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FUNCIONAMIENTO EJECUTIVO E INTERPRETACIÓN MUSICAL

LAURA HERRERO PÉREZ

Programa de Doctorado en Psicología de la Salud.
Facultad de Psicología.
DIRECTORA: DRA. NURIA CARRIEDO LÓPEZ
Departamento de Psicología Evolutiva y de la Educación

Escuela Internacional de Doctorado

EIDUNED

Laura Herrero Pérez

A mis padres, por su apoyo incondicional.

A Eloy, por cada día.

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LISTADO DE ABREVIATURAS

ANCOVA: Análisis de covarianza

BIN: Binary meter

FE: Funcionamiento ejecutivo.

FEs: Funciones ejecutivas

ICC: Intraclass correlation coefficient

LTM: Long term memory

MO: Memoria operativa

MLP: Memoria a largo plazo

RTs: Reaction times

SAS: Sistema de supervision atencional

SEM: structural equation models

SR: Music sight reading

WM: Working memory

WMC: Working memory capacity

WCST: Test de Tarjetas de Wisconsin

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Laura Herrero Pérez

LISTADO DE TABLAS Y FIGURAS

Tablas

Introducción

Estudio 1

Estudio 2

Estudio 3

Figuras

Introducción

Estudio 2

Estudio 3

RESUMEN

El estudio del funcionamiento ejecutivo (FE) y su relación con diferentes tipos de tareas cognitivas complejas es un campo de investigación de gran amplitud, que se ha abordado desde diferentes perspectivas teóricas y empíricas. En este sentido, dos de los aspectos que más interés han suscitado han sido el análisis de la relación y relevancia del FE en la eficiencia en diferentes tareas cognitivas complejas, y el análisis sobre cómo la adquisición y práctica de determinadas habilidades podría tener un impacto de mejora en el FE y su desarrollo. El objetivo principal de esta tesis es profundizar en estos dos aspectos con relación a la interpretación musical. Para ello, se han desarrollado tres estudios empíricos, estando el primero dirigido a analizar las posibles mejoras en el FE asociadas a la práctica musical, y los otros dos a estudiar la implicación del FE en una tarea musical concreta como es la lectura musical a primera vista.

El objetivo del primer estudio consistió en analizar si la práctica instrumental acumulada se podía asociar con mejoras en el desarrollo de la función de actualización en la memoria operativa (MO) entre la infancia y la adolescencia, así como determinar qué subprocesos de dicha función de actualización (mantenimiento/transformación de la información o sustitución), se podían ver más afectados por la experiencia musical acumulada. En este estudio participaron 69 músicos y 69 no músicos de entre 11 y 15 años, igualados en edad e inteligencia fluida. Los resultados mostraron que la práctica musical podía asociarse con mejoras en los procesos inhibitorios necesarios para actualizar la información en la MO, mientras que las diferencias en la capacidad para mantener y procesar la información en la MO estaban más relacionadas con la edad que con la práctica musical.

Con el segundo y el tercer estudio se trató de estudiar el papel de las funciones ejecutivas (FEs) de actualización (estudio 2) y de flexibilidad cognitiva e inhibición (estudio 3) en distintos aspectos de una tarea cognitiva compleja como es la lectura musical a primera vista.

El objetivo del segundo estudio -en el que participaron 131 instrumentistas de cuerda y viento de entre 11 y 21 años con diferentes niveles de experiencia musical- consistió en determinar si controlando los efectos de la edad y de la práctica musical, la eficiencia en los procesos de mantenimiento/transformación y sustitución subyacentes a la función de actualización en la MO podían contribuir de manera diferenciada a la eficiencia en lectura musical a primera vista en función del nivel de dificultad de la tarea musical. La lectura a primera vista fue evaluada mediante distintos índices musicales, concretamente la ejecución global, la proporción de errores, el mantenimiento del tempo musical, la precisión rítmica, la afinación, la articulación y la expresión. Los resultados mostraron que la eficiencia en el mantenimiento/transformación de la información contribuía significativamente a la lectura a primera vista independientemente de la dificultad de las tareas musicales, mientras que el proceso de inhibición cognitiva solo contribuía en las tareas musicales más fáciles. Los resultados también mostraron que ambos procesos de la función de actualización en la MO contribuían de manera diferencial a los distintos índices musicales evaluados. Concretamente, la eficiencia en los procesos de mantenimiento/transformación contribuía a un mejor rendimiento en los elementos musicales más relacionados con la continuidad en la ejecución, como son el mantenimiento del tempo musical y la expresión, mientras que el proceso de sustitución contribuía a la articulación, más relacionada con la precisión en la ejecución. Por último, tanto el mantenimiento/transformación como la sustitución contribuían a una menor proporción de errores en la ejecución y a una mayor precisión rítmica.

El objetivo del tercer estudio consistió en analizar cómo la flexibilidad cognitiva y los procesos inhibitorios involucrados tanto en el control de la interferencia de estímulos irrelevantes como en la supresión de acciones o respuestas prepotentes, podían contribuir a la fluidez y a la precisión en la tarea de lectura a primera vista en diferentes condiciones de dificultad, y si esa contribución era independiente del dominio del instrumento. En él participaron 63 músicos de entre 15 y 21 años. Los resultados mostraron que los procesos inhibitorios implicados en la supresión de acciones o respuestas prepotentes contribuían a la fluidez y a la precisión en la lectura musical a primera vista, especialmente en condiciones de baja dificultad de las tareas musicales. Los resultados también mostraron que la flexibilidad cognitiva contribuía a la fluidez y la resistencia a la interferencia a la precisión, solo en las condiciones de mayor dificultad de las tareas musicales. Asimismo, se encontró que las contribuciones de todos estos procesos ejecutivos a la lectura a primera vista eran independientes del nivel del instrumento de los participantes.

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Índice general

Laura Herrero Pérez

1. INTRODUCCIÓN

Tocar un instrumento musical es una habilidad que implica gran número de capacidades perceptivas, motoras y cognitivas. Considerada de manera global, la ejecución instrumental requiere la integración y el procesamiento de estímulos ligados a la percepción auditiva y visual, al control kinestésico, al reconocimiento de patrones, y a la memoria (Barret, Ashley, Strait, & Kraus, 2013). Específicamente, la interpretación musical requiere: a) la lectura y descifrado de la notación escrita en una partitura; b) el mantenimiento temporal de esta información y su transformación en sonidos a través de la actividad motora fina (Brodsky, Kessler, Rubinstein, Ginsborg, & Henik, 2008; Norton et al., 2005), para lo que será necesario disponer de altos niveles de procesamiento espacial, ya que la altura de las notas depende de su posición concreta en el pentagrama (Forgeard, Winner, Norton, & Schlaug, 2008); y c) contar con estrategias de agrupamiento tanto para codificar la información temporal (Chen, Penhune, & Zatorre, 2008), como para organizar y secuenciar los distintos fragmentos musicales y darles sentido completo (Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007). Teniendo en cuenta todos los procesos implicados, se ha considerado que el rendimiento musical implicaría grandes demandas cognitivas asociadas a un elevado nivel de control atencional, lo cual incluiría los procesos de atención selectiva, inhibición, cambio, actualización y supervisión (Bialystok & DePape, 2009), procesos todos ellos asociados al FE (Miyake et al., 2000).

La investigación sobre la relevancia del FE en la interpretación instrumental es relativamente reciente y se ha centrado en gran medida en la influencia de la práctica instrumental en las mejoras en el FE (Bugos, et al., 2007; Hannon & Trainor, 2007; Hou et al., 2014; Jäncke, 2009; Moreno, Bialystok, Schellenberg, Cepeda, & Chau, 2011; Schellenberg & Peretz, 2008; Schellenberg & Weiss, 2013). Sin embargo, las evidencias empíricas en relación con la implicación de procesos asociados al FE en tareas musicales específicas, como la lectura a primera vista, son muy escasas, circunscribiéndose al papel de la capacidad de MO, (Kopiez & Lee, 2006; Kopiez & Lee, 2008; Meinz & Hambrick, 2010), sin que se haya profundizado suficientemente en el papel de los procesos subyacentes a dicha capacidad.

En este contexto, el objetivo de esta tesis es doble: por una parte, analizar las posibles mejoras en el FE asociadas a la práctica musical, centrándonos en la función de actualización, y por otro, estudiar las posibles contribuciones del FE a la lectura musical a primera vista.

1.1 El funcionamiento ejecutivo

El término FE se ha utilizado de manera generalizada para referirse a diferentes procesos cognitivos considerados “ejecutivos” encargados de la regulación y la supervisión de la cognición y la conducta. Estos procesos serían relativamente independientes en cuanto a su funcionamiento, y responsables de las funciones de control de la conducta orientada a metas, y estando asociados al funcionamiento del córtex prefrontal (Best, Miller y Jones, 2009).

Históricamente, el estudio del FE ha estado ligado a la conceptualización de la MO y a la existencia de un mecanismo o sistema encargado de realizar diferentes funciones de regulación de la cognición y la conducta. Uno de los modelos más influyentes en el estudio de la MO ha sido el desarrollado por Baddeley y Hitch (1974), y revisado posteriormente por el propio Baddeley (1986, 1992, 2000). En este modelo, la MO sería un mecanismo con cuatro componentes principales (véase Figura 1): a) el *lazo* *fonológico*, que estaría compuesto por un almacén fonológico, que se encargaría de retener la información oral de forma relativamente pasiva y un mecanismo de repetición sub-vocálico que fortalecería la huella de la información contenida en el almacén fonológico evitando su decaimiento; b) la *agenda viso-espacial*, que sería responsable del mantenimiento y manipulación de las imágenes viso-espaciales y de la información verbal codificada en forma icónica; c) el *retén episódico*, que actuaría como mecanismo de enlace, cuya función sería la integración de la información perceptual de los dos componentes anteriores con la de la memoria a largo plazo; y d) el *ejecutivo central*, que sería un sistema central de control encargado de coordinar la actividad dentro de la MO y de controlar la transmisión de información a otras partes del sistema cognitivo.

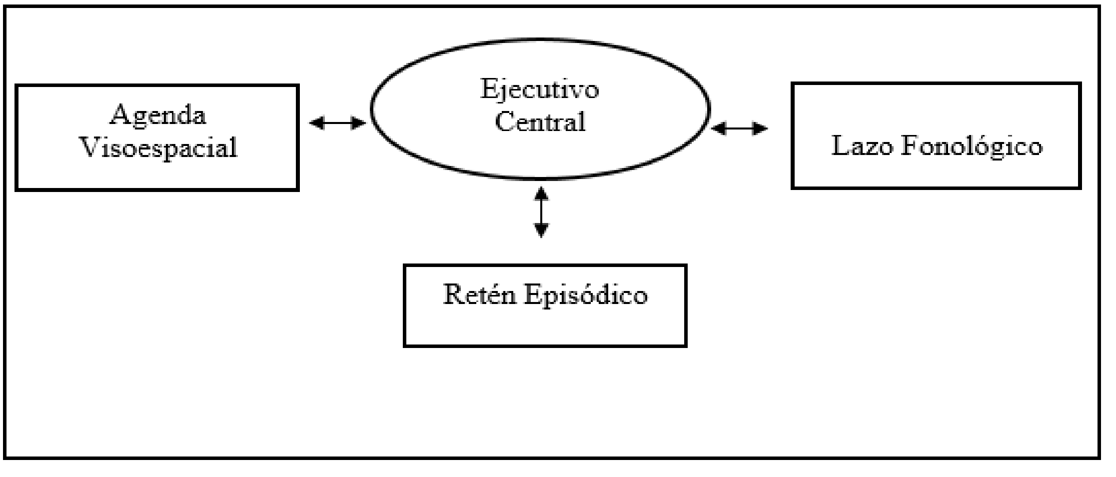

Figura 1. Modelo multicomponente de Baddeley (2000).

Baddeley (1996), describió diferentes procesos que subyacerían al funcionamiento del ejecutivo central: a) la coordinación de tareas que se llevan a cabo de manera simultánea y el cambio de atención de una tarea a otra, b) el control de la codificación y recuperación de la información almacenada temporalmente en la MO, c) la atención selectiva y la inhibición de la información irrelevante, y d) la recuperación de la información desde la memoria a largo plazo y su manipulación en la MO.

Otras teorías sobre el control cognitivo también incluyeron un componente ejecutivo (Balota, Law, & Zevin, 2000; Braver, Gray, & Burgess, 2007; Engle & Kane, 2004; Hasher & Zacks, 1988; Jacoby, Bishara, Hessels, & Toth, 2005; Logan, 2003; Miyake et.al., 2000; Posner & DiGirolamo, 1998; Shallice & Burgess, 1993), utilizando diferentes términos para describir la habilidad de coordinación y control atencional subyacente a las tareas cognitivas complejas. Entre ellos se incluyen: *sistema de supervisión atencional* (Norman & Shallice, 1986), *atención ejecutiva (*Engle, Kane & Tuholski, 1999), *control atencional* (Balota, Cortese, Duchek, Adams, Roediger, McDermott, & Yerys, 1999), *control ejecutivo* (Logan 2003), *control cognitivo* (Depue, Banich & Curran, 2006; Jacoby et al., 2005) y *control inhibitorio* (Hasher, Lustig, & Zacks, 2007). Por ejemplo, Norman y Shallice (1986), definieron el *sistema de supervisión atencional* (SAS), como aquel encargado del control y supervisión de la acción en tareas novedosas y controladas que requerirían de recursos atencionales para ser llevadas a cabo. Concretamente, el SAS regularía conductas tales como la planificación o toma de decisiones, la corrección de errores, la detección y solución de problemas, la anticipación y la supresión de respuestas prepotentes.

En una línea similar, Engle, Kane y Tuholski (1999), definieron la *atención ejecutiva* como el conjunto de procesos necesarios para alcanzar y mantener la máxima cantidad de activación disponible bajo control atencional. Estos autores conceptualizaron la *atención ejecutiva* como un sistema encargado de controlar y mantener la atención en situaciones de interferencia o distracción. De esta manera, otorgaron un papel de especial relevancia a los procesos inhibitorios que actuarían bloqueando o inhibiendo la información irrelevante para evitar la sobrecarga del sistema atencional (Kane & Engle, 2000).

Aunque los diferentes modelos teóricos no han coincidido en algunos aspectos relacionados con la conceptualización del componente ejecutivo, todas las propuestas han otorgado un rol central al control atencional. Este componente sería necesario para la coordinación y el control de la conducta a la hora de mantener el foco de atención, cambiarlo en función de las demandas de las tareas, y dividirlo entre dos tareas cuando éstas se llevan a cabo de manera simultánea (Zoelch, Seitz, & Schumann-Hengsteler, 2005). Estas funciones de control asociadas al componente ejecutivo se han relacionado con capacidades como la inhibición de respuestas prepotentes, el cambio de estrategias o de foco atencional, la supervisión y regulación de la ejecución, la actualización respecto a las metas de las tareas, el mantenimiento de metas, la planificación, y la flexibilidad cognitiva (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010).

Más allá de las distintas conceptualizaciones, el FE se ha asociado al funcionamiento del córtex prefrontal (Goldstein, Naglieri, Princiotta, & Otero, 2014), considerando que su papel sería crítico especialmente en situaciones complejas, cambiantes o novedosas (Miller & Cohen, 2001). Luria (1963, 1966, 1973), fue el primero en desarrollar un modelo neuropsicológico para explicar las áreas cerebrales implicadas en la cognición compleja. Específicamente, Luria (1963, 1980) consideró que las distintas capacidades perceptivas, visoespaciales, motoras, atencionales o de memoria, entre otras, estaban relacionadas de manera flexible, y que dicha relación se veía modulada por la interacción, también flexible, de tres unidades funcionales cerebrales. La primera unidad, implicaría a las áreas cerebrales encargadas del mantenimiento del estado de alerta necesario para la detección y selección de los estímulos relevantes. La segunda unidad, se encargaría principalmente de procesar y almacenar la información. La tercera unidad, sería la responsable de las capacidades asociadas al FE como la planificación, la regulación y la supervisión de la conducta, interactuando con las otras dos unidades al mismo tiempo que procesando la información proveniente del ambiente (Luria, 1973), y se asociaría a las áreas prefrontales del lóbulo frontal (Luria, 1980).

El estudio de la relación entre el FE y el funcionamiento del córtex prefrontal se llevó a cabo en gran medida con pacientes que presentaban daños en el lóbulo frontal, utilizando para ello tareas cognitivas asociadas a la medida del FE, como por ejemplo el Test de Tarjetas de Wisconsin (WCST). Los resultados de este tipo de estudios revelaron que mientras algunos pacientes con daños no frontales presentaban dificultades en la resolución de este tipo de tareas (Anderson, Damasio, Jones, & Tranel, 1991; Reitan & Wolfson, 1994), otros pacientes que sí tenían daños frontales mostraban una ejecución normal (Shallice & Burgess, 1991). A este respecto, algunos autores sugirieron que cada área cortical de asociación prefrontal tendría más de una función, pudiendo existir superposiciones entre las funciones de las distintas áreas, lo que respondería a un principio general de organización cortical (Carpenter, Just, & Reichle, 2000).

Además de la investigación centrada en pacientes con daños en el lóbulo frontal, otra de las áreas iniciales y prioritarias en el estudio del FE fue la centrada en el análisis y descripción de su estructura y organización. En este sentido, una cuestión controvertida en el estudio de la organización y estructura del FE fue la planteada por Teuber (1972), sobre la consideración del FE y de los procesos subyacentes al mismo como un sistema unitario, reflejo de un mismo mecanismo, o no unitario, en el que dichos procesos subyacentes tendrían una naturaleza relativamente independiente (Miyake, et al., 2000).

Desde la perspectiva unitaria, se sugirió la existencia de una base común o mecanismo unitario de carácter ejecutivo que podría caracterizar la naturaleza cognitiva de los déficits en las funciones asociadas al lóbulo frontal (e.g. Duncan, Emslie, Williams, Johnson, & Freer, 1996; Kimberg & Farah, 1993), que se reflejarían en la existencia de dificultades para planificar, organizar, supervisar y adaptar la conducta (Wilson, Evans, Alderman, Burgess, & Emslie, 1997). Esta postura unitaria fue criticada principalmente por dos motivos: por una parte, por las divergencias mencionadas anteriormente entre los estudios en pacientes con daños en el lóbulo frontal, que mostraban dificultades en la realización de algunas tareas de FE pero no en otras (Godefroy, Cabaret, Petit-Chenal, Pruvo, & Rousseaux, 1999); por otra parte, por las bajas correlaciones encontradas entre distintas tareas de FE (Burgess, 1997; Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Welsh, Pennington, & Groisser, 1991).

Desde la perspectiva no unitaria, se sugirió que el FE comprendería un rango de subprocesos relativamente independientes, entre los que destacarían la planificación (Shallice & Burgess, 1991), la coordinación entre tareas (Baddeley, Logie, Bressi, Della Salla, & Spinnler, 1986), el acceso al conocimiento consciente (Baddeley, 1996), así como la capacidad para seleccionar y controlar las actividades cognitivas (Shallice, 1988).

No obstante, diferentes autores se han situado en una posición intermedia, desde la que se consideraría al FE como unitario y no unitario al mismo tiempo, dado que las diferentes FEs podrían caracterizarse como funciones separadas, aunque relacionadas, al mostrar ciertos aspectos comunes subyacentes (Banich, 2009; Friedman et al., 2008; Garon, Bryson, & Smith, 2008; Miyake et al., 2000).

A partir del análisis de la estructura y organización del FE, el estudio del FE se ha abordado desde diferentes líneas de investigación. Por una parte, el FE se ha estudiado desde una perspectiva evolutiva tanto en la infancia (Diamond, 2002a; Fischer, Biscaldi, & Gezeck, 1997; Harnishfeger & Pope, 1996; Kail & Salthouse, 1994; Luciana, Conklin, Hooper, & Yarger, 2005), como en la adolescencia (Baumgartner, Weeda, van der Heijden, & Huizinga, 2014; Blakemore, & Choudhury, 2006), en adultos jóvenes (Lehto, 1996), y durante el envejecimiento (Lowe & Rabbitt, 1997; Salthouse, Atkinson, & Berish, 2003). Además, El FE también se ha estudiado en poblaciones con distintos tipos de déficits, incluyendo niños con dificultades de aprendizaje, problemas de comprensión y lenguaje, dificultades en matemáticas, autismo, déficit de atención e hiperactividad o problemas de conducta (e.g. Adams, Bourke, & Willis, 1998; Bull, Johnston, & Roy, 1999; Cornoldi, Barbieri, Gaiani, & Zocchi, 1999; Lehto, 1995; Lorsbach, Wilson, & Reimer 1996; Ozonoff & Jensen, 1999; Russell, Jarrold, & Henry, 1996).

Otra de las líneas de investigación fundamentales en el estudio del FE ha sido la orientada al estudio de las diferencias individuales. Desde esta línea, el FE se ha relacionado con el rendimiento en tareas asociadas habitualmente con la inteligencia (Carpenter, Just, & Shell, 1990, Engle et al., 1999; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Salthouse et al., 2003; Salthouse, Fristoe, McGuthry, & Hambrick, 1998), así como con diferentes capacidades como el razonamiento matemático o la comprensión lectora (e.g. Gómez-Veiga, Vila, García-Madruga, & Elosúa, 2013; Houdé, Rossi, Lubin, & Joliot, 2010; St Clair Thompson & Gathercole, 2006), asociadas a la competencia académica.

Además, de manera más reciente, diferentes estudios han tratado de analizar el papel del FE en distintas tareas complejas asociadas a contextos dinámicos reales (Colzato, Van Leeuwen, Van Den Wildenberg, & Hommel, 2010; Glass, Maddox, &

Love, 2013; Taylor, O'hara, Mumenthaler, Rosen, & Yesavage, 2005; Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012), con la intención de determinar la existencia de diferencias individuales en el FE asociadas a diferentes niveles de destreza, o a la práctica continuada en determinadas disciplinas o actividades.

Todas estas líneas de investigación han aportado datos empíricos relevantes para el conocimiento del FE, aunque no siempre han compartido la conceptualización desde la que han abordado su estudio. En este sentido, una de las conceptualizaciones más extendidas sobre la fragmentación del FE en diferentes funciones ha sido la descrita por Miyake y sus colaboradores (2000), que abordamos a continuación.

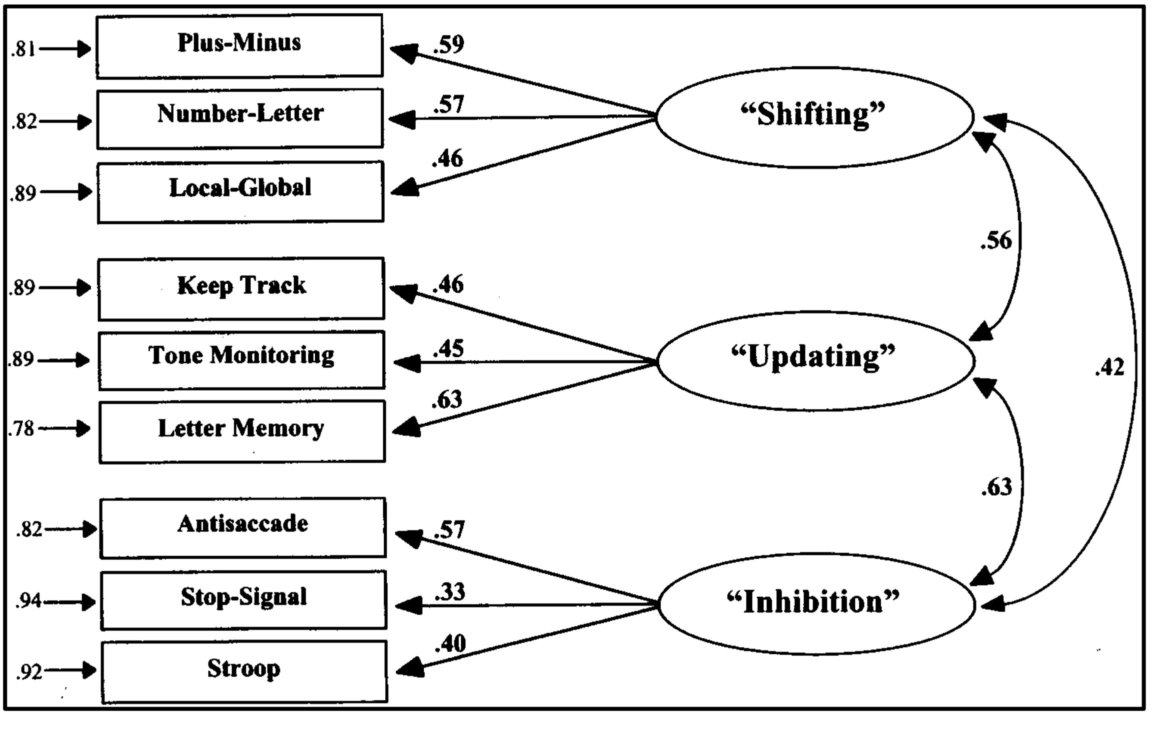

Figura 2. Modelo de tres funciones ejecutivas: cambio, actualización e inhibición (tomado de Miyake et al., 2000, p.70).

1.2 Estructura y organización del funcionamiento ejecutivo

Tal y como se ha mencionado, una de las conceptualizaciones más extendida a la hora de abordar el estudio del FE, ha sido la descrita por Miyake et al. (2000). Mediante el modelado de ecuaciones estructurales, estos autores diferenciaron tres FEs fundamentales relativamente independientes pero relacionadas: actualización, inhibición y cambio (véase Figura 2). A continuación, se conceptualizan y describen estas tres funciones.

1.2.1 Actualización de la información en la MO

La función de actualización fue definida por Morris y Jones (1990) como "el acto de modificar el estatus actual de la representación de un esquema en la memoria para acomodarse a una nueva entrada de información" (p.112). Algunos autores han señalado que la función de actualización estaría muy relacionada con la capacidad de MO (Schmiedek, Hildebrandt, Lovdén, Wilhelm, & Lindenberger, 2009), teniendo en cuenta las elevadas correlaciones encontradas entre las medidas de la función de actualización y las tareas de amplitud de MO (Conway, 1996; Engle, Tuholski, Laughlin, & Conway, 1999; Lehto, 1996; Miyake et al., 2000; Schmiedek et al., 2009; St Clair-Thompson & Gathercole, 2006; Towse, Hitch, & Hutton, 1998). Sin embargo, otros autores puntualizaron que no todas las tareas de amplitud de MO serían igualmente válidas para obtener una medida fiable de la función de actualización, y que sólo aquellas con un componente fuertemente ligado a la función de inhibición tendrían suficiente capacidad predictiva (Burgess, Gray, Conway, & Braver, 2011; Lustig, May, & Hasher, 2001; May, Hasher, & Kane, 1999).

Más allá de la relación entre las distintas tareas utilizadas, Kessler y Meyran (2008), incidieron en la conceptualización de la función de actualización, puntualizando ésta sería la encargada de reemplazar la información antigua por la nueva, inhibiendo la información que se ha vuelto irrelevante, y manteniendo activa la relevante. Estos autores distinguieron dos procesos fundamentales en la función de actualización: el primero de ellos estaría relacionado con el mantenimiento y la transformación de la información relevante en la MO, mientras que el segundo estaría asociado a la inhibición de la información almacenada en la MO que ha pasado a ser irrelevante en el curso de la tarea.

Posteriormente, Ecker, Lewandowsky, Oberauer, y Chee (2010), utilizando el modelado de ecuaciones estructurales, describieron tres procesos subyacentes a la función de actualización: a) recuperación desde la memoria a largo plazo (MLP) de la información relevante para la tarea, b) transformación de la información en la MO, y c) sustitución en la MO de la información que deja de ser relevante para la tarea. Ecker y sus colaboradores (2010) puntualizaron que los procesos de recuperación y transformación de la información podrían representar una fuente común de varianza compartida entre la función de actualización y la capacidad de MO, mientras que el proceso de sustitución de la información en la MO sería el único específico de la función de actualización y la base para diferenciar entre la función de actualización y la capacidad de MO. Es más, mientras que los procesos de recuperación y transformación más relacionados con la MO parecen desarrollarse desde la infancia tardía hasta la adolescencia, seguidos de un periodo de estabilización (Carriedo, Corral, Montoro, Herrero, & Rucián, 2016; Conklin, Luciana, Hooper y Yarger, 2007; Gathercole, Pickering, Knight y Stegmann, 2004), el proceso de sustitución continuaría su desarrollo hasta el inicio de la edad adulta (Carriedo et al., 2016), lo que incidiría aún más en su diferenciación.

Por lo tanto, aunque la función de actualización y la capacidad de MO pueden considerarse mecanismos relacionados (Belacchi, Carretti, & Cornoldi, 2010; Miyake et al., 2000; St Clair-Thompson & Gathercole, 2006), y los términos actualización y MO se han utilizado de manera intercambiable (Diamond, 2013; Garon et al., 2008), no compartirían los mismos procesos subyacentes. Los procesos de mantenimiento y transformación de la información serían compartidos por la función de actualización y la capacidad de MO, mientras que el proceso de sustitución sería específico de la función de actualización (Ecker et al., 2010).

Una cuestión relevante sobre la relación entre los procesos de mantenimiento/transformación y sustitución, es la apuntada por algunos autores que han sugerido que, teniendo en cuenta la capacidad limitada del sistema cognitivo, existiría un mecanismo de *trade-off* entre el mantenimiento/transformación y la supresión de la información, que dependería de la disponibilidad de recursos atencionales (e.g. Engle, 2002; Kane & Engle, 2000). Los procesos de atención ejecutiva serían los responsables tanto del mantenimiento activo de forma temporal de la información recuperada de la MLP, como del bloqueo de las fuentes de interferencia, distracción o conflicto (Kane, Conway, Hambrick, & Engle, 2007), lo que consumiría recursos atencionales. Una mayor eficiencia en el mantenimiento/transformación de la información liberaría recursos atencionales para suprimir aquella irrelevante, al igual que una mayor eficiencia en la supresión de la información irrelevante liberaría recursos para el mantenimiento/transformación (Kane et al., 2007). En una línea similar, Just y Carpenter

(1992), habían planteado previamente que tanto el almacenamiento como el procesamiento de la información dependerían de la cantidad de activación o recursos globales disponibles, y que la supresión eficiente de la información irrelevante sería una forma de liberar parte de dichos recursos para poder orientarla al mantenimiento, lo que repercutiría en un aumento en la eficiencia de la MO. Por su parte, Bjorklund y Harnishfeger (1990; Harnishfeger & Bjorklund, 1993), habían considerado que, durante el desarrollo cognitivo, sería la capacidad de inhibición ineficiente la que provocaría que la información irrelevante ocupara espacio de almacenamiento en la memoria operativa, dejando menos espacio disponible para mantener y procesar otra información.

Teniendo en cuenta todas estas aportaciones, es importante tener en cuenta que el estudio de la función de actualización requeriría la delimitación conceptual de los procesos subyacentes de mantenimiento/transformación y sustitución descritos por Ecker et al. (2010), de manera que se evitaran dificultades metodológicas a la hora seleccionar medidas precisas de dicha función, tal y como sugirieron Morra, Traverso, Panesi y Usai (2018).

1.2.2 Inhibición

La inhibición ha sido definida de manera general como “cualquier mecanismo que reduzca la actividad neuronal, mental o conductual” (Clark, 1996, p. 128). El término inhibición se ha utilizado para referirse al control de los distractores, de los recuerdos no deseados o irrelevantes y de las respuestas motoras inapropiadas (Aron, 2007). En este sentido, algunos autores sugirieron que la inhibición no debía ser considerada como un constructo unitario, sino como un conjunto de procesos funcionalmente diferentes (Dempster, 1993; Friedman y Miyake, 2004; Harnishfeger, 1995; Nigg, 2000).

De acuerdo con ello, se describieron distintas taxonomías en las que se conceptualizaron y definieron los procesos que abarcaría el término inhibición. Por ejemplo, Dempster (1993), utilizó el término *resistencia a la interferencia* para referirse a un constructo complejo encargado de inhibir la información irrelevante. Este autor diferenció tres tipos de inhibición en función del origen interno o externo de la interferencia y del tipo de estímulos que la provocaba. De esta forma, definió la *inhibición motora*, como la supresión de respuestas motoras prepotentes provocadas por estímulos externos, la *inhibición perceptiva*, como la resistencia a la interferencia provocada por estímulos externos, y la *inhibición verbal-lingüística*, como la supresión de información de origen interno que ha dejado de ser relevante. Por su parte, Harnishfeger (1995), diferenció los procesos inhibitorios en función de tres dimensiones, utilizando el término *inhibición cognitiva* para referirse a la supresión de la información que ha dejado de ser relevante una vez ha entrado en la MO, *inhibición conductual*, para aludir a la capacidad para controlar impulsos o respuestas motoras prepotentes, y *resistencia a la interferencia*, para denominar la capacidad para prevenir la entrada de información irrelevante en la MO. Posteriormente, Nigg (2000) estableció una diferencia fundamental entre inhibición automática de la atención e inhibición controlada, dentro de la cual describió cuatro tipos de procesos inhibitorios: *control de la interferencia* de los estímulos distractores, *inhibición cognitiva* o supresión de la información irrelevante de la MO, *inhibición conductual* o supresión de respuestas prepotentes, e *inhibición oculomotora* o inhibición de respuestas motoras asociadas a estímulos que implican movimientos sacádicos.

Aludiendo a que las diferencias conceptuales existentes entre las taxonomías descritas (Dempster, 1993; Harnishfeger, 1995; Nigg, 2000), se debían fundamentalmente a la consideración de diferentes momentos en el procesamiento de la información, más que al tipo de procesos descritos, Friedman y Miyake (2004), trataron de integrarlas. Estos autores, conceptualizaron tres procesos inhibitorios básicos: a) *resistencia a la interferencia distractora*, definida como la capacidad que permitiría resistir o solventar la interferencia provocada por la información del entorno que es irrelevante para la tarea en curso, y que se correspondería con el *control de la interferencia* de Nigg (2000), la *resistencia a la interferencia perceptual* de Dempster (1993), y *resistencia a la interferencia* de Harnishfeger(1995); b) *inhibición de respuestas prepotentes*, definida como la capacidad relacionada con la inhibición o supresión de acciones o respuestas prepotentes, y que se correspondería con la *inhibición conductual* de Harnishfeger (1995), y Nigg (2000), la *inhibición oculomotora* de Nigg (2000), y el *control de la interferencia motora* de Dempster (1993); y c) *resistencia a la interferencia proactiva*, definida como la capacidad que permitiría resistir las intrusiones en la memoria de aquella información interna o externa, que habiendo sido relevante ha dejado de serlo en el curso de la tarea, y que se correspondería con la *inhibición cognitiva* de Harnishfeger (1995).

Una vez conceptualizados estos procesos inhibitorios, Friedman y Miyake (2004) profundizaron en las relaciones entre ellos utilizando el modelado de ecuaciones estructurales, con el objetivo de establecer si estaban reflejando las mismas capacidades cognitivas. Sus resultados mostraron que la *resistencia a la interferencia proactiva o inhibición cognitiva* era un proceso inhibitorio relativamente independiente, mientras que la *resistencia a la interferencia* y la *inhibición de respuestas prepotentes* formaban un mismo constructo, que denominaron *interferencia de respuesta-distractor* (véase Figura 3).

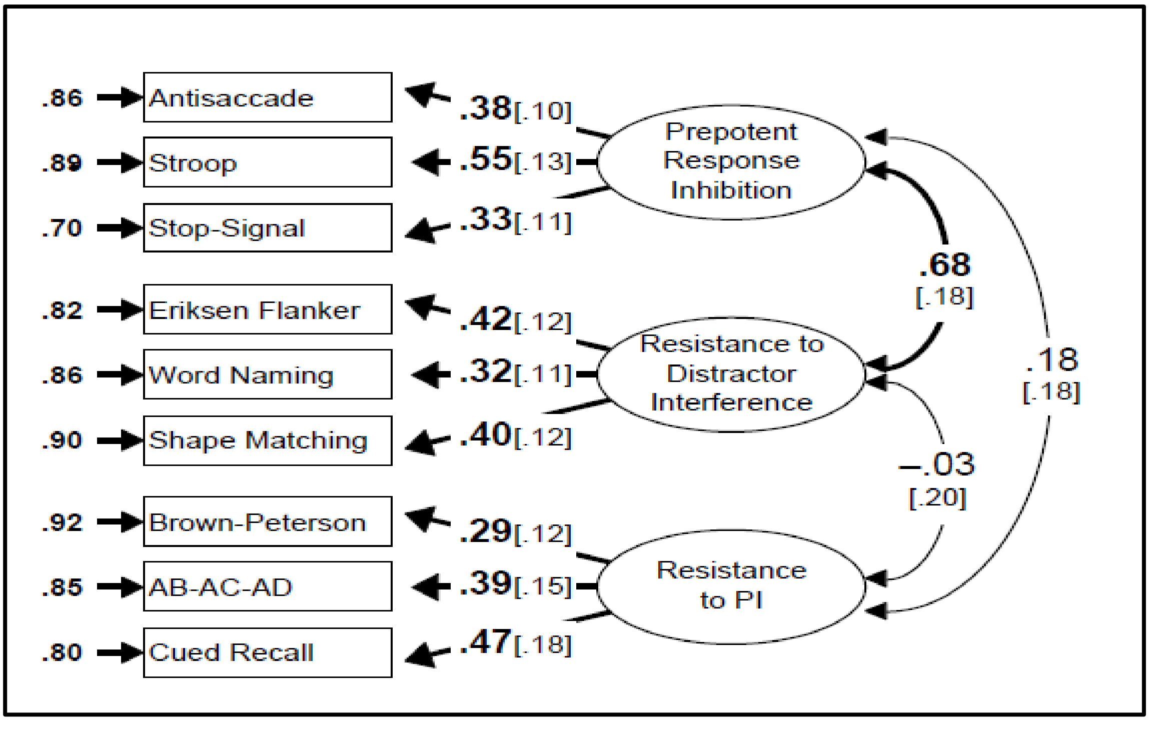

Figura 3. Modelo de las tres funciones inhibitorias: inhibición de respuestas prepotentes, resistencia a la interferencia distractora, y resistencia a la interferencia proactiva (tomado de Friedman y Miyake, 2004, p.86).

A este respecto, otros autores han sugerido que el tipo de interferencia podría diferenciarse entre la que se produce en la selección y en la ejecución de las respuestas, ya que éstas serían etapas de procesamiento distinto, en las que la detección de errores estaría asociada a diferentes áreas cerebrales (Rubia et al., 2001; Rubia, Smith, Brammer & Taylor, 2003). En este sentido, Nee, Wager y Jonides (2007), apuntaron que una mayor prepotencia a responder podría generar un conflicto mayor en la ejecución de las respuestas que en la selección adecuada de las mismas, y que la supresión de la información irrelevante para las metas de las tareas dependería del momento de procesamiento (codificación, selección o ejecución de respuestas). Por su parte, Diamond, Kirkham, y Amso (2002), puntualizaron que, aun siendo etapas de procesamiento diferenciadas, la selección y la ejecución de las respuestas estarían relacionadas, ya que las respuestas seleccionadas durante una tarea se mantendrían activas durante un periodo de tiempo pasando a ser prepotentes. Por lo tanto, si la respuesta seleccionada no fuera la correcta, requeriría un esfuerzo para inhibirla (Simpson et al., 2012).

La consideración de la resistencia a la interferencia y la inhibición de respuestas prepotentes como un único constructo psicométrico (como plantearon Friedman & Miyake, 2004) o de manera funcional diferenciada (como plantearon Nee et al., 2007; Rubia y colaboradores, 2001; 2003), pero relacionada (como plantearon Diamond et al., 2002), podría no ser una contradicción. Teniendo en cuenta que el componente *interferencia de respuesta-distractor* común a la resistencia a la interferencia y la inhibición de respuestas prepotentes sería el mantenimiento de las metas de las tareas en condiciones de interferencia (Friedman & Miyake, 2004), los procesos ligados a la resistencia a la interferencia y a la inhibición de respuestas prepotentes podrían verse implicados de manera diferenciada pero compartida en los distintos momentos del procesamiento de una misma tarea.

En este sentido, otros autores ya habían señalado previamente que la inhibición reflejaría tres funciones de control diferenciadas que compartirían el mantenimiento de las metas de las tareas en distintos momentos de procesamiento: a) la función de acceso, para prevenir la entrada en la MO de información irrelevante, b) la función de eliminación para suprimir o eliminar de la MO a información que ha dejado de ser relevante, y c) la función de restricción para evitar las respuestas con mayor prepotencia que pueden ser inapropiadas (Hasher, Zacks & May, 1999).

Por lo tanto, aunque la organización funcional de los procesos inhibitorios es una cuestión que permanece abierta (Diamond, 2013), la supresión de la información, y por tanto la implicación en las tareas de los diferentes procesos inhibitorios descritos (resistencia a la interferencia, interferencia proactiva o inhibición cognitiva, e inhibición de respuestas prepotentes), podría depender del mantenimiento de metas en distintas etapas de procesamiento de las mismas (codificación, selección y ejecución), tal y como afirmaron Nee y sus colaboradores (2007).

1.2.3 Cambio atencional.

Monsell (1996), definió el cambio como la capacidad para modificar estrategias y reglas o alternar el foco de atención cuando se deben realizar múltiples tareas, operaciones o procesos mentales.

La capacidad de cambio ha sido considerada como un componente de control esencial a la hora de supervisar y ajustar de manera flexible la ejecución en el transcurso de las tareas (Holroyd & Coles, 2002). Además, la capacidad de cambio se ha considerado fundamental en contextos asociados a la solución de problemas para seleccionar y mantener las estrategias apropiadas, suprimir aquellas estrategias irrelevantes o inapropiadas, y cambiar entre diferentes estrategias (Agostino, Johnson, & Pascual-Leone, 2010; Blair, Knipe, & Gamson, 2008; Van der Sluis, De Jong, & Van der Leij, 2007; Yeniad, Malda, Mesman, van IJzendoorn, & Pieper, 2013).

En el contexto de la solución de problemas, Krems (1994) diferenció tres mecanismos básicos de cambio asociados a la generación de respuestas flexibles: a) la capacidad para realizar diferentes interpretaciones de la información entrante y cambiar entre ellas, b) la capacidad para cambiar y adaptar las representaciones, y c) la capacidad para cambiar de estrategias en función de los cambios en las demandas de las tareas.

Por otra parte, en el contexto de las tareas dinámicas, que requieren la adaptación de las respuestas a contextos complejos bajo demandas temporales (Freed, 1998), se ha sugerido que la facilidad para cambiar el foco de atención en función de las condiciones del entorno se reflejaría en la capacidad de representación de la tarea y la selección de estrategias para adaptar las respuestas (e.g. Norman 1981, Norman & Shallice, 1980; Rasmussen 1983), especialmente en aquellas condiciones más demandantes (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Glass et al., 2013).

El concepto de cambio atencional se ha asociado al de flexibilidad cognitiva[1], entendida como la capacidad para adaptarse de manera flexible a las condiciones cambiantes del entorno o a las tareas que se están llevando a cabo, en función de las demandas de la tarea o de las prioridades de la misma (Diamond, 2013). Los conceptos de cambio y flexibilidad cognitiva se han relacionado con los déficits encontrados en pacientes con lesiones en el lóbulo frontal que mostraban perseverancia en sus respuestas aun siendo éstas inapropiadas (Luria, 1966).

El estudio de la función de cambio y del ajuste flexible, se ha llevado a cabo fundamentalmente desde el paradigma experimental del cambio (*set shifting* o *task switching*), ya que se ha considerado el adecuado a la hora de analizar el control cognitivo en la ejecución de tareas que incluyen condiciones cambiantes o novedosas (Allport,

[1] Algunos autores han considerado que la flexibilidad cognitiva sería un término más amplio que el cambio, y que podría referirse no solo a la capacidad para ajustar las respuestas a situaciones cambiantes sino también a actuar de manera no rutinaria o establecida (Morra, et al., 2018). En este sentido, podría diferenciarse entre la *flexibilidad adaptativa*, entendida como la capacidad para cambiar o adaptar las respuestas a las demandas de las tareas o problemas previamente establecidos, y la *flexibilidad espontánea*, entendida como aquella para generar respuestas diversas en situaciones relativamente poco estructuradas (Wilson, Guilford, Christensen, & Lewis, 1954), que se ha relacionado con el pensamiento divergente y la creatividad (Torrance, 1974).

Styles, & Hsieh, 1994; Jersild, 1927; Rogers & Monsell, 1995). En este paradigma, que fue originalmente desarrollado por Jersild (1927), generalmente se utilizan dos tareas simples secuenciales en las que se presentan estímulos-respuesta bivalentes con respuestas superpuestas en condiciones congruentes e incongruentes (Kiesel et al., 2010). En el desarrollo de este tipo de tareas, habitualmente se realizan series de cada una de las dos tareas simples (AAAAA/BBBBB), en las condiciones congruente e incongruente, y posteriormente se combinan (ABABAB), lo que implica un aumento de las demandas cognitivas, tanto para clasificar los estímulos como para recuperar de la memoria las reglas relativas a cada tipo de estímulo y generar las respuestas adecuadas (Monsell, 2003). Jersild (1927), comparó la ejecución en este tipo de tareas entre las series simples (AAAAA/BBBBB) y las combinadas (ABABAB), para analizar la diferencia en los tiempos de reacción entre ellas, encontrando que en las series combinadas o mixtas aumentaba el tiempo de reacción respecto a las simples. Este efecto reflejaría el llamado *coste de cambio*, que se ha relacionado con el aumento de la carga en la MO (Rogers & Monsell, 1995), y que incrementaría las posibilidades de cometer un error en la serie inmediatamente posterior (Monsell, 2003).

El análisis de los procesos implicados en la función de cambio atencional a través del paradigma del cambio ha mostrado la implicación de otros procesos cognitivos durante su ejecución.

En primer lugar, se ha sugerido que el cambio atencional o de estrategias, y la capacidad para generar respuestas flexibles precisarían recursos de la MO para mantener activas las metas de las tareas (Humphreys, Forde, & Francis, 2000).

Igualmente, el cambio precisaría de recursos inhibitorios para el control, la selección y la supresión de respuestas inapropiadas previamente aprendidas (Kimberg & Farah 1993), así como para supresión o desactivación de las perspectivas o metas de las tareas y la consiguiente activación de otras nuevas (Diamond, 2013). En este sentido, algunos autores han señalado que las tareas asociadas al paradigma del cambio podrían verse afectadas por diferentes tipos de interferencia, que aparecerían no solo en las series combinadas o mixtas sino también en las simples (e.g. Allport et al., 1994; Rubin & Meiran, 2005). Kiesel y sus colaboradores (2010), describieron tres tipos de interferencia que se producirían durante la selección y la ejecución de las respuestas: a) la que se produciría por la activación persistente de una serie o ensayo anterior, b) la que se produciría entre los estímulos bivalentes al activar respuestas superpuestas en una serie simple, y c) la asociada al coste de cambio, al tener que recodificar constantemente las respuestas generando interferencia entre ellas.

Además, se ha considerado que, en las tareas asociadas al paradigma del cambio, sería fundamental la supervisión de la ejecución, que permitiría el ajuste de las respuestas consecutivas en función de los estímulos o demandas cambiantes, o después de haber cometido un error (Crone, Somsen, Zanolie, & Van der Molen, 2006). Tal y como apuntaron Holroyd y Coles (2002), la supervisión de la ejecución que generaría el ajuste flexible se podría llevar a cabo tanto recibiendo información o *feedback* externo positivo o negativo (aciertos o errores en la ejecución), como sin recibirlo, es decir manteniendo activas las metas de las tareas de manera interna.

Finalmente, se ha considerado que, en condiciones novedosas, la detección del cambio de situación y el consiguiente ajuste flexible de las respuestas, precisaría un mayor control atencional para planificar las respuestas en función de la nueva situación, al tiempo que se reinterpreta la información que se percibe (Canas**,** Quesada, Antolí, &

Fajardo, 2003).

De manera global, la función de cambio tendría una naturaleza multifacética, que implicaría el mantenimiento de las metas y la reconfiguración de las respuestas para el ajuste flexible a las demandas de las tareas (Goshke, 2000), lo que implicaría también recursos inhibitorios para supresión o desactivación de las perspectivas o metas de las tareas y la consiguiente activación de otras nuevas (Diamond, 2013).

1.3 Funcionamiento ejecutivo e interpretación musical

La interpretación musical puede relacionarse con diferentes tipos de demandas cognitivas. En primer lugar, aquellas que tienen que ver con el procesamiento de la armonía, de la tonalidad, fraseo y medida (Gabrielsson, 1999; Palmer, 1997; Palmer & Pfordresher, 2003). En segundo lugar, las relacionadas con la lectura de la partitura, que por sí misma requiere la interpretación del código (que se lee en el plano horizontal y vertical al mismo tiempo), y su transformación en sonidos con características precisas (altura, duración e intensidad). En tercer lugar, las que afectan al control motor: fluidez, velocidad, precisión rítmica y coordinación (Drake & Palmer, 2000).

Teniendo en cuenta las demandas descritas, la práctica continuada en interpretación musical se ha relacionado con diferentes tipos de mejoras cognitivas asociadas al FE, (e.g. Bialystok & DePape, 2009; Franklin et al., 2008; George & Coch, 2011; Lee, Lu, & Ko, 2007; Ramachandra, Meighan, & Gradzki, 2012; Roden, Grobe, Bongard, & Kreutz, 2014). Por otra Parte, aunque de manera mucho más limitada, también se ha tratado de analizar la relevancia del FE en la interpretación, cuando las demandas de la tarea musical se incrementan. En este sentido, se ha explorado la implicación de la capacidad de MO relacionada con la función de actualización en la lectura a primera vista (Kopiez & Lee, 2006; Kopiez & Lee, 2008; Kopiez, Weihs, Ligges, & Lee, 2006; Meinz & Hambrick, 2010), definida como una tarea dinámica que requiere la lectura e interpretación simultánea de una partitura que no ha sido estudiada con anterioridad (Wolf, 1976).

Con el objetivo de fundamentar estos dos tipos de relación entre el FE y la interpretación musical, a continuación se presentan los aspectos más relevantes de ambas perspectivas de estudio, al igual que se revisan las aportaciones empíricas existentes al respecto.

1.3.1 Mejoras en el funcionamiento ejecutivo asociadas a la interpretación musical.

Tocar un instrumento musical es una habilidad que implica gran número de capacidades perceptivas, motoras y cognitivas. Independientemente del instrumento que se interprete, la ejecución musical supone descifrar un código con unas características precisas y transformarlo en sonidos concretos a través de la ejecución motora. Cuando hablamos de práctica instrumental nos referimos a la formación específica y extensiva en ejecución musical a través de un instrumento, con el conocimiento y utilización de los elementos propios del lenguaje musical. Dicha formación se lleva a cabo de forma individualizada, y está orientada hacia el desarrollo de los estudiantes como intérpretes.

A lo largo del tiempo, y especialmente en los últimos 15 años, diferentes autores han centrado su interés en analizar las posibles asociaciones entre la práctica instrumental acumulada y diversas capacidades perceptivo-motoras (Costa-Giomi, 2005; Forgeard, et al., 2008; Jäncke, Schlaug, & Steinmerz, 1997; Schön, Magne, & Besson, 2004), y cognitivas, como la inteligencia (Schellenberg, 2004; Schellenberg, 2011), el razonamiento no verbal (Forgeard et al., 2008), el razonamiento matemático (Costa-Giomi, 2004; Vaughn, 2000), el procesamiento verbal (Gunter, Schmidt, & Besson, 2003; Hannon & Trainor, 2007) y visual (Jakobson, Lewycky, Kilgour, & Stoesz, 2008), o la memoria verbal (Chan, Ho, & Cheung, 1998; Ho, Cheung, & Chan, 2003; Kilgour, Jakobson, & Cuddy, 2000; Moreno et al., 2011).

En este contexto, una parte de la investigación se ha centrado en el análisis de las diferencias entre músicos y no músicos asociadas a la práctica instrumental en procesos ligados al FE[2]. En la Tabla 1 se presenta un resumen de los estudios empíricos que han abordado este tema.

De todos los estudios revisados, se encontraron 15 que exploraban los efectos de la práctica musical incluyendo medidas de FE. Tal y como se puede observar en la Tabla 1, estos estudios se han llevado a cabo principalmente con diseños correlacionales, aunque también se han desarrollado algunas investigaciones experimentales, complementándose ambos tipos de diseños. Los estudios experimentales han permitido establecer relaciones causales y analizar el posible impacto positivo de la formación musical en el FE, en función de la duración de dicha formación y de su inicio en diferentes momentos evolutivos, concretamente durante la infancia (Holochwost et al., 2017; Jaschke, et al., 2018; Moreno et al., 2011; Roden et al., 2014), y en el envejecimiento (Bugos et al., 2007). Los estudios correlacionales, no han permitido establecer relaciones

[2] En los estudios revisados se han utilizado medidas de amplitud de MO como índices de FE. La función de actualización y la capacidad de MO no comparten los mismos procesos subyacentes, pero se han considerado mecanismos relacionados (Belacchi, et al., 2010; Miyake et al., 2000; St Clair-Thompson & Gathercole, 2006). Además, las tareas amplitud de MO muestran correlaciones elevadas con tareas de actualización en la MO (e.g. St Clair-Thompson & Gathercole, 2006). No se han encontrado estudios que analicen específicamente la función de actualización.

causales, pero han ofrecido la posibilidad analizar la relación entre el FE y la práctica musical acumulada durante periodos de tiempo más extensos (Amer, Kalender, Hasher, Trehub, & Wong, 2013; Bialystok & DePape, 2009; Franklin et al; 2008; George & Coch, 2011; Hou et al, 2014; Ramachandra et al., 2012; Schellenberg, 2011; Talamini et al., 2016), así como explorar si dicha relación era comparable en grupos de niños y adultos con diferentes niveles de experiencia musical (Lee at al., 2007; Zuk, Benjamin, Kenyon, & Gaab, 2014).

Considerados globalmente, los resultados de los estudios revisados mostraron que la práctica musical podía asociarse a mejoras en las distintas funciones ejecutivas, algo que ha sido respaldado por estudios de neuroimagen en los que se han encontrado cambios estructurales en el cerebro en regiones cerebrales como el área frontal inferior (Sluming et al., 2002), asociada con funciones de control ejecutivo (Aron, Robbins y Poldrack, 2004). No obstante, es preciso tener en cuenta dos aspectos fundamentales de la revisión llevada a cabo, que desarrollamos a continuación.

En primer lugar, el análisis de los participantes en los diferentes estudios revisados mostró que éstos se habían centrado en niños (Holochwost et al., 2017; Jaschke, et al., 2018; Lee et al., 2007; Moreno et al., 2011; Roden et al., 2014; Schellenberg, 2011; Zuk et al., 2014), en adultos jóvenes (Bialystok & DePape, 2009; Franklin et al., 2008; George & Coch, 2011; Hou et al., 2014; Lee et al., 2007; Ramachandra et al., 2012; Talamini, Carretti & Grassi, 2016; Zuk, 2014), o en adultos mayores (Amer et al., 2013; Bugos et al., 2007). Sin embargo, ninguno de los estudios había explorado las posibles mejoras en FE asociadas a la práctica musical entre la infancia tardía y la adolescencia, que es un período crucial para los cambios en el desarrollo de las FEs (Anderson, Anderson, Northam, Jacobs y Catroppa, 2001; Carriedo et al., 2016; Diamond & Goldman-Rakic, 1989; Fischer et al., 1997; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Zald & Iacono, 1998).

En segundo lugar, el análisis de las FEs medidas en los 15 estudios reveló que, aunque uno de ellos se centró específicamente en la inhibición (Moreno et al., 2011), y dos en la inhibición y el cambio (Bialystok & DePape, 2009; Holochwost et al., 2017), los otros 12 estudios evaluaron, de manera específica o junto con otras medidas, la capacidad de MO utilizando para ello tareas de amplitud de MO. Aunque la mayor parte de los resultados obtenidos en estos 12 estudios permitieron asociar de manera general la práctica musical a mejoras en la capacidad de MO, se encontraron algunas inconsistencias (véase en Tabla 1 Jaschke, et al., 2018; Zuk et al., 2014). No obstante, teniendo en cuenta la diversidad de tareas de amplitud de MO utilizadas, junto con las diferencias en su complejidad[3] y en las modalidades de aplicación (visual, auditiva, audiovisual), es posible que dichas inconsistencias se debieran precisamente a las diferencias entre las tareas.

Una cuestión relevante respecto a las tareas de amplitud utilizadas, y común a los 12 estudios que analizaron las mejoras en la capacidad de MO asociadas a la práctica musical, es que en todos los casos se consideró la medida de la amplitud de MO como un indicador de FE. Además, autores como Ramachandra et al., (2012), concluyeron que la práctica musical tendría efectos de mejora en la capacidad para almacenar, clasificar, y procesar información al mismo tiempo, así como para suprimir la información irrelevante,

[3] Cornoldi y Vecchi (2003), desarrollaron un modelo de dos dimensiones continuas que permitían diferenciar las propiedades de las tareas de amplitud de MO. Específicamente, una dimensión (continuo horizontal) haría referencia al dominio (visual, espacial, verbal), y la otra (dominio vertical) al grado de control atencional requerido. Estos autores diferenciaron entre las tareas que implicaban procesos pasivos con control atencional bajo entre las que se encontraría las tareas de amplitud de MO simples (por ejemplo, *Digit span forward*), y varios grados de procesamiento activo con contro atencional alto, entre las que se encontrarían las tareas de amplitud compleja (por ejemplo, *Digit span backward*), comparables a las tareas de actualización.

procesos todos ellos asociados a la función de actualización. Sin embargo, en ninguno de los estudios revisados diferenciaron entre los procesos de mantenimiento activo e inhibición (Chiappe et al., 2000), subyacentes a la función de actualización (Ecker et al., 2010). En todos ellos se registró únicamente el recuerdo correcto como índice general de capacidad de MO.

Teniendo en cuenta que la mayoría de los estudios revisados analizaron las posibles mejoras en la capacidad de MO asociadas a la práctica musical, los rangos de edad de estos estudios (niños o adultos), y que la medida de la capacidad de MO se llevó a cabo a través del exclusivamente del recuerdo correcto, se estableció el primer objetivo de esta tesis: analizar la existencia de diferencias entre músicos y no músicos en los diferentes sub-procesos de la función de actualización descritos por Ecker y sus colaboradores (2010): a) mantenimiento/transformación de la información en la MO y b) sustitución de la información irrelevante en la MO, en niños y adolescentes de 11 y 15 años.

Tabla 1. Características principales de los estudios incluidos en la revisión sobre mejoras en el FE asociadas a la práctica musical.

	Participantes					
Autores	***N***	**Edad**	**Grupos**	**Tipo de estudio**	**Medidas de FE**	**Resultados**
Amer, Kalender, Hasher,Trehub, & Wong, (2013)	42	50-77 años	18 músicos 24 no-músicos	Correlacional	Capacidad de MO (*VS*) Inhibición (*Stroop, Go/no-go, Simon Task*)	Los músicos superaron a los no-músicos en todas las tareas excepto en Go/no-go, y especialmente en las condiciones más demandantes.
Bialystok & DePape, (2009)	95	18-35 años	24 monolingües 24 bilingües 47 músicos monolingües (22 instrumentistas, 25 cantantes)	Correlacional	Inhibición (*Stroop, Simon Task*) Cambio (*TMT*)	Los bilingües y los músicos superaron a los monolingües en las tareas TMT y Simon. Los músicos superaron a los monolingües y los bilingües en la tarea Stroop. No había diferencias entre los instrumentistas y los cantantes.
Bugos, Perlstein, McCrae, (2007)	31	60-85 años	15 grupo experimental 16 grupo control	Experimental (6 meses)	Capacidad de MO (*DSF, DSB, DSy, BD, LNS*) Cambio (*TMT*)	El grupo experimental mejoró significativamente el rendimiento en TMT y DSy.
Franklin et al., (2008)	20	21-22 años	11 músicos 9 no-músicos	Correlacional	Capacidad de MO (*RS, OS*)	Los músicos superaron a los no-músicos en ambas tareas.

Tabla 1. Continuación

George & Coch, (2011)	32	18-24 años	16 músicos 16 no-músicos	Correlacional	Capacidad de MO (*DSB*, *LSB*) y Potenciales evocados (ERP)	Los músicos superaron a los no-músicos en todas las medidas de MO.
Holochwost et al., (2017)	265	7-13 años	135 grupo experimental 130 grupo control	Experimental (3 cursos escolares)	Inhibición (*Go/no-go*, *Stroop*, *Flanker*) Cambio (*TMT*) FE global (*TOL*, *WCST*)	La participación en el programa mostró mejoras en la precisión y la eficiencia en la tarea Flanker. Go/no-go, Stroop y en WCST, especialmente en los casos en los que los participantes recibieron formación durante al menos dos años.
Hou et al., (2014)	60	Adultos jóvenes (*M* = 20.46)	26 músicos, inicio antes de los 6 años, habilidad auditiva superior 16 músicos, inicio después de los 9 años, sin habilidad auditiva superior 18 no-músicos con habilidad auditiva superior	Correlacional	Capacidad de MO (*2-back; DSF*, *DSB*) Inhibición (*Stroop*, *Stop signal*) Cambio (*TMT*, *Reversal learning*)	Los participantes con entrenamiento musical (ya sea temprano o tarde) superaron significativamente a los participantes sin entrenamiento musical en la prueba 2-back de MO. No se encontraron diferencias significativas entre los tres grupos en el resto de medidas.

Tabla 1. Continuación

Jaschke, Honing, & Scherder, (2018)	147	6-7 años	38 grupo experimental con formación musical previa 42 grupo experimental sin formación musical previa 29 grupo con intervención en artes visuales 37 grupo control	Experimental (2 años y medio)	Capacidad de MO (*VS*) Inhibición (*Go/no-go*) FE global (TOL)	Los niños en el grupo de artes visuales fueron mejor en la tarea de MO en comparación con las otras tres condiciones. Los dos grupos de música mejoraron significativamente más que los de artes y controles a lo largo del tiempo en Go/no-go y TOL.
Lee, Lu, & Ko, (2007)	80	40 niños (*M* = 12) 40 adultos jóvenes (*M* = 22)	20 niños músicos 20 niños no-músicos 20 adultos músicos 20 adultos no-músicos	Correlacional	Capacidad de MO (*DSF*, *DSB*, *NWS*, *OS*, *SSS*, *CSS*)	Los adultos músicos fueron mejores que todos los niños y que los adultos no músicos en DSF y NWS. Los niños músicos fueron mejores que los niños no músicos en DSB y OS, no existiendo diferencias significativas entre los adultos músicos y no músicos estas mismas medidas.
Moreno et al., (2011)	48	4-6 años	24 formación musical auditiva 24 formación en artes visuales	Experimental (4 semanas)	Inhibición (*Go/no-go*)	El grupo con formación musical auditiva mejoró significativamente en relación al del grupo de artes visuales.

Tabla 1. Continuación

Ramachandra, Meighan & Gradzki, (2012)	60	18-24 años	30 músicos 30 no-músicos	Correlacional	Capacidad de MO (*DSB*, *RS*)	Los músicos superaron a los no músicos en las dos tareas.
Roden, Grobe, Bongard, & Kreutz, (2014)	50	7-8 años	25 formación musical 25 formación en ciencias naturales	Experimental (18 meses)	Capacidad de MO (*CTS*, *CS*, *CLSB*)	Los niños que recibieron formación musical mejoraron significativamente más que aquellos en el grupo de ciencias naturales en CTS, y CS.
Schellenberg (2011)	106	9-12 años	50 músicos 56 no-músicos	Correlacional	Capacidad de MO (*DSF*, *DSB*) Inhibición (*Stroop*) FE global (*WCST*)	Los músicos superaron a los no-músicos en la capacidad de MO.
Talamini, Carretti, & Grassi, (2016)	36	Adultos jóvenes (*M* = 22.6)	18 músicos 14 no-músicos	Correlacional	Capacidad de MO (*DSF auditory, visual, and audiovisual*)	Los músicos superaron a los no-músicos independientemente de la modalidad de la tarea.
Zuk, Benjamin, Kenyon, & Gaab, (2014)	57	27 niños 9-12 años 30 adultos 18-35 años	15 niños músicos 12 niños no-músicos 15 adultos músicos 15 adultos no-músicos	Correlacional	Capacidad de MO (*DSB)* Inhibición *(WCI*) Cambio/Flexibilidad cognitiva (*TMT*, *VF*, *SST*)	Los músicos adultos superaron a los no-músicos en las medidas de flexibilidad cognitiva (VF, y TMT) y la MO. Los niños músicos superaron a los no-músicos en las medidas de cambio/flexibilidad cognitiva (VF y TMT).

VS: Visuospatial Span; **TMT:** Trail Making Test; **DSF:** Digit Span Forward; **DSB:** Digit Span Backward; **DSy:** Digit Symbol; **BD:** Bolck Design; **LNS:** Letter Number Sequencing; **RS:** Reading Span; **OS:** Operation Span; **LSB:** Letter Span Backward; **TOL:** Tower of London; **WCST:** Wisconsin Card Sorting Test; **NWS:** Non-Word Span; **SSS:** Simple Spatial Span; **CSS:** Complex Spatial Span; **CTS:** Counting Span; **CS:** Complex Span; **CLSB:** Color Span Backward; **WCI:** Word-Colour Interference; **VF:** Verbal Fl uency; **SST:** Set Shifting Task.

1.3.2 Contribución de las funciones ejecutivas a la interpretación musical: la lectura a primera vista

La lectura musical a primera vista, ha sido considerada, junto con la interpretación de repertorio, la interpretación de memoria, la interpretación de oído y la improvisación, una de las cinco habilidades básicas de todos los músicos (McPherson & Thompson, 1998). Específicamente, la lectura musical a primera vista ha sido de definida como una tarea de transcripción dinámica que requiere la ejecución de la música escrita en una partitura por primera vez, o después de un breve ensayo (Lehmann & McArthur, 2002). La lectura musical a primera vista requiere cierto dominio del instrumento musical para ser llevada a cabo, y este dominio se ha asociado con la eficiencia en lectura a primera vista durante la adquisición del mismo (Lehmann & Ericsson, 1996). Sin embargo, algunos autores han sugerido que, debido a las complejas demandas de la lectura a primera vista, el dominio del instrumento sería una condición necesaria pero no suficiente para una interpretación eficiente (Elliott, 1982; Wolf, 1976).

Inicialmente, la investigación sobre la eficiencia en lectura musical a primera vista se centró en los aspectos relacionados con la forma de descifrar el código musical escrito en las partituras, en los movimientos oculares necesarios para ello, y en el papel de la práctica específica en lectura a primera vista. Por ejemplo, Rubinstein (1950), y posteriormente Bernstein (1981), llevaron a cabo sendos estudios con pianistas sobre la competencia en lectura musical basada en los movimientos oculares en función de la práctica específica en esta tarea, encontrando que aquellos que tenían más experiencia realizaban fijaciones oculares de menor duración, y eran más eficientes en la ejecución. Otra serie de estudios (Sloboda, 1976; Wolf, 1976), se centró en el análisis del reconocimiento de errores en las partituras durante la lectura a primera vista, concluyendo que la experiencia en este tipo de tareas generaba una lectura más eficaz y una mayor capacidad para localizar incongruencias en la notación.

Posteriormente, algunos autores han centrado su interés en el papel de diferentes procesos psicomotores asociados a la eficiencia en la lectura a primera vista, encontrando correlaciones positivas entre la lectura a primera vista y las habilidades viso-motoras (Fourie, 2004; Truitt, Clifton, Pallatsek & Rayner, 1997), la velocidad psicomotora (Kopiez & Lee, 2006; Kopiez & Lee, 2008; Kopiez, Weihs, Ligges, & Lee, 2006), o el tiempo de reacción (Thompson, 1987). Además, otra parte de la investigación en lectura a primera vista, ha explorado la implicación en esta tarea de procesos cognitivos como la planificación (Drake & Palmer, 2000; Lehmann & Kopiez; 2009), y la capacidad de razonamiento espacio-temporal (Hayward & Gromko, 2009). En este contexto, y de manera muy limitada, se han estudiado las contribuciones a la lectura a primera vista de procesos ligados al FE, centrándose la investigación en el rol de la capacidad de MO (Kopiez & Lee, 2006; Kopiez & Lee, 2008; Meinz & Hambrick, 2010). En la Tabla 2, se presenta un resumen de los estudios llevados a cabo.

Tal y como se puede observar, solo tres estudios (Kopiez & Lee, 2006; Kopiez & Lee, 2008; Meinz & Hambrick, 2010), han abordado la implicación de procesos ligados al FE en la lectura musical a primera vista, concretamente, al de la contribución de la capacidad de MO, medida a través de tareas de amplitud complejas.

En estos estudios, todos los participantes eran adultos pianistas. Sin embargo, mientras que en los dos estudios de Kopiez y Lee (2006; 2008), todos los participantes eran adultos jóvenes expertos, en el estudio de Meinz y Hambrick (2010), existía un amplio rango de edad y de experiencia musical entre los participantes. Además, Kopiez y Lee (2006; 2008), evaluaron la lectura a primera vista a través de la precisión rítmica, que se ha considerado la medida más objetiva de la ejecución (e.g. Drake y Palmer, 2000; Elliot, 1982; Gromko, 2004; Hayward & Gromko, 2009; Hodges, 1992; Kopiez & Lee, 2008; McPherson, 1994; Mishra, 2014; Waters, Underwood, & Findlay, 1997; Wurtz, Mueri, & Wiesendanger, 2009), mientras que Meinz y Hambrick (2010), lo hicieron con las puntuaciones de dos jueces respecto a la competencia técnica, la expresividad, y la ejecución global, derivando una medida combinada de estos tres índices, que no fueron analizados de manera independiente.

Respecto a la medida de la capacidad de MO, y al igual que sucedía en los estudios centrados en las mejoras en el FE asociadas a la práctica musical revisados en el epígrafe anterior, en estos tres estudios sobre lectura a primera vista las tareas de amplitud de MO fueron puntuadas en función del recuerdo correcto, limitando la consideración de los procesos inhibitorios presentes en este tipo de tareas (Chiappe et al., 2000). Estos procesos podrían ser determinantes a la hora de suprimir de la MO aquella información que ha dejado de ser relevante permitiendo la codificación de la nueva información, lo que podría afectar a la precisión de la ejecución reflejándose en elementos musicales, como el ritmo, la afinación, o la articulación.

Los resultados de los tres estudios mostraron una contribución significativa de la capacidad de MO a la lectura a primera vista, más allá de los efectos de la práctica específica acumulada en la tarea musical, concluyendo que la práctica sería una condición necesaria pero no suficiente para lectura a primera vista, como ya se había sugerido previamente (Elliott, 1982; Wolf, 1976). Sin embargo, aunque en todos se utilizaron tareas musicales de diferentes niveles de dificultad, solo Kopiez y Lee (2006) los analizaron de manera diferenciada en su primer estudio. Los resultados que obtuvieron mostraron que la capacidad de MO era un predictor significativo de la eficiencia en la lectura a primera vista, especialmente en las tareas más fáciles, disminuyendo su capacidad predictiva en las más difíciles en beneficio de otros predictores asociados a la práctica específica en lectura a primera vista. Kopiez y Lee (2006), concluyeron que en las condiciones más fáciles las tareas musicales implicarían en mayor medida a los procesos ligados a la MO porque se podrían llevar a cabo solo con conocimientos instrumentales básicos, mientras que en las condiciones más difíciles las diferencias en el nivel de experiencia específica en la lectura a primera vista serían las determinantes para la ejecución rítmica eficiente, perdiendo valor predictivo la capacidad de MO.

Teniendo en cuenta que en estos tres estudios todos los participantes eran adultos, y que la capacidad de MO se midió solo a través del recuerdo correcto, se estableció el segundo objetivo de esta tesis: determinar si controlando los efectos de la edad y de la práctica musical, la eficiencia en los procesos de mantenimiento/transformación y sustitución subyacentes a la función de actualización en la MO (Ecker et al., 2010), podían contribuir de manera diferenciada a la eficiencia en lectura musical a primera vista en instrumentistas de cuerda y viento de diferentes niveles de instrumento, en función del nivel de dificultad de la tarea musical, evaluada mediante distintos índices musicales (ejecución global, proporción de errores, mantenimiento del tempo musical, precisión rítmica, afinación, articulación y expresión).

Sin embargo, además de la implicación de la función de actualización en la lectura a primera vista, hay otros aspectos relevantes sobre la implicación de las FEs en esta tarea musical que no han sido explorados y que podrían contribuir a su eficiencia de manera significativa. En este sentido, la flexibilidad cognitiva, sería potencialmente necesaria para ajustar la ejecución a los estímulos cambiantes que se presentan en la partitura. Por su parte, los procesos inhibitorios asociados la resistencia a la interferencia distractora podrían ser necesarios para el control de la superposición entre los distintos elementos musicales, y aquellos relacionados con la supresión de acciones o respuestas prepotentes, para inhibir las respuestas motoras asociadas a patrones previamente aprendidos que pudieran ser inapropiadas para la tarea musical.

Tal y como se ha mencionado, las contribuciones a la lectura a primera vista de la flexibilidad cognitiva y los procesos inhibitorios descritos no se han explorado todavía, aunque estas FEs sí se han relacionado teóricamente con la improvisación musical (Beaty & Silvia, 2012; de Manzano & Ullén, 2012b), que requiere la generación e interpretación de ideas musicales siguiendo normas musicales concretas. La improvisación se ha comparado con la lectura musical a primera vista porque ambas tareas requieren la ejecución musical en tiempo real sin preparación previa (Thompson & Lehmann, 2004), aunque la lectura a primera vista no implicaría los aspectos creativos asociados a la improvisación (Beaty, 2015).

En este contexto, se estableció el tercer objetivo de esta tesis, que consistió en analizar cómo la flexibilidad cognitiva y los procesos inhibitorios involucrados en el control de la interferencia de estímulos irrelevantes y en la supresión de acciones o respuestas prepotentes, podían contribuir a la fluidez y a la precisión en la tarea de lectura a primera vista en instrumentistas de cuerda y viento en diferentes condiciones de dificultad de la tarea musical, y si esas contribuciones eran independientes del conocimiento del instrumento.

Tabla 2. Características principales de los estudios incluidos en la revisión sobre lectura a primera vista.

	Participantes					
Autores	***N***	**Edad**	**Instrumento/Nivel**	**Medidas lectura a primera vista**	**Medidas de FE**	**Resultados**
Kopiez & Lee (2006)	52	Adultos (*M* = 24.56)	Piano/Expertos	Precisión rítmica en 5 niveles de dificultad	Capacidad de MO (*OS*)	La capacidad de MO contribuyó solo en las tareas musicales más sencillas.
Kopiez & Lee (2008)	52	Adultos (*M* = 24.56)	Piano/Expertos	Precisión rítmica general	Capacidad de MO (*OS*)	La capacidad de MO no contribuyó significativamente (p =.06)
Meinz & Hambrick (2010)	57	Adultos (*M* = 3.9)	Piano/Rango 1-57 años de experiencia	Medida combinada subjetiva en 3 niveles de dificultad (competencia técnica, musicalidad, ejecución global)	Capacidad de MO: medida combinada (*OS*, *RS*, *MS*, *RO*)	La capacidad de MO explicaba un 7% de la eficiencia en la tarea musical más allá de los efectos de la práctica.

OS: Operation Span; **RS:** Reading Span; **MS:** Matrix Span; **ROS:** Rotation Span.

2. OBJETIVOS E HIPÓTESIS

El objetivo principal de esta tesis consistió en profundizar en la relación entre el FE y la interpretación musical desde una doble perspectiva: por una parte, desde aquella centrada en el estudio de las posibles mejoras ejecutivas asociadas a la práctica musical, y por otra desde la del análisis de la relevancia de las FEs en una tarea de interpretación musical concreta con elevadas demandas cognitivas, la lectura a primera vista. Para ello, se llevaron a cabo tres estudios diferentes con objetivos específicos que se detallan a continuación.

Estudio 1: Diferencias en los procesos de actualización entre músicos y no-músicos desde la infancia tardía hasta la adolescencia.

Objetivo:

- Explorar la relación entre la práctica musical y los procesos de mantenimiento/transformación y sustitución de la información en la MO subyacentes a la función de actualización desde la infancia tardía hasta la adolescencia, en músicos y no-músicos igualados en edad e inteligencia fluida.

Hipótesis:

- En relación a los procesos de mantenimiento y transformación asociados a la capacidad de MO, esperamos que los músicos superarán a los no músicos, especialmente en las condiciones experimentales que demanden más recursos atencionales, esto es, en las condiciones de alta carga y alta supresión.
- En relación con el proceso de sustitución, esperamos que la mayor eficiencia de los músicos en el proceso de mantenimiento y transformación liberará activación (Just & Carpenter, 1992) o recursos atencionales (Engle, 2002) para suprimir la información irrelevante, y que, por tanto, los músicos superarán a los no músicos en las condiciones más demandantes.

Estudio 2: Las contribuciones de los sub-procesos de la función de actualización en la MO en la lectura musical a primera vista más allá de los efectos de la práctica y la edad.

Objetivos:

- Analizar cómo los subprocesos de mantenimiento/transformación y sustitución subyacentes a la función de actualización de la información en la MO se relacionan con la lectura a musical a primera vista en función de la carga en la memoria y nivel de supresión de la información requerido.
- Analizar cómo la eficiencia en estos procesos subyacentes a la función de actualización pueden ser una fuente de diferencias individuales en la lectura musical a primera vista en función de la dificultad de la tarea musical y de diferentes índices musicales de rendimiento.

Hipótesis:

- Esperamos una correlación positiva entre el índice de mantenimiento/transformación de la información y la lectura a primera vista, y una correlación negativa entre el índice de sustitución de la información en la MO y la lectura a primera vista, independientemente de la dificultad de la tarea musical, cuando se controla la edad y la práctica. Sin embargo, considerando la posible existencia de un efecto de *trade-off* entre los procesos de mantenimiento / transformación y de sustitución (e.g., Engle, 2002; Just & Carpenter, 1992; Kane & Engle, 2000), su relación con la lectura a primera vista podrá variar en función de las demandas de carga en la memoria y del nivel de supresión de la tarea de actualización. Por lo tanto: a) si la lectura a primera vista depende principalmente del mantenimiento y procesamiento simultáneo de la información en la MO, entonces habrá una correlación entre las tareas musicales y la actualización en condiciones de alta carga y baja supresión; b) si la lectura a primera vista depende principalmente de la inhibición de información irrelevante, entonces habrá una correlación entre las tareas musicales y los índices de actualización en las condiciones de baja carga y alta supresión; (c) si ambos subprocesos son igualmente relevantes para la eficiencia en la lectura a primera vista, entonces habrá una correlación entre las tareas musicales y los índices de actualización de la información en la MO en las condiciones de alta carga y alta supresión.

- Independientemente de si la lectura a primera vista depende más de los sub-procesos de mantenimiento/transformación o del de sustitución, también esperamos que la eficiencia en ambos sub-procesos contribuya significativamente a la ejecución a primera vista, especialmente en las tareas musicales más demandantes.
- Además, considerando la existencia de diferentes elementos dentro de la estructura musical implicados en la interpretación, como el tempo, el ritmo, el tono o la articulación, esperamos que la eficiencia en los sub-procesos de mantenimiento/transformación y sustitución contribuirá de forma diferencial a la ejecución musical de los participantes. En primer lugar, esperamos que los participantes eficientes en el sub-proceso de mantenimiento / transformación superarán a los menos eficientes en aquellos elementos musicales más relacionados con la expresividad o la fluidez, como son el ritmo y el mantenimiento del tempo, debido a la mayor capacidad de estos participantes para mantener y procesar información en la MO. En segundo lugar, aquellos participantes eficientes en el sub-proceso de sustitución superarán a los menos

eficientes en aquellos elementos musicales más relacionados con la precisión en la ejecución, como son la afinación y la articulación, debido a su mayor capacidad para suprimir la información irrelevante de la MO. En tercer lugar, esperamos una contribución similar de la eficiencia en ambos sub-procesos de actualización en el índice de errores en la ejecución a primera vista.

Estudio 3: El rol de la flexibilidad cognitiva y la inhibición en tareas dinámicas complejas: el caso de la lectura musical a primera vista.

Objetivos:

- Analizar cómo, independientemente del dominio del instrumento musical, la flexibilidad cognitiva y los procesos inhibitorios involucrados en el control de la interferencia de estímulos irrelevantes y en la supresión de acciones o respuestas prepotentes, pueden contribuir de manera diferenciada a la fluidez y la precisión, consideradas como índices de una ejecución musical a primera vista eficiente (Thompson & Lehmann, 2004), y determinar si dichas contribuciones pueden distinguirse en función de las condiciones de dificultad de las tareas musicales basada en su organización métrica.

Hipótesis:

- Nuestra hipótesis es que la flexibilidad cognitiva contribuirá significativamente a la fluidez, especialmente en las condiciones de lectura a primera vista más difíciles (Costa et al., 2009; Glass et al., 2013), en las que el cambio necesario entre diferentes elementos musicales podría aumentar las demandas de control ejecutivo.

- También esperamos que los procesos inhibitorios de resistencia a la interferencia y de inhibición de respuestas prepotentes, contribuirán a la precisión para así lograr un rendimiento musical ajustado basado en respuestas motoras controladas. Concretamente, esperamos que la resistencia a la interferencia contribuirá a la precisión solo en las condiciones más difíciles de las tareas de lectura a primera vista, ya que el procesamiento de elementos musicales previamente aprendidos en una organización temporal más compleja aumentará la interferencia tanto en la codificación de la información como en el procesamiento y selección de las respuestas motoras apropiadas (Miller & Cohen, 2001). Además, esperamos que la contribución de la inhibición de respuestas prepotentes a la precisión no se verá afectada por la dificultad de las tareas de lectura a primera vista, ya que los patrones motores aprendidos previamente pueden ser activados incorrectamente por información familiar incluso en las condiciones más fáciles (Thompson & Lehmann, 2004).
- Finalmente, esperamos que la contribución tanto de la flexibilidad cognitiva como de los procesos inhibitorios será independiente del dominio del instrumento, dado que dicho dominio es una condición necesaria pero no suficiente para llevar a cabo la lectura a primera vista (Elliott, 1982; Wolf, 1976).

3. ESTUDIOS EMPÍRICOS

3.1 ESTUDIO 1

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Differences in updating processes between musicians and non-musicians from late childhood to adolescence

Laura Herrero[a], Nuria Carriedo[b,*]

[a] Universidad Camilo José Cela, Spain
[b] Universidad Nacional de Educación a Distancia (UNED), Spain

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ABSTRACT

The main purpose of our study was to examine whether musical training is associated with improvements in updating executive function development between late childhood and adolescence, as well as to analyse which updating sub-processes — inhibition or maintenance — are more affected by musical experience. Sixty-nine musicians (37 children aged between 10–11 years and 32 adolescents between 15–16 years) and 69 non-musicians (37 children aged between 10–11 years and 32 adolescents between 15–16 years) participated in the study and were matched in academic level and fluid intelligence. Updating function was measured by the updating task developed by De Beni and Palladino (2004), which allowed differentiating scores for maintenance and inhibition processes. The results showed that musicians outperformed non-musicians both in maintenance and inhibitory processes, specifically in resistance to proactive interference.

Differences in updating processes between musicians and non-musicians from late childhood to adolescence.

Abstract

The main purpose of our study was to examine whether musical training is associated with improvements in updating executive function development between late childhood and adolescence, as well as to analyse which updating sub-processes — inhibition or maintenance — are more affected by musical experience. Sixty-nine musicians (37 children aged between 10–11 years and 32 adolescents between 15–16 years) and 69 non-musicians (37 children aged between 10–11 years and 32 adolescents between 15–16 years) participated in the study and were matched in academic level and fluid intelligence. Updating function was measured by the updating task developed by De Beni and Palladino (2004), which allowed differentiating scores for maintenance and inhibition processes. The results showed that musicians outperformed non-musicians both in maintenance and inhibitory processes, specifically in resistance to proactive interference.

Key words:

Updating in working memory executive function, music training, development.

Highlights:

Music performance involves cognitive processes linked to executive functioning.

Musical training could be associated with developmental improvements in updating executive function.

Inhibitory processes could be responsible for the relationship between musical training and updating executive function during its development.

3.1.1 Introduction

Music performance is a complex activity that involves the integration of auditory and visual stimuli, kinaesthetic control, pattern recognition, and memory processes (Barrett, Ashley, Strait, & Kraus, 2013). For this reason, music performance has been considered to require high levels of attentional control, including selective attention, inhibition, shifting, updating, and monitoring processes (Bialystok & DePape, 2009). These processes have been linked to executive control, which essentially involves cognitive flexibility, updating information in working memory (WM), and inhibition (Miyake et al., 2000).

There is a broad number of studies that have reported improvements associated with musical training in various executive functions, such as cognitive flexibility (Zuk, Benjamin, Kenyon, & Gaab, 2014), updating information in WM (Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007; Franklin et al., 2008; George & Coch, 2011; Hou et al., 2014; Lee, Lu, & Ko, 2007; Ramachandra, Meighan, & Gradzki, 2012; Roden, Grobe, Bongard, & Kreutz, 2014), and inhibition (Bialystok & DePape, 2009; Dowsett & Livesey, 2000; Holochwost et al., 2017; Hou et al., 2014; Moreno, Bialystok, Schellenberg, Cepeda, & Chau, 2011).

The purpose of this study was to explore the relationship between musical training and one of the main executive functions: the updating of information in WM, defined as 'the act of modifying the current status of representation of schema in memory to accommodate new input' (Morris & Jones, 1990, p. 112).

WM has been characterised as a limited-capacity mechanism for the temporary maintenance and processing of information. Although several WM models have been described in the literature, it is generally assumed that WM is involved in complex cognitive tasks and highly related to controlled attention and fluid intelligence (Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Engle, Kane, & Tuholski, 1999a; Fry & Hale, 2000). According to one of the most prominent models (Baddeley & Hitch, 1974; Baddeley, 1986, 1996, 2000), WM is a mechanism that involves four main components: the phonological loop, the visuo-spatial sketchpad, and the episodic buffer (which are for temporary information storage), and the central executive, which is responsible for the control and regulation of attention. Specifically, Baddeley (1996) described four main functions of the central executive: the coordination of simultaneous tasks and the shift from one task to another, the supervision of coding and retrieving strategies, the regulation of selective attention and inhibitory processes, and the retrieval and processing of information stored in long-term memory (LTM). Given that WM has a limited capacity, these functions would be carried out with a limited amount of cognitive resources.

The limited amount of mental resources for the simultaneous storage and processing of information in WM has been conceptualised as a key factor in cognitive development (e.g. Bjorklund & Harnishfeger, 1990; Case, Kurland, & Goldberg, 1982) and language comprehension (Just and Carpenter, 1992). Both theories emphasise the trade-off between storing and processing information.

Developmental efficiency theories (Bjorklund & Harnishfeger, 1990; Case et al., 1982) suggest that available resources to store and process information in WM do not increase through development but improve their efficiency (Case et al., 1982), therefore increasing the availability of mental resources to execute cognitive processes, which could be described as the speed of activation/suppression of information (Harnishfeger, 1995). Furthermore, Just and Carpenter's (1992) computational theory of language comprehension suggests that both storage and processing rely on the amount of global activation available. These authors considered the suppression of irrelevant information as a way to release activation for maintenance, increasing WM efficiency.

On their behalf, Engle (2002) conceptualised WM as executive attention and specified that working memory capacity 'is not about memory, but about using attention to maintain and suppress information' (p. 20). In this theory, executive attention processes are responsible for the temporary maintenance of retrieved LTM traces that should be actively maintained or kept accessible in the limited focus of attention, while blocking interference, distraction, or conflict sources (Kane, Conway, Hambrick, & Engle, 2007). From this perspective, WM capacity (WMC) has been defined as 'the capability of the executive attention component of the WM system' (Kane & Engle, 2002, p. 638); they are the attentional processes available to actively maintain or accurately retrieve the relevant task information under interference conditions (Kane et al., 2007). Thus, as Kane and Engle (2000) pointed out, proactive interference could have a prominent role in WM efficiency.

WMC has been traditionally measured through complex span tasks such as the reading span task (Daneman & Carpenter, 1980), the counting span task (Case et al., 1982), and the operation span task (Turner & Engle, 1989). These tasks were created to measure the trade-off between capacity and processing resources. All of them require a secondary processing task that interferes with the primary storage task. Attentional processes would be necessary to keep memory information accessible (Conway et al., 2005). When new information or task demands appear, WM content must be updated, suppressing no-longer-relevant information and maintaining activation of information relevant to task goals (Belacchi, Carretti, & Cornoldi, 2010).

Some authors have underlined that WMC is highly related to updating executive function (e.g. Schmiedek, Hildebrandt, Lovdén, Wilhelm, & Lindenberger, 2009), based on the high correlation found between updating measures and WM complex span tasks (Conway, 1996; Engle, Tuholski, Laughlin, & Conway, 1999; Lehto, 1996; Miyake et al., 2000; Schmiedek et al., 2009; St Clair-Thompson & Gathercole, 2006; Towse, Hitch, & Hutton, 1998). However, as Ecker, Lewandowsky, Oberauer, and Chee (2010) pointed out, WMC and updating differ as a function of their underlying processes. Through structural equation models, these authors described three underlying processes: (a) retrieval of relevant information from LTM, (b) transformation of information in WM, and (c) substitution of information in WM.

Whereas the processes of retrieval and transformation could represent a common source of variance shared by WMC and updating, substitution could be the only sub-process specific to updating, and thus the basis for differentiating between updating and WMC. Moreover, the updating sub-processes could also differentiate at a developmental level. The sub-processes more related to WMC (retrieval and transformation) seem to develop from late childhood to adolescence, followed by stabilisation (Carriedo, Corral, Montoro, Herrero, & Rucián, 2016; Conklin, Luciana, Hooper, & Yarger, 2007; Gathercole, Pickering, Knight, & Stegmann, 2004), while the sub-process of substitution seems to develop up until young adulthood (Carriedo et al., 2016).

More recently, Ecker, Lewandowsky, and Oberauer (2014) focused on the substitution sub-process. These authors specified that the removal of no-longer-relevant information could be an active attentional process, and that an efficient substitution could require the ability to shift between no-longer-relevant information and the encoding of new information in its place.

Therefore, as Passolunghi and Pazzaglia (2005) pointed out, updating is a complex process that would require different levels of activation to continuously reject no-longer-relevant information and maintain activation of relevant information (see also Oberauer, Lewandowsky, Farrell, Jarrold, & Greaves, 2012; Shipstead, Lindsey, Marshal, & Engle, 2014; Unsworth & Engle, 2007; Unsworth, Fukuda, Awh, & Vogel, 2014).

Some previous studies have examined the relation between WMC and musical training using complex span tasks. For example, George and Coch (2011) and Ramachandra et al., (2012) carried out two separate studies to explore WM individual differences associated with musical training in young adult musicians and non-musicians. In both cases, the results showed that musicians significantly outperformed non-musicians at the behavioural level. Moreover, George and Coch (2011) found a shorter latency in the P300 component in musicians, which has been interpreted as an improved ability to update WM content (Steiner, Barry, & Gonsalvez, 2013). Both George and Coch (2011) and Ramachandra et al. (2012) concluded that musical training is associated with improvements in basic processes related to WM and attention—in the ability to simultaneously store and process information, in mental binding, and in the suppression of irrelevant information (i.e. less susceptibility to interference) (Franklin et al., 2008; Hou et al., 2014; Ramachandra et al., 2012). This relationship between musical training and WM was also found when controlling for general intelligence (e.g. Franklin et al., 2008; Roden et al., 2014).

Other authors (Hou et al., 2014), using complex memory span tasks and the classic n-back updating paradigm, also found improvements in updating executive function associated with musical training. Hou et al. (2014) concluded that the continuous updating of musical information stored in LTM could be a fundamental process during music performance to select adequate responses.

This empirical evidence has been supported by neuroimaging studies that reported brain structure changes associated with musical training, both in children (Habibi et al., 2014; Schlaug, Norton, Overy, & Winner, 2005) and in adults (Gaser & Schlaug, 2003; Grahn & Rowe, 2009). Moreover, neuroplasticity differences between musicians and non-musicians have been found in auditory (Bangert and Schlaug, 2006; Gaser and Schlaug, 2003; Herholz & Zatorre, 2012; Jäncke, 2009) and sensorimotor areas (Gaser and Schlaug, 2003; Jäncke, 2009), and structural differences have been found that seem to extend to other brain regions such as the inferior frontal area (Sluming et al., 2002), which is associated with executive control functions (Aron, Robbins, & Poldrack, 2004).

In conclusion, previous research has shown the existence of individual differences in WMC and updating associated with musical training, even when controlling for general intelligence (e.g. Franklin et al., 2008; Roden et al., 2014). However, to our knowledge, the vast majority of these studies have explored this association without differentiating among the processes involved—that is, between the retrieval/transformation and substitution processes. Moreover, previous research on cognitive advantages associated with musical training has been mainly focused on children (Lee et al., 2007; Roden et al., 2014; Schellenberg, 2004; Schellenberg, 2011), or on adults (Bialystok & DePape, 2009; Franklin et al., 2008; George & Coch, 2011; Talamini, Carretti, & Grassi, 2016; Ramachandra, et al., 2012), but has not yet explored advantages throughout development, specifically from late childhood to adolescence, which is a period crucial for developmental changes in executive functions (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Carriedo et al., 2016; Diamond & Goldman-Rakic, 1989; Fischer, Biscaldi, & Gezeck, 1997; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Zald & Iacono, 1998). Thus, it could be possible that musical training is associated with individual differences in retrieval/transformation and substitution processes, and that this association could vary through development.

In this context, our aim was to explore the relationship between musical training and the sub-processes of updating executive function from late childhood to adolescence. For this purpose, we carried out a study with child and adolescent musicians and non-musicians matched in age and score on Raven´s Standard Progressive Matrices (Raven, 1960), using an updating task developed by De Beni and Palladino (2004), which assesses different updating processes that could be developmentally differentiated (Carriedo et al., 2016): (a) maintenance processes, or the ability to recall incoming items; (b) the suppression of information, or the ability to inhibit stimuli that are no longer relevant or irrelevant to the goals of the task. Thus, the updating task identifies two different indexes that correspond to the components of updating executive function described by Ecker et al. (2010): (a) an index of the retrieval and transformation processes (recall of critical items) and (b) an index of the substitution process (intrusion errors).

Regarding the retrieval and transformation processes associated with WMC, we expected that musicians would outperform non-musicians, especially in experimental conditions that demand more attentional resources—that is, in high-load and high-suppression conditions.

In relation to the substitution process, we expected that musicians' increased efficiency in retrieval and transformation processing would release activation (Just &

Carpenter, 1992) or attentional resources (Engle, 2002) to suppress no-longer-relevant or irrelevant information, and that they would outperform non-musicians in increasingly demanding conditions.

3.1.2 Method

3.1.2.1 Participants

The sample for this study consisted of 138 students: 74 children in 3rd and 4th grade and 64 adolescents in 9th and 10th grade. All participants were white Spanish natives of urban populations and of middle socio-economic status. All participants attended publicly funded autonomous schools. None of them had been identified as having learning or language disabilities. Of the 74 children, 37 (26 girls, 11 boys; M = 10.9, SD = .44) were in their 3rd year of formal individual instrument training (violin, n = 10; viola, n = 3; cello, n = 3; double bass, n = 3; flute, n = 9; oboe, n = 1; clarinet, n = 2; saxophone, n = 3; trumpet, n = 1; trombone, n = 2) at the same music school, and 37 (15 girls, 21 boys; M = 11, SD = .40) had no formal musical training. Of the 64 adolescents, 32 (21 girls, 11 boys; M = 15.2, SD = .49) were in their 7rd year of formal individual instrument training (violin, n = 12; viola, n = 1; cello, n = 4; flute, n = 2; oboe, n = 4; clarinet, n = 4; saxophone, n = 2; horn, n = 1; trumpet, n = 2) at the same music conservatory, and 32 (21 girls, 11 boys; M = 15, SD = .40) had no formal musical training. Within each age group (11/15 years), participants were matched on Raven's score (11 years: musicians, M = 45.78, SD = 4.50, non-musicians, M = 46.19, SD = 3.61; 15 years: musicians, M = 52.28, SD = 4.16, non-musicians, M = 51.03, SD = 4.20)[4]. All musicians (children and

[4] In order to discard that musician group were more heterogeneous than non-musicians we analysed the variability within each participant group in relation to age, fluid intelligence and musical training (in the

adolescents) had simultaneously learned to read and perform music through traditional methodology of musical language teaching without an instrument (rhythm lecture, intonation, and music theory), and progressive scales, studies, and compositions for an instrument. All participants were evaluated at school, and parental consent was obtained in all cases. Ethical approval for this project was given by the National Distance Education University (UNED) [MICCIN EDU2011-22699].

3.1.2.2 Materials

Raven´s Standard Progressive Matrices: Sets A, B, C, D, E (Raven, 1960). This test estimates the *g* factor. It measures the immediate ability to develop a systematic method of reasoning through the understanding of meaningless figures and the relationships between them. We decided to use this test because it is considered 'the best measure of fluid *g*' (Nisbett, et al., 2012, p. 145), and due to its relationship to executive functioning (e.g. Miyake, et al., 2000; Oberauer, Lange, & Engle, 2004).

Updating in WM task: We used a Spanish-language adaptation of an updating information in WM task (Carriedo et al., 2016) developed by De Beni and Palladino (2004). The task had a total of 24 lists (20 experimental lists and four practice lists), each containing 12 words. The words were names of objects, animals, or body parts of different sizes, and abstract common nouns. Each list included words to be recalled (relevant words), words to be discarded (irrelevant words), and filler words. The frequency of each type of word varied in each list depending on the experimental condition. Thus, the number of relevant words in each list varied between three (low memory load) and five (high memory load).

musician groups) using Pearson´s variability coefficient. The results showed a coefficient below 20% that reflect an acceptable homogeneity among the participants within each group, for all the variables measured.

The number of irrelevant words varied between two (low suppression) and five (high suppression). Finally, the number of abstract filler words varied from two to seven. The composition of the lists as a function of memory load and suppression can be seen in Table 1. Target words (relevant and irrelevant) were familiar concrete nouns referring to body parts, objects, or animals that were classified by size. Filler words were abstract nouns. The 24 lists were distributed among four experimental conditions with six lists per condition. One list from each experimental condition was considered a practice list. Thus, each experimental condition comprised five lists. The total number of words to be recalled across all condition lists was 80 (practice lists were excluded): 25 for each high-load condition, and 15 for each low-load condition. In 10 of the lists, the participants were asked to remember the three smallest items (low-load conditions), whereas in the remaining 10 lists, they were asked to remember the five smallest items (high-load conditions). Likewise, for 10 of the lists, participants had to suppress previously presented items that were no longer the smallest items, which included two items for the 10 lists used in the low-suppression condition and five items for the 10 lists included in the high-suppression condition.

An example of a high-load/high-suppression list is: *árbol (tree), autobús (bus), piscina (pool), sofá (couch), cesta (basket), tema (topic), acto (act), flor (flower), dedo (finger), lápiz (pencil), oreja (ear), patata (potato)*. In this condition, the participants must: (a) recall the five smallest objects, that is, *flower, finger, pencil, ear,* and *potato*; (b) suppress the remaining five objects that are not the smallest, that is, *tree, bus, pool, couch,* and *basket*; and (c) ignore the abstract words, that is, *topic* and *act*.

Dependent variables were the proportion of correctly recalled words and the proportion of intrusion errors (incorrectly recalled words).[5]

Table 1. Composition of the lists as a function of the experimental conditions.

Low-load/low-suppression (5 Lists)	Low-load/high-suppression (5 Lists)	High-load/low-suppression (5 Lists)	High-load/high-suppression (5 Lists)
3 Relevant items 2 Irrelevant items 7 Filler items	3 Relevant items 5 Irrelevant items 4 Filler items	5 Relevant items 2 Irrelevant items 5 Filler items	5 Relevant items 5 Irrelevant items 2 Filler items

3.1.2.3 Procedure

All participants were tested individually. Twenty-four lists, each comprising 12 auditory words, were presented to the participants. Within each list, the auditory stimuli lasted less

[5] The proportion of intrusions was calculated by dividing incorrectly recalled words by the total number of words to be recalled for each experimental condition. That is, dividing the errors by 25 in the condition of high memory load and by 15 in the condition of low memory load. Reliability tests showed that both, correct recall (retrieval and transformation index) and intrusion errors (substitution index) showed good reliability (Cronbach´s α = .83, and .86 respectively) for our sample.
It could be considered that correct responses and intrusion errors were not fully independent measures (r = -.72, p < .01), and its relationship could reflect some trade-off effect. However, despite this fact, previous research probed that the indexes of retrieval/transformation and substitution could be empirically differentiated (Carretti, Borella, Cornoldi, & De Beni, 2009; Carretti, Cornoldi, De Beni, & Romanò, 2005; Carriedo et al., 2016; Chiappe et al., 2000; De Beni & Palladino, 2004; Lechuga et al., 2006; Palladino, De Beni, Cornoldi, & Pazzaglia, 2001; Passolunghi & Pazzaglia, 2005). In addition, these two indexes have shown different predictive value in different cognitive processes such as reading comprehension (Carretti et al., 2009) reading disabilities related to aging (Chiappe et al., 2000), and math problem solving (Passolunghi & Pazzaglia, 2005). Finally, it has been described differentiated developmental trajectories for the processes of retrieval and transformation and substitution measured through these indexes (Carriedo et al., 2016 Conklin et al., 2007; Gathercole et al., 2004). In this sense, even when memory load and suppression differently interact as a function of age to suppress no relevant information, a subsequently correlational analysis showed that whereas correct recall index was significantly related to age (r = .46, p < .01), intrusion errors index did not (r = -.12, p = .16), which would support the differentiated analysis carried out in our study.

than 1,000 ms and were presented at a constant speed with a two-second interval between words. The presentation order of the lists was randomised and, within each list, the item presentation was also randomised. Randomisation and time were controlled by E-Prime software, version 2.0 (Psychology Software Tools Inc; www.pst-net.com/eprime).

The participants were instructed to carefully listen to the list, and when the list was finished, they were to recall the three or five smallest animals or objects in the list. At the beginning of each list, a message was displayed on a computer screen to indicate the number of smallest items to remember (three or five). A beep then preceded the first word of the list. At the end of each list of 12 items, a different beep and a large question mark on the screen prompted the participants to recall the three or five smallest items of the current list by verbal response. To continue with the next list, participants were to press the space bar. Thus, during the task, the participants had to update words according to a semantic criterion (size), which implies substituting and inhibiting previously presented words that are no longer relevant under variable conditions of maintenance (words to be recalled) and inhibition (words to be discarded or inhibited).

3.1.3 Results

A mixed ANCOVA (2 × 2), with group (musicians/non-musicians) and age[6] (11/15) as between-subject factors, memory load (low and high) and level of suppression (low and high) as within-subject factors, and Raven´s scores as a covariate, was carried out for correct responses and same-list intrusions. As previously mentioned, correct responses

[6] Due to age differences within each group, that could be associated with updating efficiency (Carriedo et al., 2016; De Beni & Palladino, 2004; Lechuga, Moreno, Pelegrina, Gómez-Ariza, & Bajo, 2006) we also included age as between group factor in the subsequent analysis.

are considered an index of retrieval-transformation processes, and same-list intrusions are an index of suppression of information in WM. The Bonferroni correction was applied in multiple comparisons. Table 2 (panels A, B) shows the mean proportion (and standard deviation) of correct answers and error same-list intrusions by age and group (musicians/non-musicians).

Table 2. Mean proportion (and standard deviation) of correct answers and intrusion errors by group.

	Group		Musicians (Ns = 69)		Non-musicians (Ns = 69)	
	Age		11 (Ns=37)	15 (Ns =32)	11 (Ns =37)	15 (Ns=32)
Panel A. Recall of critical words	Low load	Low supression	.87 (.14)	.96 (.06)	.84 (.19)	.92 (.07)
		High supression	.85 (.14)	.93 (.07)	.81 (.20)	.86 (.10)
	High load	Low supression	.65 (.13)	.82 (.11)	.67 (.12)	.77 (.11)
		High supression	.65 (.16)	.81 (.12)	.64 (.15)	.78 (.11)
	Overall		**.76**	**.89**	**.74**	**.83**
Panel B. Intrusion errors	Low load	Low supression	.06 (.09)	.03 (.04)	.14 (.18)	.06 (.07)
		High supression	.10 (.12)	.06 (.07)	.17 (.19)	.13 (.10)
	High load	Low supression	.09 (.09)	.09 (.07)	.15 (.13)	.15 (.11)
		High supression	.17 (.14)	.11 (.09)	.22 (.17)	.18 (.12)
	Overall		**.11**	**.07**	**.17**	**.13**

Proportion of recall of critical items

Table 3 (Panel A) shows all the within and between effects and their interactions for correct recall. As expected, the results showed a significant effect of age, F (1, 133) = 11.23, p < .01, ηp^2 = .08, which showed a developmental trend in maintenance processes. Moreover, the results also showed a significant effect of memory load: F (1, 133) = 6.88,

$p < .05$, $\eta p^2 = .05$. The proportion of correct responses was lower in the high-load condition (.72) than in the low-load condition (.88) in all participants, regardless of age or musical training[7]. Finally, the results showed a significantly interaction load x age: F (1, 133) = 6.25, $p < .05$, $\eta p^2 = .05$, which reflected that the proportion of correct responses was significantly lower in children (.84; high load, .65) than in adolescents (low load, .92; high load, .80), especially in high load condition.

Proportion intrusion errors

Table 3 (Panel B) shows all the within and between effects and their interactions for intrusion errors. The results showed a significantly effect of musical training: F (1, 133) = 13.59, $p < .01$, $\eta p^2 = .09$. That is, that musicians outperformed non-musicians in all experimental conditions.

The results also showed a significantly interaction load x suppression x age F (1, 133) = 7.99, $p < .01$, $\eta p^2 = .06$, which would reflect that the interaction between load and suppression was different in children and adolescent participants. The analysis of this interaction revealed that in high memory load condition the effect of the level of suppression significantly differed at 11 and 15 years: F (1, 136) = 5.36, $p < .05$, $\eta p^2 = .04$, that is, that performance of adolescents under high memory load conditions s were less affected by high suppression than children were. The results also showed that children

[7] An anonymous reviewer suggested the existence of a possible ceiling effect. However, even when in less demanding conditions the scores were high (correct responses) or low (errors), especially for the older participants, the experimental manipulation of memory load and level of suppression conditions significantly affected to both, correct responses and errors. Our results were similar to those obtained in previous research using the same task through development (see Carriedo et al., 2016; Lechuga, Moreno, Pelegrina, Gómez-Ariza, & Bajo, 2006) and in the study of individual differences in various areas, such as arithmetic problem-solving (Passolunghi & Pazzaglia, 2005) or reading comprehension (Carretti, et al., 2009).

and adolescents also significantly differed in their performance under low suppression condition: F (1, 136) = 6.24, $p < .05$, $\eta p^2 = .04$, which reflected that children were less affected by memory load than adolescents were.

Table 3. Within and between effects/interactions for correct recall and intrusion errors.

ANCOVA (covariate Raven)						
Source of Variation	*MS*	*df*	*F*	*p-value*	ηp^2	*Power*
Panel A. Recall of critical words						
Between subjects						
Raven	**.10**	**1**	**10.15**	**.00**	**.07**	**.89**
Group	.03	1	2.91	.09	.02	.40
Age	**.11**	**1**	**11.23**	**.00**	**.08**	**.91**
Group x Age	.01	1	.49	.49	.00	.11
Within subjects						
Load	**.07**	**1**	**6.88**	**.01**	**.05**	**.74**
Load x Raven	.01	1	1.25	.27	.01	.20
Load x Group	.02	1	2.29	.14	.02	.32
Load x Age	**.06**	**1**	**6.25**	**.01**	**.05**	**.70**
Load x Group x Age	.01	1	.54	.46	.00	.11
Suppression	.00	1	.15	.70	.00	.07
Suppression x Raven	.00	1	.36	.55	.00	.09
Suppression Group	.00	1	.72	.40	.01	.13
Suppression x Age	.00	1	.04	.84	.00	.05
Suppression x Group x Age	.00	1	.17	.68	.00	.07
Load x Suppression	.05	1	1.77	.19	.01	.26
Load x Suppression x Raven	.04	1	1.38	.24	.01	.21
Load x Suppression x Group	.01	1	.47	.50	.00	.10
Load x Suppression x Age	.06	1	2.15	.15	.01	.30
Load x Suppression x Group x Age	.02	1	.68	.41	.00	.13

Table 3. Continued

Source of Variation	*MS*	*df*	*F*	*p-value*	ηp^2	*Power*
Panel B. Intrusion errors						
Between subjects						
Raven	.01	1	1.26	.26	.01	.20
Group	**.13**	**1**	**13.59**	**.00**	**.09**	**.96**
Age	.01	1	1.44	.23	.01	.22
Group x Age	.00	1	.13	.72	.00	.07
Within subjects						
Load	.00	1	.10	.76	.00	.06
Load x Raven	.01	1	.71	.40	.01	.13
Load x Group	.00	1	.02	.89	.00	.05
Load x Age	.00	1	.11	.74	.00	.06
Load x Group x Age	.01	1	1.10	.30	.01	.18
Suppression	.01	1	1.00	.32	.01	.17
Suppression x Raven	.02	1	2.35	.13	.02	.33
Suppression x Group	.00	1	.08	.78	.00	.06
Suppression x Age	.02	1	3.29	.08	.02	.44
Suppression x Group x Age	.00	1	.63	.43	.01	.12
Load x Suppression	.03	1	1.62	.21	.01	.24
Load x Suppression x Raven	.04	1	1.89	.17	.01	.28
Load x Suppression x Group	.00	1	.24	.63	.00	.08
Load x Suppression x Age	**.15**	**1**	**7.99**	**.00**	**.06**	**.80**
Load x Suppression x Group x Age	.01	1	.69	.41	.01	.13

MS: main square sume; *df:* degrees of freedom.

3.1.4 Discussion

Music performance is a complex activity that demands high levels of cognitive control. For this reason, it has been associated with some executive functions, such as updating information in WM and cognitive inhibition. The aim of our study was to analyse differences in updating ability associated with musical training in the retrieval, transformation, and substitution processes of updating information in WM executive function, using an updating task (De Beni & Palladino, 2004). The updating task allowed us to differentiate among these processes and manipulate memory load and level of suppression independently.

Regarding the processes of retrieval and transformation associated with WMC, we had hypothesised that musicians would outperform non-musicians, and this would be reflected in a greater ability to retrieve and transform information in WM, especially in experimental conditions that demand more attentional resources (i.e. in high-load and high-suppression conditions).

The results showed that the ability to retrieve and transform information in WM was mainly affected by age—the 11-year-olds were significantly less efficient than the 15-year-olds. However, there were no significant differences that could be related to musical training. These results contradict our hypothesis of musicians having a greater WMC, but corroborate previous studies showing important developmental differences in executive functioning (Anderson et al., 2001; Carriedo et al., 2016; Luna et al., 2004; Zald & Iacono, 1998), specifically in the retrieval and transformation processes that develop from late childhood to adolescence (Carriedo et al., 2016; Gathercole et al., 2004; Conklin et al., 2007), using the same task (Carriedo et al., 2016) and complex WM tasks (Gathercole et al., 2004; Conklin et al., 2007). Our results seem to contradict previous research that found advantages for musician adults (Franklin et al., 2008; George & Coch, 2011; Ramachandra et al., 2012) and children (Roden et al., 2014) using WM complex span tasks. However, a subsequent analysis controlling for the effect of age showed that the effect of musical training on the ability to retrieve and transform information in WM was nearly of significance (p = .06). Thus, it seems that developmental efficiency associated with age (Bjorklund & Harnishfeger, 1990; Case et al., 1982), rather than musical training, would be the most significant predictor of the ability to retrieve and transform information in WM when comparing musicians and non-musicians through development. However, the fact that the differences between musicians and non-musicians when age is controlled fell short of the standard levels of significance, would probably show that musical training enhances the development of rehearsal (Franklin et al., 2008), coding (Roden et al., 2014), or processing (George & Coch, 2011; Ramachandra et al., 2012) strategies, as suggested in previous research, a topic that deserves further investigation using different kind of updating tasks.

However, when we found clearly significant differences between musicians and non-musicians, it was in relation to the process of substitution. Our results revealed that musical training could be associated with improved global efficiency of resources that allow for the active suppression of information, as suggested by the limited resource theories of WM (Engle, 2002; Just & Carpenter, 1992). This shows that that musical training could increase efficiency, preventing the overload of the WM system (Baddeley, 1996). Thus, our results reflect that although the attentional resources available may be limited by development, (Bjorklund & Harnishfeger, 1990; Case et al., 1982), the efficiency in the ability to update WM content would also be increased by musical training. That is a general effect that it is not restricted to more demanding conditions as hypothesized.

In addition, the significant interaction load x suppression x age reflected differential performance between 11-year-olds and 15-year-olds, in both, high load and low suppression conditions, due to its differential developmental trajectories (Carriedo et al., 2016).

What we found is that in high load conditions the performance of children would be more affected than it would in adolescents, since their executive processes related to the maintenance of the information are still developing (Carriedo et al., 2016). High memory load conditions overwhelmed attentional resources leaving less available resources for suppression in younger participants where the suppression condition was the most demanding. Nevertheless, the adolescents who were more efficient maintaining information in WM had enough resources to independently suppress the variable demands on it.

Taking into account that both, maintenance and suppression are active processes which consume attentional resources (Ecker et al., 2014), these results could be explained through those developmental (Bjorklund & Harnishfeger, 1990; Case et al., 1982) and efficiency theories (Engle, 2002; Just & Carpenter, 1992; Kane & Engle, 2000), in which WM efficiency should rely on a trade-off mechanism between maintenance and suppression processes. From these perspectives, an increased efficiency in maintenance could release activation to supress irrelevant information. Thus, efficiency in maintenance processes would be responsible for the increased ability of the adolescent participants to suppress irrelevant information even in high demanding conditions. Importantly, these results would corroborate that developmental differences in updating information in WM are driven by memory load, as previous research has shown (Carriedo et al., 2016, De Beni & Palladino, 2004).

In the same line, under low suppression conditions, children would not be affected by memory load due to the fact that even low load conditions could be very demanding for younger children (there would be a floor effect). The adolescents with a greater efficiency of the inhibitory processes associated to cognitive development, would be more affected by only high memory load.

The most novel contribution of these results is that they could provide an alternative explanation to the relationship found between musical training and WMC using complex span tasks. It has been suggested that this type of task involves inhibitory processes that suppress no-longer relevant information and enable the active maintenance of relevant information (Belacchi et al., 2010). Moreover, the analysis of intrusion errors in WM complex span tasks has revealed the relevance of inhibitory processes in the study of individual differences in WMC (e.g. Chiappe et al., 2000; Friedman & Miyake, 2004). However, the traditional scoring followed by these studies (Franklin et al., 2008; George & Coch, 2011; Hou et al., 2014; Ramachandra et al., 2012; Roden et al., 2014) was based only on correct recall without considering intrusion errors, and therefore did not differentiate between the active maintenance and inhibition sub-processes necessary for WM efficiency (Chiappe et a., 2000). Thus, without discarding the described relationship between musical training and advantages in storage/maintenance abilities, it could be possible that the substitution process—unique to updating (Ecker et al., 2010)—could also be related to the improvements in WMC shown by musicians in previous studies.

3.1.5 Conclusions

In summary, we found that musicians were more efficient than non-musicians in the ability unique to updating (Ecker et al., 2010), to supress no-longer or irrelevant information, even when fluid intelligence was controlled for. Whereas there were no significant differences in the ability to retrieve and transform information in WM between musicians and non-musicians, there were ability differences related to age. In this sense, it has been suggested that musicians strength in areas such as nonverbal reasoning (Forgeard, Winner, Norton, & Schlaug, 2008), mathematical reasoning (Costa-Giomi, 2004; Vaughn, 2000), verbal processing (Gunter, Schmidt, & Besson, 2003; Hannon & Trainor, 2007), visual processing (Jakobson, Lewycky, Kilgour, & Stoesz, 2008), and verbal memory (Chan, Ho, & Cheung, 1998; Ho, Cheung, & Chan, 2003; Kilgour, Jakobson, & Cuddy, 2000; Moreno et al., 2011) are relevant if we consider, as George and Coch (2011) suggested, that the ability to continuously update information in WM is the mechanism that mediates all such improvements in different domains of knowledge. Although this idea would obviously require more thorough research, there could be benefits gained from establishing extensive school programmes of musical training, which could allow for longitudinal studies of the effects of musical training in diverse populations. Moreover, if musical training enhances cognitive abilities connected with academic achievement, it may be beneficial to develop specific musical training programmes for children with learning disabilities or executive function deficits.

A possible criticism of this work is its focus on musical training as the only variable responsible for the differences found between musicians and non-musicians.

It is possible that musicians have cognitive advantages that make them more likely to engage in musical activities. In this sense, Schellenberg (2011), who did not find any relationship between musical training and executive control, concluded that musicians are high-functioning children who decide to take music lessons. However, we do not believe that this is the case, because the musicians and non-musicians in our study were matched in terms of fluid intelligence, which has been shown to have a significant relationship with the updating task used in our study (Carretti, Belachi, & Cornoldi, 2010), and was controlled for in all analyses. Moreover, neuroimaging longitudinal studies of children have found no pre-existing neural, cognitive, or musical differences between musicians and non-musicians (Habibi et al., 2014; Norton et al., 2005). Finally, even when children can decide to enrol in extra-curricular musical activities, at this age, musical involvement seems to be temporary (Lamont, Hargreaves, Marshall, & Tarrant, 2003), and they cannot assume the training intensity it takes to become in ‘real musicians’. However, as some studies have revealed a significant correlation between the intensity of musical training and the degree of structural brain changes in adult musicians (e.g. Gaser & Schlaug, 2003), training intensity must be a variable of consideration in subsequent studies of children, in addition to other variables such as personality and motivation.

Differences between musicians and non-musicians could also be related to environmental experiences during development. Without discarding this possibility, it is relevant to note that executive functions have appeared to be highly heritable (Friedman et al., 2008), and age has been considered the most obvious predictor of differences in executive function tasks during development (Ardila, Roselli, Matute, & Guajardo, 2005). In addition, although some environmental factors such as socio-economic status (SES) seem to be highly related to cognitive development (e.g. Baydar & Brooks-Gunn, 1994; Liaw & Brooks-Gunn, 1994), it has been suggested that the effect of SES may appear only when SES differences among groups are large (Hackman and Farah, 2009), what was not the case in this study in which this variable was previously controlled by carefully selecting children and adolescents of middle SES.

One limitation of this study is that we used one task to measure updating. Although the task used in our study has been shown as a reliable measure of updating in WM executive function (Carretti et al., 2009; Carriedo et al., 2016; De Beni & Palladino, 2004; Lechuga et al., 2006; Passolunghi & Pazzaglia, 2005), other updating measures such as WM complex span tasks should be included in subsequent studies. Finally, an anonymous reviewer has pointed out that the auditory presentation of the task in our study may have benefitted the musician group. Although it could be assumed that musical training may enhance auditory memory, empirical evidence has shown contradictory results. Some studies have found positive relationships between musical training and auditory memory (Franklin et al., 2008; Talamini et al., 2016), whereas others have not (Strait, Kraus, Parbery-Clark, & Ashley, 2010). Moreover, in some cases, visual memory has also been shown to be positively related to musical training (Degé, Wehrum, Stark, & Schwarzer, 2011). Thus, this study opens some questions that can be addressed in future research.

3.2 ESTUDIO 2

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The Contributions of Updating in Working Memory Sub-Processes for Sight-Reading Music Beyond Age and Practice Effects

Laura Herrero[1] and Nuria Carriedo[2]*

[1]Facultad de Educación y Salud, Universidad Camilo José Cela, Madrid, Spain

[2]Departamento de Psicología Evolutiva y de la Educación, Facultad de Psicología, Universidad Nacional de Educación a Distancia (UNED), Madrid, Spain

Music sight reading (SR), has been described as a complex task which involves the simultaneous reading of new non-rehearsed material and performance. Although practice related skill have revealed as the most significant predictor of SR, working memory (WM) processes have shown its relevance in the study of individual differences in SR. We aimed to determine how the updating in WM sub-processes of retrieval/transformation and substitution, could differentially contribute to SR when the effects of age and practice were controlled, and according to the difficulty of the SR tasks and the different indexes of performance measured (SR error, tempo maintenance, rhythmic accuracy, pitch accuracy, articulation accuracy and expressiveness). 131 music students of different ages and levels of instrument knowledge participated in the study. The results showed that whereas the efficiency in the retrieval/transformation sub-processes contributed to SR regardless of the difficulty of the SR tasks, the substitution sub-process also contributed to performance at sight but only in low demanding SR tasks. The results also showed all the updating sub-processes were engaged in SR regarding the proportion of error and rhythmic accuracy. However, both expressiveness and tempo maintenance seemed to be uniquely driven by efficiency in the retrieval/transformation sub-processes, whereas articulation accuracy relied on the efficiency to suppress irrelevant information from WM.

The contributions of updating in working memory sub-processes for sight-reading music beyond age and practice effects

Abstract

Music sight reading (SR), has been described as a complex task which involves the simultaneous reading of new non-rehearsed material and performance. Although practice related skill have revealed as the most significant predictor of SR, working memory (WM) processes have shown its relevance in the study of individual differences in SR. We aimed to determine how the updating in WM sub-processes of retrieval/transformation and substitution, could differentially contribute to SR when the effects of age and practice were controlled, and according to the difficulty of the SR tasks and the different indexes of performance measured (SR error, tempo maintenance, rhythmic accuracy, pitch accuracy, articulation accuracy and expressiveness). 131 music students of different ages and levels of instrument knowledge participated in the study. The results showed that whereas the efficiency in the retrieval/transformation sub-processes contributed to SR regardless of the difficulty of the SR tasks, the substitution sub-process also contributed to performance at sight but only in low demanding SR tasks. The results also showed all the updating sub-processes were engaged in SR regarding the proportion of error and rhythmic accuracy. However, both expressiveness and tempo maintenance seemed to be uniquely driven by efficiency in the retrieval/transformation sub-processes, whereas articulation accuracy relied on the efficiency to suppress irrelevant information from WM.

Keywords: music sight-reading, updating in working memory, retrieval, transformation, substitution, practice.

3.2.1 Introduction

Music sight reading (SR), has been considered as one of the five basic abilities for all musicians (McPherson & Thompson, 1998). SR has been described as a complex transcription task involving the simultaneous reading of new non-rehearsed material and performance (Sloboda, 1982; Thompson, 1987; Waters, Townsend, & Underwood, 1998; Waters, Underwood, & Findlay, 1997). Contrary to rehearsed music, which offers certain automation of performance though deliberate practice, SR would be considered as a novel task. In addition, SR could be considered as a kind of multitasking performance because it requires at least: (a) the processing of visual information linked to reading, including decoding and understanding the score; (b) the motor control linked to performance, including fine motor control and musicality; and (c) the processing of auditory information linked to the adjustment of performance to the printed material, all in real time. Thus, due to the fact that SR requires the simultaneous execution of various tasks in a brief period of time it could be linked to executive functioning (Oswald, Hambrick, & Jones, 2007).

In this context, our main objective was to analyse the role of updating information in working memory (WM) executive function in SR performance, in string and wind musicians of different ages and levels of instrument knowledge.

Updating information in WM is one of the functions related to executive control (Miyake et al., 2000). It was initially defined by Morris and Jones (1990), as the mechanism responsible for the replacement of WM content that is no longer relevant in the ongoing task for new novel material, and of the adjustment of remaining material to the incoming new material. Updating information in WM has been highly related to WM capacity (WMC) (Belacchi, Carretti, & Cornoldi, 2010; Miyake et al., 2000; St Clair-Thompson & Gathercole, 2006). However, Ecker, Lewandowsky, Oberauer, and Chee (2010) —using structural equation models (SEM)— concluded that WMC and updating could be distinguishable in terms of their underlined sub-processes, specifically: (a) retrieval of the relevant information from Long Term Memory (LTM); (b) transformation of information in WM; and (c) substitution of information in WM. According to Ecker et al., (2010), the substitution sub-process may be the only sub-process specific for updating, whereas both retrieval and transformation could be a shared source of variance between WMC and updating. Thus, substitution would be the base for differentiating between updating and WMC. Other authors have also empirically differentiated between the sub-processes of retrieval/transformation and substitution (Carretti, Borella, Cornoldi, & De Beni, 2009; Carretti, Cornoldi, De Beni, & Romanò, 2005; Carriedo, Corral, Montoro, Herrero & Rucián, 2016; Chiappe, Siegel & Hasher, 2000; De Beni & Palladino, 2004; Lechuga, Moreno, Pelegrina, Gómez-Ariza, & Bajo, 2006; Passolunghi & Pazzaglia, 2005), showing different developmental patterns (Carriedo et al., 2016; Lechuga et al., 2006), and also different predictive values in the study of individual differences in some complex skills such as reading comprehension (Carretti et al., 2009; Chiappe et al., 2000) or math problem solving (Passolunghi & Pazzaglia, 2005).

Other subsequent study carried out by Ecker, Lewandowsky and Oberauer (2014), in which the substitution sub-process was analysed, revealed that the efficient substitution of no longer relevant information could require the continuous shifting between between removal and the encoding. They proposed that the active removal could be critical to allow the WM system to efficiently focus on relevant information. Other authors such as Lavie, Hirst, De Fockert, and Viding (2004) suggested that it may be the increase in memory load which could drain the availability of attentional resources to reject no relevant information. Finally, efficiency theories posted the existence of a trade-off effect of the attentional resources available to simultaneously maintain and suppress information in WM (e.g. Engle, 2002; Just & Carpenter, 1992; Kane & Engle, 2000).

To our knowledge, there is no empirical evidence that addresses the role of updating information in WM sub-processes in SR performance. However, some previous studies revealed the involvement of the related WMC in it. Specifically, Kopiez and Lee (2006), focused in expert adult pianists to analyze rhythmic accuracy in SR, considered the most objective and reliable measure of SR execution (e.g. Drake & Palmer, 2000; Elliot, 1982; Gromko, 2004; Hayward & Gromko, 2009; Hodges, 1992; Kopiez & Lee, 2008; McPherson, 1994; Mishra, 2014; Waters et al., 1997; Wurtz, Mueri, & Wiesendanger, 2009). They proposed a dynamic model using five SR tasks of an increasing level of difficulty. These authors considered three different types of predictors of SR: (a) general cognitive skills (WM, short-term music memory, short-term numerical memory, and fluid intelligence); (b) elementary cognitive skills (tapping speed, simple reaction time, trilling speed, and information processing speed); (c) practice-related skills (practicing solo, sight treading, and auditory representation skills practice). Their results showed that practice was the most significant predictor, but that WM also predicted SR performance. However, its influence changed as the level of difficulty of the SR task did, increasing for the easiest levels and decreasing for the most difficult ones. Thus, Kopiez and Lee (2006) concluded that the predictive value of WM and practice related skills for SR would be dynamic, varying in its significance as a function of the complexity of SR tasks.

In a later study with a similar sample, Kopiez and Lee (2008) found that psycho-motor speed, early acquired expertise, mental speed, and the ability for auditory imagery were significant predictors of SR performance, whereas the influence of WM came near of the standard levels of significance (*p* = .06).

These apparent contradictory results of both studies could be associated to methodological differences between them. In their first study, Kopiez and Lee (2006) analysed the relation among the different predictors and SR separately by the level of difficulty of the SR tasks. In their second study (Kopiez & Lee, 2008), these relationships were explored taking together all levels of difficulty. Thus, it could be possible that the type of analysis carried out in the second study overshadowed the existing complex relationship between WM and SR.

Another subsequently study carried out by Meinz and Hambrick (2010) with adult pianists of a wide range of instrument knowledge found that WM could also predict SR efficiency independently from general music performance skills[8].

Considering all these studies, it may be suggested that (a) practice SR related skills could be considered as one of the main predictors of SR performance (but see for a different account: Mishra, 2014; Zukhov, 2017); (b) WM processes seem to be involved in SR performance both among expert musicians and those with different levels of instrument knowledge; (c) regardless of effect of practice, WM could play a role in SR performance, both in rhythm accuracy and in global subjective performance, but the influence of WM is complex and probably depends on the type of indexes of SR

[8] As Lehmann and Ericsson (1996) suggested, general music performance skills could be highly related to SR in musicians of varied music skill levels, whereas general music performance skills and SR could be dissociated in expert groups in favour of specific SR practice. Thus, practice related skills could refer to both, level of instrument knowledge and specific SR training accumulated.

performance obtained, or on the kind of WM task used (Kopiez & Lee, 2008).

Taking into account this rationale, our main aim was to analyse how the sub-processes of retrieval, transformation and substitution underlying updating in WM were related to SR as a function of the demands on memory load and level of suppression, and to analyse how the efficiency in these updating sub-processes could be a source of individual differences in SR as a function of the difficulty of the SR task and of different indexes of performance.

For this purpose, we used an updating task (De Beni & Palladino, 2004), that provided three different indexes — under variable demands of load and suppression— that would correspond to the components of updating executive function described by Ecker et al., (2010): (a) an index of the retrieval and transformation sub-processes (recall of critical items) more related to WMC measures, and (b) two indexes of the substitution sub-process: same lists intrusions, as an index of suppression of information in WM; and previous lists intrusions, as an index of proactive interference or suppression of irrelevant information retrieved from LTM. In addition, we used two different SR tasks of two levels of difficulty which were measured through separate elements of performance (SR error, tempo maintenance, rhythmic accuracy, pitch accuracy, articulation accuracy and expressiveness).

We expected a positive correlation between the retrieval/transformation updating index and SR, and a negative correlation between the substitution updating index and SR, both regardless of difficulty of the SR task when age and practice were controlled for. However, considering the possible existence of a trade-off effect between updating sub-processes of retrieval/transformation and substitution (e.g. Engle, 2002; Just & Carpenter, 1992; Kane & Engle, 2000), their relationship to SR could vary as a function of the demands of memory load and level of suppression of the updating task. Thus: (a) if SR were mainly driven by the simultaneous maintenance and processing of information in WM, then there will be a correlation between SR tasks and updating in WM indexes in high load and low suppression condition; (b) if SR were mainly driven by the inhibition of irrelevant or no longer relevant information, then there will be a correlation between SR tasks and updating in WM indexes in low load and high suppression condition; (c) if both sub-processes were equally relevant for an efficient SR, then then there will be a correlation between SR tasks and updating in WM indexes in high load and high suppression condition.

Regardless of whether SR relies more on the retrieval/transformation or on the substitution sub-processes, we also expected that the efficiency in both sub-processes would significantly contribute to SR performance, especially in the most demanding SR tasks.

In addition, considering the existence of different elements within the musical structure involved in performance such as tempo, rhythm, pitch or articulation, we expected that the efficiency in the sub-processes of retrieval/transformation and substitution could differently contribute to the proficiency of participants. First, we expected that those efficient participants in the retrieval/transformation sub-process outperformed less efficient ones in those musical elements more related to expressiveness or fluency such as rhythm and tempo maintenance, due to their increased ability to maintain and process information in WM. Secondly, we expected that those efficient participants in the substitution sub-process would outperform less efficient ones in those musical elements more related to accuracy in the execution, such as pitch and articulation, due to their increased ability to suppress no longer relevant information. Thirdly, we expected a similar contribution of the efficiency in both updating-sub-processes regarding SR error index.

3.2.2 Material and Methods

3.2.2.1 Participants

131 music students that have been receiving music lessons of string or wind instruments participated in this study. Participants were classified into four groups according to age and level of instrument knowledge (see Table 1) : (1) elementary-low level, formed by 37 children aged 10-11 (*M* = 10.9, *SD* = .44; 26 females, 11 males), that have been receiving string or wind instrument lessons for at least 2 years; (2) elementary-high level, formed by 31 pre-adolescents aged 12-13 (*M* = 13.2, *SD* = .48 ; 25 females, 6 males), that have been receiving string or wind instrument lessons for at least four years; (3) intermediate level, formed by 32 adolescents aged 15-16 (*M* = 15.2, *SD* =.49 ; 21 females, 11 males, that have been receiving string or wind instrument lessons for at least six years; and (4) superior level, formed by 31 young adults (*M* = 22.3, *SD* = 1.34; 14 females, 17 males), that have been receiving string or wind instrument lessons for at least 12 years.

All the participants have learned to read music and to play simultaneously, through a traditional methodology of musical language teaching (rhythm lecture, intonation and music theory without an instrument) and progressive scales, studies and compositions for the instrument without specific SR training. Parents or guardians of the participants under 18 were informed in writing, and signed the consent of participation of their children in all cases. Young adult participants personally agreed to participate by signing a written informed consent form. Ethical approval was provided by the bioethics committee of Universidad Nacional de Educación a Distancia (UNED).

Table 1. Instrumental training of the musicians by level of instrument knowledge (means and standard deviations for individual instruction in years and for current individual practice).

Group	Elementary-low	Elementary-high	Intermediate	Superior
Accumulated individual instruction in years	2.9 (.32)	4.6 (.44)	6.8 (.28)	12.9 (.46)
Individual instruction in minutes per week	30	45	60	90
Group instruction in hours per week	2	3	5	7
Current individual practice in hours per week	2.46 (1.50)	3.19 (2.03)	7.77 (3.10)	21.23 (8.44)

3.2.2.2 Materials

Sight Reading test (SR test). Two different pieces from “Sound at Sight Series” (Trinity College of London, 2003a,b, 2004, 2007a,b,c,d,e, 2008, 2009a,b) were selected by instrument specialists for each kind of instrument. This series includes specific pieces for each instrument in 8 difficulty grades developed for sight reading examination in classical western music style. Pieces were selected as a function of the level of general performance of the participants: grade 3 (elementary-low level), grade 5 (elementary-high level), grade 6 (intermediate level), and grade 8 (superior level). The pieces within each level and instrument had similar difficulties regarding key, tempo, rhythm, melodic range and leap size. Taking into account that the participants played different string, wood wind and brass wind instrument which involve technical performance differences, key, rhythm, melodic range or leap size could be different among instruments within a similar level of general difficulty. Thus, the difficulty criterion was the time bar, based on previous research which has been shown that binary patterns and subdivisions are easier than ternary ones both in reproduction tasks (Drake, 1993) and in auditory discrimination ones (Smith & Cuddy, 1989). We choose a 2/4 or 4/4 piece (binary time bar and binary subdivision) such as a binary test for all the levels and instruments. In relation to the participant´s instrument knowledge, we selected the ternary pieces using both time bar and subdivision as criterion, that is, a 3/4 piece (ternary time bar and binary subdivision) for the elementary-low level, a 6/8 or 12/8 piece (binary time bar and ternary subdivision) for the elementary-high level, and a 6/8, 12/8, 3/8 or 9/8 (binary or ternary time bar and ternary subdivision) for the intermediate and superior levels.

In order to obtain a complete index of performance at sight, we selected as dependent variables different measures of performance: tempo maintenance, measured as the ability to maintain a fixed tempo during performance with the exception of tempo changes indicated in the score; rhythmic accuracy, measured as the correct proportion between notes and their corresponding rests, which allowed us to control not only the first note in a beat, but also all the notes or rests written in the score; pitch accuracy, measured as the correct tuning; articulation accuracy, measured as the correct performance of articulation signs. We also included an index of expressiveness, measured as general phrasing and musicality, and in the adjustment to dynamics, tempo changes or either expressive indications printed in the score. All these variables were blindly and independently evaluated from zero to ten by two expert musicians. They were professional musicians with a full education degree in classical western music (piano and viola), which include ten years of instrument training together with solfeggio, choir, harmony, art and music history, aesthetics, acoustics, organology, improvisation, accompanying, chamber music and/or orchestra. They both had more than 15 years of teaching and interpreting experience. They also had at least 10 years of experience as evaluators in music student competitions.

We derived two global indexes of SR. An index of global performance at sight was calculated by the means of the first four variables (tempo maintenance, rhythmic accuracy, pitch accuracy, articulation accuracy). Moreover, another global index of proportion of SR error (SR error) was calculated by dividing the total number of failed notes or rests by the total number of notes and rests written in the score. To obtain this index, the total notes and rests of each score were counted by the evaluators. The raters listened the recordings and marked with lines in a paper copy of the score of each participant the notes failed as a function of rhythm, pitch or articulation, together with repetitions or failed rests. Then, the number of errors was counted and its proportion calculated for each participant and score.

Updating Task. We used a Spanish adaptation of the updating task (Carriedo et al., 2016) developed by De Beni and Palladino, (2004). This task allowed us to obtain three different indexes — under variable demands of load and suppression—that would correspond to the components of updating executive function described by Ecker et al., (2010): (a) an index of the retrieval and transformation sub-processes (recall of critical items) more related to WMC measures, and (b) two indexes of the substitution sub-process: same lists intrusions, as an index of suppression of information in WM; and previous lists intrusions, as an index of proactive interference or suppression of irrelevant information retrieved from LTM. This task was used in previous research as part of a larger project. For a complete description of the stimulus see Carriedo et al. (2016), and Herrero and Carriedo (2018).

Practice related skills: we collected information through interviews about the number of years of instrument individual lessons from the beginning up to the present. We also collected information (in hours per week) about the amount of current practice, adding the time of individual and group lessons (chamber music, band or orchestra) and the amount of individual solo practice at home. Data concerning participants under the age of 18 was obtained by their parents.

3.2.2.3 Procedure

All participants were tested individually. The order of the tasks was counterbalanced as well as the order of the binary (A) and ternary (B) SR tests. All participants were evaluated at their music schools.

SR tests. All participants performed two consecutive scores. They were instructed to carefully look at the first score (tempo, bar, key signature) for 30 seconds to immediately perform the score trying not to make breakdowns or repetitions. Once finished, the same procedure was carried out for the second score. All the performances were audio-registered (SONY® IC Recorder ICD-UX71F) to be subsequently analysed and evaluated by two independent expert musician judges. Inter-rater correlations for all the SR indexes in both binary and ternary tests were significantly high (average r = .97, p = .010). To obtain a unique range of punctuations, the values of all the variables ranged from zero to ten were divided by ten.

Updating task. The stimulus of the task were auditorily presented in a computer. The presentation order of the stimulus and the items was randomized. E-Prime software, version 2.0 (Psychology Software Tools Inc; www.pst-net.com/eprime), was used for randomization and time control (see Carriedo et al., 2016; Herrero & Carriedo, 2018).

3.2.3 Results

We first tested whether binary and ternary SR tests differed in difficulty as a function of the time bar. Student *t* test showed that ternary tests were more difficult than binary ones (all *ps* < .050). Thus, we decided to analyse binary and ternary measures separately.

In order to analyse how the global index of SR was related to the three indexes of updating (recall of critical items, same-list intrusions and previous-list intrusions) as a function of both, the difficulty of the SR tasks and the demands on memory load and level of suppression, Pearson´s partial correlations controlling for age and practice (accumulated and current) were computed. As shown in Table 2, the global index of SR in both, binary and ternary tasks was significantly related to the recall of the critical items index (retrieval and transformation) only in high memory load and low suppression condition (binary: r = .22, p = .012; ternary: r = .18, p < .039). In addition, the global index of SR was significantly related to the proportion of same-list intrusions (index of inhibition in WM) in high load and low suppression condition, but in only binary task (r = .21, p < .018). No other significant result was found.

Taking into account the results of the partial correlations, we analysed how each specific index of SR could be differently affected by efficiency in the updating sub-processes as a function of the difficulty of the SR task. Thus, we selected those participants more and less efficient in both, the recall of critical items and the proportion of same-list intrusions in high memory load and low suppression condition. Participants who scored above the upper quartile in the recall of critical items were assigned to the "efficient recall" group (n = 43), and those who scored below the lower quartile were assigned to the "less efficient recall" group (n = 42). In a similar way, participants who scored above the upper quartile in the proportion of same-list intrusions were assigned to the "efficient suppression" group (n = 34), and those who scored below lower quartile were assigned to the "less efficient suppression" group (n = 40). Importantly, the sample in the case of the measure of expressiveness was reduced to n = 21 for the upper quartile and to n = 24 to the lower quartile, given that both, elementary-low and elementary-high groups scored zero in this measure. For the same reason, the sample was reduced to n = 20 for the upper quartile and to n = 22 to the lower quartile.

Multiple mixed ANCOVA 2 × 2, with group (efficient/less efficient) as between-subject factor, and SR task (binary/easy and ternary/difficult) as within-subject factor, and age and practice (accumulated and current) as covariates were carried out for all indexes of SR performance.

Table 2. Pearsons´partial correlations between global SR performance and updating indexes as a function of memory lead and level of suppression (controlled age and practice). Significant results are in bold (* $p < 0.05$, ** $p < 0.01$).

		SR_BIN N= 131	SR_TERN N =131
Recall	Low load-low suppression	.16	.08
	Low load-high suppression	.07	.07
	High load-low suppression	**.22***	**.18***
	High load-high suppression	.11	.02
Intrusions same-lists	Low load-low suppression	-.11	-.02
	Low load-high suppression	-.06	-.03
	High load-low suppression	**-.21***	-.09
	High load-high suppression	-.13	-.03
Intrusions previous lists			
	Low load-low suppression	-.06	-.05
	Low load-high suppression	-.07	-.12
	High load-low suppression	-.03	-.01
	High load-high suppression	-.02	-.02

Table 3 (panels A to G) shows the within and between effects/interactions of all the multiple ANCOVA regarding efficiency in the retrieval and transformation sub-processes. In relation to the global indexes of SR performance, the results showed a significant effect of group in the proportion of SR errors, F (1, 80) = 5.07, p = .027, ηp_2 = .06, whereas there was no significant effect regarding global performance at sight.

Table 3. Summary of the multiple ANCOVA. Within and between effects/interactions for all the SR variables as a function of efficiency in the correct recall of critical words. Significant results are in bold (* $p < 0.05$, ** $p < 0.01$).

ANCOVA (covariates Age, Accumulated practice, Current practice)							
Source of Variation	*N*	*MS*	*df*	*F*	*p-value*	ηp^2	*Power*
Panel A. Proportion of errors							
Between subjects							
Age	85	.01	1	.17	.71	.00	.07
Accumulated practice	85	.10	1	.26	.61	.00	.08
Current practice	85	.00	1	.02	.87	.00	.05
Group	**85**	**.20**	**1**	**5.07**	**.03**	**.06**	**.61**
Within subjects							
Error	85	.01	1	.64	.43	.01	.12
Error × Age	85	.01	1	.43	.51	.01	.10
Error × Accumulated practice	85	.00	1	.38	.54	.01	.09
Error × Current practice	85	.00	1	.08	.79	.00	.06
Error × Group	85	.00	1	.36	.55	.00	.09
Panel B. Global SR (SR)							
Between subjects							
Age	85	.01	1	.21	.65	.00	.07
Accumulated practice	85	.02	1	.36	.55	.00	.09
Current practice	85	.02	1	.15	.76	.00	.06
Group	85	.23	1	3.77	.06	.05	.48
Within subjects							
SR	85	.00	1	.62	.43	.01	.12
SR × Age	85	.00	1	.53	.47	.01	.11
SR × Accumulated practice	85	.00	1	.60	.44	.01	.12
SR × Current practice	85	.00	1	.54	.45	.01	.11
SR × Group	85	.00	1	.55	.46	.01	.11

Table 3. Continued

Source of Variation	*N*	*MS*	*df*	*F*	*p-value*	ηp^2	*Power*
Panel C. Tempo maintenance (T maint.)							
Between subjects							
Age	85	.00	1	.02	.89	.00	.05
Accumulated practice	85	.00	1	.02	.81	.00	.06
Current practice	85	.00	1	.03	.85	.00	.05
Group	**85**	**.29**	**1**	**4.15**	**.05**	**.05**	**.52**
Within subjects							
T maint.	85	.00	1	.05	.82	.00	.06
T maint. × Age	85	.00	1	.03	.87	.00	.05
T maint. × Accumulated practice	85	.00	1	.11	.75	.00	.06
T maint. × Current practice	85	.10	1	3.75	.06	.04	.49
T maint. × Group	**85**	**.15**	**1**	**5.39**	**.02**	**.06**	**.63**
Panel D. Rhythmic accuracy (Rhythm)							
Between subjects							
Age	85	.04	1	.48	.49	.01	.11
Accumulated practice	85	.07	1	.79	.39	.01	.14
Current practice	85	.08	1	.94	.33	.01	.16
Group	**85**	**.39**	**1**	**4.48**	**.04**	**.05**	**.55**
Within subjects							
Rhythm	85	.01	1	.58	.45	.01	.12
Rhythm × Age	85	.01	1	.45	.51	.01	.10
Rhythm × Accumulated practice	85	.01	1	.30	.59	.00	.08
Rhythm × Current practice	85	.02	1	1.08	.30	.01	.18
Rhythm × Group	85	.01	1	.52	.47	.01	.11
Panel E. Pitch accuracy (Pitch)							
Between subjects							
Age	85	.06	1	.46	.50	.01	.10
Accumulated practice	85	.09	1	.69	.41	.01	.13
Current practice	85	.00	1	.00	.97	.00	.05
Group	85	.29	1	2.14	.15	.03	.30
Within subjects							
Pitch	85	.00	1	.12	.73	.00	.06
Pitch × Age	85	.00	1	.10	.75	.00	.06
Pitch × Accumulated practice	85	.00	1	.09	.77	.00	.06
Pitch × Current practice	85	.00	1	.00	.99	.00	.05
Pitch × Group	85	.04	1	2.43	.12	.03	.34

Table 3. Continued

Source of Variation	*N*	*MS*	*df*	*F*	*p-value*	ηp^2	*Power*
Panel F. Articulation accuracy (Artic.)							
Between subjects							
Age	85	.03	1	.20	.65	.00	.07
Accumulated practice	85	.06	1	.39	.65	.00	.07
Current practice	85	.02	1	.11	.75	.00	.06
Group	85	.52	1	3.66	.06	.04	.47
Within subjects							
Artic.	85	.00	1	.31	.58	.00	.08
Artic. × Age	85	.00	1	.24	.62	.00	.08
Artic. × Accumulated practice	85	.00	1	.17	.69	.00	.07
Artic. × Current practice	85	.01	1	.45	.50	.01	.10
Artic. × Group	85	.00	1	.03	.86	.00	.05
Panel G. Expressiveness (Express.)							
Between subjects							
Age	45	.07	1	1.13	.30	.03	.18
Accumulated practice	45	.03	1	.50	.48	.01	.11
Current practice	45	.02	1	.24	.63	.01	.08
Group	**45**	**.31**	**1**	**5.08**	**.03**	**.11**	**.60**
Within subjects							
Express.	45	.00	1	.04	.85	.00	.05
Express. × Age	45	.00	1	.16	.69	.01	.07
Express. × Accumulated practice	45	.00	1	.23	.63	.01	.08
Express. × Current practice	45	.01	1	.49	.49	.02	.10
Express. × Group	45	.00	1	.04	.88	.00	.05

MS: main square sume; *df:* degrees of freedom.

In relation to the specific indexes of performance, the results showed a significant effect of group in rhythmic accuracy, F (1, 80) = 4.48, p = .037, ηp_2 = .05, tempo maintenance, F (1, 80) = 4.15, p = .045, ηp_2 = .05, and expressiveness, F (1, 41) = 5.08, p = .050, ηp_2 = .11. In addition, the results showed a significant interaction group × tempo maintenance, F (1, 80) = 5.39, p = .023, ηp_2 = .06. The analysis of this interaction revealed that whereas efficient participants were not affected by the difficulty of the task, less efficient were (see Figure 1). The results showed no significant effects regarding either pitch and articulation accuracy.

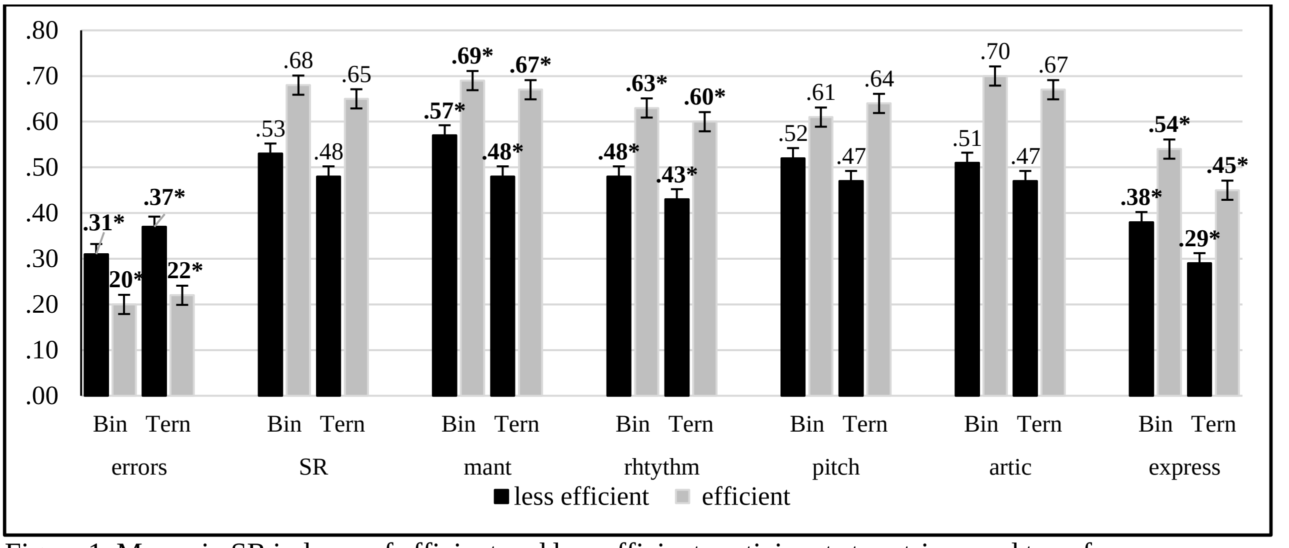

Figure 1. Means in SR indexes of efficient and less efficient participants to retrieve and transform relevant information from WM (errors during performance in binary (Bin) and ternary (Tern); rhythmic accuracy (Bin/Tern); tempo maintenance (Bin/Tern); expressiveness (Bin/Tern).

Table 4 (panels A to G) shows the within and between effects/interactions of all the multiple ANCOVA regarding efficiency suppressing irrelevant information from WM. In relation to the global indexes of SR performance, the results showed significant interactions in both SR global indexes: group × proportion of SR error, F (1, 70) = 3.88, p = .050, ηp_2 = .05, group × global SR, F (1, 70) = 4.82, p = .031, ηp_2 = .06.

The analysis of these interactions showed that efficient participants were affected by the difficulty of the SR task whereas those less efficient were not (see Figure 2). Regarding the specific indexes of performance, the results showed a significant interaction group × rhythmic accuracy, F (1, 70) = 4.86, p = .031, ηp_2 = .07, and group × articulation accuracy, F (1, 70) = 11.93, p = .001, ηp_2 = .15.

Table 4. Within and between effects/interactions for all the variables as a function of efficiency in the suppression of no longer relevant words. Significant results are in bold (* $p < 0.05$, ** $p < 0.01$).

ANCOVA (covariates Age, Accumulated practice, Current practice)							
Source of Variation	*N*	*MS*	*df*	*F*	*p-value*	ηp^2	*Power*
Panel A. Proportion of errors							
Between subjects							
Age	74	.00	1	.03	.88	.00	.06
Accumulated practice	74	.01	1	.16	.69	.00	.07
Current practice	74	.01	1	.17	.69	.00	.07
Group	74	.06	1	1.53	.22	.02	.23
Within subjects							
Error	74	.00	1	.15	.70	.00	.07
Error × Age	74	.01	1	.27	.61	.00	.08
Error × Accumulated practice	74	.01	1	.23	.63	.00	.08
Error × Current practice	74	.01	1	.25	.62	.00	.08
Error × Group	**74**	**.11**	**1**	**3.88**	**.05**	**.05**	**.50**
Panel B. Global SR (SR)							
Between subjects							
Age	74	.00	1	.02	.88	.00	.05
Accumulated practice	74	.03	1	.23	.63	.00	.08
Current practice	74	.05	1	.42	.52	.01	.10
Group	74	.23	1	1.90	.17	.03	.28
Within subjects							
SR	74	.00	1	.01	.93	.00	.05
SR × Age	74	.00	1	.05	.82	.00	.06
SR × Accumulated practice	74	.00	1	.13	.72	.00	.06
SR × Current practice	74	.00	1	.29	.59	.00	.08
SR × Group	**74**	**.03**	**1**	**4.82**	**.03**	**.06**	**.58**
Panel C. Tempo maintenance (T maint.)							
Between subjects							
Age	74	.00	1	.00	.99	.00	.05
Accumulated practice	74	.00	1	.04	.84	.00	.06
Current practice	74	.02	1	.26	.61	.00	.08
Group	74	.09	1	1.29	.26	.02	.20
Within subjects							
T maint.	74	.00	1	.06	.82	.00	.06
T maint. × Age	74	.00	1	.05	.83	.00	.06
T maint. × Accumulated practice	74	.01	1	.42	.52	.01	.10
T maint. × Current practice	74	.10	1	3.60	.06	.05	.47
T maint. × Group	74	.01	1	.36	.55	.01	.09

Table 4. Continued

Panel D. Rhythmic accuracy (Rhythm)							
Between subjects							
Age	74	.01	1	.08	.78	.00	.06
Accumulated practice	74	.04	1	.50	.48	.01	.11
Current practice	74	.21	1	2.37	.13	.03	.33
Group	74	.26	1	2.90	.09	.04	.39
Within subjects							
Rhythm	74	.00	1	.05	.83	.00	.06
Rhythm × Age	74	.00	1	.16	.70	.00	.07
Rhythm × Accumulated practice	74	.01	1	.33	.57	.01	.09
Rhythm × Current practice	74	.00	1	.24	.63	.00	.08
Rhythm × Group	**74**	**.07**	**1**	**4.86**	**.03**	**.07**	**.59**
Panel E. Pitch accuracy (Pitch)							
Between subjects							
Age	74	.01	1	.07	.80	.00	.06
Accumulated practice	74	.03	1	.27	.61	.00	.08
Current practice	74	.05	1	.40	.53	.01	.10
Group	74	.15	1	1.15	.29	.02	.19
Within subjects							
Pitch	74	.03	1	2.34	.13	.03	.33
Pitch × Age	74	.04	1	2.77	.10	.04	.37
Pitch × Accumulated practice	74	.04	1	2.93	.09	.05	.38
Pitch × Current practice	74	.03	1	2.21	.14	.03	.31
Pitch × Group	74	.04	1	3.04	.08	.04	.40
Panel F. Articulation accuracy (Artic.)							
Between subjects							
Age	74	.00	1	.00	.95	.00	.05
Accumulated practice	74	.01	1	.06	.81	.00	.06
Current practice	74	.01	1	.07	.79	.00	.06
Group	74	.28	1	1.85	.18	.03	.27
Within subjects							
Artic.	74	.00	1	.07	.80	.00	.06
Artic. × Age	74	.00	1	.13	.72	.00	.07
Artic. × Accumulated practice	74	.01	1	.48	.49	.01	.10
Artic. × Current practice	74	.04	1	3.11	.08	.04	.41
Artic. × Group	**74**	**.13**	**1**	**11.93**	**.00**	**.15**	**.93**

Table 4. Continued

Panel G. Expressiveness (Express.)							
Between subjects							
Age	42	.16	1	2.70	.11	.06	.36
Accumulated practice	42	.08	1	1.38	.25	.03	.21
Current practice	42	.07	1	1.12	.37	.01	.17
Group	42	.12	1	2.00	.16	.04	.28
Within subjects							
Express.	42	.06	1	1.69	.20	.04	.25
Express. × Age	42	.08	1	2.35	.13	.05	.32
Express. × Accumulated practice	42	.09	1	2.79	.10	.06	.37
Express. × Current practice	42	.07	1	2.12	.12	.05	.35
Express. × Group	42	.01	1	.19	.67	.00	.07

MS: main square sume; *df:* degrees of freedom.

As in the case of the global indexes, the analysis of these interactions showed that efficient participants were affected by the difficulty of the SR task whereas those less efficient were not (see Figure 2). There were no significant effects or interactions regarding tempo maintenance, pitch accuracy and expressiveness.

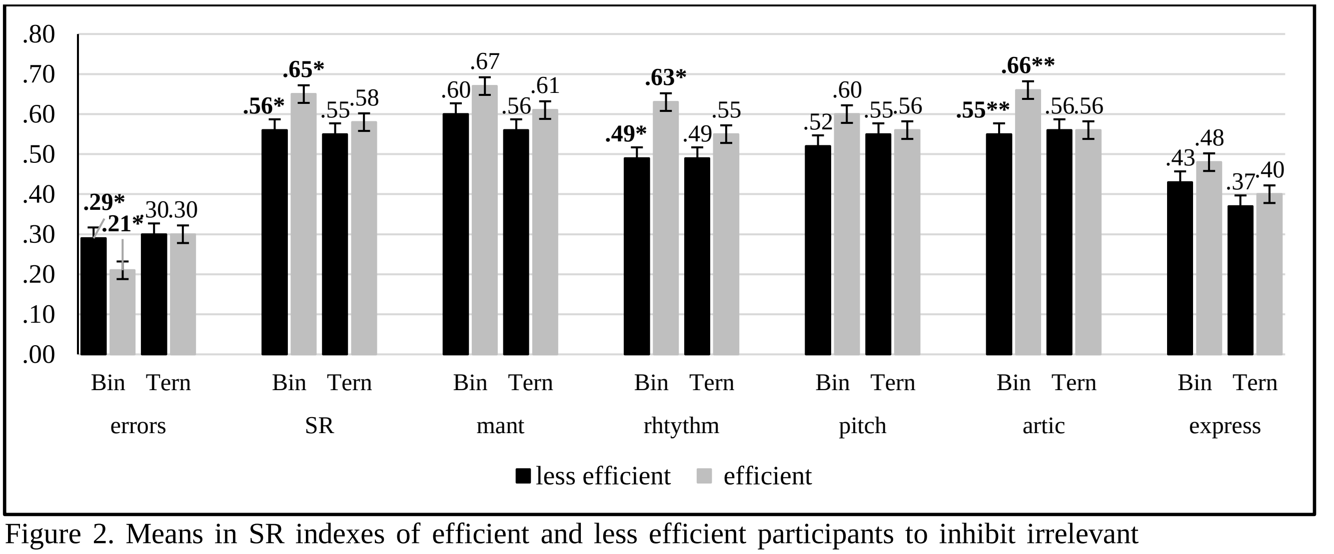

Figure 2. Means in SR indexes of efficient and less efficient participants to inhibit irrelevant information from WM (errors during performance in binary (Bin) and ternary (Tern); rhythmic accuracy (Bin/Tern); articulation accuracy (Bin/Tern).

3.2.4 Discussion

We aimed to analyse how the sub-processes of retrieval, transformation and substitution underlying updating in WM were related to SR as a function of the demands on memory load and level of suppression. We also intended to analyse how the efficiency in these updating sub-processes could be a source of individual differences in SR as a function of the difficulty of the SR task and of different indexes of performance.

Regarding the retrieval and transformation sub-processes, the results of the correlational analysis showed that once age and practice were controlled, both SR tasks were significantly related to these sub-processes in high memory load and low suppression condition. These results corroborated our expected relationship and could reflect that SR would rely on memory load more than on interference. Thus, efficient sight readers could have an increased ability to simultaneously maintain and transform into motor movements a greater amount of musical material than less efficient ones, as Meinz and Hambrick (2010) had been already suggested.

The results of the efficiency analysis showed that those participants efficient in retrieving and transforming relevant information in WM committed fewer errors during performance and produced a more expressive execution than less efficient ones. A possible explanation for these results is that the increased ability of our efficient participants could generate improved memory associations between musical fragments. Thus, their range of planning could be enhanced, allowing them to perform without breakdowns or production errors (Drake and Palmer, 2000). In a similar way, the increased range of planning may be responsible for an increased ability to add musical expression to the performance as Lehmann and Kopiez (2009) suggested. Our results also showed that the efficient participants outperformed less efficient ones regarding rhythmic accuracy, which corroborated those results obtained by Kopiez and Lee (2006) with adult expert pianists. However, in our case, the involvement of the retrieval and transformation sub-processes in rhythmic performance were not dependent of the difficulty of the SR tasks as it was in the study of Kopiez and Lee (2006). A possible explanation of these differences could be related to the measurement of rhythmic accuracy in both studies: as metronomic accuracy in the case of Kopiez and Lee or as proportion among notes and rests in our case. In addition, the results showed that efficient participants not only outperformed less efficient ones by maintaining tempo, but neither were their affected by the difficulty of the task, whereas less efficient ones were. It has been suggested that updating in WM could be central to the processing of temporal information due to its involvement in the active maintenance of sequences of events (Carelli, Forman, & Mäntylä, 2008). Thus, in ternary tasks – the most demanding ones– those less efficient participants maintaining information in WM had a worse performance keeping a constant speed.

In relation to the substitution sub-process, the results showed a significant relationship to SR in high memory load and low suppression condition, when age and practice were controlled. However, the relationship was significant in only binary tasks. Taking into account the suggested existence of a trade-off effect between maintenance and suppression sub-processes as a function of the availability of attentional resources (e.g. Engle, 2002; Kane & Engle, 2000). However, these attentional resources may be only available in the less demanding SR task, because the difficulty of the ternary tasks could increase memory demands draining the resources to suppress irrelevant information (Lavie et al., 2004). The efficiency analysis also corroborated the lack of resources to inhibit irrelevant information from WM in more demanding SR tasks, which only affected the efficient participants. Specifically, whereas in binary tasks (the easiest ones), the efficient participants committed fewer SR errors than less efficient ones, and outperformed them in rhythmic and articulation accuracy, in ternary tasks (the most difficult task), efficient and less efficient participants performed at about the same level. In this sense, Engle (2002) had been suggested that people with a poorer executive attention would not be affected by the cognitive load to suppress irrelevant information from WM because they would not have attentional resources available even under less demanding conditions, while increasing proactive interference in most demanding ones would decrease performance of the most efficient participants.

Contrary to our hypothesis, the results showed that pitch accuracy did not seem to be affected by the efficiency in both, the retrieval and transformation and the substitution process. A subsequent correlational analysis showed that pitch accuracy was significantly related to accumulated practice, both regarding binary (r = .18, p = .037) and ternary (r = .24, p = .004) SR tasks. Thus, it seems that pitch accuracy could be more related to instrument practice than for updating abilities during SR. In addition, the results showed that global performance at sight was no affected by efficiency in the retrieval and transformation sub-processes whereas it was affected by efficiency in the substitution one. An explanation for these results is that, because global performance at sight index was a derived measure the significant or no significant effects/interactions of this index would be modulated by the effects/interactions and degree of significance of its components.

Globally, our results corroborated the relevant role of the retrieval and transformation sub-processes in SR, regardless of the difficulty of the SR tasks, which may probably be associated with the implication of WM in this kind of complex activities (Redick et al., 2016). Moreover, our results showed that the substitution sub-process was also involved in performance at sight, but only in low demanding SR tasks. Importantly, our results showed that the updating in WM sub-processes were differently involved in SR according to the different indexes of SR performance. All the updating sub-processes were engaged in SR regarding the proportion of error and rhythmic accuracy, corroborating its reliability as general indexes of SR performance (e.g. Drake & Palmer, 2000; Hayward & Gromko, 2009; Kopiez & Lee, 2008; Mishra, 2014; Wurtz et al., 2009). However, both expressiveness and tempo maintenance seemed to be uniquely driven by efficiency in the retrieval and transformation sub-processes, whereas articulation accuracy relied in the efficiency to suppress irrelevant information from WM. In this sense, expressive indications are associated to a specific musical sequence or fragment to give them full meaning. Moreover, tempo maintenance implies maintaining a constant speed. Thus, it is possible that neither of them require the active suppression of previous information whenever performance continues. However, articulation implies that any musical pattern with concrete rhythm and pitch could appear printed on the score more than once with different articulatory indications. Consequently, the active suppression of previous articulation indications in WM may be necessary to produce a fluent performance.

To conclude, our results support the relevance of updating in WM for SR beyond the effects of age and practice. However, some caution is needed, due to the fact that only two different SR tasks were used. Future research must be done considering a large range

Escuela Internacional de Doctorado EIDUNED

of difficulty tasks, especially in order to replicate or to refute the lack of relevance of inhibition in WM in the most difficult tasks. In addition, it is necessary to analyse the contribution of other inhibitory processes such as response-distractor interference, that has been showed to represent an inhibitory factor unrelated to cognitive inhibition measured in our study. Similarly, the role of cognitive flexibility must be also analysed due to its association with multitasking performance and its involvement in the execution of complex dynamic tasks.

3.3 ESTUDIO 3

Herrero, L., & Carriedo, N. (enviado). The role of cognitive flexibility, and inhibition in complex dynamic tasks: the case of sight reading music.

The role of cognitive flexibility, and inhibition in complex dynamic tasks: the case of sight reading music.

Abstract

Sight reading (SR) is a dynamic task which requires the performance of the music printed in a score whithout previous practice (Lehmann & McArthur, 2002). Our main aim was to analyse how cognitive flexibility and the inhibitory processes involved in the control of interference of irrelevant stimulus and in the suppression of preponderant actions or responses, could differently contribute to fluency and accuracy in SR, as a function of the conditions of difficulty of the SR tasks. We also aimed to determine if these contributions were independent of instrument knowledge. 63 students of melodic instruments participated in the study. The results revealed a significant contribution of the inhibitory processes involved in the suppression of preponderant actions or responses to both fluency and accuracy, even in low difficult conditions of the SR tasks. Our results also revealed significant contributions of cognitive flexibility to fluency and of resistance to interference to accuracy only in high difficult conditions of the SR tasks. All these contributions were independent of instrument knowledge.

Keywords

Sight reading; cognitive flexibility; resistance to interference; prepotent response inhibition.

Statements

Sight reading music is a dynamic task, which requires cognitive resources associated with executive functioning.

Instrument knowledge is not sufficient for an efficient music sight reading.

Cognitive flexibility in involved in fluency and resistance to interference in accuracy during performance at sight only in high demanding conditions.

Preponderant response inhibition is involved in fluency and accuracy during performance at sight especially in low demanding conditions.

3.3.1 Introduction

Dynamic tasks are characterised by their temporal interaction with changing environments to achieve goals in a fluent way (Kiesel et al., 2010; Taatgen, 2005). These kind of tasks require the flexible control of behaviour in response to the input of varying information as well as the continuous assessment of actions and the outcomes of these actions in a limited amount of time (Ridderinkhof, Van Den Wildenberg, Segalowitz, & Carter, 2004).

Cognitive flexibility or set shifting[9], involves processes related to changes between multiple tasks, operations, or mental sets (Monsell, 1996). It has been considered as a core executive control process responsible for the adjustment of behaviour in response to changing environmental demands or priorities (Diamond, 2013) as occurs in

[9] Some authors have considered that cognitive flexibility would be a broader term than set shifting, and that it could refer not only to the ability to adjust responses to changing situations but also to act in a non-routine or established way (Morra, Traverso, Panesi, & Usai 2018). In this sense, it has been differentiated between adaptive flexibility, understood as the ability to change or adapt the responses to the demands of previously established tasks or problems, and spontaneous flexibility, understood as that to generate diverse responses in relatively unstructured situations (Wilson, Guilford, Christensen, & Lewis, 1954), which has been linked to divergent thinking and creativity (Torrance, 1974).

dynamic tasks, especially in high demanding conditions (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Glass, Maddox, & Love, 2013). In addition, inhibitory executive processes involved in the control of interference of irrelevant stimulus and in the suppression of prepotent actions or responses have also been posted as an executive control mechanism necessary in dynamic contexts (Miller & Cohen, 2001). Our main aim was to analyse the specific contributions of cognitive flexibility and inhibitory processes to sight reading music (SR), a dynamic task that implies a sequence of controlled movements in response to a series of visually presented novel musical stimuli.

SR has been defined as a dynamic transcription task that requires the performance of the music written in a score for the first time, or after brief rehearsal (Lehmann & McArthur, 2002). It has been considered an open skill that requires the continuous adaptation to changing demands. SR could be summarised as two main coordinated components: a) quickly encoding and processing the incoming stimuli, and b) executing it through accurate motor movements without breaks or stops (Thompson & Lehmann, 2004).

A certain amount of instrument knowledge is necessary to perform at sight. General performance level has been associated with SR efficiency when comparing musicians of different skill levels (Lehmann and Ericsson (1996). However, it has been suggested that general performance abilities would be necessary but not sufficient for an efficient SR performance due to its complex demands (Elliott, 1982; Wolf, 1976). The encoding and processing component requires the reading and understanding of the information printed in the score, while the focus of attention shifts among different elements of musical structure such as tempo, rhythm, pitch, and articulation (Jakobson, Lewycky, Kilgour & Stoesz 2008). The execution component involves the selection of the adequate motor responses (Brodsky, Kessler, Rubinstein, Ginsborg, & Henik, 2008; Jänke, 2006), and the suppression of the already activated irrelevant ones (Barrett, Ashley, Strait, & Kraus 2013; Gunter, Schmidt, & Besson, 2003), while changing acoustic events are produced (Foxton et al., 2003). The skilled coordination of these two components will produce both a fluent and accurate performance (Thompson & Lehmann, 2004), that is, an execution without breaks or stops in which all the musical elements were produced with precision.

Previous research in SR has mainly focused on the analysis of what kind of predictors could determine efficiency in SR performance. In this sense, it's worth mentioning specific SR practice (Kopiez & Lee, 2006; Kopiez & Lee, 2008; Kopiez, Weihs, Ligges, & Lee, 2006; Lehmann & Ericsson, 1996; Lehmann & McArthur, 2002; Meinz & Hambrick, 2010) and some musical activities such as solfeggio, aural training or composition (Mishra, 2014). Nevertheless, beyond the effects of practice and these musical activities, several studies have found positive correlations between SR and different cognitive processes, such as visuo-motor abilities (Fourie, 2004; Truitt, Clifton, Pallatsek, & Rayner, 1997), psychomotor speed (Kopiez & Lee, 2006; Kopiez & Lee, 2008; Kopiez, Weihs, Ligges, & Lee, 2006) reaction time (Thompson, 1987), planning abilities (Drake and Palmer, 2000; Lehmann and Kopiez; 2009), spatial-temporal reasoning (Hayward & Gromko, 2009), working memory capacity (Kopiez & Lee, 2006; Kopiez & Lee, 2008; Meinz & Hambrick, 2010), or updating executive function sub-processes (Herrero & Carriedo, 2019). Taken together, these cognitive processes could contribute to anticipating the execution and to a faster translation of the visual stimulus in fine motor movements during SR. Even when when the correlations found between SR and the different aforementioned cognitive processes may not be too high, it has been suggested that their relevance in SR could be decisive at the ultimate level of performance (Meinz & Hambrick, 2010). It is important to note that when considering the limited amount of attentional resources available to maintain the goal of the tasks under interference conditions (Kane, Conway, Hambrick, & Engle, 2007), the relevance of the executive processes, such as updating executive function and inhibition, in SR increase as the difficulty of the tasks do (Herrero & Carriedo 2019).

To our knowledge, the role of cognitive flexibility and the inhibitory processes involved in the control of interference of irrelevant stimulus and in the suppression of prepotent actions or responses has not yet been explored in SR. However, these executive processes have been related to musical improvisation (Beaty and Silvia, 2012; de Manzano & Ullén, 2012b), which has been compared to SR because both tasks require real-time performance without previous preparation, and share the components of encoding/processing and executing (Thompson and Lehmann, 2004). Specifically, Thompson and Lehmann (2004) concluded that SR and improvisation could require planning abilities for performance in real-time, and that the main difference between them would be associated with the nature of the stimuli which would determine what is to be played. In SR, all the musical elements to be performed would be written in the score whereas in improvisation the musical elements would be internally generated by the intentions of the performer following established musical norms.

Thus, although SR is unimaginative and does not involve the creative component linked to improvisation (Beaty, 2015), we suggest that SR, as improvisation may demand cognitive flexibility resources to continuously adapt the execution to the incoming information. In addition, we suggest that SR could require inhibitory control to both, resisting the interference among internal or external musical stimulus, and to suppressing the inappropriate prepotent motor responses activated.

In this sense, even when it has been suggested that prepotent response inhibition and resistance to interference would reflect a common inhibitory ability, response-distractor interference, (Friedman & Miyake, 2004), some authors have pointed out that the selection and the execution of the responses may be separable processing stages in which conflict must be resolved (Rubia et al., 2001; Rubia, Smith, Brammer, & Taylor, 2003). Thus, an enhanced prepotency to respond may generate greater conflict in execution than in the selection response (Nee, Wager, & Jonides, 2007). In this sense, Thompson and Lehmann (2004), noted that there should be a distinction made between those errors where the selection of the appropriate response would fail because of interference while the information is encoded and processed, and where an inappropriate response based on previous learned motor patterns is activated during the execution of the motor responses. The activation of inappropriate motor responses may appear even in easy fragments because of the presence of unexpected notes among previous learned familiar patterns (Thompson & Lehmann, 2004). Consequently, in SR, the specific role of resistance to interference could be more relevant during the encoding and processing component which allows for the selection of correct responses, while prepotent response inhibition could be related to the execution one.

The purpose of this study was to analyse how, independently from the instrument knowledge necessary to perform at sight, cognitive flexibility and the inhibitory processes involved in the control of interference of irrelevant stimulus and in the suppression of prepotent actions or responses, could differently contribute to fluency and accuracy, as musical indexes of an efficient SR (Thompson & Lehmann, 2004), and whether these contributions could be distinguished as a function of the conditions of difficulty of the SR tasks, based on their metrical organization.

We hypothesised that cognitive flexibility could significantly contribute to fluency especially in more difficult SR conditions (Costa et al., 2009; Glass et al., 2013), in which the necessary shift among different musical elements, could increase the executive control costs.

We also hypothesised that both the inhibitory processess of resistance to interference and prepotent response inhibition, would contribute to accuracy in order to produce a precise performance based on fine motor responses. We particularly expected a significant contribution of resistance to interference to accuracy in only more difficult conditions of the SR tasks, since the processing of well-learned musical elements in a more complex temporary organization could increase interference both the encoding and the processing component and in the selection of the appropriate motor responses (Miller & Cohen, 2001).

In addition, we expected that the significant contribution of prepotent response inhibition to accuracy would be not affected by the condition of difficulty of the SR tasks, due to the fact that previous learned motor patterns may be improperly activated by familiar information even in easier conditions (Thompson & Lehmann, 2004).

Finally, we expected that the contribution of both cognitive flexibility and inhibitory processes would be independent of instrument knowledge given that it is a necessary but not sufficient condition to perform at sight (Elliott, 1982; Wolf, 1976).

3.3.2 Method

3.3.2.1 Participants

The participants were 63 wind and string students. Of the total, 32 participants were adolescents aged 15-16 (*M* = 15.2, *SD* =.49; 21 females, 11 males), that had been receiving instrument lessons for at least six years (*M* = 6.8, *SD* =.28); the remaining 31 participants were young adults (*M* = 22.3, *SD* = 1.34; 14 females, 17 males), that had been receiving instrument lessons for at least twelve years (*M* = 12.9, *SD* =.46).

All the participants have studied in music conservatories following classical Western music methodology based on solfeggio (music theory, rhythmic lecture, intonation and harmony), choir, instrument (scales, studies and compositions), wind band/orchestra and chamber music lessons. None of them had received specific SR training. Parental consent was obtained for all adolescent participants by a written informed consent form. Young adults signed their written consent form personally. Ethical approval for this project was given by National Distance Education University (UNED) [MICCIN EDU2011-22699].

3.3.2.2 Materials

Sight Reading task. On the advice of specialists of wind and string instruments, two different SR pieces from "Sound at Sight Series" (Trinity College of London, 2003-2009) were selected for each kind of instrument and level of instrument knowledge. These series include a set of SR pieces for each instrument graded as a function of instrument knowledge, which allows comparison in performance among different instruments within each level of difficulty. From the eight difficulty grades of SR classical western music style pieces included in these series, two were chosen as a function of the level of general performance of the participants: two pieces from grade 5 for the adolescent participants, and two pieces from grade 8 for the adult participants. Each pair of tasks had similar difficulties regarding key, tempo, melodic range and leap size but differed in the time bar, which was determined as the criterion of difficulty.

A 2/4 or 4/4 piece (binary beat and binary subdivision), was chosen as binary task (BIN). Binary time bars (2 or 4 beats per measure and simple subdivision), are the most common in western music (Temperley, 2010). They have been associated with human locomotion (Sadeghi et al., 2000), and seems to maximize the expectancy of musical structure (Vuust, & Witek, 2014), which could increase anticipation during SR. A 6/8, 9/8, or 12/8 piece (binary or ternary beat and ternary subdivision), was chosen as ternary one (TER). Previous research has shown that binary beats and subdivisions are easier than ternary ones both in auditory discrimination tasks (Smith & Cuddy, 1989), and in reproduction ones (Drake, 1993).

SR was blindly and independently evaluated as a function of two different indexes of performance: (1) fluency, or the ability to perform the complete piece without breaks, stops or repetitions; (2) accuracy, or the ability to precisely perform the musical elements printed in the score (tempo, rhythm, pitch, articulation and dynamics). Fluency and accuracy were scored from zero to ten by two professional musicians with a full education degree in piano and viola classical western music (instrument training together with solfeggio, choir, harmony, art and music history, aesthetics, acoustics, organology, improvisation, accompanying, chamber music and/or orchestra). They also had more than 15 years of teaching and interpreting experience and an extended experience of at least 10 years as evaluators in music student competitions.

Executive tasks

*Inhibition tasks.*We used the flanker task as a measure resistance to interference, and the go/no-go task as a measure of prepotent response inhibition. Considering that SR implies the reading of the musical material from the score, we also included the antisaccade task as a measure of prepotent response inhibition, which is based on the suppression of reflexive saccades (Nigg, 2000).

Antisaccade task (Hallet, 1978, Hallet & Adams, 1980). The task had two experimental conditions, prosaccade and antisaccade. Each trial of the prosaccade condition began with a fixation point in the center of the screen. The fixation point disappeared after a range of 1,500-3,500 ms (at randomized intervals). Then, a white square appeared at 11.5 ° to the left or right of the fixation point. After 400ms, the white square disappeared and there was a 2.0 ° box containing an arrow pointing left, right or up. The arrow was displayed for 150ms and then hidden with a stain, remaining hidden for 1,500 ms, or until the participant responded. The side on which the stimulus appeared was counterbalanced in all trials. Participants had to do 12 practice trials, followed by 60 experimental ones. The antisaccade task was identical, with the exception that the arrow always appeared on the opposite side of the white square. The participants were instructed to respond as quickly as possible and encouraged to make as few errors as possible to determine the direction of the arrow by pressing the corresponding arrow (left, right or up) on the keyboard of the computer. The dependent variable was the mean RT/percentage of correct answers in the antisaccade trials. Figure 1 shows the sequence of events in the prosaccade and antissacade conditions of the antisaccade task.

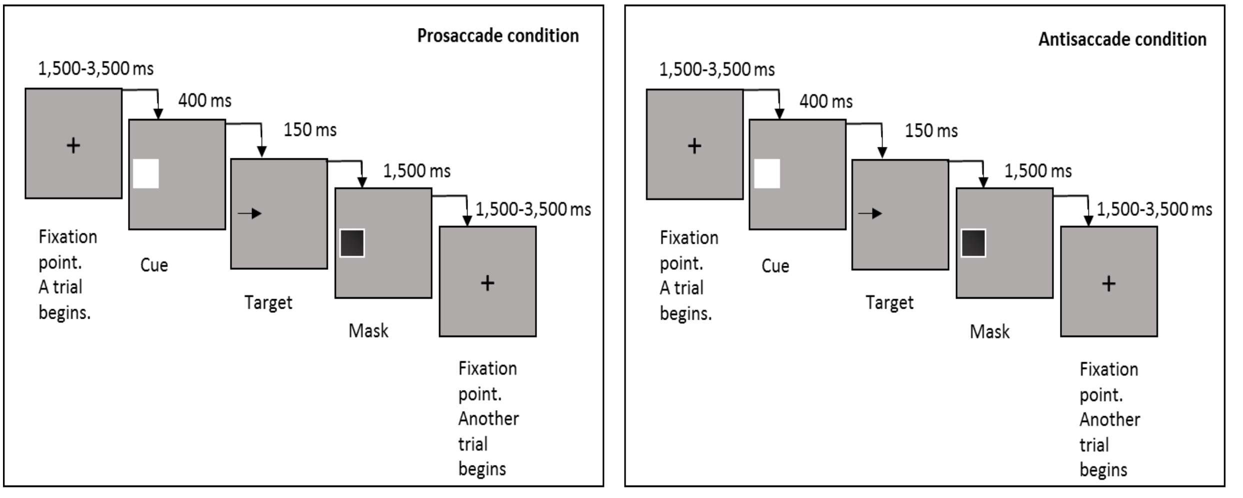

Figure 1. Sequence of events in the prosaccade and atisaccade experimental conditions of the antisaccade task.

Go/no-go task. This task requires a quick response by pressing a button as different stimulus appears (go trials), and no response when certain stimulus is presented (no go trials). The dependent variable was the proportion of correct answers (no responses) in no-go trials. For a detailed description of the stimulus, see Carriedo et al., (2016).

Flanker task (Eriksen & Eriksen, 1974). In this task, a central stimulus is presented together with irrelevant flanker ones. The task requires a quick and accurate response by pressing a button following the central stimulus. In the congruent condition, the central and the flanker stimulus are presented following the same criterium (compatible), whereas in the incongruent conditions the central stimulus and the flankers are presented following the opposite criterium (incompatible). The dependent variable was the mean RT/percentage of hits in the incongruent condition.

For a detailed description of the stimulus, see Carriedo et al., (2016).

Cognitive flexibility task. Cognitive flexibility was measured with the third block of the flanker task, in which congruent and incongruent conditions were combined so that, in some trials, participants had to switch attention from center to flanker and vice versa. The dependent variable was RT/percentage of hits.

3.3.2.3 Procedure

All the participants were evaluated individually at their music conservatories, with no disruptions in their routine classes. The order of the tasks was counterbalanced as well as the order of the binary (BIN) and ternary (TER) SR tasks

The SR performances were audio-registered (SONY® IC Recorder ICD-UX71F). The participants performed the two tasks consecutively following the same procedure. They were instructed to look carefully the score (tempo, bar, key signature) for 30 seconds to immediately perform the task according to the printed indications without stops or repetitions. The performances were analysed and measured from zero to ten as a function of fluency and accuracy by two independent judges. Inter-rater consistency among the scores of the two SR indexes as calculated using the intraclass correlation coefficient (ICC). The significantly high (fluency $r = .98$, $p < .01$; accuracy $r = .87$, $p < .01$). The values obtained were divided by ten.

The executive tasks were controlled by a computer. Randomization and time for stimulus presentation were controlled by E-Prime software, version 2.0 (Psychology Software Tools Inc.: www.pst-net.com/eprime).

3.3.3 Results

For the Flanker and Antisaccade tasks in which RTs were computed, RTs < 200 ms, as well as RTs for trials immediately following errors were eliminated (Friedman et al., 2008). We applied a within-subject trimming procedure which is robust to nonnormality (Wilcox & Keselman, 2003), to obtain the best measure of central tendency for each condition of both tasks.

Considering that the participants belong to different age groups, and that age is a significant variable in executive functioning (see for example Carriedo, et al., 2016) we first tested whether both groups of participants differed in the varying executive tasks. The results of the Student *t* comparisons for independent groups showed no differences between both age groups in any executive task (all *ps* > .050). Consequently, we collapsed both groups for subsequent analysis.

Table 1 shows the means and standard deviations for all the variables measured.

To analyse the contributions of both, cognitive flexibility and inhibitory processes, to fluency and accuracy, four multiple linear regression analyses were carried out, one for each index of SR (fluency and accuracy,) as dependent variables for each condition of difficulty of the SR task (binary and ternary).

Table 1. Means and standard deviations of all the variables measured.

	N	*M*	*SD*
Cognitive flexibility	63	622.37	124.13
Oculo-motor inhibition	63	474.92	60.67
Prepotent response inhibition	63	405.39	56.70
Resistance to interference	63	.92	.070
Instrument knowledge	63	9.73	3.19
Binary condition			
Fluency	63	.67	.24
Accuracy	63	.78	.18
Ternary condition			
Fluency	63	.67	.26
Accuracy	63	.78	.16

Proportions of scores are presented for all the SR measures. Proportion of correct responses (no-response) are presented forprepotent response inhibition. RT in ms are provided for cognitive flexibility, oculo-motor inhibition andresistance to interference. Instrument knowledge is in years.

Cognitive flexibility, oculo-motor inhibition, prepotent response inhibition and interference control were included as predictor variables in all the regression analyses. Instrument knowledge was also included as a predictor variable in order to control the independence of its contribution regarding the executive measures. This was common to all analyses. To reduce the risk of a Type II error (Field, 2009), the backward method for multiple linear regression was followed in all cases. Table 2 (panels A to D) shows the results of each regression analysis. We will discuss the results by conditions of difficulty.

Binary condition (easiest task)

Regarding the fluency index, Model 2, was the one that explained the highest percentage of total variance, a 22% (F (1, 57) = 5.40, p = .001). The predictors that significantly contributed to this model were those referring to prepotent response inhibition, antisaccade (β_i = -.24, p = .042), and go/no-go (β_i = .29, p = .023), whereas cognitive flexibility (β_i = -19, p = .103), and instrument knowledge (β_i = .20, p = .099), did not. Resistance to interference was excluded from the model (see Table 2, panel A).

In relation to accuracy, Model 3 and Model 4 were the only significant models, by explaining both the same percentage of total variance, a 9% (Model 3: F (1, 58) = 3.02, p = .037; Model 4: F (1, 59) = 4.19, p = .023. In these models, the only significant contributing predictor was the go/no-go index of prepotent response inhibition (β_i = .29, p = .020), whereas resistance to interference did not (β_i = -.24, p = .060). Cognitive flexibility, instrument knowledge and the antisaccade score of prepotent response inhibition were excluded from the model (see Table 2, panel B).

Table 2. Summary of the multiple linear regression analyses for fluency and accuracy as a function of the difficulty condition of the Sr task (binary and ternary). Significant results are in bold (* p < .05, ** p < .01).

Binary condition								
Panel A. Dependent variable: fluency								
1	β_i	p	R^2	ΔR^2	F	df	f^2	$1-\beta$
Overall model		**.002****	**.21**		**4.24**	**5, 57**	**.27**	**.98**
Constant		.221						
Cognitive flexibility	-.20	.121						
Oculo-motor inhibition	**-.24**	**.046***						
Prepotent response inhibition	**.29**	**.026***						
Resistance to interference	.01	.915						
Instrument knowledge	.20	.107						
2	β_i	p	R^2	ΔR^2	F	df	f^2	$1-\beta$
Overall model		**.001****	**.22**	**.00**	**5.40**	**1, 57**	**.27**	**.98**
Constant		.200						
Cognitive flexibility	-.19	.103						
Oculo-motor inhibition	**-.24**	**.042***						
Prepotent response inhibition	**.29**	**.023***						
Instrument knowledge	.20	.099						
3	β_i	p	R^2	ΔR^2	F	df	f^2	$1-\beta$
Overall model		**.001****	**.20**	**-.04**	**6.10**	**1, 58**	**.25**	**.97**
Constant		.265						
Oculo-motor inhibition	**-.26**	**.029***						
Prepotent response inhibition	.24	.058						
Instrument knowledge	.21	.095						

Table 2. Continued

Panel B. Dependent variable: accuracy								
1	β_i	*p*	R^2	ΔR^2	*F*	*df*	f^2	*1- ß*
Overall model		.102	.07		1.19	5, 57	.08	.57
Constant		.094						
Cognitive flexibility	-.14	.298						
Oculo-motor inhibition	-.02	.888						
Prepotent response inhibition	**.36**	**.012***						
Resistance to interference	-.17	.216						
Instrument knowledge	-.11	.374						
2	β_i	*p*	R^2	ΔR^2	*F*	*df*	f^2	*1- ß*
Overall model		.056	.09	.00	2.46	1, 57	.10	.68
Constant		**.044***						
Cognitive flexibility	-.14	.292						
Prepotent response inhibition	**.36**	**.009****						
Resistance to interference	-.18	.193						
Instrument knowledge	-.12	.374						
3	β_i	*p*	R^2	ΔR^2	*F*	*df*	f^2	*1- ß*
Overall model		**.037***	**.09**	**-.01**	**3.02**	**1, 58**	**.10**	**.69**
Constant		.037						
Cognitive flexibility	-.14	.318						
Prepotent response inhibition	**.32**	**.013***						
Resistance to interference	-.19	.163						
4	β_i	*p*	R^2	ΔR^2	*F*	*df*	f^2	*1- ß*
Overall model		**.023***	**.09**	**-.01**	**4.20**	**1, 59**	**.10**	**.70**
Constant		.041						
Prepotent response inhibition	**.29**	**.020***						
Resistance to interference	-.24	.061						

Table 2. Continued

Ternary condition								
Panel C. Dependent variable: fluency								
1	β_i	*p*	R^2	ΔR^2	*F*	*df*	f^2	*1- ß*
Overall model		**.012***	**.15**		**3.22**	**5, 57**	**.18**	**.91**
Constant		.138						
Cognitive flexibility	**-.28**	**.037***						
Oculo-motor inhibition	-.18	.153						
Prepotent response inhibition	.19	.159						
Resistance to interference	.03	.819						
Instrument knowledge	.23	.068						
2	β_i	*p*	R^2	ΔR^2	*F*	*df*	f^2	*1- ß*
Overall model		**.006****	**.17**	**-.00**	**4.08**	**1, 57**	**.20**	**.94**
Constant		.115						
Cognitive flexibility	**-.27**	**.030***						
Oculo-motor inhibition	-.17	.154						
Prepotent response inhibition	.19	.148						
Instrument knowledge	.24	.060						
3	β_i	*p*	R^2	ΔR^2	*F*	*df*	f^2	*1- ß*
Overall model		**.005****	**.15**	**-.03**	**4.66**	**1, 58**	**.18**	**.91**
Constant		.408						
Cognitive flexibility	**-.29**	**.021***						
Prepotent response inhibition	.23	.085						
Instrument knowledge	.25	.054						
Panel D. Dependent variable: accuracy								
1	β_i	*p*	R^2	ΔR^2	*F*	*df*	f^2	*1- ß*
Overall model		**.006****	**.18**		**3.69**	**5, 57**	**.22**	**.95**
Constant		**.007****						
Cognitive flexibility	-.23	.074						
Oculo-motor inhibition	.07	.553						
Prepotent response inhibition	**.31**	**.018***						
Resistance to interference	**-.34**	**.010***						
Instrument knowledge	.00	.992						
2	β_i	*p*	R^2	ΔR^2	*F*	*df*	f^2	*1- ß*
Overall model		**.002****	**.19**	**.00**	**4.70**	**1, 57**	**.23**	**.97**
Constant		**.007****						
Cognitive flexibility	-.23	.071						
Oculo-motor inhibition	-.07	.548						
Prepotent response inhibition	**.31**	**.013***						
Resistance to interference	**-.34**	**.009****						
3	β_i	*p*	R^2	ΔR^2	*F*	*df*	f^2	*1- ß*
Overall model		**.001****	**.20**	**-.00**	**6.21**	**1, 58**	**.25**	**.97**
Constant		**.000****						
Cognitive flexibility	-.23	.073						
Prepotent response inhibition	**-.33**	**.010***						
Resistance to interference	**.30**	**.015***						

β_i : standarized regression coefficient; ΔR^2.: change in R squared; *df*: degrees of freedom; f^2: effect size; *1- ß*: statistical power.

Ternary condition (most difficult task)

Regression analysis results for fluency allowed for three significant models. Model 2 explained the highest percentage of total variance, a 17%.(F (1, 57) = 4.08, p = .006), The only predictor that significantly contributed to this model was cognitive flexibility (β_i = -.27, p = .030), whereas prepotent response inhibition, (antisaccade: β_i = -.17, p = .154, and go/no-go: β_i = .19, p = .148), and instrument knowledge (β_i = .24, p = .060), did not. Resistance to interference was excluded from the model (see Table 2, panel C).

The results of the regression analysis in terms of accuracy indicated three significant models, Model 1 being the one to explain the highest percentage of the variance, a 20% (F (1, 58) = 6.21, p = .001). Here, the go/no go index of prepotent response inhibition (β_i = -.33, p = .010), and resistance to interference (β_i = .30, p = .015), significantly contributed to the model, but cognitive flexibility (β_i = -.23, p = .073), did not. The antisaccade index of prepotent response inhibition and instrument knowledge were excluded from the model (see Table 2, panel D).

3.3.4 Discussion

Our main aim was to determine the specific role of cognitive flexibility and the inhibitory processes involved in the control of interference of irrelevant stimulus and in the suppression of prepotent actions or responses in SR performance, a kind of dynamic task in which fine motor movements are generated in response to printed musical material that has not been previously rehearsed. We specifically wanted to analyse whether these executive processes contributed differently to fluency and accuracy as a function of the difficulty of the SR tasks, and whether these contributions were independent of instrument knowledge.

We had hypothesised a significant contribution of cognitive flexibility to fluency and of resistance to interference and prepotent response inhibition to accuracy, and that these contributions would be independent of instrument knowledge. We had also hypothesised that the contributions of cognitive flexibility to fluency and of resistance to interference to accuracy would be significant in only more demanding conditions, whereas prepotent response inhibition would significantly contribute to accuracy regardless of the difficulty of the SR tasks.

As expected, our results corroborated that the contributions of cognitive flexibility and the inhibitory processes to fluency and accuracy were independent of instrument knowledge, which did not show any significant contribution. However, its role regarding fluency in ternary conditions was very close to statistical significance ($\beta_i = .24$, $p = .060$), which could reflect not only the previously found association between the general level of performace and SR ability (Lehmann & Ericsson, 1996), but also the assumption that instrument knowledge would be a necessary but not sufficient condition for an efficient SR (Elliott, 1982; Wolf, 1976). In turn, we will discuss the influence of flexibility and inhibitory processes on fluency and on accuracy.

Fluency

In relation to fluency, according to our first hypothesis, our results showed the significant contribution of cognitive flexibility in more demanding conditions, in line with those obtained previously by other authors (Costa et al., 2009; Glass et al., 2013). In fact, it has been suggested that the binary and ternary metrical organization of music generates different expectancies during the encoding of music, which allows for the making of predictions about the incoming information (Vuust, & Witek, 2014). These expectancies could rely, among other factors, on previous knowledge and familiarity of the music piece

(Altenmuller, 2001). Due to the fact that most classical western music is written in binary patterns (Temperley, 2010), binary expectancies would be more salient than ternary ones and could facilitate anticipation in performance (Fujioka, Zendel, & Ross, 2010). Thus, it is possible that even in unfamiliar pieces or fragments in which well-learned musical elements are combined in a novel way, the binary metrical organization could benefit fluency and require fewer cognitive flexibility resources for the encoding and processing of the incoming information in order to generate the adequate motor responses. Subsequently, the ternary metrical organization, in which anticipation is limited by reduced expectancies, demanded more of the cognitive flexibility needed for a fluent performance.

Unexpectedly, our results regarding on fluency also revealed the contribution of prepotent response inhibition in the easiest condition (binary metrical organization), which reflecting that the activation of inappropriate motor responses may affect fluency even in easy fragments (Thompson & Lehmann, 2004).

Thus, in binary conditions, in which anticipation would be more accessible and previously learned eye-hand patterns may be easily activated, inhibitory control of prepotent responses would be necessary to suppress the inappropriate ones activated, in order to fluently perform at a given time. Furthermore, in ternary conditions in which the increased difficulty of the task may be associated with longer saccadic movements and more regressive fixations (Wurtz, Mueri, & Wiesendanger, 2009), inhibition of previous learned oculo-motor patterns during execution would lose relevance in favour of the generation of new ones. This may be because reducing anticipation would also reduce the amount of inappropriate responses activated.

Accuracy

In relation to accuracy, according to our second hypothesis, our results showed a significant contribution of resistance to interference only in more demanding conditions (ternary metrical organization), and of prepotent response inhibition regardless of the difficulty conditions of the SR tasks.

Our results concurred both with the proposal of Rubia et al., (2001, 2003), who dissociate the interference produced in the selection and execution of responses and with the differentiation of errors in SR as a function of the encoding/processing and executing components posted by Thompson and Lehmann (2004). Taking into account that the responses in SR are associated with previously acquired motor patterns, it seems that in the easiest conditions (binary), the enhanced prepotency to respond could generate a greater conflict to execute than to select the responses (Nee et al., 2007). Thus, an accurate error free in binary conditions would require prepotent response inhibition resources to suppress the inappropriate motor responses activated by external cues. However, in high demanding conditions (ternary), accuracy would be affected not only by prepotent response activation but also by an increased level of interference caused by the temporal organization of the notation which could increase the cognitive demands required to select a correct response (Fujioka et al., 2010). To prevent errors during performance in high demanding conditions, inhibitory resources may be necessary to both, resist the interference in order to select the correct responses and to prevent the execution of those prepotent inadequate ones.

At this point, it is relevant to note that that although we used the go/no-go and the antisaccade task to measure prepotent response inhibition, the contribution to accuracy of this inhibitory process was restricted to the go/no-go task. It is possible that the lack of significant contribution of the antisaccade task to accuracy could be related to the specific requirements of both tasks, as stipulated for the impurity problem of the inhibition tasks posted by Friedman and Miyake (2004). Whereas the antisaccade task is based on the suppression of reflexive saccades (Nigg, 2000), the go/no-go task does not involve ocular movements. Thus, even when both tasks require the suppression of prepotent motor responses, it seems that accuracy would not depend on the saccadic movements involved in the continuous reading of the musical notation printed in the score as fluency does.

Taken together, our results revealed the relevance of the inhibitory processes involved in the suppression of prepotent actions or responses regarding fluency and accuracy, and especially in conditions of low difficulty (binary), which in turn would be associated with the tendency to activate previous learned motor patterns when musical information is being read. Our results also revealed that the role of cognitive flexibility in fluency and of resistance to interference in accuracy is significant only in high difficult conditions (ternary), when the complexity of the incoming information increases the environmental demands. Importantly, even when the effect size in each regression analysis was not to high, statistical power was acceptable.

It is possible that the very nature of SR, based on the generation of novel patterns of fine motor responses previously learned supports the basic role of prepotent response inhibition either in fluency and accuracy, while the specific demands of more complex tasks (ternary) are responsible of the contributions of cognitive flexibility to fluency and resistance to interference to accuracy, emphasising the relevance of the availability of attentional resources to maintain the task goals in more demanding conditions (Kane et al., 2007). However, some caution is needed because in our study only two different SR difficulty conditions were used. Thus, further research including a large range of SR tasks must carried out.

In conclusion, our results corroborated the significant role of cognitive flexibility and the inhibitory processes involved in the control of interference of irrelevant stimulus and in the suppression of prepotent actions or responses in SR. This may be consistent with the cognitive demands of the encoding/processing and executing components of SR described by Thompson and Lehmann (2004). Although other kind of predictors such as SR specific training (Kopiez & Lee, 2006, 2008; Kopiez et al., 2006; Lehmann & Ericsson, 1996; Lehmann & McArthur, 2002; Meinz & Hambrick, 2010), ear training (Mishra, 2014), or rhythmic audiation (Gromko, 2004), could explain a greater amount of variance in performance at sight, it is possible that the specific contributions of the executive processes may be determinant for an efficient SR. These results could complement the findings of previous research on working memory capacity (Meinz & Hambrick, 2010), as well as the sub-processses of retrieval, transformation and substitution underlying updating executive function (Herrero & Carriedo, 2019). Moreover, our results allow opening the possibility of exploring the implication of cognitive flexibility and the inhibitory processes in other dynamic tasks considering fluency and accuracy rather than evaluating them globally.

4. DISCUSIÓN GENERAL Y CONCLUSIONES

A lo largo de la introducción teórica se ha llevado a cabo una revisión sobre la conceptualización del FE, su estudio y su estructura y organización, así como sobre su relación con la interpretación musical, abordando las dos grandes líneas de investigación que se han llevado a cabo al respecto: la centrada en las posibles mejoras en el FE asociadas a la práctica musical continuada y la orientada a analizar la relevancia de las FEs en una tarea musical específica de grandes demandas cognitivas como es la lectura musical a primera vista.

Teniendo en cuenta la fundamentación teórica presentada y las evidencias empíricas previas de ambas líneas de investigación, nuestros estudios se orientaron hacia la obtención de nuevos resultados que permitieran concretar y ampliar el conocimiento existente en este campo.

Concretamente, nuestro primer estudio tuvo como objetivo analizar la relación entre la práctica musical acumulada y los procesos de mantenimiento y supresión de la información durante la actualización de la información en la MO entre el final de la infancia y la adolescencia. En relación a los procesos de mantenimiento y transformación asociados a la capacidad de MO, esperábamos que los músicos superaran a los no músicos, especialmente en las condiciones experimentales que demandaran más recursos atencionales, esto es, en las condiciones de alta carga y alta supresión de la información en la MO. Además, en relación con el proceso de sustitución, esperábamos que la mayor eficiencia de los músicos en el proceso de mantenimiento y transformación liberara activación (Just & Carpenter, 1992) o recursos atencionales (Engle, 2002) para suprimir la información irrelevante o que ha dejado de ser relevante, y que por tanto los músicos superaran a los no músicos en las condiciones más demandantes.

Los resultados obtenidos mostraron que, cuando se controlaba la inteligencia fluida, las diferencias en la capacidad para mantener y procesar la información en la MO estaban más relacionadas con la edad, contradiciendo nuestra primera hipótesis. Igualmente, nuestros resultados contradecían los de otros estudios previos que, utilizando tareas complejas de MO, habían encontrado relaciones significativas entre la práctica musical y la capacidad para mantener y procesar la información en la MO tanto en niños (Roden et al., 2014), como en adultos (Franklin et al., 2008; George & Coch, 2011; Ramachandra et al., 2012). Por lo tanto, en lugar del entrenamiento musical, la eficiencia en la capacidad para mantener y procesar la información en la MO asociada al desarrollo (Bjorklund & Harnishfeger, 1990; Case et al., 1982), era el predictor más significativo al comparar músicos y no músicos entre el final de la infancia y la adolescencia.

Sin embargo, un análisis posterior controlando el efecto de la edad mostró que la relación entre la práctica musical y la capacidad para mantener y transformar la información en la MO estaba cerca de los niveles estándar de significación ($p = .06$). Este hecho podía reflejar que, cuando se controla la edad, la práctica musical podía mejorar la codificación (Roden et al., 2014), o el procesamiento (George & Coch, 2011; Ramachandra et al., 2012), de la información en la MO como se había sugerido en estudios previos.

La contribución diferencial de la edad o de la práctica musical a los diferentes subprocesos evidenciaron la necesidad de seleccionar tareas de actualización que permitan diferenciar entre los distintos procesos subyacentes a esta función ejecutiva, al igual que corroboraron que las diferencias evolutivas en la función de actualización afectaban principalmente al mantenimiento/transformación de la información en la MO, en línea con lo obtenido en estudios previos por Carriedo et al. (2016) y De Beni y Palladino (2004).

Además, los resultados obtenidos proporcionaron nuevas evidencias en relación a los beneficios cognitivos de la práctica musical en el proceso de sustitución -que implica la capacidad para suprimir la información que ha dejado de ser relevante- y que es exclusivo de la función de actualización (Ecker et al., 2010). Estos resultados podían generar una explicación alternativa a la relación encontrada entre el entrenamiento musical y la capacidad de MO en estudios previos en los que se utilizaron tareas de amplitud de complejas (e.g. Franklin et al., 2008; George & Coch, 2011; Hou et al., 2014; Ramachandra et al., 2012; Roden et al., 2014). Aunque las tareas de amplitud compleja implican procesos inhibitorios (Belacchi et al., 2010), en los estudios previos solo se registró el recuerdo correcto sin considerar los errores de intrusión y, por lo tanto, no se distinguió entre los subprocesos de mantenimiento/transformación y sustitución necesarios para la eficiencia de la MO (Chiappe et al., 2000). Por lo tanto, sin descartar que la relación descrita entre la práctica musical y las mejoras para mantener y transformar la información en la MO encontradas en los estudios previos, sería posible que el proceso de sustitución, también pudiera relacionarse con dichas mejoras en la capacidad de MO mostradas por los músicos en otros estudios.

En conclusión, los resultados de este estudio confirmaron los esperados efectos de mejora en la función de actualización en la MO asociados a la práctica musical, limitándose éstos a la capacidad para suprimir de la MO la información irrelevante, mientras que la eficiencia en la capacidad para mantener y procesar la información en la MO, no se podía asociar a la práctica musical sino al desarrollo de la función de actualización fruto del desarrollo cognitivo que tiene lugar en estas edades (Carriedo et al., 2016).

A partir de los resultados obtenidos en nuestro primer estudio, podíamos asumir que la FE de actualización, al menos en su componente inhibitorio, estaba implicada en la interpretación musical de manera general, y que por ese motivo la práctica continuada se podía asociar a mejoras en el subcomponente de inhibición dicha función durante el desarrollo. Sin embargo, no podíamos determinar hasta qué punto podía ser relevante la capacidad para actualizar la información en la MO en el contexto de tareas musicales específicas con elevadas demandas cognitivas-como lo es la lectura a primera vista-más allá de la práctica en la propia tarea musical (Kopiez & Lee, 2006; Kopiez & Lee, 2008; Kopiez et al., 2006; Lehmann & Ericsson, 1996; Lehmann & McArthur, 2002; Meinz & Hambrick, 2010).

En este contexto, llevamos a cabo nuestro segundo estudio para profundizar nuevamente en el papel de los diferentes procesos subyacentes a la función de actualización: mantenimiento, transformación y sustitución en músicos de diferentes edades y niveles de ejecución musical en lectura a primera vista, evaluada a través de diferentes índices musicales (mantenimiento del tempo, ritmo, afinación, articulación y expresión), y en dos condiciones de dificultad diferentes de la tarea musical.

Partíamos de la hipótesis de que existiría una correlación positiva entre el mantenimiento / transformación de la información en la MO y la lectura a primera vista, así como una correlación negativa entre la sustitución de la información en la MO y la lectura a primera vista, independientemente de la dificultad de la tarea musical, y controlando la edad y la práctica. Considerando la posible existencia de un efecto de *trade-off* entre los procesos de mantenimiento / transformación y sustitución de la información en la MO (e.g. Engle, 2002; Just & Carpenter, 1992; Kane & Engle, 2000), su relación con la lectura a primera vista podrá variar en función de las demandas de carga en la memoria y nivel de supresión de la tarea de actualización.

Tal y como esperábamos, los resultados de este segundo estudio mostraron correlaciones significativas entre la lectura musical a primera vista y los sub-procesos de mantenimiento / transformación y sustitución de la información en la MO, independientemente de la dificultad de las tareas musicales, y controlando la edad y la práctica. Además, los resultados mostraron que la ejecución musical a primera vista se relacionaba principalmente con las condiciones de alta carga y baja supresión de la tarea de actualización utilizada (De Beni & Palladino, 2004), lo que reflejaba que la lectura a primera vista dependía de la capacidad para mantener y procesar la información en la MO, más que de la de suprimir la información que ha dejado de ser relevante. Estos resultados podían reflejar que la eficiencia en la lectura a primera vista implicaba una mayor capacidad para mantener en la MO más información musical y para transformarla en respuestas motoras, como ya habían sugerido previamente Meinz y Hambrick (2010).

Asimismo, los resultados del segundo estudio corroboraron, tal y como esperábamos, que la eficiencia en los procesos de mantenimiento, transformación y sustitución subyacentes a la función de actualización contribuían de manera significativa a la lectura musical a primera vista. Específicamente, la eficiencia en el mantenimiento/transformación de la información contribuyó significativamente a la lectura musical a primera vista al margen de la dificultad de las tareas musicales, algo que ya habían mostrado estudios previos centrados en el análisis de la relevancia de la capacidad de MO en esta tarea musical (Kopiez & Lee, 2006; Kopiez & Lee, 2008; Meinz

& Hambrick, 2010). Este resultado podía implicar una mayor capacidad de los instrumentistas más eficientes para codificar, mantener y procesar la información en la MO, estableciendo asociaciones entre los distintos fragmentos musicales, y ampliando por tanto su capacidad para planificar la ejecución y evitar paradas o errores (Drake and Palmer, 2000).

Sin embargo, la eficiencia en el proceso de sustitución solo contribuyó de manera significativa a la lectura a primera vista en las tareas musicales más fáciles, no existiendo diferencias en aquellas tareas musicales de mayor dificultad entre los participantes eficientes y menos eficientes en la sustitución de la información en la MO, lo que contradecía nuestra hipótesis. Estos resultados podían explicarse en función de la disponibilidad de recursos atencionales y el mecanismo de *trade-off* descrito entre el mantenimiento y la sustitución de la información de la información de la MO (e.g. Engle, 2002; Kane & Engle, 2000). Es decir, dado que el mantenimiento y transformación de la información consumen recursos atencionales, el aumento de las demandas cognitivas en las tareas musicales más difíciles, solo afectaba a los participantes más eficientes en el proceso de sustitución, porque los menos eficientes no contaban con recursos atencionales disponibles para suprimir la información que ha dejado de ser relevante, ni siquiera en las tareas más fáciles, al ocuparlos en el mantenimiento de la información (Engle, 2002). En suma, los resultados obtenidos en este estudio nos permitieron concluir que, independientemente de la edad y el nivel de instrumento musical, la eficiencia en los procesos de mantenimiento, transformación y sustitución subyacentes a la función de actualización en la MO contribuía significativamente a esta tarea musical, pero que mientras que la contribución de los procesos de mantenimiento y transformación de la información era independiente de la dificultad de las tareas musicales, la del proceso de sustitución solo era significativa en las tareas musicales más fáciles.

A partir los resultados obtenidos en este segundo estudio, nos planteamos un tercer estudio cuyo objetivo fue ampliar las evidencias empíricas en relación a la implicación de las FEs en la lectura musical a primera vista, analizando las contribuciones de las otras dos funciones ejecutivas identificadas por Miyake et al. (2010): la flexibilidad cognitiva y los procesos inhibitorios involucrados en el control de la interferencia de estímulos irrelevantes y en la supresión de acciones o respuestas prepotentes, que no habían sido exploradas con anterioridad. En este caso, se evaluó la ejecución musical de adolescentes y adultos con diferentes niveles de dominio musical en dos tareas musicales de diferente nivel de dificultad. Se tomaron como índices de ejecución musical a primera vista la fluidez y la precisión, que han sido considerados como índices generales de la coordinación eficiente entre los componentes de codificación y mantenimiento de la información y la ejecución motora en la lectura a primera vista (Thompson & Lehmann, 2004).

En este tercer estudio esperábamos que la flexibilidad cognitiva contribuyera significativamente a la fluidez, especialmente en las condiciones de lectura a primera vista más difíciles (Costa et al., 2009; Glass et al., 2013), en las que el cambio necesario entre diferentes elementos musicales podía aumentar las demandas de control ejecutivo. Además, esperábamos que los procesos inhibitorios de resistencia a la interferencia e inhibición de respuestas prepotentes, contribuyeran a la precisión para producir un rendimiento musical ajustado basado en respuestas motoras controladas. Concretamente, esperábamos que la resistencia a la interferencia contribuyera a la precisión solo en las condiciones más difíciles de las tareas de lectura a primera vista, ya que el procesamiento de elementos musicales previamente aprendidos en una organización temporal más compleja podía aumentar la interferencia tanto en el proceso de codificación de la información como en el procesamiento y selección de las respuestas motoras apropiadas (Miller & Cohen, 2001). Además, esperábamos que la contribución de la inhibición de respuestas prepotentes a la precisión no se vería afectada por la dificultad de las tareas de lectura a primera vista, ya que los patrones motores aprendidos previamente pueden ser activados incorrectamente por información familiar incluso en las condiciones más fáciles (Thompson & Lehmann, 2004).

Los resultados de este tercer estudio mostraron que la flexibilidad cognitiva contribuía de manera significativa a la fluidez, y la resistencia a la interferencia a la precisión, especialmente en las tareas más difíciles, lo que incidía en la relevancia de la disponibilidad de recursos atencionales para mantener las metas de las tareas en las condiciones de mayor demanda cognitiva (Kane et al., 2007), corroborando nuestras hipótesis al respecto. Además, los resultados mostraron que la inhibición de respuestas prepotentes contribuía tanto a la fluidez como a la precisión, algo que en contradecía nuestras expectativas respecto a su implicación exclusiva en la precisión. Los resultados también mostraron que dicha implicación era especialmente relevante en las tareas más fáciles, lo que podía estar asociado a una mayor tendencia a activar patrones de respuestas motoras aprendidas previamente, en aquellas condiciones más asequibles, y que corroboraba nuestra hipótesis respecto a su implicación incluso en las condiciones más fáciles de las tareas musicales.

Una cuestión relevante a tener en cuenta respecto a la implicación de la inhibición de respuestas prepotentes, tanto en la fluidez como en la precisión, es que en este estudio se utilizaron dos tareas diferentes para medir la inhibición de respuestas prepotentes: go/no go y antisacádica. Aunque ambas tareas contribuyeron a la fluidez, la contribución a la precisión se restringió a la tarea go/no go. En este sentido, es posible que la falta de contribución de la tarea antisacádica a la precisión se relacione con las demandas específicas de ambas tareas de inhibición (Logan, Cowan y Davis, 1984; Roberts & Pennington,1996). Mientras que en la tarea antisacádica la presentación de los estímulos se basa en la supresión de movimientos sacádicos que pueden generar interferencia (Nigg, 2000), la tarea go/no go no implica dichos movimientos oculares. Por lo tanto, incluso cuando ambas tareas requieren la supresión de las respuestas motoras prepotentes, parece que los movimientos sacádicos involucrados en la lectura continua de la notación musical serían relevantes para llevar a cabo una ejecución fluida, pero no tanto para hacerla precisa.

Globalmente, los resultados obtenidos en este estudio nos permitieron llegar a la conclusión de que las contribuciones de la flexibilidad cognitiva, la resistencia a la interferencia y la inhibición de respuestas prepotentes a la lectura musical a primera vista eran independientes del nivel de dominio del instrumento musical, y que mientras la flexibilidad cognitiva y la resistencia a la interferencia contribuían a la lectura a primera vista en las tareas musicales más difíciles, la contribución de la inhibición de respuestas prepotentes era significativa en las tareas musicales fáciles y difíciles, aunque especialmente relevante en aquellas tareas más fáciles.

Considerados de manera conjunta, los resultados obtenidos en estos tres estudios corroboran la relación entre el FE y la interpretación musical, tanto desde la perspectiva de las mejoras en las FEs asociadas a la práctica instrumental acumulada, como desde la implicación de las diferentes FEs en la interpretación musical a primera vista, que eran los objetivos principales de esta tesis.

En relación a la interpretación musical, una de las aportaciones más relevantes de los estudios llevados a cabo, es que, si bien la práctica instrumental podía mejorar los procesos asociados al FE, dichas mejoras no implicaban que las FEs dejaran de ser relevantes en tareas de interpretación musical en las que las demandas cognitivas aumentaban, como es el caso de la lectura a primera vista. Este hecho corroboraba la asunción de que la práctica sería una condición necesaria pero no suficiente para interpretar a primera vista (Elliott, 1982; Wolf, 1976). Otra aportación relevante de nuestros estudios a la interpretación musical estaba relacionada con los resultados obtenidos en los estudios sobre lectura a primera vista (estudios 2 y 3), que corroboraron que las tareas musicales organizadas temporalmente de manera ternaria eran más difíciles e implicaban mayores recursos cognitivos en su ejecución que aquellas organizadas de manera binaria (Drake, 1993; Smith & Cuddy, 1989), incluso entre músicos con cierto nivel de dominio del instrumento. La organización métrica binaria es las más común en la música occidental y que parece maximizar las expectativas en cuanto a la estructura musical (Vuust, y Witek, 2014), mientras que la organización métrica ternaria resultaría más novedosa. Por lo tanto, la sugerencia de Kane et al., (2007), respecto al aumento de las demandas de control ejecutivo provocadas por la competencia entre las respuestas habituales, y la consiguiente interferencia cuando el contexto es novedoso, podía hacerse extensible al contexto de la interpretación musical a primera vista.

Además de las aportaciones de nuestros estudios a la interpretación musical, los resultados de los tres estudios nos permiten profundizar sobre la naturaleza de las FEs y sobre su relación con diferentes aspectos de la interpretación musical, lo que analizamos a continuación.

En relación a la función de actualización, nuestros resultados han corroborado la diferenciación de los subprocesos de mantenimiento/transformación y sustitución (Ecker et al., 2010; Kessler & Meyran, 2008), tanto en relación a sus diferentes trayectorias de desarrollo en línea con lo obtenido por Carriedo et al. (2016) (estudio 1), como a la existencia de un mecanismo de *trade-off* entre ambos subprocesos dependiente de los recursos atencionales disponibles (e.g. Engle, 2002; Kane & Engle, 2000) (estudios 1 y 2). Concretamente, los subprocesos de mantenimiento/transformación serían responsables del mantenimiento activo de la información de forma temporal, mientras se bloquean las fuentes de interferencia, distracción o conflicto (Kane, et al., 2007), lo que consumiría recursos atencionales. Por lo tanto, una mayor eficiencia en el mantenimiento podría liberar parte de esos recursos atencionales para eliminar información irrelevante (Engle, 2002; Kane & Engle, 2000). Es más, nuestros resultados también mostraron que los procesos de mantenimiento/transformación y sustitución estaban implicados de manera diferenciada en los distintos elementos musicales de la misma tarea de lectura musical a primera vista (estudio 2). Nuestros resultados reflejaron que aquellos aspectos más relacionados con la continuidad, como el mantenimiento del tempo o la expresividad, dependían más de la capacidad para mantener y procesar la información. Los aspectos relacionados con la precisión, como la articulación, requerían recursos inhibitorios para suprimir la información irrelevante de la MO. Finalmente, los índices generales de ejecución, como la precisión rítmica y la detección de errores (e.g. Drake & Palmer, 2000; Hayward & Gromko, 2009; Kopiez & Lee, 2008; Mishra, 2014; Wurtz et al., 2009), implicaban tanto al proceso de mantenimiento/transformación como al de sustitución.

Estos resultados abren la posibilidad de explorar la implicación de los subprocesos de la función de actualización en otras tareas cognitivas a través de la medida de diferentes índices de ejecución, más allá de considerarlas de manera global.

Respecto a los procesos inhibitorios, los resultados de nuestro primer estudio mostraron que la práctica musical continuada mejora los procesos de inhibición cognitiva. Además, los resultados obtenidos en nuestro segundo y tercer estudio corroboraron la implicación de los procesos inhibitorios -inhibición cognitiva, resistencia a la interferencia e inhibición de respuesta- como mecanismo de control ejecutivo necesario en contextos dinámicos, tal y como sugirieron Miller y Cohen (2001). Asimismo, estos resultados mostraron la especial relevancia de los procesos inhibitorios a la hora de llevar a cabo una interpretación a primera vista de manera precisa. Concretamente, la resistencia a la interferencia y la inhibición de respuestas prepotentes estaban implicadas en la precisión general con la que se interpreta la partitura (estudio 3); mientras que la supresión de la información irrelevante o inhibición cognitiva medida en el segundo estudio lo estaba solo en la articulación, una medida específica de precisión.

Asimismo, la tarea secuencial de lectura a primera vista que se empleó en los estudios 2 y 3 permitía diferenciar los componentes de codificación/procesamiento de partitura musical y ejecución de respuesta motora (Thompson & Lehmann, 2004), lo que a su vez permitiría determinar la influencia de los procesos inhibitorios en los distintos momentos del procesamiento (Rubia et al., 2001; Rubia et al., 2003).

En este sentido, los resultados en el tercer estudio reflejaron que la resistencia a la interferencia parecía ser más relevante durante la codificación/procesamiento de la información musical a la hora de evitar errores en la selección de respuestas causados por la interferencia entre los distintos elementos musicales. Por su parte, la inhibición de respuestas prepotentes era especialmente relevante durante la ejecución motora para evitar errores relacionados con la activación de patrones motores inapropiados previamente aprendidos. Además, los resultados obtenidos en nuestro segundo estudio en relación a la inhibición cognitiva, permitían plantear su implicación tanto en la codificación/procesamiento como en la ejecución. La notación musical escrita con una determinada articulación que se codifica en la MO, pasaría a ser información con mayor nivel de activación y, por tanto, debería ser suprimida activamente de la MO cuando la misma notación apareciera escrita en otro lugar de la partitura con una articulación diferente. Estos resultados también podían indicar la existencia de interferencia entre los diferentes elementos musicales en distintos momentos de procesamiento. Así, durante la codificación, los elementos musicales podrían interferir entre ellos porque tienen que ser leídos de manera simultánea; durante el procesamiento porque una vez codificados en la MO deben activarse los elementos relevantes y suprimirse los irrelevantes; y durante la ejecución porque la información más sobreaprendida de cada elemento musical tendería a activarse aun siendo inapropiada. Por lo tanto, nuestros resultados sugieren que el estudio del papel de la inhibición en tareas secuenciales dinámicas debería tener en cuenta los diferentes momentos de procesamiento, aunque ésta es una cuestión que debe ser corroborada empíricamente en estudios posteriores.

Finalmente, y en relación a la función de cambio atencional o flexibilidad cognitiva, nuestros resultados corroboraron su relevancia en tareas dinámicas que precisan adaptación continua en contextos cambiantes (Diamond, 2013), y especialmente en las condiciones más demandantes (Costa et al., 2009; Glass et al., 2013), proporcionando fluidez a la ejecución. Nuestros resultados estarían en línea con los mecanismos de cambio descritos por Krems (1994) a la hora de generar respuestas flexibles en el contexto de la solución de problemas. Considerando la lectura a primera vista desde esta perspectiva, la flexibilidad cognitiva eficiente implicaría: a) la capacidad para interpretar la información entrante y cambiar entre los diferentes elementos musicales; b) la capacidad para cambiar y adaptar las representaciones de dichos elementos musicales para mantener la fluidez de la ejecución; y c) la capacidad para cambiar de estrategias en función de los cambios en las demandas de las tareas que en este caso se representarían en la información musical conocida organizada de manera novedosa, especialmente las tareas más difíciles.

En conclusión, los estudios llevados a cabo en esta tesis no solo han ampliado el conocimiento respecto a la implicación del FE en un área no demasiado explorada como es la interpretación musical, sino que han aportado evidencias empíricas acerca de la diferenciación de los distintos procesos subyacentes a las FEs, su implicación en tareas dinámicas en contextos complejos, y su posible mejora a través de la práctica continuada, algo que podría hacerse extensible a otro tipo de actividades o tareas con demandas similares.

Escuela Internacional de Doctorado EIDUNED

Laura Herrero Pérez

5. LIMITACIONES Y FUTURAS DIRECCIONES

Los resultados obtenidos en nuestros tres estudios han contribuido a profundizar en el conocimiento del FE, así como a ampliar la evidencia empírica existente respecto a su relación con la interpretación musical. Sin embargo, aunque se han podido extraer conclusiones relevantes, los estudios no están exentos de algunas limitaciones.

En relación al primer estudio, una de las limitaciones principales sería la utilización de una única tarea de actualización para medir la eficiencia en dicha función. Aunque la tarea utilizada en nuestro estudio ha mostrado fiabilidad (Carretti et al., 2009; Carriedo et al., 2016; De Beni & Palladino, 2004; Lechuga et al., 2006; Passolunghi & Pazzaglia, 2005), utilizar más de una tarea de actualización con estímulos de distinto tipo o presentada en diferentes modalidades permitiría establecer conclusiones más precisas.

Otra limitación de nuestro primer estudio es que, aunque todos los participantes pertenecían a un estatus socio-económico medio y estaban igualados en inteligencia fluida, el diseño correlacional utilizado no permitía establecer relaciones causales, ni controlar la posible existencia de una mayor predisposición a la práctica musical continuada en los grupos de músicos (Schellenberg, 2011), así como otro tipo de experiencias que pudieran estar promoviendo el desarrollo cognitivo en este grupo de participantes.

El segundo y tercer estudio llevados a cabo presentaban una limitación común, la de haber utilizado solo dos tareas musicales de distinto nivel de dificultad cuando se estaban analizando las contribuciones de las FEs en función de dicha dificultad. Un mayor número de tareas musicales con un rango más amplio de dificultad, permitiría ampliar las conclusiones.

Además, ambos estudios estaban limitados en cuanto a la evaluación de las tareas musicales, ya que en los dos casos se contó con solo dos jueces. No obstante, la fiabilidad inter-jueces fue muy elevada. Es más, el grado de especialización necesario para evaluar tareas musicales dificultaría la posibilidad de ampliar su número, algo que ya se ha considerado como una limitación general de este tipo de estudios (Meinz y Hambrick, 2010).

No obstante, y a pesar de las limitaciones descritas, los estudios llevados a cabo en esta tesis doctoral han aportado evidencias novedosas sobre la relación entre el FE y la interpretación instrumental, abriendo nuevas perspectivas de estudio en este campo.

Más allá de la posibilidad de replicar los estudios tratando de superar las limitaciones presentadas, se plantea la posibilidad de desarrollar nuevas investigaciones atendiendo a los siguientes aspectos.

En relación a la posible mejora de las FEs asociadas a la práctica musical, se podría profundizar en este campo de investigación utilizando diseños cuasi-experimentales, con el objetivo de determinar los efectos de la práctica musical en las diferentes FEs, así como el tiempo mínimo necesario de práctica musical acumulada para generar mejoras, los límites de estas mejoras, su perduración en el tiempo una vez dejada la práctica. Igualmente, se podría explorar si los diferentes tipos de práctica o actividad musical (individual, de conjunto, composición, improvisación, entre otras), tendrían efectos similares o no, utilizando para ello una mayor variedad de tareas de FE.

En relación a los estudios centrados en la lectura a primera vista, nuestros resultados en el estudio 2 abren la posibilidad de explorar la implicación de los subprocesos de la función de actualización en otras tareas cognitivas dinámicas a través de la medida de diferentes índices de ejecución, más allá de considerarlas de manera global. Igualmente, los resultados de los estudios 2 y 3 sugieren que el papel de la inhibición en tareas secuenciales dinámicas podría variar en función de los distintos momentos de procesamiento, lo que también abre la posibilidad de corroborarlo empíricamente en otro tipo de tareas secuenciales dinámicas.

Finalmente, dado que la lectura musical a primera vista se ha relacionado con la improvisación por sus demandas cognitivas (Thompson & Lehmann, 2004), esta actividad musical sería una buena candidata para ampliar las evidencias aportadas en esta tesis. Por una parte, por la posibilidad de explorar si la implicación de las FEs en ambas tareas es similar, y por otra explorando la relación entre las FEs y los aspectos creativos asociados a la interpretación musical (Zabelina, Friedman y Andrews-Hanna, 2019), que a su vez se han relacionado con la flexibilidad cognitiva (Wilson et al., 1954).

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