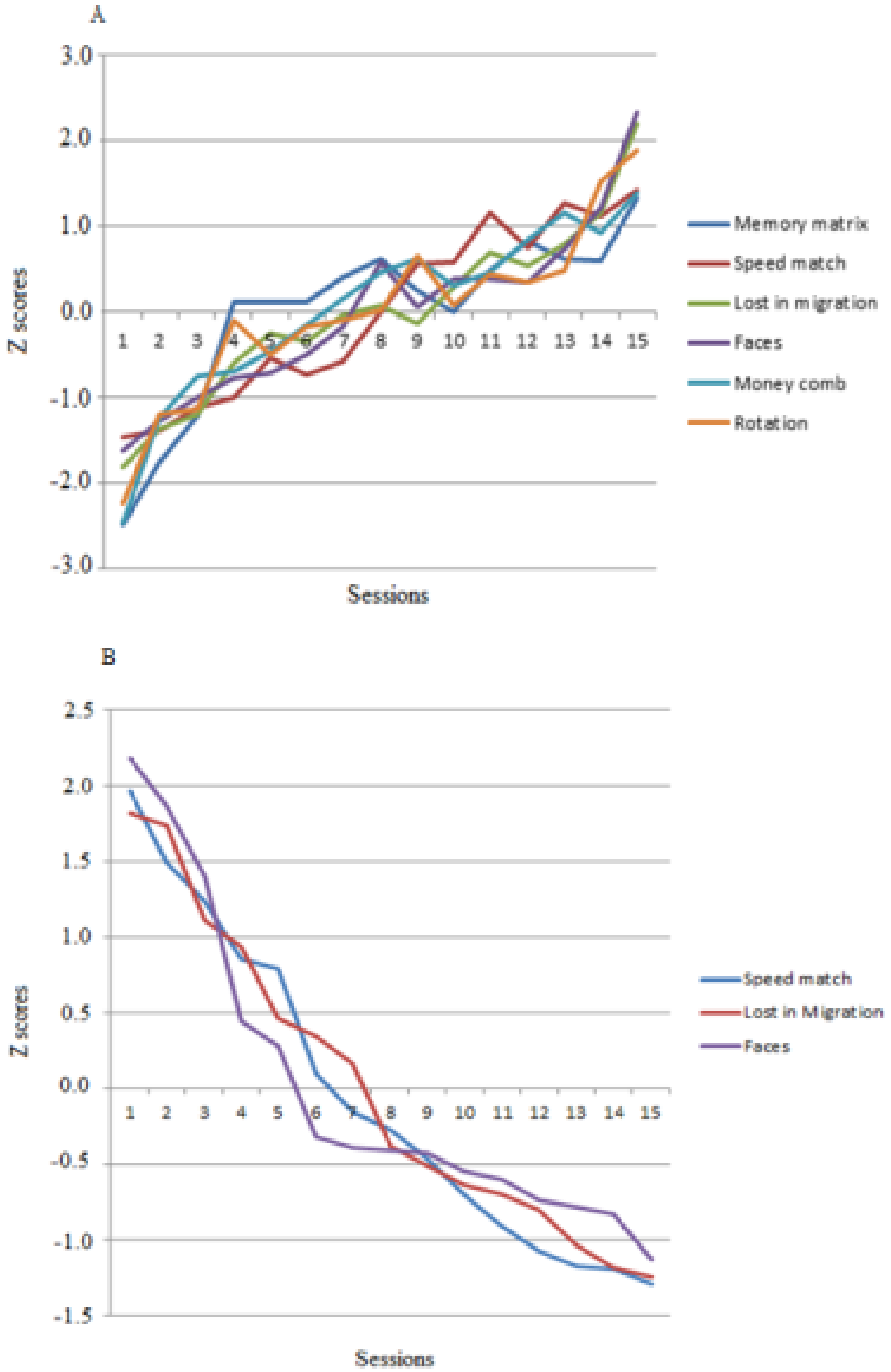

Figure 1. (A) Average performance scores obtained in the 6 non-action video games across the 15 sessions in Z scores (mean 0; standard deviation 1). (B) Average response times of 4 video games across the training sessions in Z scores.

11.4.2. Effects of Video Game training on viso-spatial working memory tasks and other memory tests

We investigated whether training with video games improved memory abilities that decline with age, especially visuospatial WM and episodic memory. We addressed two questions. The first was whether training older adults with video games would transfer to performance on a series of memory tasks (transfer effects). The second was whether these possible enhancements would remain after a 3-month no-contact period (maintenance). To answer these questions, we investigated whether group (trained vs. control) interacted with session (pre-test, post-test, follow-up) with regard to performance on the different memory tests.

Jigsaw-Puzzle Task

A Group (2) x Session (3) x Level of fragmentation (3) mixed ANOVA with Group as the between-subjects factor and Session and Level of fragmentation as the within- subjects factor was performed on the proportion of correct puzzles completed at each level of fragmentation. The results showed that the main effect of Group was statistically significant [$F(1, 37) = 12.10, MSe = 3.03, p < 0.05, \eta_p^2 = 0.84$]. The trained group performed better (mean = 0.52, *SD* = 0.17) than the control group (mean = 0.33, *SD* = 0.17). Session was also statistically significant [$F(2, 74) = 8.71, MSe = 0.32, p < 0.05, \eta_p^2 = 0.19$]. Participants performed better at post-test (mean = 0.41, *SD* = 0.12) than at pre-test (mean = 0.36, *SD* = 0.18), but there was no difference between post-test and 3-month follow-up ($p = 0.29$). Level of fragmentation was also significant [$F(2, 74) = 207.56$, $MSe = 12.70$, $p < 0.05$, $\eta^2_p = 0.84$], showing that performance deteriorated with higher levels of fragmentation (level 4, mean =

0.75, *SD* = 0.18; level 6, mean = 0.43, *SD* = 0.24; level 9, mean = 0.09, *SD* = 0.12). The two-way Session by Group interaction was statistically significant [$F(2, 74) = 13.30$, $MSe = 0.49$, $p < 0.05$, $\eta^2_p = 0.26$], showing that the trained group performed better at post-test (mean = 0.61, *SD* = 0.13) than the control group (mean = 0.32, *SD* = 0.13). The trained group performed better (mean = 0.55, *SD*=0.13) at the 3-month follow-up assessment than the control group (mean = 0.32, *SD* = 0.13), while the performance of the control group did not differ between sessions. No other interaction was significant (all $ps > 0.05$). See Figure 2 (bottom right).

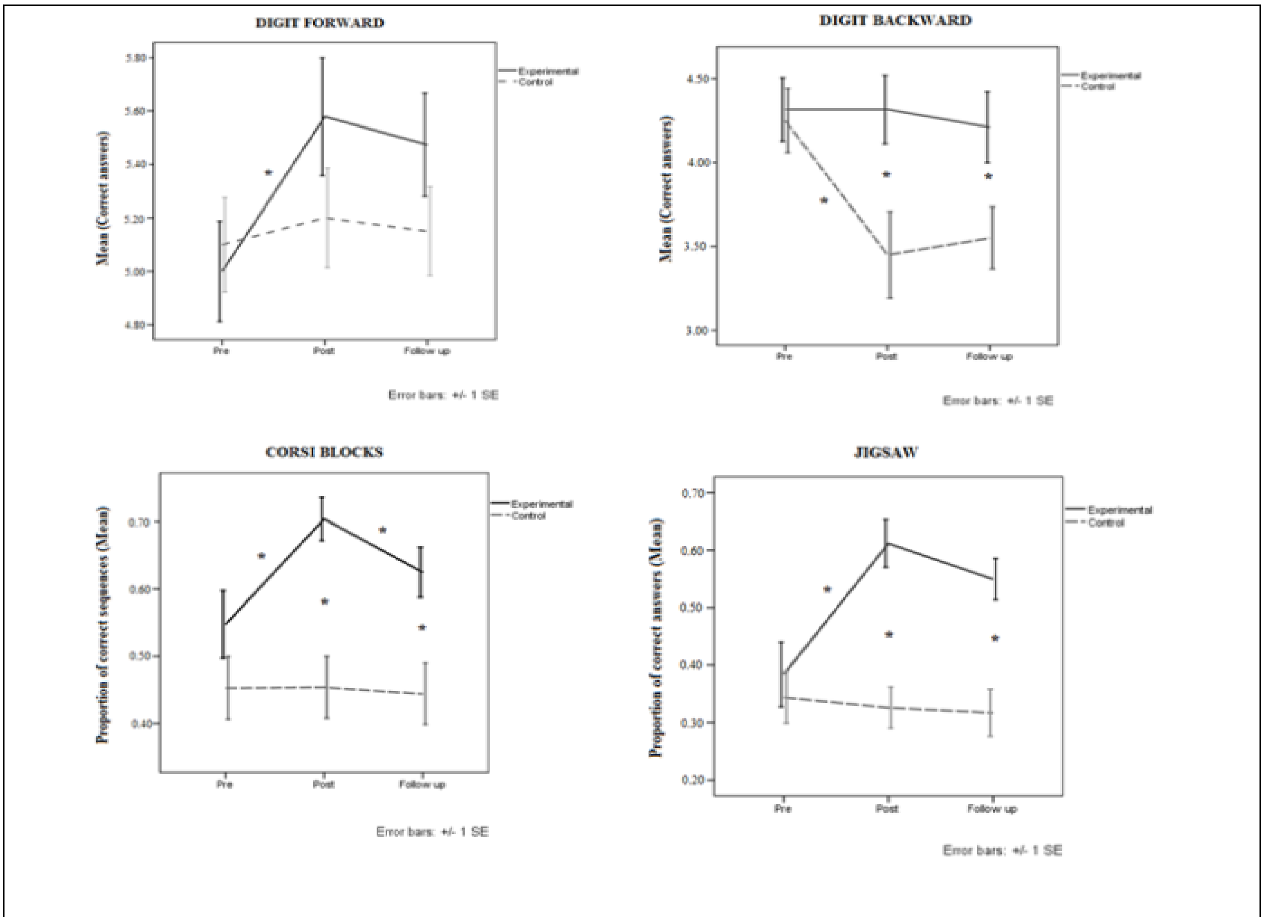

Figure 2. Top: Mean performance of trained and control groups at pre, post and follow-up assessments in Digit forward (left) and Digit backward (right). Bottom: Mean performance of trained and control groups at pre, post and follow-up assessments in the working memory tasks (left: Corsi blocks; right: Jigsaw puzzle tasks). Error bars represent plus and minus 1 standard error. * p < 0.05

Corsi Blocks task

A Group (2) x Session (3) x Corsi level (2, 3, 4 and 5 blocks) mixed ANOVA with Group as the between-subjects factor and Session and Corsi level as within-subjects factors were conducted on the proportion of correct sequences per level. The results showed that the main effect of Group was statistically significant [$F(1,37) = 10.04$, $MSe = 3.55$, $p < 0.05$, $\eta^2_p = 0.21$], showing that the trained group (mean = 0.62, *SD* = 0.17) outperformed the control group (mean = 0.45, *SD* = 0.17). The main effect of Session was also statistically significant [$F(2,74) = 5.43, MSe = 0.24, p < 0.05, \eta_p^2 = 0.12$], with better performance at post-test (mean = 0.58, *SD* =0.12) than at pre-test (mean = 0.50, *SD* = 0.18).There were significant differences between pre-test and post-test assessments ($p < 0.05$). Moreover, there were marginally significant differences ($p = 0.054$) between post-test (mean = 0.58, *SD* =0.12) and 3-month follow-up (mean = 0.53, *SD* = 0.12), while performance at pre-test and 3-month follow-up ($p > 0.05$) did not differ. The main factor of Corsi level was also significant [$F(3,37) = 285.84, MSe = 12.84, p < 0.05, \eta_p^2 = 0.88$], showing that performance deteriorated as the number of blocks increased (Corsi 2, mean = 0.89, *SD* = 0.06; Corsi 3, mean = 0.67, *SD* =0.18; Corsi 4, mean = 0.46, *SD* =0.24; Corsi 5, mean = 0.12, *SD* = 0.12).

The two-way Session by Group interaction was also statistically significant [$F(2,74) = 5.25, MSe = 0.23, p < 0.05, \eta_p^2 = 0.12$]. The analysis of this interaction showed that there were significant differences ($p < 0.001$) between pre- and post-test in the trained group (mean pre-test = 0.55, *SD* = 0.21; mean post-test = 0.70, *SD* = 0.17), but a reverse trend was observed in the control group. There were also significant differences in the trained group between post-test and 3-month follow-up (mean post-test = 0.70, *SD*= 0.17; mean follow-up = 0.62, SD = 0.17), with lower performance at the 3-month follow-up. Differences between pre- and post-test were not significant ($p > 0.05$) in the control group (mean pre-test = 0.45, *SD*= 0.22; mean post-test = 0.46, *SD* = 0.17). The two-way Group by Level interaction was also significant [$F(3, 111) = 5.67, MSe = 0.24, p < 0.05, \eta_p^2 = 0.13$]. The analysis of this interaction showed that there were significant differences (*ps* < 0.05) between groups at all Corsi levels. In the trained group, the means for each level were: level 2 = 0.94, *SD* = 0.08; level 3 = 0.78, *SD* = 0.17; level 4 = 0.60, *SD* = 0.26; level 5 = 0.17, *SD* = 0.13. In the control group the means were: level 2 = 0.84, *SD* = 0.08; level 3 = 0.54, *SD* = 0.17; level 4 = 0.32, *SD* = 0.26; level 5 = 0.07, *SD* = 0.13). Although the trained group performed better that the control group in this task, performance deteriorated in both groups as the number of blocks increased. See Figure 2 (bottom left).

Digit Forward Test

The ANOVA conducted with Group (2) and Session (3) on the numbers of correct digits reported showed that Session was significant [F (2,74) = 3.97, MSe = 1.23, $p < 0.05$, η^2_p=0.09], with better performance at post-test (mean = 5.38, *SD* = 0.87) than at pre-test (mean = 5.05, *SD* = 0.74), but there were no significant differences between post-test and 3-month follow-up ($p > 0.05$). The trained group performed better at post-test that at pre-test (p < 0.05), but there was no difference between post-test and 3-month follow-up ($p > 0.05$). Group as a main factor was not significant ($p > 0.05$), as the performance of the trained group (mean= 5.35, *SD* = 0.69) was similar to that of the control group (mean = 5.15, *SD* = 0.71). No other factors or interactions were significant (all *ps* > 0.05). See Figure 2 (top left).

Digit Backward Test

An ANOVA with Group (2) and Session (3) was conducted on the numbers of correct digits reported. The main factor of Group was significant $[F(1,37) = 5.09, MSe = 1.72, p = 0.03, \eta_p^2 = 0.12]$, showing that the trained group performed better (mean = 4.29, *SD* = 0.73) than the control group (mean =3.75, *SD* = 0.67). The main effect of Session $[F(2,74) = 5.24, MSe = 1.96, p < 0.05, \eta_p^2 = 0.12]$ was significant. Performance at pre-test was better than at post-test (mean pre-test = 4.28, *SD*= 0.81; mean post-test = 3.88, *SD* = 0.93). The control group performed worse at post-test than at pre-test. The two-way Group by Session interaction was also significant $[F(2,74) = 4.69, MSe = 1.75, p < 0.05, \eta_p^2 = 0.11]$. Simple effects analysis showed no significant differences in the trained group between pre-test, post-test and 3-month follow-up evaluations (p > 0.05). Participants performed similarly in the three assessment sessions (mean 4.31, *SD* =0.82; = 4.31, *SD*= 0.80; mean = 4.26, *SD*= 0.87, for pre-test, post-test and 3-month follow-up, respectively). By contrast, there were significant differences in the control group between pre- and post-test ($p < 0.05$) due to poorer performance at post-test (mean post-test = 3.45; *SD* = 1.14) than at pre-test (mean = 4.25, *SD* = 1.14), but there were no differences (p > 0.05) between post-test and 3-month follow-up. See Figure 2 (top right).

Episodic Memory Test (Faces)

The results of the episodic memory tests are shown in Figure 3 and Table 3.

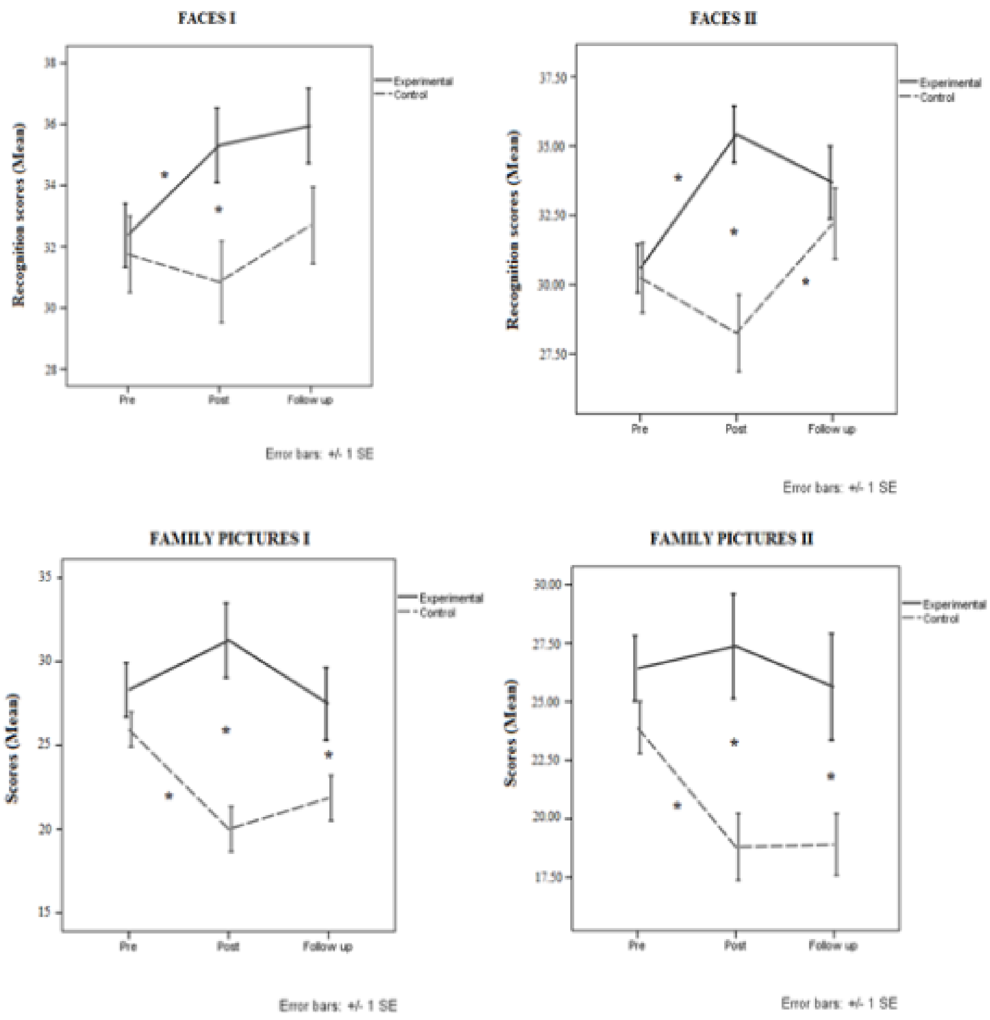

Figure 3. Mean performance of trained and control groups at pre, post and follow up in the episodic memory tasks. Top: Faces I (left) and Faces II (right). Bottom: Family pictures I (left) and Family picture II (right). Error bars represent plus and minus 1 standard error. * $p < 0.05$.

Table 3. Pre, post and follow-up training performance on working memory and episodic memory tasks corresponding to the trained and control groups. *M* (Mean), *SD* (Standard deviation).

TASK	***EXPERIMENTAL***			***CONTROL***		
	Pre	***Post***	***Follow up***	***Pre***	***Post***	***Follow up***
	M (SD)	***M (SD)***	***M (SD)***	***M (SD)***	***M (SD)***	***M (SD)***
Corsi Blocks task						
2 Serial position (Proportion)	0.86 (0.20)	0.98 (0.03)	0.95 (0.07)	0.79 (0.17)	0.86 (0.12)	0.86 (0.13)
3 Serial position (Proportion)	0.68 (0.30)	0.86 (0.13)	0.81 (0.16)	0.59 (0.24)	0.53 (0.27)	0.55 (0.29)
4 Serial position (Proportion)	0.50 (0.33)	0.73 (0.26)	0.57 (0.30)	0.35 (0.35)	0.36 (0.35)	0.28 (0.32)
5 Serial position (Proportion)	0.14 (0.21)	0.23 (0.24)	0.15 (0.21)	0.08 (0.17)	0.07 (0.18)	0.08 (0.16)
Jigsaw puzzle task						
4 pieces (Proportion)	0.68 (0.32)	0.93 (0.11)	0.92 (0.15)	0.67 (0.28)	0.59 (0.27)	0.65 (0.23)
6 pieces (Proportion)	0.42 (0.36)	0.64 (0.21)	0.58 (0.27)	0.32 (0.34)	0.22 (0.27)	0.29 (0.35)
9 pieces (Proportion)	0.05 (0.18)	0.18 (0.21)	0.14 (0.24)	0.05 (0.14)	0.02 (0.08)	0.02 (0.06)

Digit forward							
Score	5.00 (0.81)	5.57 (0.96)	5.47 (0.84)		5.10 (0.78)	5.20 (0.83)	5.15 (0.74)
Digit backward							
Score	4.31 (0.82)	4.32 (0.74)	4.26 (0.82)		4.25 (0.85)	3.45 (1.14)	3.55 (0.82)
Faces I							
Score	32.37 (4.53)	35.31 (5.30)	35.94 (5.32)		31.75 (5.58)	30.85 (5.95)	32.70 (5.59)
Faces II							
Score	30.58 (3.79)	35.42 (4.43)	33.68 (5.71)		30.25 (5.67)	28.25 (6.19)	32.20 (5.71)
Family pictures I							
Score	28.16 (7.15)	31.42 (9.13)	27.47 (9.43)		25.95 (4.63)	20.00 (6.03)	21.85 (6.07)
Family pictures II							
Score	26.42 (6.08)	27.36 (9.74)	25.10 (9.42)		23.90 (4.98)	18.75 (6.36)	18.90 (5.91)

Faces I

An ANOVA with Group (2) and Session (3) was performed on the recognition scores (Faces I). The analysis showed that Group was not significant although there was a trend in that direction (p = 0.07). Session was significant [F (2, 74) = 4.37, MSe = 50.11, p < 0.05, η^2 partial = 0.10] with better performance at the 3-month follow-up (mean = 34.32, *SD*= 5.42) than at pre-test (mean = 32.05, *SD*= 5.05). There were no significant differences between pre-test (mean = 32.05, *SD*= 5.05) and post-test (mean = 33.08, *SD*= 5.61), of between post-test (mean= 33.08, *SD*=5.61) and 3-month follow-up (mean= 34.32, *SD*=5.42). The two-way Group by Session interaction was significant [$F(2,74) = 3.28, MSe = 37.67, p < 0.05, \eta_p^2 = 0.08$]. The analysis of this interaction showed that there were significant differences between groups at post-test (p < 0.05), but only a trend was found at 3-month follow-up (p = 0.07). The trained group performed better at post-test than at pre-test (p < 0.05), but with similar performance at post-test and 3-month follow-up evaluations (p > 0.05). By contrast, the control group performed similarly in the three evaluation sessions (p > 0.05).

Faces II

The ANOVA conducted with Group (2) and Session (3) on the recognition scores (Faces II) showed that the effect of Group was statistically significant [$F(1,37) = 4.20, MSe = 262.15, p < 0.05, \eta_p^2 = 0.10$]. The trained group performed better (mean= 33.22, *SD*= 4.52) than the control group (mean= 30.23, *SD*=4.55). Session was also significant [$F(2,74) = 5.40, MSe = 62.57, p < 0.05, \eta_p^2 = 0.12$]. There were no differences between pre-test and post-test scores ($p > 0.05$), or between post-test and 3-month follow-up scores ($p > 0.05$), but performance was better at 3-month follow-up (mean = 32.94, *SD*=5.61) than at pre-test (mean =30.41, *SD*=4.80). The two-way Group by Session interaction was also statistically significant $[F(2,74) = 11.29, MSe = 130.70, p < 0.05, \eta_p^2 = 0.23]$, suggesting that groups differed at post-test ($p < 0.05$), but not at the 3-month follow-up assessment ($p > 0.05$). The trained group improved from pre-test to post-test ($p < 0.05$), but not between post-test and 3-month follow-up ($p > 0.05$). Moreover, there were significant differences between pre-test and 3-month follow-up, suggesting that performance at follow-up (mean= 33.68, *SD*=5.69) was better than at pre-test (mean= 30.57, *SD*=4.82). In the control group there were no significant differences between pre-test and post-test ($p > 0.05$), but participants in this group performed better at 3-month follow-up than at post-test ($p < 0.05$). Differences between pre-test and 3-month follow-up were not significant ($p > 0.05$).

Episodic memory tests (Family pictures)

Family Pictures I

An ANOVA with Group (2) and Session (3) performed on the recall scores (Family Pictures I) showed a significant effect of Group $[F(1,37) = 11.18, MSe = 1203.86, p < 0.05, \eta_p^2 = 0.23]$, indicating that the trained group performed better (mean = 29.01, *SD* = 5.95) than the control group (mean = 22.60, *SD* =5.94). Session was not significant ($p = 0.06$), but the Session x Group interaction was significant $[F(2,74) = 8.47, MSe = 211.37, p < 0.05, \eta_p^2 = 0.18]$. The analysis of this interaction suggests that there were significant differences between groups at post-test and 3-month follow-up ($p < 0.05$). Performance of the trained group did not differ between sessions ($p > 0.05$), but the control group performed worse at post-test than at pre-test ($p < 0.05$) with no difference between post-test and 3-month follow-up. However, the control group performed worse at 3-month follow-up than at pre-test ($p < 0.05$).

Family Pictures II

The ANOVA Group (2) x Session (3) conducted on the recall scores (Family pictures II) showed that the effect of group was significant [$F(1, 37) = 8.89, MSe = 977.08, p < 0.05, \eta_p^2 = 0.19$], suggesting that the trained group performed better (mean= 26.29, *SD*= 6.00) than the control group (mean= 20.51, *SD*=6.03). The effect of Session was also statistically significant [$F(2, 74) = 4.09, MSe = 100.71, p < 0.05, \eta_p^2 = 0.10$]. There were no significant differences between post-test and 3-month follow-up or between pre-test and post-test ($p > 0.05$), but scores differed significantly between pre-test and 3-month follow-up ($p < 0.05$). Performance was worse at 3-month follow-up (mean= 22.00, *SD*=7.08) than at pre-test (mean= 25.16, *SD*=4.90). The Group by Session interaction was significant [$F(2, 74) = 3.73, MSe = 91.87, p < 0.05, \eta_p^2 = 0.09$], showing that the trained group performed better than the control group at both post-test and 3-month follow-up assessments. The trained group did not differ between sessions ($p > 0.05$), but the control group performed worse at post-test than at pre-test ($p < 0.05$). Moreover, the control group performed similarly at post-test and 3-month follow-up ($p > 0.05$), but this group performed worse ($p < 0.05$) at the 3-month follow-up test (mean = 18.90, *SD* = 7.82) than at pre-test (mean = 23.90, *SD* =5.54).

11.5. DISCUSSION

The study yielded three main findings. First, the trainees improved their video game performance across sessions. Second, and most important, the trainees performed the Jigsaw puzzle, Corsi Blocks, Digit forward, and Faces I and II tasks better than the control group. Third, the improved performance of the trained group was maintained from baseline to the three-month follow-up for the Jigsaw puzzle task, which is a visuospatial WM task, and on the Digits forward, and Faces I and II tasks, but not on the Corsi Blocks, the other visuospatial WM task. These results are encouraging considering the age-related declines that occur in these memory functions.

11.5.1. Non-action video games training transferred to working memory

The improvements found in the present study are in line with previous findings reported in other video game training studies conducted with older adults (e.g., Anguera et al., 2013; Basak et al., 2008). Basak and colleagues (2008) found improvements on working memory tasks after training older adults for 23.5 hours with a real-time strategy video game (action video game). Anguera et al. (2013) trained older adults (60-75 years) for 4 weeks with an adaptive version of Neuroracer. Participants reduced multitasking costs at the post-training evaluation compared to an active control group and a no-contact control group. Moreover, the benefits of training were extended to an untrained working memory task, and gains persisted for 6 months.

The results of this longitudinal study are in agreement with those of other researchers who trained older adults using computerized training programs. For example, Buschkuehl et al. (2008) conducted an adaptive visual WM training study with oldest-old adults (mean age = 80 years). They found substantial gains in the trained task and improvements immediately after training in visual WM, which disappeared at the 1-year follow-up. Li et al. (2008) also investigated the effects of WM training on performance improvement, transfer and short-term maintenance of practice gains. In their study, young and older adults practiced a spatial WM task for 45 days, about 15 minutes per day. In both age groups, these researchers found improvements on the practiced tasks, and near transfer to spatial and numerical *n*-back tasks. Moreover, practice gains and near transfer effects were maintained at 3-month follow-up, but performance after training was lower in older than in young adults. Dahlin et al. (2008) conducted a computer–based training study with young and older adults based on updating information in WM. The results showed that both trained groups showed significantly greater improvement on the letter memory criterion task than the control group. Interestingly, gains were maintained 18 months later in young adults but not in older adults. Recently, Zinke and colleagues (2014) trained WM in older adults in 9 sessions over 3 weeks and found near transfer effects in a Corsi blocks task at post-test compared with pre-test.

The results of the present study also agree with findings of a recent meta-analysis (Karbach & Verhaeghen, 2014). The authors showed that executive functions and WM training led to significant improvements in performance in the trained tasks as well as large near transfer effects in older adults. However, the findings of the present study do not agree with the results of Maillot, Perrot, and Hartley (2012) who found that after a 24-hour training program the trainees improved more than controls in measures of executive control and processing speed functions, but not in visuospatial measures. The present results conflict with those of Ballesteros et al. (2014), who did not find any improvement in visuospatial WM tasks (Corsi

Blocks and Jigsaw puzzle tasks) or executive functions after 20 one-hour training sessions with 10 non-action video games selected from the *Lumosity* platform, although the video game training intervention was effective for improving reaction time, attention, and episodic memory.

11.5.2. Video game training enhanced some episodic memory tests

The present study also found improvements in some episodic memory tests after training, similar to the results of our previous study (Ballesteros et al., 2014), in which we found effects of training in episodic memory (Family Pictures I and II). However, in the present study we found improvements after training in Faces (I and II), which were maintained over a 3-month period without contact. Our results are in line with those of Buschkuehl et al. (2008) who conducted a WM training study with 80-year-old adults who trained twice a week for 3 months. Participants showed improvements in the trained tasks (visual WM tasks) and, to a lesser degree, in a visual episodic memory task (visual free recall) in which they had to look for differences between two almost identical pictures.

11.5.3. Results at 3 month-follow up

The usefulness of the intervention depends on both the occurrence of transfer effects and the durability of the training effects. Accordingly, it was important to ascertain whether the benefits found at post-training on some working memory tasks and short- and long-term memory tests were maintained after a 3-month no-contact follow-up period. In this study, transfer effects were maintained in the Digit forward test, the Jigsaw puzzle task, and in the Faces I and Faces II tests. However, significant improvements in the Corsi blocks task were not maintained.

Our results are in line with those of Anguera et al. (2013) who trained older adults for 4 weeks with an adaptive version of *Neuroracer* and found benefits after training. Specifically, they reported reduced multitasking costs in the trained group compared to the control group. The benefits found after training extended to an untrained working memory task, and gains persisted for 6 months. The 3-month maintenance found in the present study is in line with the results of Li et al. (2008) who found specific improvements in young and older adults in a WM task and maintenance of near transfer effects at 3-month follow-up.

11.5.4. The video games training debate

The conflicting results obtained in cognitive and brain-training studies with computerized cognitive exercises and video games have been explored in several recent meta-analyses (Lampit et al., 2014; Karbach & Verhaeghen, 2014; Toril et al., 2014). Specifically, we found that short training interventions conducted with older adults produced better results than long regimes (Toril et al., 2014). Training sessions are exciting at first, but older adults get tired and bored during the last sessions. Karbach and Kray (2009) found significant transfer effects in older adults after just four training sessions, as did Kramer, Larish, and Strahyer (1995) who provided a limited number of training sessions. Lampit et al. (2014) concluded that unsupervised at-home training regimes were less effective than group-based sessions, and that training more than three times a week was also ineffective. Another important variable was the number of video games used during the training sessions. Although not significant, Toril et al. (2014) found a trend in the analysis indicating that it is better to use a small set of video games than a large set.

It is important to stress that, on the basis of previous results (Ballesteros et al., 2014, 2015; Lampit et al., 2014), we designed the present study as a group-based training program with the presence of the experimenter throughout. The presence/absence of the experimenter might affect the participants' interest in training (Borella, Carreti, Riboldi, & De Beni, 2010). It is important to note that in our previous training study (Ballesteros et al., 2014) the experimenter was always present during each training session, but each session involved only 2-3 participants and not the whole group. The lack of improvement after training in visuospatial WM in our previous study (Ballesteros et al., 2014) and the positive results obtained in the present study might be due to the larger number of video games used in the earlier study (10) compared to just 6 specially selected to train visuospatial WM in the present study. The training regime of the present study was focused on enhancing WM, and this might explain the positive training effects obtained here.

Another important question regarding cognitive training concerns transfer. The evidence of transfer from video game training to untrained tasks is mixed, with both positive and negative results. Some researchers (Melby-Lervag & Hulme, 2013) argue that WM training has positive effects on tasks close to the trained tasks (near transfer). By contrast, Owen et al. (2010) examined whether some training tasks would improve cognitive performance, and concluded that there was no transfer to untrained tasks. In our study, we found positive near transfer effects, as well as smaller transfer effects on other untrained episodic memory tasks.

11.5.5. Conclusions, limitations of the present study and future directions

To summarize, the results of the present study suggest that training older adults with non-action video games can be an effective way of improving visuospatial WM performance in tasks designed to assess this type of memory and episodic memory tests. Importantly, the effects were maintained over a 3-month no-contact follow-up period in the Jigsaw puzzle task, Digit forward (short-term memory), and Faces I and Faces II (episodic memory). Transfer effects were not maintained on Corsi blocks. These findings suggest that older brains retain plasticity, but that some periodic boosting sessions are needed to maintain the benefits.

The present study has several limitations. First, our sample was smaller than in other studies (e.g., Anguera et al., 2013; Mozolic et al., 2011). However, it is important to stress that we did not have any drop-outs, which is unusual in longitudinal training studies, which lose between 30 and 40% of participants at follow-up. This suggests that training programs carried out in places that older adults attend regularly, and training sessions attended by the whole group with the presence of the experimenter are more effective than training individually at home or in small groups. Secondly, we did not examine the effects of training older adults with video games on everyday life tasks. This is an important issue for future studies. Thirdly, the control group in the present study was passive. However, most studies have also used a passive control group (e.g., Ballesteros et al. 2014; Basak et al., 2008; Goldstein et al., 1997; Maillot et al., 2012) to compare with the trained group, only a few training studies involving both an active and a passive control group (e.g., Anguera et al., 2013; Boot et al., 2013; Stern et al., 2011; Torres, 2008). However, it is worth mentioning that in their meta-analysis, Toril et al. (2014) calculated the effect sizes of the published studies that included both an active and a passive control group (5 out of the 20 studies in the meta-analysis). The mean effect size (Cohen´s *d*) was 0.36 for the active control group and 0.37 for the passive group. The difference was not statistically significant.

It would be interesting in future studies to include a questionnaire to assess expectation (anticipated cognitive gains from game play) and the effects of the social contact with the experimenter and the other older adults. Furthermore, video game designers need to work with researchers in aging to create attractive and useful games specifically designed for older adults. Video games have to be interesting to motivate older adults to play them.

Commercial brain-training programs are currently generating millions of dollars, with very large revenues for the brain-training industry. Video game training is a very active area of research, but there are still important intervention-based factors that require further research. Large-scale longitudinal studies with long follow-up assessments of trained and control groups are necessary before researchers can answer many important questions related to the effectiveness of video-games to improve cognition (Anguera & Gazzaley, 2015; Boot & Kramer, 2014; Boot, Simons, Stothart, & Stutts, 2013; Green, Strobach, & Schubert, 2014).

In conclusion, future research should investigate ways of designing video game training regimes that produce and maintain training benefits in older adults. Further research should take into account multi-domain interventions that can be carried out in social settings, involving computerized cognitive training (e.g., video game training) and physical exercise (Ballesteros et al., 2015b). In sum, future studies would benefit from using well-supported neuroscience findings to design multi-domain, longitudinal intervention studies to investigate the possible benefits for older adults, and then validate the benefits of the intervention.

12. CAPÍTULO 7. RESUMEN Y CONCLUSIONES DE LA TESIS DOCTORAL

En esta Tesis Doctoral se ha estudiado el envejecimiento y su influencia en procesos cognitivos, tan importantes como la memoria. Las investigaciones realizadas en la Tesis nos han permitido extraer conclusiones acerca de la influencia del envejecimiento en la memoria de los mayores sanos, y la efectividad del entrenamiento con videojuegos como medida para paliar los efectos negativos del proceso de envejecimiento en algunas funciones cognitivas de los mayores sanos.

Los principales resultados y conclusiones de los estudios de esta tesis aparecen a continuación:

Estudio 1. (Ver Capítulo 3). “El envejecimiento afecta a las pruebas de compleción de raíces y reconocimiento pero no a la generación de categorías”. En este estudio investigamos el efecto de la edad en dos tareas de memoria implícita (prueba de compleción de raíces y prueba de generación de categorías), y otra de memoria explícita (reconocimiento). La hipótesis planteada fue que los jóvenes actuarían mejor que los mayores en la prueba de reconocimiento, mientras que ambos grupos mostrarían un *priming* similar en ambas pruebas de memoria implícita. Comparamos la actuación de jóvenes y mayores en estas tres pruebas. Los resultados mostraron que en ambos grupos (jóvenes y mayores) hubo *priming* (mejora en la actuación de los sujetos para los estímulos presentados previamente en comparación con estímulos no presentados o nuevos). Además, los jóvenes mostraron más *priming* que los mayores en la tarea de compleción de raíces mientras que el *priming* fue similar en ambos grupos en la tarea de generación de categorías. Por último, los jóvenes actuaron mejor que los mayores en la prueba de memoria explícita (reconocimiento). Estos resultados mostraron la existencia de disociaciones entre las tareas de memoria implícita y explícita, sino también entre las dos tareas de memoria implícita en función de la edad.

Los resultados de este estudio concuerdan con la literatura existente sobre este tema. La edad tuvo un efecto entre las tareas de memoria implícita y explícita. Concretamente, los resultados encontrados en la prueba explícita de reconocimiento son consistentes con los resultados que encontramos en la literatura, y que muestran un efecto negativo de la edad en la memoria explícita (La Voie & Light, 1994; Redondo, et al., 2010; Verhaeghen & Salthouse, 1997). Además, los resultados obtenidos en la tarea implícita de compleción de raíces concuerdan con los resultados de otros estudios que han utilizado la misma tarea (Osorio et al., 2010) encontrando *priming* tanto en jóvenes como en mayores. Otro resultado importante de este estudio fue que el *priming* en los jóvenes fue mayor que en el grupo de mayores. Este resultado concuerda con lo que han encontrado otros investigadores (Abbenhuis et al., 1990; Chiarello & Hoyer, 1988; Daselaar et al., 2005) en este ámbito de estudio. El último resultado que obtuvimos fue que el *priming* fue similar tanto en jóvenes como en mayores, en la prueba de memoria implícita conceptual. Este resultado concuerda con los de otros estudios que muestran que el *priming* conceptual se mantiene en el envejecimiento (Light & Albertson, 1989; Isingrini, Vazou, & Leroy, 1995).

En resumen, los resultados de este estudio apoyan la existencia de dos sistemas de memoria diferentes implicados en la memoria implícita y explícita. Además, podrían existir disociaciones dentro de estos sistemas en función de la edad. Es posible que los componentes perceptivo-conceptuales asociados a la pruebas de memoria implícita no sigan el mismo proceso evolutivo (Billingsley, Smith, & McAndrews, 2002). Es posible que unas tareas implícitas sean más sensibles que otras a la hora de detectar los cambios que se producen durante el proceso de envejecimiento en este sistema de memoria (Mitchell & Bruss, 2003) de manera similar a lo que ocurre en las pruebas de reconocimiento y recuerdo (memoria explícita).

Estudio 2 (Ver Capítulo 4). “Effects of age and type of picture on visuospatial working memory assessed with the computerized jigsaw-puzzle task”. Este estudio consta de dos experimentos. El objetivo del Experimento 1 fue explorar el efecto del color en la tarea informatizada del “jigsaw” (puzles) en 25 mayores sanos y 25 jóvenes. Los estímulos fueron puzles en blanco y negro y en color de 4, 6 y 9 piezas. Esperamos que los mayores actuaran mejor con los puzles con color que con los puzles en blanco y negro. Sin embargo, los resultados mostraron que los mayores actuaron mejor con los puzles en blanco y negro mientras que los jóvenes actuaron mejor con los puzles en color. En el Experimento 2 presentamos los mismos puzles a 20 mayores y a 20 jóvenes para que identificaran lo antes posible y escribieran el nombre del dibujo. Los resultados mostraron que los mayores fueron más rápidos identificando los dibujos en blanco y negro que en color mientras que en jóvenes no hubo diferencias entre ambos tipos de puzles. Estos resultados sugieren que los mayores inhiben peor que los jóvenes información irrelevante (color) en esta tarea de memoria de trabajo. Además, jóvenes y mayores podrían utilizar estrategias cognitivas diferentes en este tipo de tarea de memoria de trabajo viso-espacial.

Los resultados de este estudio concuerdan con los estudios que muestran que la memoria de trabajo es uno de los procesos cognitivos que se deterioran en el proceso de envejecimiento (Borella et al., 2008; Park et al., 2002). Además, estos resultados están en línea con los de investigadores que usaron la tarea “*jigsaw puzzle task*” para evaluar la memoria de trabajo viso-espacial (Richardson & Vecchi, 2002). En este estudio, los mayores fueron más rápidos identificando y resolviendo los puzles en blanco y negro que los de color. En este caso, parece que el color no ayudó a la resolución de los puzles y pudo producir interferencia en el reconocimiento de objetos y, por tanto, en la realización de la tarea (Zacks & Hasher, 1994). Otra posible explicación a estos resultados es que los mayores utilizan diferentes estrategias cognitivas que los jóvenes a la hora de realizar la tarea (Dunslosky & Hertzog, 2001; Gandini et al., 2008). Otra posible explicación a los resultados de este estudio es que exista un déficit en la habilidad de los mayores para asociar correctamente las características de los objetos (*binding)*. En este sentido, Brown y Brockmole (2010) explicaron que este déficit en esta habilidad puede generar un deterioro en la memoria de trabajo visual en condiciones en las que la tarea exija alta carga atencional, como sería el caso de la tarea utilizada en nuestro estudio (Cornoldi & Vecchi, 2003).

Estudio 3 (Ver Capítulo 5). "Video game training enhances cognition of older adults: A meta-analytic study". En este meta-análisis se puso a prueba la hipótesis de que el entrenamiento con videojuegos mejora las funciones cognitivas de los mayores sanos. Para realizar este estudio meta-analítico incluimos 20 estudios publicados desde 1986 a 2013, que entrenaron con videojuegos y que tenían medida pre y post entrenamiento. Los resultados mostraron que el entrenamiento con videojuegos tiene efectos positivos en algunas funciones cognitivas: tiempo de reacción, memoria y aspectos cognitivos globales. Sin embargo, los videojuegos parecen ser menos efectivos para mejorar las funciones ejecutivas. Este resultado concuerda con el hallazgo de otros estudios (Kuider et al., 2012; Lampit et al., 2014; Powers et al., 2013) que no encontraron efecto del entrenamiento en funciones ejecutivas. Además, los resultados de este meta-análisis mostraron que la magnitud del efecto de los videojuegos en las funciones cognitivas está modulado por variables moderadoras como la duración del entrenamiento y la edad de los participantes. La duración del entrenamiento se postula como una variable importante en este tipo de intervenciones. Los resultados muestran que los entrenamientos cortos (1-6 semanas) son más efectivos que los entrenamientos largos (7-12 semanas). Esto patrón de resultado puede explicarse por la pérdida de motivación de los mayores según avanzan las sesiones de entrenamiento. Este resultado concuerda con el resultado de otro meta-análisis reciente (Lampit et al., 2014). Otra variable importante es la edad de los participantes incluidos en los entrenamientos. Los resultados muestran que los mayores (71-80 años) se benefician del entrenamiento más que los mayores más jóvenes (60-70 años) debido a que empiezan con puntuaciones más bajas en línea base, que los mayores más jóvenes (60-70 años), y muestran mayores incrementos y mejoras. Estos hallazgos sugieren que existe plasticidad cerebral en el envejecimiento, y aportan nuevos datos de los entrenamientos con videojuegos a este área de estudio con resultados tan diversos.

Estudio 4 (Ver Capítulo 6). "Video game training enhances visuospatial working memory and episodic memory in older adults". En este estudio investigamos los efectos de un programa de entrenamiento con videojuegos en la memoria de trabajo viso-espacial y en la memoria episódica. Las hipótesis planteadas fueron: 1) el entrenamiento con videojuegos sería efectivo y mejoraría las funciones entrenadas; 2) el entrenamiento tendría efectos después del entrenamiento y 3 meses después, en el grupo de participantes entrenados. Se seleccionaron dos grupos de mayores, con características demográficas similares. Uno de los grupos recibió entrenamiento con videojuegos durante 15 horas en un periodo de 7-8 semanas. Los videojuegos fueron seleccionados del paquete comercial "Lumosity". Los resultados de este estudio mostraron que los participantes que fueron entrenados mejoraron su actuación en los videojuegos a lo largo de las sesiones. Este resultado concuerda con otros estudios (Reddick, 2013; Ballesteros et al., 2014). Además, encontramos mejoras después del entrenamiento en las medidas de memoria viso-espaciales y de memoria episódica en el grupo de entrenados y ningún cambio en el grupo de los participantes no entrenados. Nuestros resultados concuerdan con otros estudios (Basak et al., 2008; Anguera et al., 2013; Ballesteros et al., 2014). Sin embargo, nuestro estudio no concuerda con los resultados de otros estudios (Maillot et al., 2012; Ballesteros et al., 2014) ya que no encontraron mejoras después del entrenamiento en pruebas de memoria viso-espacial. Es posible que los diferentes resultados que encontramos entre este estudio y Ballesteros et al. (2014) se deban a que en este estudio hemos utilizado menos videojuegos y más focalizados a entrenar la memoria de trabajo, que en el otro estudio desarrollado en nuestro laboratorio, donde se utilizaron 10 videojuegos que entrenaban diferentes funciones cognitivas. No obstante, en ambos estudios encontramos mejoras en la memoria episódica de los mayores después del entrenamiento.

Los resultados obtenidos en la evaluación de seguimiento realizada tres meses después de la finalización el entrenamiento concuerdan con los de Anguera et al. (2013) que encontraron mejoras post-entrenamiento y esas mejoras persistieron después de 6 meses de finalizar el entrenamiento. Además, los resultados de este estudio concuerdan con los de Buschkuehl et al. (2008). Estos investigadores encontraron mejoras en tareas de memoria de trabajo y memoria episódica después del entrenamiento, y estas mejoras duraron 1 año. En resumen, estos resultados de este estudio de entrenamiento sugieren que: 1) el cerebro de los mayores muestra plasticidad; y 2) los videojuegos pueden ser una buena herramienta de intervención para mejorar memoria de trabajo viso-espacial y la memoria episódica en los mayores sanos.

La integración de los resultados de los diferentes estudios mostrados en esta Tesis Doctoral proporciona información relevante, que en unos casos confirman los hallazgos de otros estudios, y en otros aportan información importante para futuras investigaciones.

Teniendo en cuenta los resultados obtenidos en esta Tesis Doctoral y la literatura científica, creemos que sería interesante incluir en futuras intervenciones cuestionarios para evaluar los efectos del contacto social con el experimentador. Además, los creadores de videojuegos tienen que trabajar junto a los investigadores para crear juegos atractivos y diseñados específicamente para mayores, que sean capaces de motivarles. Es posible que las futuras investigaciones sean más efectivas si son "multi-dominio", es decir, intervenciones en las que se incluya: 1) Entrenamiento cognitivo incluyendo entrenamiento con videojuegos; 2) Ejercicio físico y; 3) un ambiente social enriquecedor.

13. CAPÍTULO 8. COGNITIVE AGING: EFFECTS OF VIDEO GAME TRAINING IN VISO-SPATIAL WORKING MEMORY IN OLDER ADULTS

THEORETICAL INTRODUCTION

During the past few decades there have been demographic changes of developed countries due to medical and improvements in the living conditions. Precisely, the ageing of the population is postulated as one of the greatest achievements of our society. Governments must to pay attention because the population is getting older. For example, Spain will be one of the oldest countries in the world in 2050 (United Nations, 2010).

Ageing is a complex process that profoundly affects the cognitive processing and the brain activity and function of all individuals**.** Ageing research as found declines in processing speed, executive functions, attention, working memory and episodic memory (e.g., Salthouse, 1996; Baltes & Lindenberger, 1997; Nilsson, 2003; Rönnlund et al., 2005). In contrast, other cognitive abilities including verbal abilities, implicit memory, and word knowledge are preserved across the life span (Park et al, 2002; Mitchell & Bruss, 2003; Craik & Bialystok, 2006). Memory is one of the cognitive processes that deteriorated most with ageing. However, not all the types of memory are impaired. For example, implicit memory is relatively unaffected by age. Implicit memory is an involuntary memory that is preserved in healthy older adults (e.g., Ballesteros, Bischof, Goh, & Park, 2013; Mitchell & Bruss, 2003; Osorio et al., 2010; Wiggs et al., 2006) and even in Alzheimer´ Disease patients (e.g., Ballesteros & Reales., 2004). In contrast, explicit memory assessed using recognition, free recall and cued-recall tests, deteriorates with age. These dissociations between implicit and explicit memory suggest that the underlying occipital brain structures that support implicit memory remain relatively intact in older adults while explicit memory that relies on the hippocampus and medial temporal lobe structures are affected by ageing (Daselaar et al, 2005). Working memory is a type of memory responsible for the active maintenance and manipulation of information central to cognition. This type of memory also shows a significant decline with age (e.g., Bopp & Verhaeghen, 2005; Johnson, 2003; Park, Lautenschlanger, Hedden, Davidson, Smith, & Smith, 2002). This capacity limited system, serves as the mind´s workspace, and its size is key for the individual´s ability to perform a variety of cognitive tasks and daily life activities (Kane et al., 2004). A growing literature suggests that the WM capacity can be expanded with training (e.g., Jaeggi et al., 2008; Morrison & Chein, 2011; Westenberg et al., 2007). A central goal of this Thesis (see Studies 3 and 4) is to find out whether training cognitively healthy older adults with non-action video games improved visuospatial WM after training and if these possible improvements are maintained after a period of no contact.

Below, I describe briefly the studies comprised in this Doctoral Thesis and the publications derived from them.

This Doctoral Thesis includes 4 studies. Studies 1 and 2 were conducted to investigate two types of long-term memory (implicit and explicit memory) and working memory in young and older adults. The last two studies dealt with the possibility to maintain older brain functionality, especially visuospatial working memory by training healthy older adults with video games.

Study 1 was conducted to investigate the effects of ageing in implicit and explicit memory. The results of this investigation were published in an article entitled “Aging affects word-stem completion and recognition but not category generation" (Toril, Mayas, Reales, & Ballesteros, 2012).

Study 2 investigated the effects of age and type of picture on the visuospatial working memory. This study produced the following article: **"**Effects of age and type of picture on visuospatial working memory assessed with the computerized jigsaw-puzzle task" (Toril, Reales, Mayas, & Ballesteros, submitted).

The goal of Study 3 was to conduct a meta-analysis of the published longitudinal training studies that used video games to train older adults. In our XXI century technological society, computer-based training programs and video games have interested ageing researchers as a tool for improving and/or maintaining perceptual and cognitive functions in older adults. However, so far, scientific evidence of the potential of these interventions is at best mixed. The result of this meta-analytic study has been recently published in the journal *Psychology and Aging*. Its title is "Video game training enhances cognition of older adults: A meta-analytic study" (Toril, Reales, & Ballesteros, 2014). The results of this meta-analytic study suggested that training older adults with video games enhances aspects of cognition and might be a valuable intervention for cognitive enhancement.

Finally, Study 4 was motivated by the results of Study 3 and is the core of this Thesis. This study presents the results of a longitudinal randomized intervention study with trained and control groups conducted to investigate both, the effects of training older adults with video games on visuospatial WM and long-term visual recognition memory to investigate transfer effects as well as maintenance after 3-month of not contact follow-up period. In the design of this intervention study, we applied what we learnt from the results of the meta-analytic study.

The title of this study is "Video game training enhances visuospatial working memory and episodic memory in older adults" (Toril, Reales, Mayas, & Ballesteros, submitted).

SUMMARY OF THE EMPIRICAL STUDIES AND THE META-ANALYSIS

STUDY 1. The goal of the study "Aging affects word stem completion and recognition but not category generation", was to investigate the effect of aging in two implicit memory tasks (word-stem completion and category generation), and an explicit recognition task. We expected better performance in young adults than in older adults in the explicit memory task and similar performance in the implicit memory task. The results showed better performance of young adults compared to that of older adults in explicit recognition. Moreover, both groups showed implicit memory, but priming (as a measure of implicit memory) was greater in young adults compared to older adults in the word-stem completion task. However, both groups showed similar levels of priming in the category generation task. The results suggested dissociations as a function of age not only between explicit and implicit memory tasks, but also between the two implicit memory tasks.

STUDY 2. The second study included in this Doctoral Thesis was related to working memory decline in older adults. In this study, we investigated the effect of colour in a computerized version of the jigsaw puzzle task. The study comprises two experiments. In Experiment 1, 25 older adults and 25 young adults were presented with two types of puzzles, colour and black-and-white, varying in difficulty from 4 to 9 pieces. We hypothesized that both groups would perform the task better with colour than with black-and-white jigsaws. The results showed that young adults performed better than older adults in both conditions. Contrary to our expectation, the older group performed the task better with the black-and-white stimuli, while the younger adults performed better with the colour ones. In Experiment 2, 20 older adults and 20 young adults were presented with the same puzzles and they had to identify the stimuli as fast and accurately as possible. The results showed that the older group identified the black-and-white pictures faster than those presented in colour, while the younger adults identified the two types of stimuli similarly. These results suggest that older adults are less likely to inhibit irrelevant colour information in working memory. Additionally, the two age groups could use different cognitive strategies to solve the task.

Researchers on ageing have proposed several forms to minimize the impact of ageing. In this line, different studies showed that physical exercise (Colcombe et al, 2006), performing of intellectual activities (Wilson et al, 2003), good health (Schaie, 1994) and high education (Osorio, Fay, Pouthas, & Ballesteros, 2010) can decrease the negative effects of ageing. There is some evidence that the ageing brain is malleable and cognitive function can be facilitated trough cognitive training (Park & Bischof, 2013). The older brain shows some plasticity in response to external stimulation. The observed increase in neural volume in response to cognitive training is an important indicator of brain change (Boyke, Driemeyer, Gaser, Büchel & May, 2008).

Encouraged by previous finding showing that cognitive training interventions can improve cognition in healthy older adults (Ball et al., 2002; Basak et al, 2008; Belchior, 2008) there is a growing interest in video game training as an effective way to improve some aspects of cognition and neural plasticity in older adults (Anguera et al., 2013, Ballesteros, 2014; Nouchi, 2012). Although some studies have found improvements after training older adults with video games (Basak, 2008, Goldstein, 1997; Nouchi, 2012, Ballesteros et al., 2014), other studies have not found significant transfer after training (Ackerman, Kanfer & Calderwood, 2010; Boot et al., 2013). These mixed findings motivated the last two studies.

STUDY 3. Due to the mixed results, we conducted a meta-analysis to examine the hypothesis that video game training enhances cognitive function in older adults (Toril, Reales, & Ballesteros, 2014). Twenty studies published between 1986 and 2013, that met the inclusion criteria were included in this meta-analysis. The results showed that video game training enhances some cognitive functions in older adults. For example, reaction time, attention, memory and global cognition. However, video game training seems to be less effective to improve executive functions. The magnitude of the training effect was moderated by methodological and personal factors, including the age of the trainees and the duration of the training schedule. The results of this meta-analysis showed that short training regimes (from 1 to 6 weeks) are more effective than long training (from 7 to 12 weeks) ones in older adults. Other interesting result suggested that benefits of training increases as participants get older. To summarize, the results of this meta-analysis suggest neurocognitive plasticity in the aging brain and video game training enhances some cognitive functions in older adults.

In a previous longitudinal training study with video games, Ballesteros et al. (2014; 2015) conducted a randomized controlled trial to investigate the effects of 20 1-h video game training sessions on a series of age-declined cognitive functions and subjective wellbeing. Two groups of healthy older adults participated in this training study, the experimental group who received the training and the control group who attended several meetings with the experimenters. The results showed significant improvements, and no change in the control group after training in processing speed, attention, immediate and delayed visual recognition memory as well as a trend to improve in Affection and Assertivity (dimensions of the

Wellbeing Scale). Visuospatial working memory and executive control did not improve after training. Overall, these pre-training/post-training results support the view that training older adults with non-action video games improves some cognitive abilities but not others. Moreover, the assessment conducted after a 3-month no-contact interval showed that significant improvements in processing speed, attention and long-term memory become non-significant. Improvement was found only in the two dimensions of the Wellbeing Scale. Participants in the trained group neither showed transfer to executive control nor to spatial WM from pre-test to 3-month follow-up.

There is a current debate in scientific community regarding the effectiveness of working memory training in older adults. Several recent studies have addressed the effects of training WM (Boot, Blakely, & Simons, 2011; Dahlin, Bäckman, Nely, & Nyberg, 2008; Klingberg, 2010; Morrison & Chein, 2011; Perrig et al., 2009; Shipstead et al., 2010; Takeuchi, Taki, & Kawashima, 2010). The results of these studies are at best mixed. Some researchers concluded that WM training is effective (Morrison & Chein, 2011; Karbach & Verhaeghen, 2014) while others concluded that WM training is not effective (Shipstead et al., 2010; Melby-Lervag & Hume, 2013). Three recent meta-analyses (Toril et al., 2014; Lampit, Hallock & Valenzuela, 2014; Karbach & Verhaeghen, 2014) showed that one of the reasons of these mixed results is the great variability in the interventions (e.g., the intensity of the training program, the duration of sessions, and the age of the participants). Considering the importance of working memory for older adults, the interest in a possible improvement is an important endeavor in ageing research. For this reason, and knowing that there are many questions yet to be answered regarding video games training effects in visuospatial WM, we conducted a new video intervention trying to provide new insights in this important field of research. The training study also was interested in investigation the effect of training in short-term and episodic memory tasks.

STUDY 4. We conducted a longitudinal intervention study with a group that received training and a control group to investigate the effects of video game training in the visuospatial working memory of older adults. Nineteen volunteer older adults (mean = 69.95, *SD*= 6.73) received 15 1-hr video game training sessions with a series of non action video games. The results of the trained group were compared with the results of a control group composed by 20 healthy older adults (mean = 73.20, *SD*= 6.72). The results showed that the trainees improved significantly in all the video games after completing the training sessions. Most important, we found significant improvements after training in the trained group, and no change in the control group, in two computerized tasks designed to assess spatial working memory, the Corsi blocks task and the Jigsaw puzzle task. We also found effects of training in Faces I and II and Digit forward after training. Importantly, at the follow-up evaluation, some improvements in working memory and episodic memory tasks were maintained. These results suggest that video game training might be an effective intervention tool to improve working memory and other cognitive functions in older adults.

DISCUSSION AND GENERAL CONCLUSIONS

The results of the studies includes in this Doctoral Thesis are as follow:

The results of Study 1 showed that (1) young adults performed better than older adults in the recognition task; and (2) both groups showed priming in the implicit memory tasks, although priming was greater in young adults compared to older adults in the word-stem completion task, whereas both groups showed similar levels of priming in the category generation task. These results are in line with the literature, suggesting that aging affects explicit memory but implicit memory is preserved in older adults. Specifically, the results are in line with studies that found age decline in explicit memory in older adults (La Voie & Light, 1994; Verhaeghen & Salthouse, 1997). Moreover, the results agree with studies that found similar priming in older adults in category generation task (Light & Albertson, 1989; Isingrini, Vazoy & Leroy, 1995) and word-stem completion (Osorio et al., 2010). An important finding of the study was that there are dissociations not only between implicit and explicit memory tasks but also between implicit memory tasks (word-stem completion and category generation).

The results of the second study were: (1) Young adults performed better than older adults in both conditions (black-and-white *vs* colour stimuli); and (2) the older group performed the task better with the black-and-white stimuli, while the younger adults performed better with the colour ones. These results are in line with studies that found age decline in the visuospatial WM using “jigsaw puzzle task” to assess this type of memory (Richardson & Vecchi, 2002). Moreover, colour, a feature that could help to solve the visuospatial WM task (jigsaw puzzle task) because it adds information, did not help older adults to solve the task but produced interference. It is possible that colour interfered with object recognition. However, color was useful to solve the task in young adults. This result might be explained by the idea that aging coincides with a decrease in the effectiveness to control interference. Older adults have more difficulty to access relevant information in WM and deleting irrelevant information (Zacks & Hasher, 1994). This is in line with findings of Borella, Carretti and De Beni (2008), suggesting that age is negatively associated with WM performance and positively correlated with inhibitory performance. The present results might also be explained by the use of different cognitive strategies with age to perform the jigsaw puzzle task. Older adults might use different strategy repertoires (Dunslosky & Hertzog, 2001; Gandini, Lemaire, Anton, & Nazarian, 2008). An alternative explanation of the present findings comes from the idea of age-related binding deficits (Brown & Brockmole, 2010). Age-related binding deficits could contribute to a general decline in visual WM under conditions of high attentional load, as occur with the "jigsaw puzzle task" used in this study.

The results of the meta-analysis (Study 3) includes in this Doctoral Thesis indicated that video games training produce positive effects on several cognitive functions, including attention, memory, reaction time and global cognition, but they seems not to be effective to improve executive functions (Kueider et al., 2012; Lampit et al., 2014). Moreover, the positive effects were moderated by methodological and personal factors. For example, the results of our meta-analytic study suggested that short training regimes are better than long training schedules for this type of intervention with older adults. This finding might be explained by the lack of motivation of the older adults in the last training sessions. This result is in line with the results of Lampit and colleagues (Lampit et al., 2014). Other important variable is the age of the trainees. In summary the duration of training and the age of the trainees are important factors to be considered in the design of this type of interventions and should be the focus on future research. Moreover, it is important to note that although video game training has positive effects in older adults, the benefits not transfer to all cognitive functions.

The results of the longitudinal intervention (Study 4) suggested that training older adults with non-action video games could be effective to improve visuospatial WM and some episodic memory. We designed this intervention considering the results of Toril et al.´s (2014) meta-analysis. Based on these results, we designed a short training protocol with 15-1 hour sessions. Studies that did not find improvements in visuospatial measures followed long training schedules (Maillot et al., 2012) while studies that found improvements after training followed short training designs (Anguera et al., 2013). Other important variable (Toril et al., 2014) was the number of video games. Although not significant, we found a trend in the meta-analysis indicating that it is better to train with a small set of video-games than with a wide set. So, we selected 6 non-action video games to train mainly working memory. Some researchers (Melby-Lervag & Hulme, 2012) have argued that working memory training has positive effects on tasks close to the trained tasks (near transfer). It is possible that we found positive effects in WM because the trained tasks were close to evaluated tasks. However, it is important to stress that we designed this intervention with the presence of the experimenter in each session attended by all the trainees. The variable presence/absence of the experimenter might increase the interest in training (Borella, Carreti, Riboldi, & De Beni, 2010) and group-based training has been shown to be more effective than home-based training without the presence of the experimenter (Lampit et al., 2014).

These results of this study are in line with other studies that found improvements after video game training (Basak, Boot, Voss & Kramer, 2008; Nouchi et al., 2012; Anguera et al., 2013; Ballesteros et al., 2014). Most important, the results of this study are in line with studies that found improvements in working memory in older adults after video game training (Morrison & Chein, 2011; Zinke et al., 2013; Karbach & Verhaeghen, 2014). However, these findings are not in line with other studies that did not find improvements after video game training (Maillot and Perrot, 2012).

In 3-month follow-up evaluation some improvements in working memory and episodic memory tasks maintained significant after this no-contact period. These findings are in line with Anguera et al. (2013). They found improvements after training and these improvements persisted over 6 months without training, and with the results of Li et al. (2008). These researchers found specific improvements in a WM task and maintenance of near transfer effects at 3 months-follow-up of no- contact in young and older adults. Our finding also agreed with results from Buschkuehl et al. (2008). These researchers reported improvements in working memory and visual episodic memory tasks after training, and these improvements persisted over a year.

In conclusion, video game training might be considered a promising way to improve some aspects of cognition that decline with age. However, although videogames training has positive effects for older adults, the literature on this topic showed that the benefits not always are transferred to all cognitive functions. The positive effects after video game training are moderated by personal and methodological factors. An important topic for future research is whether the effects of training in older adults are transferable to untrained tasks. Moreover, the video game industry would benefit from designing in collaboration with aging neuroscientists video games specifically adapted to the needs of a large segment of the population, the older adults.

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