

UNIVERSIDAD COMPLUTENSE DE MADRID
FACULTAD DE PSICOLOGÍA
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PROCESOS COGNITIVOS Y LOGOPEDIA



TESIS DOCTORAL

Impacto del entrenamiento cognitivo NEXXO sobre la atención y funciones ejecutivas en edad escolar

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PRESENTADA POR
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AGRADECIMIENTOS Y DEDICATORIAS

La tesis: un recorrido lleno de implicación emocional, de ilusión, de ganas de aprender y de aportar algo en el devenir del conocimiento y de la investigación. Algo que pueda aplicarse en la sociedad, un ínfimo granito de arena que sumando voluntades e ilusiones genere pequeños cambios.

Sería iluso decir que la tesis sólo se trata de eso, pues también es un camino que consume tiempo y dedicación (unas horas más infructuosas que otras), cansancio, y, a veces hasta de cierta desesperación. Pero si de algo sabemos en psicología es que la desesperación puede ir seguida de resiliencia y de coraje. La resiliencia nos genera oportunidades para enfrentar los retos y abrir nuevos caminos. ¿Por dónde empezar entonces la redacción de la tesis? Sería injusto comenzar por cualquier otra parte que no fueran los agradecimientos.

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“Las situaciones que nos hacen crecer de verdad son precisamente aquellas que no dominamos”.

Jacques Philippe

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Resumen en inglés y castellano

Abstract

The origin of this thesis comes from my own clinical practice with children with attention deficit disorder (ADHD). To intervene neuropsychologically with these patients, I realised about the need of developing a program aimed to attention and executive functions (EF), such as vigilance and inhibitory control (Figuroa y Youmans, 2012; Rueda, Posner y Rothbart, 2005) with the final goal of training attentional and executive control. This program should be directed by professionals who applied metacognitive strategies to better implement the training. By doing this, there are a higher likelihood of transference. As mentioned, the original idea was to train vigilance and inhibition, aspects were ADHD patients have some handicaps as it seems in tests such as Conners Continuous Performance Test II (CPT-II) (Conners et al., 2000), Conners Kiddie Continuous Performance Test (K-CPT V.5) (Conners y Staff, 2001) or CSAT-R (task of sustained attention in childhood) (Servera y Llabrés, 2015). When designing the training, we focused on attentional and executive control as well as processes related. The training had to be applied with some strategies to better assimilate it, those strategies are metacognitive. “Nexxo” training emerged from a specific need: to train basic processes of attention and EF with a particular scope (from child neuropsychology). A program that incorporates metacognitive strategies to better assimilate training, a program that does not previously exist.

Parasuraman y Giambra (1991) consider vigilance and sustained attention as the same ability, an ability in which observers must maintain their focus of awareness and alertness for prolonged periods. The main distinction is that in vigilance tasks, observers must respond to infrequently occurring signals (Hauke, Fimm, y Sturm, 2011). Those are easily detected in short periods but not in long ones. These abilities are relevant to develop attention tasks; this is relevant in daily life (Figuroa y Youmans, 2012). Failures in this process have been found in attention deficit hyperactivity disorder (ADHD) (Huang-Pollock, Karalunas, Tam, y Moore, 2012; Michelini et al., 2016), anxiety (Price et al., 2013) and autism (Christakou et al., 2013). Inhibition is one of the core elements of EF (Miyake y Friedman, 2012; Miyake et al., 2000). Inhibition is not only the ability to suppress a dominant response but also the ability to select relevant stimuli when a distractor appears (Miyake et al., 2000; Tamm y Nakonezny, 2015) Failures in inhibitory processes have been found in disorders such as ADHD (Barkley, 1997), obsessive-compulsive disorder, and autism (Ozonoff y Jensen, 1999). For these reasons, both aspects are relevant to the design of attention and EF training.

Regarding the metacognitive strategies applied, we need to clarify what is understood by metacognition and types of strategies. Metacognition is a term introduced by Flavell (1979), which is an introspective ability that enforces memory and learning. The same author distinguishes between declarative metacognition and self-regulated metacognition. Self-regulated metacognition is referred to as “procedural metacognition”, a relevant aspect in the regulation of cognitive processes. For our training, we have

selected this type of strategy. The kind of self-regulation strategies applied in “Nexxo” are motor and verbal strategies, instructions comprehension, and self-instructions. The idea of incorporating these strategies comes from previous literature of cognitive training, which includes metacognitive strategies showing positive results (Graziano y Hart, 2016; Partanen, Jansson, Lisspers, y Sundin, 2015; Pozuelos, Combata, Abundis, Paz-Alonso, Conejero, Guerra, y Rueda, 2018a). We believe that this type of training offers higher possibilities of generalization. Most cognitive training can be classified into two categories: process-based training and strategy-based training (Jolles y Crone, 2012; Morrison y Chein, 2011a). Both approaches involve a practice or intentional instruction to improve cognitive skills. The main difference is that strategy-based training uses more explicit task instructions than process-based training (Jolles y Crone, 2012). An example of this kind of guidance is scaffolding, or metacognitive strategies, designed in combination with the training (Pozuelos, Combata, Abundis, Paz-Alonso, Conejero, Guerra, y Rueda, 2018b). Further research on this type of training is crucial as it offers a new direction for cognitive training interventions.

The creation of this program and the consequent study of it was done after carefully reviewing the literature, clinical studies, and other programs. For this, we reviewed main studies of computer-based trainings of attention and/or EF in children and adolescents. In this review, we analysed trainings in terms of neuroplasticity and transference as well as studies designs (article 1: Rossignoli-Palomeque, T., Perez-Hernandez, E., y González Marqués, J. (2018). *Brain training in children and adolescents: Is it scientifically valid? Frontiers in Psychology, 9*, 565. Analysing 70 results, we observed that only 10 studies (14.2%) have been found that support neuroplasticity and the majority of brain training platforms claimed to be based on such concepts without providing any supporting scientific data. Thirty-six studies (51.4%) have shown far transfer (seven of them are non-independent), and only eleven (15.7%) maintained far transfer at follow-up. Considering the methodology, forty studies (68.2%) were not randomized and controlled; for those randomized, only nine studies (12.9%) were double-blind, and only thirteen studies (18.6%) included active controls in their trials. It is crucial to test cognitive trainings, especially in the terms analysed and overcome the limitations founded in studies designs.

Intending to overcome the limits found in previous studies, we implemented a study were test “Nexxo” training in typically developing children over attention and EF (article 2: Rossignoli-Palomeque, T., Perez-Hernandez, E., y González Marqués, J. (2019) *Training effects of attention and EF strategy-based training “Nexxo” in school-age students* (under review in *Acta Psychologica*). Considering models of attention and EF and their development in children, we decided to test training in children aged 6-7 years old and 8-9. The reason yield in the hypothesis that in 7-8 years old could be a substantial developmental improvement in inhibition and vigilance. For this reason, we expect to find different results in both age groups. We conducted a randomized active-controlled trial involving 108 typically-developing children: 1st grade (N = 61, M = 6.46

years, $SD = 0.35$) and 3rd grade ($N = 47$, $M = 8.5$ years, $SD = 0.27$), randomly assigned to: (1) experimental, (2) active-control, or (3) passive-control groups. A 2-month follow-up was carried out after the intervention. Dependent variables related to attention, EF and supervision were assessed through parent questionnaires using “the system of children and adolescents assessment” (SENA) (Fernández-Pinto et al., 2015) and the Spanish version of the Behaviour Rating of Executive Functions-2 (BRIEF-2) (Gioia, Isquith, Guy, y Kenworthy, 2000). “Nexxo” training was the independent variable. This training combines the use of the iPad application (“Nexxo”), the original idea of the Ph.D. student, an app of “go/no-go” and “stop signal tasks,” with metacognitive strategies (such as self-instructions, motor, and verbal self-regulation strategies and instructions comprehension). These strategies were applied by one instructor. In addition to general strategies to the whole group (experimental group), we provide compensatory strategies to those participants who experience higher difficulties while training (e.g., repeating instruction, child or instructor verbalization, etc.). The “Nexxo-training” occurred over a 5-week intervention period (2 sessions per week/15 minutes each) in groups of 8 in school time. Active-control group spent the same time as the experimental group and under the same conditions playing ludic app games. The passive-control group received no intervention and continued as usual. Results showed that the 3rd grade experimental group displayed a significant reduction in attentional problems at follow-up compared to both control groups. Executive function problems were also reduced at follow-up in the experimental group. Participants in this group improved in supervision (self-monitoring) at post-intervention and follow-up compared to passive-controls. Although the group effect was not significant at t1, it was significant at post measures in the experimental group compared to passive-controls. “Nexxo-training” revealed a trend-level improvement in attention and executive functions for children in the 3rd grade. Regarding the 1st grade group, there were no significant results. Although the results are moderately significant, it must be considered that this trial is extremely rigorous as it includes: (1) an active-control group, (most studies of CT do not feature this design), (2) examiners and parents were blind to the group assignment of participants, and, (3) rigorous control in inclusion criteria to ensure a typically-developing sample. On the other hand, intervention time is short.

Finally, we analysed the strategies and the cognitive variables which could better predict better or worse performance in vigilance and inhibition tasks (article 3: Rossignoli-Palomeque, Quiros-Godoy, M; T., Perez-Hernandez, E., y González Marqués, J (2019). *Schoolchildren’s compensatory strategies and skills in relation to Attention and Executive Function App training. Frontiers in Psychology, 10*, 2332. For this study, we use data from a previous randomized active-controlled study (under review in *Acta Psychologica*), in which forty-six typically developing children aged between 6 and 8 years old (24 girls/22 boys) were enrolled in the training group. The selected children were in the 1st grade ($n=28$, $x\bar{x} = 78.32 \pm 4.037$ months) and 3rd grade of primary education ($n=18$, $x\bar{x} = 102.11 \pm 3.445$). We collected data on EF training performance, compensatory

strategies needed, and neuropsychological assessments before and after training. Neuropsychological tests applied were the DIVISA-R “Trees Simple Visual Discrimination Test-Revised” (Santacreu, Shih, y Quiroga, 2010) to measure attention, intelligence using the Reynolds Intellectual Screening Test (RIST) (Reynolds, C. y Kamphaus, 2003), the Five Digit Test (FDT) (Sedó, 2007) to measure inhibition and cognitive flexibility, and, processing speed assessment through the Wechsler Intelligence Scale for Children-fourth edition (WISC-IV) (Wechsler, 2003). We also collect information about users’ performance in inhibition and vigilance tasks (obtained through the application), as well as the compensatory strategies needed for each participant (collected by instructors).

Results showed that a total of 80.43% of participants required some form of compensatory strategy during training. Regarding required compensatory strategies, those who had lower scores in EF training needed more compensatory strategies, in particular, instructional comprehension ($r = -0.561$, $p < 0.001$ for inhibition-tasks; $r = -0.342$, $p < 0.001$ for vigilance-tasks). Concerning developmental factors, age significantly predicted better performance in both EF tasks ($\beta = 0.613$, $p < 0.001$ for inhibition; $\beta = 0.706$, $p < 0.001$ for attention). As regards task performance, those with better performance in inhibition tasks also had better performance in vigilance tasks ($r = 0.72$, $p < 0.001$). Finally, regarding cognitive skills, participants with higher performance in fluid intelligence (Q1, $n = 12$) had higher scores ($U = 14.5$, $p < 0.05$) than the group with the lowest performance (Q4, $n = 11$) in vigilance.

Moreover, considering the whole group regarding vigilance score, those with higher scores in fluid intelligence ($\beta = .389$, $p = .002$) lower omissions ($\beta = -.479$, $p < .001$) and cognitive flexibility ($\beta = -.279$, $p = .02$), had better performance on vigilance. In conclusion, as previous literature suggests, inhibition is one of the core processes of EF. Therefore, we should focus on training on the core EF processes. Inhibition and vigilance are closely related processes. In terms of the use of compensatory strategies, these are more needed for participants with lower levels of performance in inhibition or vigilance.

Regarding strategy analysis, instructional comprehension, and self-instruction (goal setting and planning) seem to be the most useful strategies for those with difficulties in inhibitory and vigilance task performance. Regarding development, as expected, age moderates task performance in inhibition and attention. Finally, cognitive skills, such as fluid intelligence and cognitive flexibility, predicted better results in attention. EF training using not only an App but also compensatory strategies based on user performance is a new research direction offering more opportunities to generalize EF training in everyday life. In the future, we would like to include a score of processing speed regarding user performance. The analysis of strategies gathers a lot of practical issues that should be considered when designing training of attention and/or EF. Complementary, this analysis of the cognitive skills related to task performance helps us to better understand the nature of the components involved.

In the future, we would like to test “Nexxo-training” up to 8 years old (considering the results), duplicating intervention time (applying level 1 plus level 2). Also, considering that the ADHD population presents handicaps in the trained processes, we would like to test “Nexxo-training” in this population.

Resumen

El origen de esta tesis se remonta a la propia práctica clínica con niños con Trastorno por Déficit de Atención e Hiperactividad (TDAH). Abordando la intervención psicoeducativa y neuropsicológica de este trastorno observé la necesidad de implementar un programa de intervención que tratase aspectos básicos de la atención y de las funciones ejecutivas, como son la vigilancia y la inhibición (Figuroa y Youmans, 2012; Rueda, Posner y Rothbart, 2005), con el objetivo final de entrenar el control atencional y el control ejecutivo. Un programa que, además, fuese dirigido por profesionales donde, además, se aplicasen pautas y estrategias metacognitivas que consolidasen y generalizasen la intervención. Como se ha dicho anteriormente, la idea inicial fue abordar el entrenamiento de la vigilancia y de la inhibición, aspectos deficitarios para estos pacientes en las reconocidas pruebas de ejecución continua como *Conners Continuous Performance Test II* (CPT-II) (Conners et al., 2000), *Conners Kiddie Continuous Performance Test* (K-CPT V.5) (Conners y Staff, 2001) o CSAT-R tarea de atención sostenida en la infancia revisada (Servera y Llabrés, 2015). Al diseñar el entrenamiento, nos centramos en el control atencional y ejecutivo, y los procesos relacionados con los mismos. Entre otras cosas, por ello, entrenamiento debía estar acompañado de ciertas pautas y estrategias que pudieran ayudar a asimilar de forma más adecuada el entrenamiento, estrategias metacognitivas. El entrenamiento “Nexxo” surgió de una necesidad: entrenar procesos básicos de atención y funciones ejecutivas con un enfoque determinado (desde la neuropsicología infantil), un programa que además incorporase estrategias metacognitivas para su consolidación; un programa inexistente en el mercado, y, por tanto, inaccesible en ese momento.

Parasuraman y Giambra (1991) consideran la vigilancia y la atención sostenida como la misma habilidad, una habilidad en la que el observador debe mantener su foco de atención y su estado de alerta durante tiempos prolongados. La principal distinción es que en las tareas de vigilancia la frecuencia con la que el observador debe detectar un estímulo relevante es baja (Hauke et al., 2011). Esta habilidad se considera crucial para el desempeño de tareas de atención sostenida y de atención dividida, aspectos relevantes para la vida diaria (Figuroa y Youmans, 2012). La vigilancia se ha visto afectada en trastornos como el Trastorno por Déficit de Atención e Hiperactividad (TDAH) (Huang-Pollock, Karalunas, Tam, y Moore, 2012; Michelini et al., 2016), ansiedad (Price et al., 2013) y autismo (Christakou et al., 2013) entre otros. Por su parte la inhibición es uno de los aspectos principales de las funciones ejecutivas (Miyake y Friedman, 2012; Miyake et al., 2000). La inhibición supone dos habilidades básicas, por un lado, la habilidad de suprimir una respuesta automática o una tendencia en favor de otra, lo que se conoce como inhibición de respuesta, por otro, la selección de la información relevante en presencia de distractores, conocido como control de la interferencia (Miyake et al., 2000; Tamm y Nakonezny, 2015). Déficits en inhibición se encuentran en trastornos como TDAH, (Barkley, 1997), trastorno obsesivo-compulsivo y autismo (Ozonoff y Jensen, 1999). Se consideran por tanto aspectos relevantes a incorporar en un entrenamiento de la atención y las funciones ejecutivas.

En cuanto a las estrategias metacognitivas aplicadas, es preciso aclarar qué se entiende por metacognición y la tipología de las habilidades metacognitivas aplicadas. La metacognición, término introducido por Flavell (1979), es una capacidad de introspección que refuerza la memoria y el aprendizaje. El mismo autor diferenciaba entre metacognición declarativa y metacognición de autorregulación. Este último se ha denominado metacognición procedimental (*procedural metacognition*) aspecto relevante para la regulación de procesos cognitivos. Para el programa de intervención propuesto, nos hemos centrado en proporcionar estrategias metacognitivas de tipo procedimental. El tipo de estrategias metacognitivas procedimentales aplicadas en “Nexxo” son de autorregulación (motoras y verbales), comprensión de instrucciones y autoinstrucciones. El hecho de incorporar este tipo de estrategias radica en el hecho de que estudios sobre intervenciones de entrenamiento cognitivo combinadas con estrategias metacognitivas muestran resultados positivos (Grazinano y Hart, 2016; Partanen et al., 2015; Pozuelos et al., 2018) Creemos que este tipo de entrenamiento ofrece mayores posibilidades de generalización. La mayoría de los programas de entrenamiento cognitivo pueden clasificarse en dos categorías: entrenamiento basado en el proceso (*process-based training*) y entrenamiento basado en estrategias (*strategy-based training*). Ambos persiguen optimizar habilidades cognitivas, los primeros a través de la repetición de una tarea de entrenamiento, mientras que los segundos además de ello incorporan estrategias para desempeñar la tarea (Jolles y Crone, 2012; Morrison y Chein, 2011b). Un ejemplo de ello serían las estrategias metacognitivas (Pozuelos et al., 2018) Este es un nuevo enfoque en el entrenamiento cognitivo con un gran potencial en futuras investigaciones.

La creación de este programa y la puesta en marcha de un estudio empírico sobre el mismo se efectúa no sin antes realizar un exhaustivo estado de la cuestión. Para ello, se realizó una revisión sobre los principales estudios de entrenamiento cognitivo computarizado sobre atención y/o funciones ejecutivas en niños y adolescentes. En tal revisión se analizaron los diversos entrenamientos en términos de neuroplasticidad y transferencia, así como el diseño de los estudios (artículo 1: Rossignoli-Palomeque, T., Perez-Hernandez, E., y González Marqués, J. (2018). *Brain training in children and adolescents: Is it scientifically valid? Frontiers in Psychology, 9, 565*. Analizando 70 resultados, observamos que sólo 10 estudios (14.2%) proporcionaron resultados positivos en términos de neuroplasticidad, y, la mayoría de los desarrolladores de productos de *brain training* (entrenamiento cerebral) dicen basarse en este concepto, sin aportar datos científicos que lo sustenten. 36 estudios (51.4%) mostraron *far transfer* (transferencia lejana), es decir transferencia en otras áreas no entrenadas (siete de ellos no son estudios independientes), pero, en tan sólo once (15.7%) se mantienen los resultados en el seguimiento. Respecto a la metodología, cuarenta estudios (68.2%) no fueron controlados ni aleatorizados; entre los estudios aleatorizados (veintisiete), tan sólo nueve (12.9%) fueron doble-ciego, y, tan sólo trece (18.6%) incluyeron un grupo placebo en el diseño.

Es conveniente aportar entrenamientos puestos a prueba, especialmente en los términos analizados, superando las limitaciones metodológicas de estudios anteriores.

Procurando superar las limitaciones de estudios anteriores, se realizó un estudio donde poner a prueba el impacto del entrenamiento “Nexxo” en niños con desarrollo típico sobre los procesos de atención y funciones ejecutivas (artículo 2: Rossignoli-Palomeque, T., Perez-Hernandez, E., y González Marqués, J. (2019) *Training effects of attention and EF strategy-based training “Nexxo” in school-age students*(en revisión en Acta Psychologica). Tras considerar los modelos vigentes en la actualidad y el desarrollo de la atención y las funciones ejecutivas se decidió poner a prueba el entrenamiento en niños de 6-7 años y en niños de 8-9 años. Ello es así ante la hipótesis de que a los 7-8 años pudiera haber un cambio madurativo sustancial en inhibición y vigilancia y, por tanto, encontrarse resultados diferentes en ambos grupos de edad. Para ello se realizó un estudio aleatorio controlado que incluye un grupo placebo. Participaron 108 niños con desarrollo típico: Primero de Primaria (N = 61, M = 6.46 años, SD = 0.35) y Tercero de Primaria (N = 47, M = 8.5 años, SD = 0.27), aleatoriamente asignados a los diferentes grupos: (1) experimental, (2) control activo o placebo y (3) control pasivo. Se realizó una media pre-intervención, post intervención y seguimiento a los dos meses. Las variables dependientes analizadas fueron relativas a la atención, funciones ejecutivas y supervisión valoradas desde el ámbito familiar a través del Sistema de Evaluación de Niños y Adolescentes (SENA) (Fernández-Pinto et al., 2015) y la versión española del *Behaviour Rating of Executive Functions-2* (BRIEF-2) (Gioia et al., 2000). La variable independiente fue el entrenamiento “Nexxo”. Este entrenamiento combina el uso de la aplicación para Ipad “Nexxo” (idea original de la doctoranda), una aplicación basada en tareas de *go/no-go* (hacer/no-hacer) y *stop signal* (parar ante una señal), junto con estrategias metacognitivas procedimentales (como el uso de autoinstrucciones, estrategias de autorregulación motora y verbal, y comprensión de instrucciones escritas) dirigidas por un instructor. Además de estas estrategias que fueron proporcionadas a todo el grupo experimental, en el diseño del programa incluimos una serie de estrategias compensatorias para aquellos participantes que mostraran dificultad durante los entrenamientos (p.e. repetir la instrucción, verbalizaciones por parte del niño o del instructor etc.). Los entrenamientos se realizaron en grupos de 8 participantes, 2 días a la semana durante 5 semanas. Las sesiones tuvieron una duración de 15 minutos, llevadas a cabo en horario escolar. Bajo las mismas condiciones, el grupo placebo entrenó a través de actividades lúdicas informáticas. El grupo de control pasivo no recibió ninguna intervención. Los resultados mostraron que en tercero de primaria el grupo experimental redujo los problemas de atención en el seguimiento comparado con los dos grupos de control. Además, los problemas de funciones ejecutivas se redujeron en el seguimiento en el grupo experimental. Este grupo mejoró también en cuanto a supervisión tanto en la evaluación post-intervención como en el seguimiento comparado con el grupo de control pasivo. En cuanto al grupo de primero de primaria no se encontraron resultados significativos. Pese a que los resultados son modestos, debe considerarse que el estudio

incluye un grupo de placebo, y que los criterios de inclusión aplicados para garantizar que la muestra es típica fueron exhaustivos. Por otro lado, el tiempo de intervención es un período corto.

Por último, se analizaron las estrategias, así como las variables cognitivas que pudieran predecir un mayor o menor desempeño en inhibición y vigilancia (artículo 3: Rossignoli-Palomeque, Quiros-Godoy, M; T., Perez-Hernandez, E., y González Marqués, J (2019). *Schoolchildren's compensatory strategies and skills in relation to Attention and Executive Function App training. Frontiers in Psychology, 10*, 2332. Para este estudio se analizó una muestra de 46 participantes del grupo experimental (del estudio anterior) Primero de Primaria (n =28, \bar{x} = 78.32 \pm 4.037 meses) y Tercero de Primaria (n =18, \bar{x} =102.11 \pm 3.445). Se valoraron las funciones ejecutivas, atención e inteligencia a través de pruebas neuropsicológicas, efectuadas antes de la intervención y después de la misma. Las pruebas empleadas fueron el test de discriminación simple de árboles-R (DIVISA-R) (Santacreu, Shih, y Quiroga, 2010), el test de inteligencia breve de Reynolds (RIST) (Reynolds, C. y Kamphaus, 2003), el test de los cinco dígitos (FDT) (Sedó, 2007) y la subpruebas de memoria de trabajo y velocidad de procesamiento de la escala de inteligencia Wechsler para niños-cuarta edición (WISC-IV) (Wechsler, 2003). También se recogió información sobre el desempeño por parte de los participantes en inhibición y vigilancia (recogido por la aplicación), así como el uso de estrategias compensatorias requeridas durante la intervención (recogido por los instructores). Los resultados mostraron que el 80.43% de los participantes precisaron estrategias compensatorias en algún momento del entrenamiento. En cuanto a las estrategias compensatorias se observó que aquellos con puntuaciones más bajas en inhibición y vigilancia (en el desempeño del entrenamiento) necesitaron más estrategias compensatorias, en concreto la estrategia de comprensión de instrucciones ($r = -.561$, $p < .001$ para tarea de inhibición; $r = -.342$, $p < .001$ para tareas de vigilancia). En cuanto a los factores de desarrollo, la edad predice un mejor desempeño en ambas tareas ($\beta = .613$, $p < .001$ para inhibición; $\beta = .706$, $p < .001$ para vigilancia). En cuanto a la ejecución de las tareas, aquellos con mejor desempeño en inhibición tuvieron también mejor desempeño en vigilancia ($r = .72$, $p < .001$). Por último, en cuanto a las habilidades cognitivas, aquellos participantes con niveles más altos en inteligencia fluida (Q1, n=12) tuvieron puntuaciones más altas ($U = 14.5$, $p < .05$) que el grupo con puntuaciones más bajas (Q4, n=11) en vigilancia. Además, considerando todo el grupo respecto a la puntuación en vigilancia, aquellos con puntuaciones más altas e inteligencia fluida ($\beta = .389$, $p = .002$) más bajas en omisiones según la prueba de atención individual aplicada ($\beta = -.479$, $p < .001$) y flexibilidad cognitiva ($\beta = -.279$, $p = .02$), obtuvieron un mejor desempeño en vigilancia. En conclusión, según los resultados obtenidos podemos decir que la inhibición y la vigilancia son procesos relacionados. En cuanto al uso de estrategias compensatorias, éstas fueron más necesarias para aquellos que presentaron más dificultades durante el entrenamiento (puntuaciones más bajas en inhibición y vigilancia). En cuanto al análisis de estrategias, parece que la estrategia de comprensión de instrucciones y autoinstrucciones fueron las

estrategias más útiles para los que mostraron dificultades durante el entrenamiento. En cuanto al desarrollo, tal y como cabía esperar, la edad modera el desempeño en Inhibición y vigilancia. Por último, respecto a habilidades cognitivas, la inteligencia fluida y la flexibilidad cognitiva predijeron mejor los resultados en vigilancia. En adelante, en próximos estudios nos gustaría incorporar una medida de velocidad de procesamiento respecto a la ejecución del participante en la aplicación. El análisis de estrategias supone una aplicación práctica en el diseño de éste y de otros programas de intervención de la Atención y las funciones ejecutivas. De forma complementaria, el análisis de capacidades y desempeño en las tareas nos ayuda a disponer de una mayor comprensión sobre la naturaleza de los procesos entrenados.

En adelante quisiéramos probar el entrenamiento, a partir de los 8 años (dados los resultados obtenidos en primero de primaria), duplicando el tiempo de intervención (aplicando no sólo el nivel 1 del programa sino también el nivel 2). Por su parte, dado que la población con TDAH presenta dificultades de atención y funciones ejecutivas, convendría realizar el estudio en esta población.

INTRODUCCIÓN

1. Los procesos en los que se fundamenta “Nexxo”.

Los conceptos que a continuación tratamos son indispensables para comprender el diseño del entrenamiento “Nexxo” (objeto de esta tesis). Los tres parámetros (atención, funciones ejecutivas (FFEE) y metacognición) están presentes en el mismo. Presentaremos una revisión de estos conceptos en los que nos hemos basado para el diseño del programa, analizando los principales modelos teóricos.

1.1 Atención:

La atención es un constructo ampliamente estudiado en el ámbito de la psicología. Desde William James (1842-1910), considerado uno de los padres de la psicología, el concepto ha evolucionado desde una consideración de atención como un único factor hacia una concepción multifactorial (James, Burkhardt, Bowers, y Skrupskelis, 1890). Por la complejidad conceptual, neuroanatómica y funcional de la misma se considera que la atención está formada por diferentes complejos cerebrales (Van Zomeren y Brouwer, 1994) y, de hecho, la neurociencia cognitiva así lo ha demostrado (Posner y Rothbart, 2007). De forma general, puede decirse que en el proceso atencional intervienen regiones subcorticales (el sistema reticular activador, el tálamo, ganglios basales (estriado), sistema límbico) y el córtex parietal posterior y prefrontal (Estévez-González, García-Sánchez, y Junqué, 1997). Puede decirse que la atención supone focalizar selectivamente nuestra conciencia, seleccionando los estímulos relevantes, resolviendo la competencia entre estímulos para su procesamiento en paralelo. Con posterioridad, supone temporizar las respuestas apropiadas para dar una respuesta (Desimone y Duncan, 1995). Se entiende que la atención se refiere a la focalización y selección de ciertos aspectos de nuestro ambiente físico o ideas de nuestra mente. De forma continua, los estímulos externos nos “bombardean” y la principal misión del cerebro es filtrar únicamente los estímulos necesarios, establecer un orden de prioridades y de secuenciación temporal de respuesta para cada ocasión (Portellano Pérez, 2005). Es por ello que la atención es la base de los demás procesos cognitivos; una alteración de los procesos atencionales siempre producirá déficits cognitivos de menor o mayor gravedad. Además, existe un funcionamiento cerebral conjunto o “en red” que apoya la existencia de una estrecha relación entre los procesos atencionales y los demás procesos cognitivos, tales como la memoria o las funciones ejecutivas (Tirapu Ustárroz, 2012). Por esta razón enfocamos esta investigación apoyándonos en una herramienta que pensamos que podría ser un apoyo para las redes implicadas en los procesos atencionales, así como los relativos a un proceso concerniente a las funciones ejecutivas como es la inhibición, requisito fundamental en la mejora de los procesos atencionales y reguladores de la conducta.

1.1.1 Modelo de Luria

Si nos basamos en un enfoque neuropsicológico, sería preciso hablar sobre el modelo atencional propuesto por Luria (1974). Para este autor la atención es el factor responsable de extraer los elementos esenciales para la actividad mental y el proceso que mantiene

una estrecha vigilancia sobre el curso preciso y organizado de ésta. La atención es un proceso que supone seleccionar la información de forma consciente. Una vez filtrada la información y seleccionada la relevante, es necesario llevar a cabo un plan de acción y mantener un control permanente sobre el mismo (Luria, 1974). El modelo atencional de Luria estima que los factores determinantes de la atención son dos:

- Los estímulos: si son novedosos o no, la intensidad y el número de veces con la que se presentan, y la estructura que poseen.
- El individuo: sus intereses y necesidades y el grado de automatización de la tarea.

Además de los factores, habría tres componentes independientes que actuarían sobre la atención:

- La selección de estímulos que van a ser procesados: este concepto es importante ya que el sistema atencional es limitado; los procesos inhibitorios son los encargados de inhibir los estímulos irrelevantes para focalizar la atención.
- El control atencional: se pone en marcha en caso de que la actividad tenga que ser detenida o retomada o que haya actividades paralelas. Este concepto está íntimamente relacionado con la memoria operativa y la planificación.
- La vigilancia: asegura que las metas se mantendrán en el tiempo.

Como podemos ver en el modelo de Luria, la atención y las funciones ejecutivas se ven íntimamente relacionadas. Por su parte, no sólo aspectos cognitivos juegan un papel fundamental en la atención sino también factores motivacionales. La atención está integrada por factores perceptivos y motores (ya que regula la entrada de información, la orientación a la misma, su procesamiento y creación de respuesta), y también aspectos motivacionales (Mesulam, 1990).

1.1.2. Modelo de Posner y Petersen

El estudio de la atención ha cobrado especial relevancia especialmente desde los años 90, llegando incluso a ser considerada como un “sistema” (sistema atencional), de igual categoría que los dos sistemas cerebrales básicos integrantes del sistema nervioso (sistema motor y sistema sensorial) (Posner y Petersen, 1990). Desde 1990, Posner y Petersen formularon un modelo de atención (sistema atencional) que permanece vigente en la actualidad (Petersen y Posner, 2012) dado cuenta con un amplio soporte neurocientífico (Fernandez-Duque, Baird, y Posner, 2000a; Pacheco Ungueti, Acosta, y Lupiáñez, 2010; Rueda et al., 2005). La atención se compone de tres redes interrelacionadas:

1. **La red de alerta:** esta red está relacionada con la entrada de información ambiental. Algunos autores consideran esta red no sólo como estado mínimo de alerta *arousal* sino como vigilancia o atención sostenida (Raz y Buhle, 2006). Este proceso básico supone una activación de regiones frontales y temporales derechas.

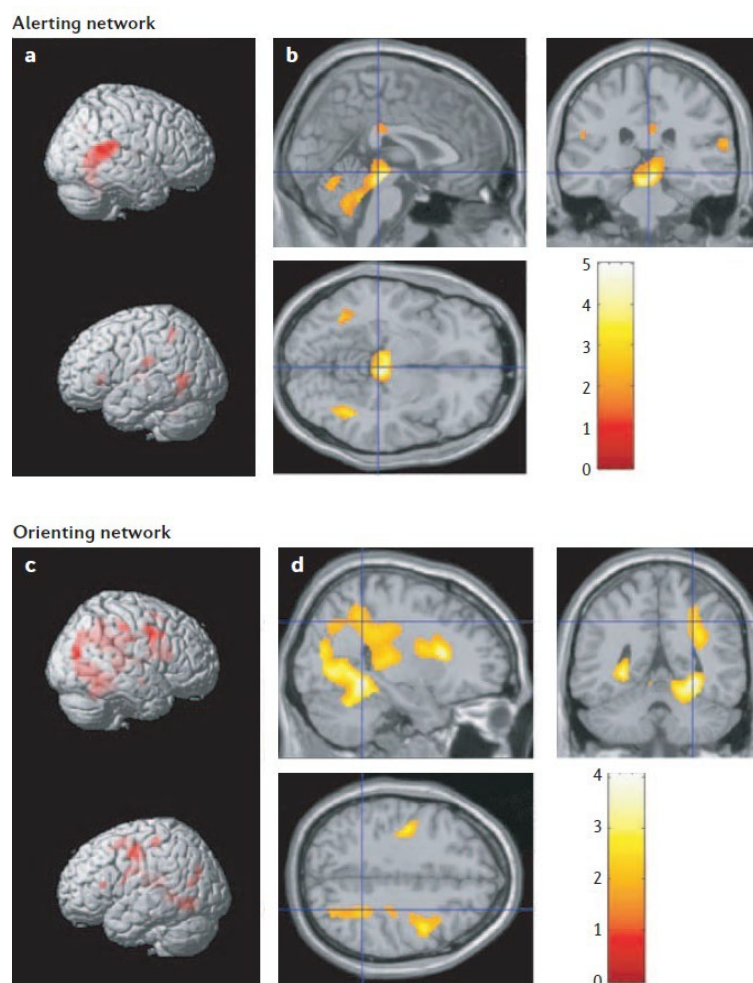
2. **La red de orientación:** es la capacidad de seleccionar información para su procesamiento mientras se inhibe información irrelevante, o la habilidad de seleccionar información específica de entre múltiples estímulos. La activación se produce en regiones relacionadas con el procesamiento sensorial como el pulvinar, colículos superiores, lóbulo parietal superior, la junta temporoparietal, el lóbulo temporal superior y áreas frontales relacionadas con la visión. Corbetta y Shulman (2002) proponen dos sistemas de orientación, uno que dirige la atención al objetivo basándose en los conocimientos previos, las propias expectativas, la información estimular (*goal-directed* o *goal- or schema- driven*) o sistema de atención *top-down* (arriba-abajo), y otro que además de tener en cuenta los factores anteriores reorienta la atención hacia la información relevante en función de la acción precisa, o sistema de atención *bottom-up* (abajo-arriba). Referidas también como red frontoparietal dorsal, responsable de la orientación espacial de la atención, y red frontoparietal ventral, responsable de la orientación de la atención antes estímulos y tareas novedosas.

3. **La red ejecutiva o red de control:** es un mecanismo de control voluntario que monitorea y regula el input sensorial, la conducta y la emoción (Posner y Dehaene, 1994). Supondría la capacidad de resolución de un conflicto estimular ya que se activa en situaciones de conflicto, situaciones que requieren toma de decisiones, planificación, control inhibitorio o regulación emocional (Raz y Buhle, 2006). Esta red se activa también ante la detección del error (Dehaene, Posner, y Tucker, 1994), así como en situaciones donde resolver conflictos ante respuestas automáticas por defecto (Botvinick, Braver, Barch, Carter, y Cohen, 2001). Esta red es fundamental en el desarrollo del autocontrol (Rothbart y Posner, 2007). Esta red también se conoce como atención ejecutiva (*executive attention*), o control consciente de la atención (*effortful control*) (Rothbart et al., 2007). En este caso la activación de regiones frontales medias es indispensable. Precursores de este sistema serían los formulados por Norman y Shallice (1986), Sistema Atencional Supervisor, un sistema que se activa para el control de los procesos cognitivos; y el Ejecutivo Central de Baddeley (2000), sistema que focaliza, divide y distribuye la atención de manera flexible controlando el resto de los componentes de la memoria operativa. La red ejecutiva guía la atención para la acción (Fernandez-Duque et al., 2000a). Permite a la persona procesar múltiples objetivos, alternando el foco atencional y activando la actualización de la memoria de trabajo (Ocasio, 2011).

Más tarde, dadas las evidencias a través de técnicas de neuroimagen, los mismos autores relacionan las tres redes atencionales propuestas con tres redes a nivel neurofuncional: **Red Atencional Posterior**, **Red Atencional Anterior**, y **Red de Vigilancia** (Posner y Rothbart, 2007). El sistema atencional posterior sería el encargado de la orientación hacia la fuente de información seleccionando lo más importante (se

corresponde con la red de orientación). Precisa de estructuras temporoparietales y áreas relacionadas con la visión, como los campos oculares frontales, y los colículos superiores. En cuanto a neurotransmisores, la acetilcolina sería el principal implicado. Por su parte, el sistema atencional anterior se ocuparía de la red ejecutiva o el control de la atención. Esta red precisa estructuras cerebrales frontales, el cíngulo y ganglios basales. En lo referente a los neurotransmisores, el principal implicado es la dopamina. Finalmente, la red de vigilancia se ocuparía de la red de alerta. En esta red intervienen áreas de la corteza frontal y parietal (especialmente derecha) y el locus coeruleus. En cuanto a neurotransmisores, el más implicado sería la norepinefrina (Lupiáñez et al.,).

La figura 1 muestra la activación funcional de las diferentes redes.



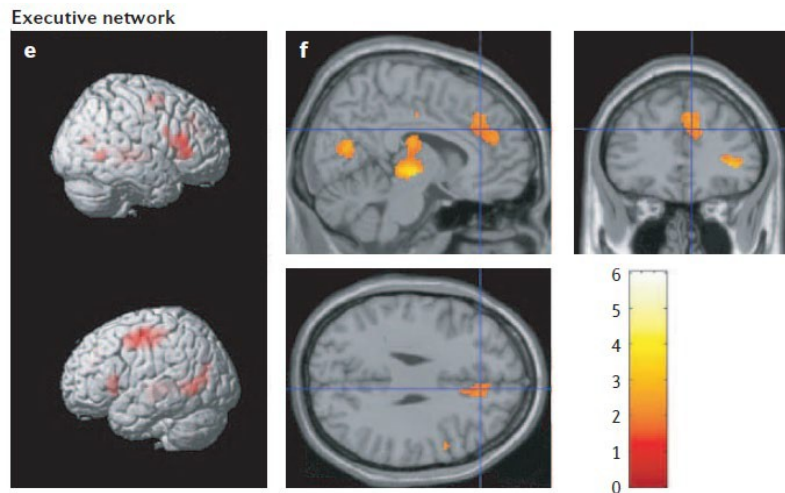


Figura 1: Typologies of attentional networks. Recuperado de Raz, A., y Buhle, J. (2006). *Nature Reviews Neuroscience*, 7(5), 367. Copyright REF. 85 © (2004) Wiley InterScience. Reproducida con permiso.

La tabla 1 muestra los neurotransmisores implicados en cada una de las redes atencionales, así como su correlato con los términos red de vigilancia, red posterior y red anterior.

Función Implementación neural		
Red de Alerta	Vigilancia / Alerta / Arousal	Corteza frontal y parietal, principalmente derecha, y locus coeruleus. Neurotransmisor: norepinefrina
Red de Orientación (red Posterior)	Orientación Voluntaria / Involuntaria	Corteza parietal, y unión temporo-parietal, campos oculares frontales, y colículos superiores. Neurotransmisor: acetilcolina
Red de Control (red Anterior)	Autorregulación / Control	Corteza prefrontal, corteza cingulada anterior y ganglios de la base. Neurotransmisor: dopamina

Tabla 1: Modelo de redes atencionales de Posner. Recuperado de Lupiáñez, J., Correa, Á., Chica, A., Vivas, A., Callejas, A., Sanabria, D., y Botella, J (2016). Introducción histórica y conceptual. En *Atención: libro homenaje a Pío Tudela*. (pp. 117-150). Reproducida con permiso.

1.1.3. Modelo de Sturm, basado en el modelo de Van Zomerer y Brouwer

Si tratamos de analizar aspectos más básicos de la atención podemos hacer referencia al modelo propuesto por Sturm (2008), quien propone un modelo atencional dos componentes: (1) intensidad y (2) selectividad. Este modelo toma como referencias el modelo de Mesulam (1985), modelo explicativo de atención que se compone de tres aspectos: orientación, exploración y vigilancia o concentración, y, más concretamente el modelo de Van Zomerer y Brouwer (1994), quienes propusieron un modelo de dos subsistemas: (1) intensidad de alerta y atención mantenida y (2) procesos de selección y atención dividida.

La intensidad es el factor clave para el desarrollo de otros componentes atencionales de orden superior (Luria, 1974; Sturm, Walter y Willmes, 2001). La intensidad se subdivide en tres grupos (Hauke et al., 2011):

- **Alerta tónica y fásica:** la alerta tónica es el control del sistema de arousal de *bottom-up* (abajo-arriba). Se refiere a un arousal intrínseco que fluctúa de minutos a horas (DeGutis y Van Vleet, 2010). Esto es, un estado de alerta mínima que regula la entrada de información su procesamiento, ejercida sin influencia de estímulos externos. La alerta regula la entrada de información. Se denomina *bottom-up* porque la activación a nivel cerebral sería del mesencéfalo (abajo) al córtex (arriba). La alerta tónica es ampliamente requerida en tareas de atención sostenida, así como otras funciones cognitivas superiores como la memoria de trabajo o el control ejecutivo (o atención ejecutiva). Por su parte la alerta fásica es el estado de alerta que se activa ante la presencia de un estímulo desencadenante (Sturm, Walter, Willmes, Orgass, y Hartje, 1997) y será básica para la activación de la red de orientación y atención selectiva (Posner, 2008).
- **Atención sostenida:** se activa ante la detección de cambios estimulares durante un período prolongado de tiempo. La atención sostenida es la habilidad de mantener alerta y concentración durante un tiempo (McAvinue et al., 2012). Tanto la intensidad como la atención sostenida residen en áreas parietales y frontales.
- **Vigilancia:** denominando por Sturm (2008) como “estado de alerta sostenida” es precisa en períodos largos de tiempo cuando la detección de cambios es se realiza de forma poco frecuente (Hauke et al., 2011).

Para Parasuraman y Giambra (1991) la atención sostenida y la vigilancia son la misma habilidad, una habilidad en la que el observador debe mantener su estado de alerta y foco atencional durante períodos largos de tiempo que van desde minutos a horas. La diferencia fundamental es que en tareas de vigilancia el observador debe responder ante estímulos con una ratio de aparición baja. La vigilancia o atención sostenida es el proceso por el que el individuo mantiene la concentración en un estímulo particular (Osorio, 2011). Tradicionalmente, las tareas de atención sostenida (referida también como “vigilancia”) requieren que el sujeto responda a *targets* infrecuentes (o estímulos) donde hay una alta probabilidad de aparición de estímulos no objetivo (*nontarget*) durante un largo período de tiempo. Este tipo de operaciones cognitivas requieren un procesamiento *top-down* controlado durante el procesamiento de la información (Pontifex, Scudder, Drollette, y Hillman, 2012). En este tipo de tareas, la motivación suele reducirse, aspecto relevante en la atención como hemos citado con anterioridad en el modelo de Luria. De tal modo, los observadores suelen perder concentración cuando las tareas son repetitivas o solo han de responder de forma ocasional (Figuerola y Youmans, 2012). Desde un punto de vista neuroanatómico, tanto la atención sostenida como la vigilancia residen en la

misma red cerebral, concretamente en la red fronto-parietal del hemisferio derecho (Pardo, Pardo, Janer, y Raichle, 1990).

Parasuraman y Giambra (1991, p.156-157) sostienen que:

En la mayoría de las tareas de vigilancia, los individuos han de detectar señales críticas *targets* (objetivos) que se presentan de forma poco frecuente, presentados contra otros más frecuentes y neutrales *nontargets* (no objetivos). Pese a que los *nontargets* precisan que la persona no dé respuesta, suponen una gran influencia en la precisión a la hora de detectar los *targets* (*hit rate*) y en el declive de esta precisión a lo largo de la tarea (*vigilance decrement*).

Por esta razón podemos sostener, que las tareas de vigilancia precisan los procesos de atención selectiva (identificar los *targets* de entre otros *nontargets*), inhibición (no dar respuesta ante los *nontargets*) y atención sostenida (mantener la atención durante un período de tiempo).

Por su parte la selectividad se refiere a la atención selectiva y atención dividida.

- **Atención selectiva:** es la habilidad de centrar el procesamiento en las características relevantes de los estímulos mientras se ignoran las irrelevantes, en el contexto de una limitada capacidad de atención o procesamiento.
- **Atención dividida:** consiste en atender o procesar dos tareas de forma simultánea o en alternar la atención de una a otra (Kramer y Madden, 2008).

Pese la diversidad de conceptualizaciones de la atención, las técnicas de neuroimagen nos permiten distinguir tres tipos de atención: atención selectiva, vigilancia o atención sostenida y atención ejecutiva (Ocasio, 2011). Finalmente, en el ámbito clínico se manejan los tipos de atención propuestos por Sohlberg y Mateer (1987): atención sostenida, atención alternante o dividida y atención selectiva, previamente definidos.

Para el desarrollo del programa de entrenamiento “Nexxo” hemos tomado como referencia el modelo propuesto por Posner y Petersen (1990, 2012) y el Van Zomeren y Brouwer (1994). El control atencional y la vigilancia o atención sostenida serán parámetros clave en el entrenamiento.

1.1.4. Resumen neurofuncional de la atención

Luria (1986) sostiene que el desarrollo de la capacidad atencional depende del funcionamiento del lóbulo frontal y de su coordinación con otras estructuras del cerebro. Esta región cerebral, más concretamente la región prefrontal, es la que muestra un mayor número de conexiones con el resto del cerebro. Pero sin duda, el proceso atencional no puede ser ubicado en una región cerebral particular, sino que las neuronas responsables de los procesos de atención se ubican en diferentes regiones del sistema nervioso central. En general, parece que en actividades de control ejecutivo hay una activación del cíngulo anterior y áreas prefrontales laterales y conexión entre ambas (Tang y Posner, 2009).

Específicamente, según Tirapu Ustárroz, (2012) las regiones encargadas de los procesos atencionales son:

- El córtex frontal dorsolateral, y más concretamente la zona dorsomedial, se relaciona con el mantenimiento activo de la información. De la inhibición de planes de acción y de respuestas no deseadas se encarga la zona prefrontal inferior y el giro frontal inferior. En tareas del tipo *go/no-go* (hacer-no hacer), ésta sería la región encargada de llevar a cabo el patrón de conducta.
- El córtex cingulado anterior se relaciona con procesos de atención selectiva y de supervisión en situaciones de conflicto.
- El área motora suplementaria interviene en tareas de cambio de set atencional, o lo que es lo mismo, flexibilidad cognitiva.
- Como se mencionó anteriormente, no es únicamente el lóbulo frontal el encargado de llevar a cabo el proceso atencional, los lóbulos parietales intervienen activamente en diferentes procesos tales como la actualización de las categorías perceptivas que deben atenderse, en la reorientación de la atención y en el mantenimiento voluntario de la atención. Además, la corteza parietal aporta un mapa interno del mundo exterior, necesario para la correcta dirección de la atención.
- Las estructuras subcorticales realizan conexiones aferentes del lóbulo frontal con el tronco encefálico, el hipotálamo y el sistema límbico que nos informa sobre el estado interno, los ganglios basales que intervienen en la formación de memorias motoras y el cambio de set atencional, y las regiones posteriores de la corteza que se encargan de la integración sensomotora de alto nivel.

En definitiva, la atención debe considerarse como una red conjunta en la que intervienen diversas estructuras cerebrales en concordancia (Barcelo, Periañez, y Nyhus, 2008). Por último, hay que añadir que mencionar el sistema de neurotransmisores implicados en la atención. Existe además un importante componente reticular ascendente (activación tronco-corteza) con sistemas ascendentes colinérgicos, noradrenérgicos y dopaminérgicos, que aportan el nivel necesario de activación para que pueda funcionar el resto de los componentes de la atención (Burgess, Alderman, Volle, Benoit, y Gilbert, 2009). Por tanto, tal y como se mencionaba en el modelo de redes atencionales, la acetilcolina, noradrenalina y dopamina serían los neurotransmisores más implicados en la atención.

1.1.5. Relación de la atención con otros procesos

Según Ríos, Periañez y Muñoz-Céspedes (2004) los siguientes procesos estarían íntimamente relacionados con la atención, y son cruciales para garantizar el rendimiento cognitivo: velocidad de procesamiento, control de la interferencia, flexibilidad cognitiva y memoria operativa, a los que, los mismos autores en conjunto denominan “control atencional”.

- **Control de la interferencia:** sería el mecanismo cognitivo que permite el control de la tendencia de respuestas automáticas o sobreaprendidas.
- **Flexibilidad cognitiva:** es la habilidad para cambiar el set atencional y modificar por tanto la respuesta.
- **Memoria operativa:** se refiere a la capacidad de mantener información previa y manipularla, no estando ésta disponible en el entorno.
- **Velocidad de procesamiento:** cantidad de información que puede ser procesada por unidad de tiempo o la velocidad a la que pueden realizarse una serie de operaciones cognitivas. También podría considerarse como el tiempo que transcurre desde la aparición del estímulo hasta la ejecución de una respuesta. El término “velocidad de procesamiento” se refiere a con qué rapidez una persona es capaz de realizar una tarea cognitiva. Para medir este concepto se ha recurrido a medir el tiempo de reacción o por ejemplo la rapidez de denominación; tareas que requieren que el sujeto nombre tantos estímulos como le sea posible en un tiempo corto de tiempo prefijado (generalmente inferior a un minuto) (Christopher et al., 2012).

Para un buen funcionamiento atencional parece necesaria la inhibición de la información irrelevante y la focalización de la información relevante con el mantenimiento de ésta por periodos prolongados (Barkley, 1997; Davidson, Amso, Anderson, y Diamond, 2006a; Rosselli, Matute, y Ardilla, 2011). Ambos procesos (**inhibición y memoria operativa**) forman parte de aspectos básicos de las funciones ejecutivas (Miyake y Friedman, 2012; Miyake et al., 2000). En relación con la memoria operativa (*updating*), ésta también precisa de mecanismos para combatir la interferencia (Conway, Kane, y Engle, 2003). El control ejecutivo se relaciona con la memoria de trabajo en situaciones que requieren control atencional y concentración (Rabipour y Raz, 2012).

Como hemos mencionado anteriormente, el proceso de inhibición es especialmente relevante en el mantenimiento de la atención (Davidson, Amso, Anderson, y Diamond, 2006b). Existe una relación entre la capacidad de atención sostenida y el proceso de inhibición, por ejemplo, los niños que muestran una mejor capacidad de atención sostenida muestran a su vez una mejor capacidad de control inhibitorio (Reck y Hund, 2011) del mismo modo que niños con menor rendimiento en atención sostenida tienen también menor rendimiento en control inhibitorio (Pérez-Edgar et al., 2010). Por su parte, los problemas en vigilancia también han sido relacionados con impulsividad cognitiva (Lovejoy y Rasmussen, 1990) y con la flexibilidad cognitiva (Figueroa y Youmans, 2012).

Otros autores sostienen que las redes atencionales estarían supeditadas a la **regulación emocional y autorregulación**, al control consciente de la atención y al control inhibitorio (Posner, Rothbart, Sheese, y Voelker, 2012; Raz y Buhle, 2006). La

autorregulación ha sido estrechamente relacionada con el control atencional (o red ejecutiva) (Friedman y Miyake, 2004). En esa autorregulación, jugará un papel fundamental la interrelación entre la memoria de trabajo (tener en la memoria claro el objetivo) y la inhibición (inhibir la conducta no deseada e inhibir distracciones, requisito de la atención selectiva) (Arnedo, Bembibre, Montes, y Triviño, 2015).

Como vemos, existe una fuerte relación entre la atención y las funciones ejecutivas (Rebollo y Montiel, 2006). De hecho, algunos de los componentes de la atención se solapan con ciertos componentes de las funciones ejecutivas (Rueda, Checa, y Cómbita, 2012), lo que explicaría en gran medida el grado de interacción entre ambos procesos.

Por último, queremos mencionar un factor que por sus características estaría intrínsecamente relacionado con la red ejecutiva o control atencional, como es la **metacognición** (Fernandez-Duque et al., 2000a). La metacognición es el conocimiento que tenemos sobre nuestros propios procesos cognitivos, esto es, por ejemplo, utilizar una estrategia de asociación para recordar un número de teléfono o una estrategia de planificación (p.e. decirse en voz alta lo que tenemos que hacer) para no saltarnos ningún paso. Según Flavell (1979), la metacognición puede dividirse en metacognición declarativa (p.e. estrategias de asociación, categorización...) que ayudan a memorizar o aprender, y la metacognición de regulación. La metacognición de regulación se refiere a los procesos que coordinan la cognición. Nos permite supervisar nuestros propios procesos cognitivos (Shimamura, 2000). Ésta es la que se relaciona de forma directa con el control atencional, ya que incluye procesos de tipo *bottom-up* como es la supervisión (p.e. detección del error) y *top-down* como es el control cognitivo (p.e. resolución del conflicto, corrección del error, inhibición, planificación) (Nelson y Narens, 1994; Reder y Schunn, 2014). La metacognición es una capacidad de orden superior que, no es considerada como una función ejecutiva sino un proceso de mayor nivel (van den Heuvel, Odile et al., 2003) No obstante, es una de las funciones que residen en los lóbulos frontales y que guarda relación con la atención y las funciones ejecutivas (Stuss, 2011).

Desde nuestro punto de vista, dada la relación de la atención con las funciones ejecutivas y la metacognición, cobra especial sentido que las intervenciones sobre atención incorporen las tres dimensiones, como es el caso del entrenamiento “Nexxo” que se describe en próximos capítulos. A continuación, la figura 2 resume la interrelación entre la atención y otros procesos cognitivos.



Figura 2: Relación de la atención con otros procesos.

1.2. Funciones Ejecutivas

Lezak (1989) fue quien acuñó el término de “funciones ejecutivas”, y quien tiempo después las definió como funciones que regulan nuestro comportamiento ante actividades con una intencionalidad o meta (Lezak, Loring, y Howieson, 2004). Sin embargo, años antes, Luria (1966) analizó una serie de déficits producidos por lesiones del lóbulo frontal (como la falta de iniciativa, de autocontrol y planificación). Ello le llevó a plantear la existencia de un sistema regulador de la conducta dirigida a metas que debía depender de los lóbulos frontales.

La función ejecutiva puede entenderse como un amplio constructo teórico que incluye la habilidad de control y de dirigir las propias capacidades mentales para completar una tarea o alcanzar un objetivo (Reck y Hund, 2011). Son una serie de procesos psicológicos que participan en el control consciente de nuestros pensamientos y acciones (Zelazo y Müller, 2002). Por su parte, Rosselli et al. (2011) consideran que las funciones ejecutivas engloban una serie de operaciones cognitivas de orden superior, que participan en la consecución de un comportamiento dirigido hacia una meta. Entre dichas operaciones estos autores incluyen la memoria operativa, la selectividad de los estímulos, la capacidad de abstracción, la planificación, la flexibilidad cognitiva y el autocontrol. Por su parte, Tirapu Ustárroz (2012), añade el término de “funcionamiento ejecutivo” que hace referencia a una serie de mecanismos implicados en la optimización de los procesos cognitivos para orientarlos hacia la resolución de situaciones complejas o novedosas. Los mismos autores señalan que las funciones ejecutivas afectarán a otros procesos cognitivos (procesamiento *top-down*), pero también otros procesos cognitivos influirán en un adecuado funcionamiento ejecutivo (procesamiento *bottom-up*).

1.2.1. Funciones de los lóbulos frontales

Tal y como hemos mencionado anteriormente, las funciones ejecutivas residen en los lóbulos frontales. Para Stuss (2011) la función de los lóbulos frontales puede clasificarse en cuatro categorías según sus áreas o regiones implicadas:

- **Energización:** es el proceso de iniciación y mantenimiento de una respuesta. Déficits en este proceso se observan en lesiones del lóbulo frontal área superior medial (Stuss y Alexander, 2007). Sobre esto residirían procesos atencionales propuestos en el apartado anterior como la alerta o la atención sostenida (Shallice, Stuss, Alexander, Picton, y Derkzen, 2008).
- **Funciones ejecutivas:** englobaría a su vez dos procesos (1) configuración de la tarea (*task setting*) y (2) monitorización (*monitoring*). La configuración de la tarea requiere procesos de lógica, programación y toma de decisiones, mientras que la monitorización supone la supervisión de la acción en marcha. La configuración

de la tarea supone establecer una relación estímulo-respuesta y podría variar en función del aprendizaje por ensayo-error. En este proceso intervienen áreas frontales laterales izquierdas, especialmente ventromediales (Stuss y Alexander, 2007). Por su parte la monitorización de la tarea supone la comprobación de la misma a lo largo de toda la ejecución, así como la implementación de posibles ajustes. En este proceso estarían implicados especialmente áreas del lóbulo frontal derecho.

- **Regulación emocional y conductual:** implican un tipo de procesamiento del riesgo/beneficio y/o recompensas para el sujeto o para otros individuos (Stuss, 2011).
- **Metacognición:** es difícil de definir y de medir, pero en ella están también implicados los lóbulos frontales. Parece residir en áreas ventromediales y del córtex frontal. Sería una función que integra y coordina todos los procesos anteriores (energización, motivación y aspectos socioemocionales y las funciones ejecutivas) necesarias para la consecución de una meta o una tarea novedosa (Stuss, 2011).

1.2.2. Funciones ejecutivas “frías y calientes.”

Zelazo y Müller (2002) diferenciaban además entre FFEs “calientes” y “frías”. Esta terminología está estrechamente asociada a la afectividad contextual al realizar una determinada tarea. Los problemas de la vida diaria, en los que se ponen en marcha las funciones ejecutivas, a menudo están imbuidos por la emoción, tal y como sugiere el modelo más actual (Zelazo, Qu, y Kesek, 2010). Las funciones ejecutivas frías se ponen en marcha en situaciones descontextualizadas o relativamente abstractas, mientras que las calientes en aquellas situaciones o problemas que se caracterizan por su tinte emocional. Las funciones ejecutivas consideradas “frías”, es decir, con un predominio de tipo cognitivo (por ejemplo, la planificación, metacognición, atención selectiva, inhibición etc.), se servirían de los circuitos prefrontales orbitofrontales y dorsolaterales, mientras que las funciones ejecutivas con mayor relación emocional, tradicionalmente denominadas “calientes” (toma de decisiones, motivación etc.), se relacionan más con el circuito ventromedial. (Tirapu Ustároz, 2012). Esta teoría encaja con los estudios realizados por Damasio (1994) en su teoría del “marcador somático”. La corteza orbitofrontal está implicada en el procesamiento de asociaciones aprendidas, asociaciones afectivas que se realizan en diferentes escenarios y que juegan un papel crucial en la toma de decisiones. Por ejemplo, un olor que me resultó desagradable en un momento particular puede condicionar una decisión futura de entrar o no en un lugar con un olor semejante. De algún modo, las experiencias previas (ligadas a un factor emocional) condicionan la toma de decisiones (Bechara, Damasio, y Damasio, 2000). Esto no significa que las

decisiones se tomen de forma exclusiva por experiencias previas o marcadores somáticos. Un problema de carácter afectivo puede ser solucionado tratando de neutralizar dicho componente emocional, a través del uso de las funciones ejecutivas frías. Esto es así ya que ambos tipos de funciones ejecutivas forman parte de un sistema coordinado (Damasio, 1994). Las funciones ejecutivas “calientes” requieren el desarrollo de la corteza orbitofrontal, mientras que las que son consideradas más cognitivas o “frías” el desarrollo de la corteza dorsolateral (Zelazo y Müller, 2002). Esto puede deberse, en parte, a la existencia de mayores conexiones entre la corteza orbitofrontal con el sistema límbico (estrechamente vinculado con el procesamiento emocional) respecto a la corteza dorsolateral. En cualquier caso, el lóbulo frontal estaría implicado en ambos tipos. Integrando funciones ejecutivas frías y calientes, junto con la teoría de Damasio, puede decirse que las funciones ejecutivas organizan y expresan la conducta, y se modifican a través de la interacción del individuo con su entorno (Rebollo y Montiel, 2006). La figura 3 resume la clasificación de funciones ejecutivas frías y calientes.



Figura 3. Funciones ejecutivas frías y calientes según el modelo de Zelazo y Müller (2002).

1.2.3. Funciones ejecutivas orientadas a la resolución de problemas

Si tomamos en cuenta los estudios de Zelazo, Carter, Reznick, y Frye, (1997) y de Anderson (2002,2010) podemos de alguna manera tener una visión de fases dentro de las funciones ejecutivas cuando se ponen en marcha para la resolución de un objetivo. Según Zelazo et al. (1997) las funciones ejecutivas se desempeñan siguiendo una serie de fases, tal y como muestra la figura 4.

1. **Representación mental del problema:** consiste en representar el problema de manera propicia. Para ello entra en juego la atención selectiva (seleccionando la información relevante) y la atención alternante, o cambio de set atencional para

guiar y buscar información. Esta capacidad será muy inmadura en la etapa de educación infantil.

2. **Planificación:** supone diseñar una actuación (aunque no sea necesariamente llevada a cabo). Esta tarea se desarrolla de forma paulatina con el apoyo del desarrollo de la comprensión de instrucciones y en la capacidad de atención dirigida (lo que actualmente denominamos “control atencional”). La planificación supone seleccionar reglas de actuación, lo que será clave en la ejecución.
3. **Ejecución:** implica tener un plan en la mente (intencionalidad) y las reglas disponibles para su ejecución (uso de regla o reglas). En este proceso entrarían en juego la memoria operativa, la atención sostenida y la sensibilidad a la interferencia. La clave para la ejecución será el uso de reglas que se rigen por una lógica condicional (si ocurre “x” entonces haz “y”).
4. **Evaluación** (detección del error/corrección): supone el reconocimiento de que se ha cumplido el objetivo de forma satisfactoria. Primeramente, el individuo debe ser consciente de cuando la tarea ha finalizado, detectar posibles errores y corregirlos. Pese a darse en la etapa infantil, los más pequeños tienen a aplicar lo que les ha sido útil en una situación a otras situaciones, sin detectar que pueden necesitarse cambios.

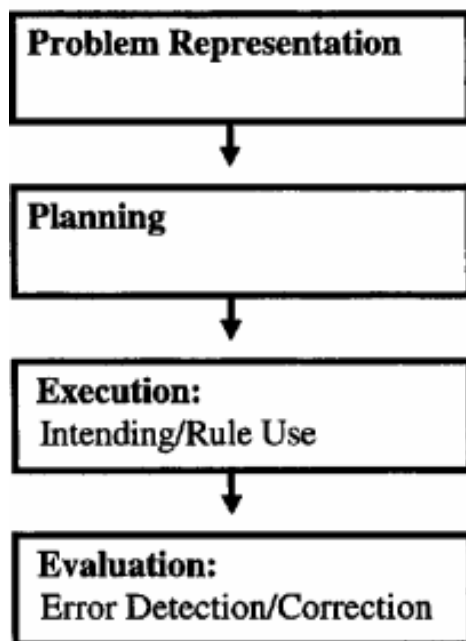


Figura 4: Fases de las funciones ejecutivas. Recuperado de Zelazo, Carter, Reznick, and Frye (1997). Early development of executive function: A problem-solving framework. Review of General Psychology, 1, 198–226. Reproducida con permiso.

Al igual que en el modelo anterior, el Sistema de Control Ejecutivo propuesto por Anderson (2002, 2010) puede adaptarse a una serie de estadios que interrelacionan entre sí. Este sistema estaría formado por cuatro componentes independientes que interactúan entre sí:

Control atencional: incluye tanto la atención selectiva (seleccionar la información relevante) como sostenida (mantener el foco de atención durante períodos largos de tiempo). El control atencional regula y supervisa, o monitorea las acciones para ejecutar la acción de la forma planificada. Son componentes de la misma el control inhibitorio y la capacidad de demora de la gratificación.

Establecimiento del objetivo: supone iniciar un plan o actividad. Requiere por tanto la habilidad de planificación; “la capacidad de planificación implica anticipar eventos futuros, formular una meta o punto final e idear una secuencia de pasos o acciones que logren la meta o el estado final” (Anderson, 2008 p.17). Tales secuencias de acción han de ser estratégicas o diseñadas de forma lógica. Factores como la organización y la memoria de trabajo son relevantes para esta dimensión.

Procesamiento de la información: se refiere a la fluencia, la eficacia y la velocidad de respuesta. Existe una relación bidireccional entre el procesamiento de la información y las funciones ejecutivas_ el procesamiento de la información influye en la calidad de las funciones ejecutivas y, el uso de estrategias ejecutivas influye en el procesamiento de la información_. Este domino está supeditado a la eficiencia de las conexiones neurales del lóbulo prefrontal.

Flexibilidad cognitiva: se considera el componente fundamental del modelo. Supone la habilidad de cambiar una respuesta ante un posible error, aprender de los errores, plantear diferentes estrategias y alternativas. En este dominio serán claves la atención dividida (una capacidad que nos permite procesar diferentes estímulos de forma simultánea) y la memoria de trabajo.

En la figura 5 se muestra la relación entre las diferentes dimensiones y sus subcomponentes o procesos implicados.

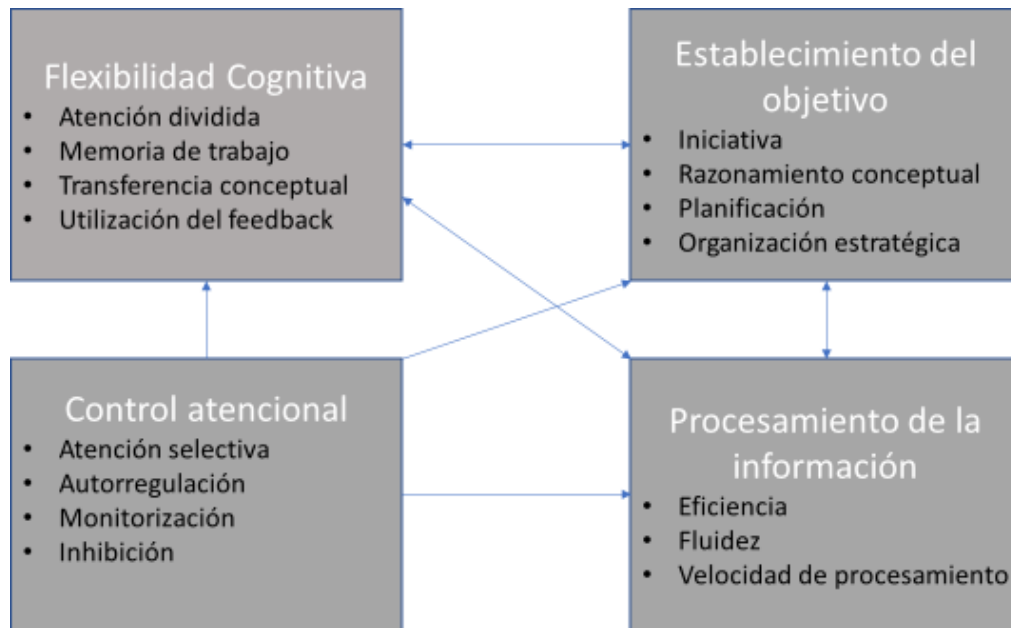


Figura 5: El sistema de control ejecutivo. Adaptado de “Assessment and development of executive function (EF) during childhood” en P. Anderson, 2002, *Child Neuropsychology*, 8(2), p.71.

1.2.4. Modelo de funciones ejecutivas de Miyake y Friedman, (2012)

Por la amplia aceptación del modelo de Miyake et al. (2000) y su vigencia en la actualidad (Miyake y Friedman, 2012), hemos querido finalizar la conceptualización de las funciones ejecutivas a través de este modelo. Estos autores proponen un modelo jerárquico de FFEE de tres componentes fundamentales interrelacionados. Esta distinción también se sostiene en población escolar (McAuley y White, 2011; Rose, Feldman, y Jankowski, 2011):

Inhibición (*inhibition*): implica diferentes tipos de inhibición. Por un lado, es la capacidad de suspender una respuesta dominante en favor de otra (inhibición de la respuesta prepotente o dominante), lo que se conoce como inhibición de respuesta. También es la capacidad de seleccionar la información en presencia de distractores (resistencia a la interferencia y a la distracción), lo que se conoce como control de la interferencia (Diamond, 2013; Miyake et al., 2000; Tamm y Nakonezny, 2015) Ambos tipos de inhibición están estrechamente relacionados (Friedman y Miyake, 2004). La inhibición puede ser de carácter cognitivo, motor o emocional. Este proceso está íntimamente presente en procesos atencionales, especialmente en la red de orientación. La inhibición es uno de los procesos de las FFEE que antes madura y es responsable del desarrollo de otros más complejos (Dempster, 1992; Gandolfi, Viterbori, Traverso, y Usai, 2014).

Actualización (*updating*): es la habilidad de almacenar y actualizar la información relevante durante un período corto de tiempo (Klingberg, Forssberg, y Westerberg, 2002; Miyake, Akira et al., 2000). Es un sistema que permite simultáneamente mantener, actualizar y manipular información en la mente. Está implicada en una gran variedad de procesos cognitivos como la lectura, el aprendizaje o la inteligencia fluida (de Abreu, Conway, y Gathercole, 2010). Esta habilidad es crucial para el aprendizaje e incluso para el rendimiento académico (Conway et al., 2003). La actualización nos sirve para actualizar y supervisar la información que va a ser codificada. Es requisito previo para la implementación de información en la memoria a largo plazo (aprendizaje) y es fundamental en tareas de planificación (Karch y Unger, 2014).

Flexibilidad (*shifting*): es la habilidad de cambiar un set mental, tarea, objetivo o de una regla a otra (Miyake, Akira et al., 2000) (como alternar entre seleccionar objetos según su forma a seleccionarlos según su color). Implica la desconexión de la información que ya no es relevante para centrarse en la nueva información relevante (Monsell, 2003). La inhibición se relaciona con el cambio de set atencional, aspecto crucial de la flexibilidad cognitiva (Tamm y Nakonezny, 2015; van der Ven, Kroesbergen, Boom, y Leseman, 2013). La flexibilidad nos permite pensar de forma creativa y divergente, respondiendo ante posibles imprevistos, alternando y ofreciendo diferentes soluciones a un mismo problema (Karch y Unger, 2014).

Para el entrenamiento “Nexxo” hemos considerado todos estos modelos, siendo especialmente relevantes el modelo de Stuss (2011) el control atencional propuesto por Anderson (2002, 2010) y el modelo de Miyake y Friedman (2012).

1.2.5. Resumen de las bases neurofuncionales de las FFEE

Las regiones cerebrales relacionadas por excelencia con el funcionamiento ejecutivo (planificación, flexibilidad cognitiva, inhibición y autorregulación de la conducta) son los lóbulos frontales (parte anterior del córtex). Por lo general, se admite que la sede de las funciones ejecutivas se distribuye en las regiones dorsal, lateral y orbital del lóbulo frontal (Semrud-Clikeman y Ellison, 2011). A su vez estas áreas realizan múltiples conexiones con el resto del parénquima cerebral, en especial con los núcleos estriados. Pese a que el córtex prefrontal tenga un papel fundamental, otras regiones como áreas parietales, motoras, estructuras subcorticales como los ganglios basales o el tálamo también tienen implicación en tareas de función ejecutiva (Duncan y Owen, 2000).

Por su parte, según el modelo de Zelazo y Müller (2002) sobre las funciones ejecutivas “frías”, es decir con un predominio de tipo cognitivo, se serviría de los circuitos prefrontales orbitofrontales y dorsolaterales, mientras que las funciones ejecutivas con mayor relación emocional “calientes” se relacionan más con el circuito ventromedial

(Tirapu Ustárruz, 2012). Específicamente, según este mismo autor las podemos diferenciar tres circuitos del córtex frontal implicados en las funciones ejecutivas:

- Circuito dorsolateral: se ha relacionado con memoria de trabajo, atención selectiva y flexibilidad cognitiva.
- Circuito orbital-lateral: relacionado con el control inhibitorio. En tareas de inhibición parecen estar implicadas áreas prefrontales laterales, así como el cíngulo anterior.
- Circuito ventromedial: implicado en el procesamiento de señales emocionales que guían la toma de decisiones; se relaciona con la alerta ante situaciones novedosas y la motivación.

Si tenemos en cuenta el modelo de Miyake et al. (2000), conviene destacar la participación de estructuras frontales y parietales. Las tareas de flexibilidad, actualización, e inhibición predisponen activación frontal (área dorsolateral), del cíngulo anterior y regiones parietales (como el precúneo); activación básica de la red ejecutiva denominada “red frontoparietal” (Karbach y Unger, 2014).

Por su parte, Lázaro y Solís (2008) resumen las áreas corticales implicadas en las FFEE en las siguientes regiones del lóbulo frontal: área dorsolateral, corteza premotora y motora, corteza prefrontal dorsolateral, corteza orbitofrontal y corteza frontomedial.

1.3. Metacognición

La metacognición, término introducido por Flavell (1979), es una capacidad de introspección que refuerza la memoria y el aprendizaje. El mismo autor diferenciaba entre metacognición declarativa (p.e. estrategias de asociación, categorización...) y metacognición de autorregulación. Este último se ha denominado también metacognición procedimental (*procedural metacognition*) aspecto relevante para la regulación de procesos cognitivos (Shimamura, 2000). La metacognición es un factor que por sus características estaría intrínsecamente relacionado con la red ejecutiva o control atencional (Fernandez-Duque, Baird, y Posner, 2000b; Nelson y Narens, 1994) aspecto clave en el entrenamiento que hemos desarrollado. Por su parte, el conocimiento sobre el pensamiento de uno mismo y el de los demás (o teoría de la mente) también es considerado por diversos autores, incluyendo Flavell, como un aspecto de la metacognición (Blankson et al., 2017).

La metacognición es una capacidad de orden superior que, no es considerado como una función ejecutiva sino un proceso de mayor nivel (van den Heuvel et al., 2003) No obstante, es una de las funciones que residen en los lóbulos frontales y que guarda estrecha relación con la atención y las funciones ejecutivas (Fernandez-Duque et al., 2000b; Stuss, 2011). Además, las FFEE y, concretamente la metacognición de regulación comparten un desarrollo similar (Roebbers y Feurer, 2016). De hecho, estudios anteriores muestran cómo el uso de estrategias como decirse a uno mismo lo que tiene que hacer (estrategia metacognitiva de autorregulación o procedimental) favorece mejores resultados en tareas de inhibición (Diamond, Barnett, Thomas, y Munro, 2007).

Los niños utilizan estrategias de autocontrol no sólo cuando utilizan estrategias verbales proporcionadas por los adultos, sino de forma espontánea. Verbalizaciones espontáneas o estrategias motoras para resolver tareas donde está presente el control inhibitorio (Manfra, Davis, Ducenne, y Winsler, 2014a). Este tipo de estrategias como las autoinstrucciones, el lenguaje interno, las verbalizaciones y las estrategias motoras de autorregulación forman parte de la metacognición y serán objeto de nuestro programa de intervención “Nexxo”.

Por su parte, las autoinstrucciones permiten una mayor comprensión de las instrucciones y una ejecución reflexiva. Conllevan tres fases: (1) Previsión (*forethought*), lo que supone establecer el objetivo (p.e. ¿qué tengo que hacer?), (2) ejecución/control voluntario (*performance/volitional control*) requiere procesos de planificación, monitorización y control cognitivo (pe. ¿cómo lo voy a hacer? ¿Qué necesito? ¿Qué pasos debo seguir?), y (3) autorreflexión (*self-reflection*) requiere autoevaluar el resultado, precisa flexibilidad cognitiva ante la posible necesidad de realizar cambios o adaptaciones. Estas tareas metacognitivas pueden ser aplicadas en el aprendizaje autorregulado (Dina y Efklides, 2009).

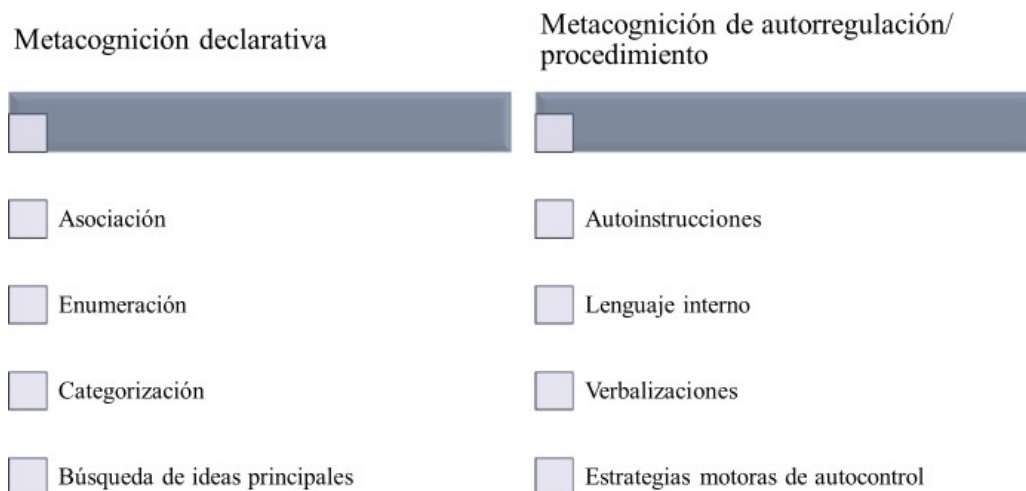


Figura 6: Tipos de metacognición según Flavell (1979) y ejemplos de estrategias metacognitivas.

El estudio de la metacognición abarca diferentes procesos relacionados, como es lo que se denomina conocimiento metacognitivo (*metacognition knowlegde*), experiencias metacognitivas (*metacognitive experience*) y estrategias metacognitivas, las cuales dan lugar a la metacognición declarativa y procedimental. Dicho de otro modo, en Efklides (2009, p. 76):

La metacognición, entendida como conocimiento metacognitivo —en este caso, creencias acerca del aprendizaje—, aporta la información a partir de la cual el aprendiz selecciona las estrategias apropiadas para regular el aprendizaje. No obstante, la regulación estratégica presupone que el aprendiz es consciente de que el proceso de aprendizaje no discurre por los cauces adecuados, no fluye, o que simplemente ha fracasado. Esta conciencia toma la forma de experiencia metacognitiva, es decir, sentimientos, estimaciones o juicios relativos a las tareas de aprendizaje, sobre cómo tiene lugar el procesamiento cognitivo, así como su resultado. El aspecto crítico de la experiencia metacognitiva es su carácter afectivo, el cual facilita el acceso a los componentes cognitivo y afectivo del bucle regulatorio de la conducta. Como parte de la dimensión afectiva del bucle, la experiencia metacognitiva tiene que ver con la motivación y los procesos del yo; como parte de la dimensión cognitiva del bucle se vincula con el conocimiento y las habilidades metacognitivas, lo que posteriormente dará lugar al conocimiento declarativo y procedimental. Por tanto, la experiencia metacognitiva supone la conciencia que une las experiencias de aprendizaje presentes y pasadas, y facilita o inhibe la autorregulación del aprendizaje en el presente y en el futuro.

En líneas generales, los mismos autores resumen las estrategias metacognitivas en las siguientes:

- Estrategias de orientación: su finalidad es fijar de forma clara el objetivo para que el aprendiz oriente sus recursos a la tarea. Supone preguntarse lo que hay que hacer, así como aclarar posibles controversias. Repetir varias veces la instrucción o leerla varias veces, o subrayar lo importante en la misma también forman parte de este tipo de estrategias.
- Estrategias de planificación: supone establecer un objetivo u objetivos y la secuencia de actuación (p.e. ¿qué tengo que hacer? ¿qué pasos debo seguir?).
- Estrategias para regular el procesamiento cognitivo: cuando no se está procesando de forma adecuada, entran en juego las estrategias de regulación. Por ejemplo, si un alumno no consigue centrar su atención en la tarea, proporcionarle una estrategia de control atencional (p.e. eliminar distractores del ambiente, o, verbalizar en voz alta lo que se está haciendo).
- Estrategias para supervisar o monitorizar el plan en marcha: supone calibrar si el plan está transcurriendo como se esperaba, en el tiempo fijado, detectando posibles errores durante la ejecución, e incluso identificar necesidades nuevas durante la ejecución.
- Estrategias para la evaluación del resultado: consiste en evaluar la planificación, la ejecución y la monitorización, de tal forma que se reconozca si el resultado ha sido o no adecuado.
- Estrategias de recapitulación y autorregulación: consiste en evaluar todo el proceso, yendo más allá que en el apartado anterior, analizando debilidades y fortalezas, reflexionando sobre el proceso.

La combinación de estrategias de orientación, de planificación, regulación y supervisión requieren que la persona dirija el flujo de información, lo que algunos autores también refieren como *self-monitoring* (auto monitorización) (Nelson 1996, en Riemer y Schrader, 2019), identificando la tarea y valorando su ejecución. Este proceso es clave para el aprendizaje (Efklides, 2011) y especialmente útil en contextos de aprendizaje multimedia (Riemer y Schrader, 2019). La metacognición también es considerada un elemento clave en lo que se ha denominado “aprendizaje autorregulado” (*self-regulated learning*). Este proceso abarca la monitorización y el control de la cognición y el comportamiento, distinguiéndose cuatro componentes que se relacionan entre sí: (1) cognición, (2) metacognición, (3) motivación, (4) afecto y voluntad (Boekaerts, 1996 en Pennequin, Questel, Delaville, Delugre y Maintenant, 2019).

Las estrategias metacognitivas proporcionadas en el entrenamiento “Nexxo”, se basan en lo que se denomina estrategias de autorregulación y procedimiento, y en el tipo de estrategias propuestas resumidas en este apartado.

2. Desarrollo de los procesos en los que se fundamenta “Nexxo”

Previamente a indagar en el desarrollo de la atención y de las funciones ejecutivas, es preciso revisar unos principios básicos en el desarrollo. A nivel filogenético (como especie) las áreas sensoriomotoras son las que maduran antes, permitiendo procesos básicos para la supervivencia, mientras que las áreas asociativas y frontales maduran de forma más tardía. Así mismo las áreas dorsales, laterales y rostrales (aquellas relacionadas con la abstracción, la planificación, la inhibición) maduran de forma más lenta respecto a las áreas ventrales, mediales y caudales (relacionadas con el procesamiento de estímulos, funciones emocionales y de aprendizaje) (Arnedo et al., 2015). Recordemos que los lóbulos parietales (en especial el derecho) y los lóbulos frontales están implicados en la atención.

Respecto a las funciones ejecutivas, estarían especialmente implicados los lóbulos frontales. Así mismo las conexiones frontotemporales y las frontoparietales maduran de forma más lenta, desde el nacimiento hasta la juventud (Lebel et al., 2012), lo que es relevante en cuanto al desarrollo de la atención y de las funciones ejecutivas. En este sentido, parece hacer tres momentos de crecimiento y de conexión entre los lóbulos frontales y el resto de lóbulos (parietal, temporal y occipital), que son: entre el primer y quinto año de vida, de los cinco a los diez años y un último de los 10 a los 14 años (Arnedo et al., 2015).

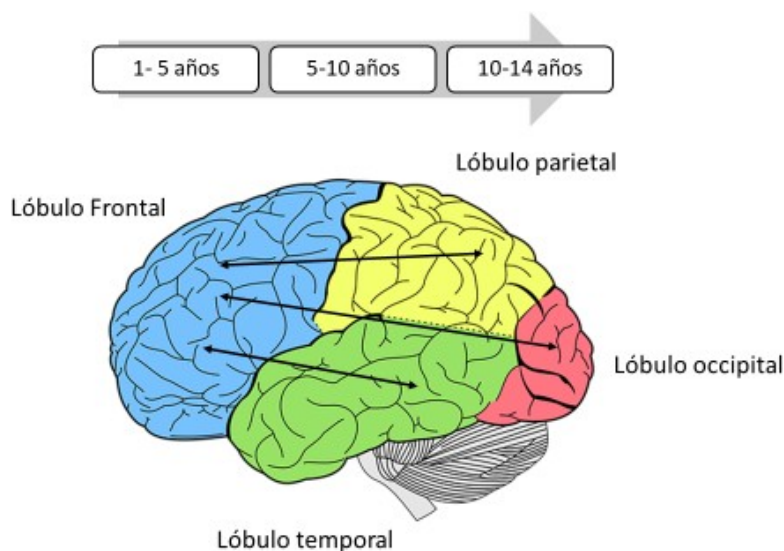


Figura 8: Etapas de crecimiento y de establecimiento de mayores conexiones entre el lóbulo frontal y los demás lóbulos.

Por otra parte, es preciso incidir en que durante el desarrollo se producirán tres etapas o podas sinápticas. Las podas sinápticas eliminan aquellas sinapsis ineficaces,

corrigen errores de migración, y, permiten refinar aquellas conexiones más efectivas. Una primera poda se produce a los dos años, otra en la adolescencia y una tercera en la etapa de la vejez (Kolb y Fantie, 2009). Precisamente, la poda sináptica sobre las áreas prefrontales es de las últimas en concluirse (Arnedo et al., 2015). La corteza prefrontal tiene su máximo desarrollo durante la adolescencia (Blakemore, 2012), lo que explicaría el proceso de refinamiento sobre las funciones ejecutivas en esta etapa y en la juventud.

2. 1. Desarrollo de la atención

2. 1.1. Desarrollo de la orientación o atención selectiva

Las formas más primigenias de atención (orientación hacia el estímulo) suceden en torno a los 3-6 meses de edad. Respecto a la modalidad sensorial, la atención selectiva auditiva es previa a la sensorial (Perez-Hernandez, 2009). A partir de los 6 meses los niños controlan más dónde fijar la mirada inhibiendo distractores y manteniendo más tiempo la atención (Reynolds y Romano, 2016). Entre los 6 y los 18 meses seguirá con la mirada un objeto, aunque todavía no fije su atención en el objeto que mira el adulto (Perez-Hernandez, 2009). A partir de los 2 años de edad, gracias a un mayor desarrollo cerebral de las áreas atencionales y conectividad entre las mismas, se produce un mayor control de la atención (Cuevas y Bell, 2014). Entre los 2-2'5 años de edad los niños muestran mirada anticipatoria, una forma primigenia de control atencional donde el niño anticipa la aparición de un estímulo y dirige su atención (Jones, Rothbart, y Posner, 2003). Debido a mejoras en la mielinización, podemos decir que a los 4 años de edad se procurará una mejora significativa en la capacidad de atención selectiva (Perez-Hernandez et al., 2008). La capacidad de inhibir los estímulos que nos distraen, y, por tanto, atender a lo fundamental (requisitito fundamental respecto a la atención selectiva), alcanza su pleno desarrollo a la edad de 6 años (Welsh, Pennington, y Groisser, 1991). Como hemos visto en apartados anteriores, la atención selectiva precisa del control inhibitorio. Estudios anteriores, utilizando tareas de hacer/no-hacer (*go/no-go*) sostienen que hay una mejora en el desempeño en tareas de inhibición entre los 6 y los 8 años (Becker, Isaac, y Hynd, 1987). La inhibición es un proceso que se desarrolla de forma especial entre los 5 y los 10 años (Urban, van der Linden, y Barisnikov, 2011). Es de suponer que las mejoras en inhibición ayudarán al proceso de atención selectiva.

2. 1.2. Desarrollo del control atencional

Por su parte, el control atencional o también conocido como “atención ejecutiva” supone el control consciente de la atención (Raz y Buhle, 2006), tal como hemos visto en apartados anteriores. Ello implica una capacidad de atención selectiva, especialmente desarrollada a partir de los 2 años, así como un mantenimiento de la atención (atención sostenida) mientras se realiza la tarea, especialmente desarrollada entre los 3 y 5 años (Garon, Bryson, y Smith, 2008). Desde los 3 años de edad, existe un rápido desarrollo de las áreas cerebrales implicadas en los diferentes subprocesos, evolucionando

significativamente hasta los 6 años, gracias a un mayor desarrollo del cíngulo anterior y de áreas prefrontales (Diamond et al., 2007; Rothbart, 2001). Este período será especialmente susceptible al desarrollo del control atencional. Por otro lado, el control atencional está estrechamente relacionado con la capacidad de cambiar el foco atencional, es decir, dejar de atender a unos estímulos que dejan de ser relevantes para centrar la atención en otros que pasan a serlo en otro momento dado resolviendo de forma interna dicho conflicto (Garon et al., 2008). Esta capacidad supone retener en la memoria de trabajo una regla (qué es relevante en este momento), además de la flexibilidad para cambiar de regla (lo que ha dejado de ser relevante). Esta capacidad mejora entre los 4 y los 5 años de forma significativa respecto a los niños de 3 años (Zelazo, Frye, y Rapus, 1996; Zelazo y Müller, 2002). Hay un segundo período crítico en el desarrollo del control atencional sobre los 9 y los 12 años (Pozuelos, Paz-Alonso, Castillo, Fuentes, y Rueda, 2014).

2. 1.3. Desarrollo de la atención sostenida

La atención sostenida es la encargada de mantener en el tiempo el procesamiento de la información relevante para la consecución de la tarea (Ríos et al., 2004), además del compromiso con la tarea (Perez-Hernandez y Capilla, 2011). La atención sostenida comienza a desarrollarse desde los 2 años de forma progresiva, de tal manera que, con 5 años, por ejemplo, el niño es capaz de llevar a cabo una tarea atencional visual durante un periodo ininterrumpido de 14 minutos (Ruff y Rothbart, 2001). Con el tiempo y a partir de su experiencia, los niños mantendrán la atención durante períodos más largos. Esta capacidad es especialmente desarrollada entre los 3 y 5 años (Garon et al., 2008) y continúa su desarrollo durante el período escolar. Se produce un segundo cambio significativo en la atención sostenida desde los 6-7 años hasta los 10-11 años (Lewis, Reeve, Kelly, y Johnson, 2017b) siendo más sutil el cambio entre los 8 y los 11 años (Lewis, Reeve, Kelly, y Johnson, 2017a); según Halperin (1996) existe un desarrollo significativo de la atención sostenida entre los 7-9 años de edad (en Perez-Hernandez et al., 2008). Durante este período, entre los 7 y los 9 años, se produce una mejora del control atencional y de la atención sostenida gracias al aumento en la actividad de las regiones prefrontales así como la integración de las conexiones de larga distancia del hemisferio derecho (Perez-Hernandez. y Capilla, 2011). Por último, al igual que en atención selectiva, la modalidad sensorial (visual o auditiva) difiere en cuanto a su desarrollo. Así como en atención sostenida visual parece que el desarrollo se completa en torno a los 10 años (Shepp, Barrett, y Kolbet, 1978, en Perez-Hernandez et al., 2008) en atención sostenida auditiva se calcula que en torno a los 12 años (Sanders y cols, 2006, en Perez-Hernandez et al., 2008).

2.2. Desarrollo de las Funciones Ejecutivas

A nivel general podemos decir que las primeras manifestaciones de las FFEE ocurren durante el primer año de vida, dándose un desarrollo más rápido durante la niñez temprana, periodo de gran maleabilidad (Carlson et al. 2013). En términos de neuroplasticidad, existe un período crítico para la eficiencia de conexiones sinápticas responsables de las funciones ejecutiva entre los 5 y los 8 años, en este período se produce un perfeccionamiento de la inhibición, la memoria de trabajo y de la autorregulación (Arnedo et al., 2015). Otros autores como Diamond (2012) destacan tres momentos evolutivos relevantes respecto a la corteza prefrontal (que se manifiestan en el desarrollo de las funciones ejecutivas) que son el primer año de vida, de los 3 a los 6 y de los 7 a los 11 años. A partir de los 12 años se alcanza un nivel similar al del adulto, sin embargo, algunos componentes como la planificación, la fluidez verbal y la secuenciación continúan en desarrollo durante la etapa adulta (Zelazo y Müller, 2002; Zelazo et al., 2010). Además del desarrollo de la corteza prefrontal, el proceso de mielinización (que se produce durante toda la vida) también tiene que ver con el desarrollo de las funciones ejecutivas (Osorio, 2015). Por su parte, las funciones ejecutivas “frías” maduran antes que las funciones ejecutivas “calientes”, desarrollándose estas últimas de forma más notable en la adolescencia (Hooper, Luciana, Conklin, y Yarger, 2004; Prencipe et al., 2011). Según Diamond (2013), el desarrollo de las funciones ejecutivas, que depende del desarrollo del lóbulo frontal, se inicia en la infancia, pero no concluirá hasta pasada la adolescencia. Así el desarrollo de la planificación, la resolución de problemas continúa en desarrollo en la juventud (Romine y Reynolds, 2005). La mayoría de las investigaciones sostienen un desarrollo más global de función ejecutiva en la etapa infantil que evoluciona hacia un desarrollo de subcomponentes de la misma en la etapa de primaria y secundaria (Karchach y Unger, 2014).

2. 2.1. La inhibición y la autorregulación

Durante el primer año de vida podemos observar las primeras manifestaciones de las funciones ejecutivas. Por ejemplo, de la memoria de trabajo y de la inhibición. El bebé ha de tener presente en la memoria un objetivo (p.e. coger un juguete) e inhibir conductas automáticas para conseguir tal fin, conductas reflejas (Arnedo et al., 2015), lo que proporciona un primer escalafón en el control voluntario de la conducta. A esta edad también podrán resistir la distracción. A partir de los 2-3 años, los niños tienen más éxito en tareas de inhibición. Gerardi-Caulton (2000) demuestra en su estudio sobre una tarea simple de inhibición (presenta un conflicto espacial, con escaso contenido verbal), que los niños tienen éxito en la misma a los 3 años, según este autor queda claro que entre los 2 y 5 años los niños tienen éxito en tareas de resolución de conflicto o inhibición. Por su parte, Jones, Rothbart y Posner (2003) en su estudio realizado con niños de 3 a 4 años sobre una tarea de control inhibitorio (el niño debe responder ante la instrucción de uno de los dos animales presentados (oso u elefante) inhibiendo la instrucción de uno de los dos, tomando como modelo la tarea de *Simon Says*), demuestran que entre los 3.5-4 años

se produce una mejora significativa de esta habilidad, donde los niños de edad cercana a los 4 años apenas cometen errores en los ensayos de inhibición (91% de aciertos en inhibición frente a un 22% de aciertos de inhibición a las 3.0-3.2 años). A su vez observaron que los niños de esta edad tienden a utilizar un mayor número de estrategias físicas durante la inhibición (sujetarse una mano, por ejemplo) como estrategias de autorregulación, frente a estrategias verbales. Entre los 3-4 años hay una mejora en la habilidad para inhibir una respuesta dominante (Hughes, 1998). Sin embargo, los niños de 5 años muestran un mayor desempeño, es decir, mayor inhibición de respuesta preponderante, en tareas tipo *go/no-go* en comparación con niños de 3 y 4 años (Dowsett y Livesey, 2000). Por último, la inhibición aumenta significativamente entre los 5-10 años (Jones et al., 2003), considerándose los 10 años como el punto máximo de desarrollo (Davidson et al., 2006).

Por su parte, la capacidad de autorregulación comienza su desarrollo en torno a los 2-3 años gracias al desarrollo del lenguaje. El autocontrol emocional, como por ejemplo la precaución frente al miedo (latente a los 2-3 años), es la base para un autocontrol más de tipo cognitivo con posterioridad en el desarrollo (Aksan y Kochanska, 2004). Inicialmente los niños regularán su conducta gracias a las verbalizaciones del adulto, pero, posteriormente (en torno a los 4 años) podrán hacer uso de autoinstrucciones (Herreras, 2010). Los niños de 3 años utilizan estrategias verbales de autorregulación (no sólo cuando se las proporciona el adulto) y estrategias físicas para la inhibición motora (Manfra, Davis, Ducenne, y Winsler, 2014). A partir de los 4 años, usarán más estrategias verbales en lugar de físicas, de forma espontánea para ayudarse en el proceso de control inhibitorio (Jones et al., 2003), este cambio puede deberse a un mayor desarrollo en el lenguaje, lo que se ha relacionado con un mayor desarrollo en las funciones ejecutivas (Best, Miller, y Jones, 2009). Según Moriguchi y Hiraki (2011) las estrategias de regulación verbal estarían más presentes en niños de entre 5.5-12 años.

2. 2.2. Desarrollo de la memoria de trabajo

La forma más básica de memoria de trabajo se investiga a través de experimentos sobre la permanencia del objeto, donde a partir de 8-9 meses de edad los niños pueden tener éxito (Reynolds y Romano, 2016). Gracias a la permanencia del objeto se constata un primer desarrollo de la memoria de trabajo, lo que posibilitará la capacidad de imitación (Arnedo et al., 2015). Las habilidades más básicas respecto a la memoria de trabajo, la inhibición o la flexibilidad reflejan un incremento en su desarrollo a partir de los 3 años (Hughes, 1998). La memoria de trabajo se halla en pleno desarrollo entre los 4 y los 12 años, coincidiendo con la maduración del córtex prefrontal (Luciana y Nelson, 1998). En los niños de 3 a 5 años el rendimiento es más bajo cuando deben recordar más de 2 representaciones (material visual) en la memoria de trabajo (MT), mientras que a los 7 años son ya capaces de recordar 3 o más representaciones (Simmering, 2012). Riggs McTaggart, Simpson y Freeman (2006) sostienen que la capacidad en MT se desarrolla con la edad, siendo en valores medios a los 5 años de aproximadamente 1,52

representaciones, de 2,89 a los 7 años, y acercándose a la capacidad de los adultos a los 10 años (3,83 representaciones). Brocki y Bohlin (2004) identificaron tres periodos de maduración respecto a la inhibición, a la memoria de trabajo y a la velocidad de procesamiento (6-8, 9-12 y 14-15 años) siendo el último período en el que se alcanzarían valores similares a los de los adultos. Concretamente en relación con la memoria de trabajo otros autores consideran que se alcanza su punto máximo a los 13 años (Davidson et al., 2006).

2. 2.3. Desarrollo de la flexibilidad cognitiva, la toma de decisiones y la planificación

En cuanto a la flexibilidad cognitiva, niños de 3- 4 años ya son capaces de cambiar entre tareas considerando dos reglas de actuación (Moriguchi y Hiraki, 2011; Zelazo, 2004). Sin embargo, a partir de los 5-6 años se adaptan mejor al cambio (lo que fomenta la capacidad de generar nuevas ideas) y reducen los comportamientos rituales más característicos de los cursos anteriores ligado a un pensamiento más rígido (Tregay, Gilmour, y Charman, 2009). Entre los 3-5 años se produce un primer “pico” en el desarrollo de la inhibición y la flexibilidad cognitiva, entre los 5-7 se producirá un segundo (Anderson, P., Anderson, Northam, y Taylor, 2000; Zelazo et al., 2003). A los 10 años se produce un perfeccionamiento en la flexibilidad cognitiva (Arnedo et al., 2015). Según Anderson (2002) las tareas de flexibilidad cognitiva y planificación se desarrollan en un período crítico entre los 7-9 años perfeccionándose a los 12. Otros autores coinciden en señalar los 12 años como edad de perfeccionamiento de la flexibilidad (De Luca et al., 2003).

En cuanto a la toma de decisiones, es cierto que la valoración de riesgo-beneficio es una de las capacidades que inician su desarrollo en la primera infancia (Flores-Lázaro y Castillo-Preciado y Jiménez-Miramonte, 2014), a partir de los 4 años son más capaces de tomar decisiones ventajosas (y no elegir aquellas más desventajosas) gracias a un mayor desarrollo de las funciones ejecutivas “calientes”. A su vez, son capaces de elegir opciones entre aquellas que suponen una mayor gratificación, no de forma inmediata, y para más participantes que sólo ellos mismos (Kerr, A. y Zelazo, 2001; Zelazo y Müller, 2002). Sin embargo, este proceso madura de forma especial durante la adolescencia (Hooper et al., 2004; Prencipe et al., 2011).

En lo que respecta a la planificación, los niños de 4 años son capaces de anticipar posibles problemas que puedan presentarse ante la consecución de una tarea simple (Pillow, 1988; en Perez-Hernandez y Capilla, 2011). Entre los 4-5 años mejoran sus habilidades de planificación, la selección de un plan adecuado de actuación (Zelazo y Müller, 2002). Sin embargo, a partir de los 5 años tienen una mejor representación mental del problema que en años anteriores (Zelazo y Müller, 2002; Zelazo et al., 2010), lo que les ayudará en la planificación. Existe una mejora en la capacidad de planificación a partir de los 5 años (Best et al., 2009). El habla privada aparece como estrategia para guiarse durante la realización de la tarea (a partir de los 2 años), pero es entre los 3-8

progresivamente cuando ese habla muestra información relevante para la resolución de la tarea (Alderson-Day y Fernyhough, 2015). Por su parte, el proceso de planificación secuencial se perfeccionará en torno a los 15 años (De Luca et al., 2003; Flores-Lázaro y Castillo-Preciado, Rosa E. y Jiménez-Miramonte, 2014).

2. 2.4. Desarrollo de la fluidez verbal y la abstracción

Son escasos los estudios sobre fluidez verbal, pero parece que existe una evolución desde sustantivos a verbos cada vez más abstractos en la adolescencia (Flores-Lázaro et al., 2014) Inicialmente (5-7 años), producen verbos más relacionados con las experiencias concretas en lugar de más abstractos (Kemmerer y González-Castillo, 2010; en Flores-Lázaro et al., 2014).

Por su parte la abstracción es un proceso que se desarrolla desde las primeras formas de categorización. La abstracción requiere además del refinamiento de las funciones ejecutivas, el refinamiento del lenguaje (Flores-Lázaro y Castillo-Preciado y Jiménez-Miramonte, 2014). Este proceso continuará en desarrollo durante toda la escolaridad (Gentner y Namy, 1999).

La figura 7 resume las etapas de desarrollo de las funciones ejecutivas según Flores-Lázaro et al., (2014).

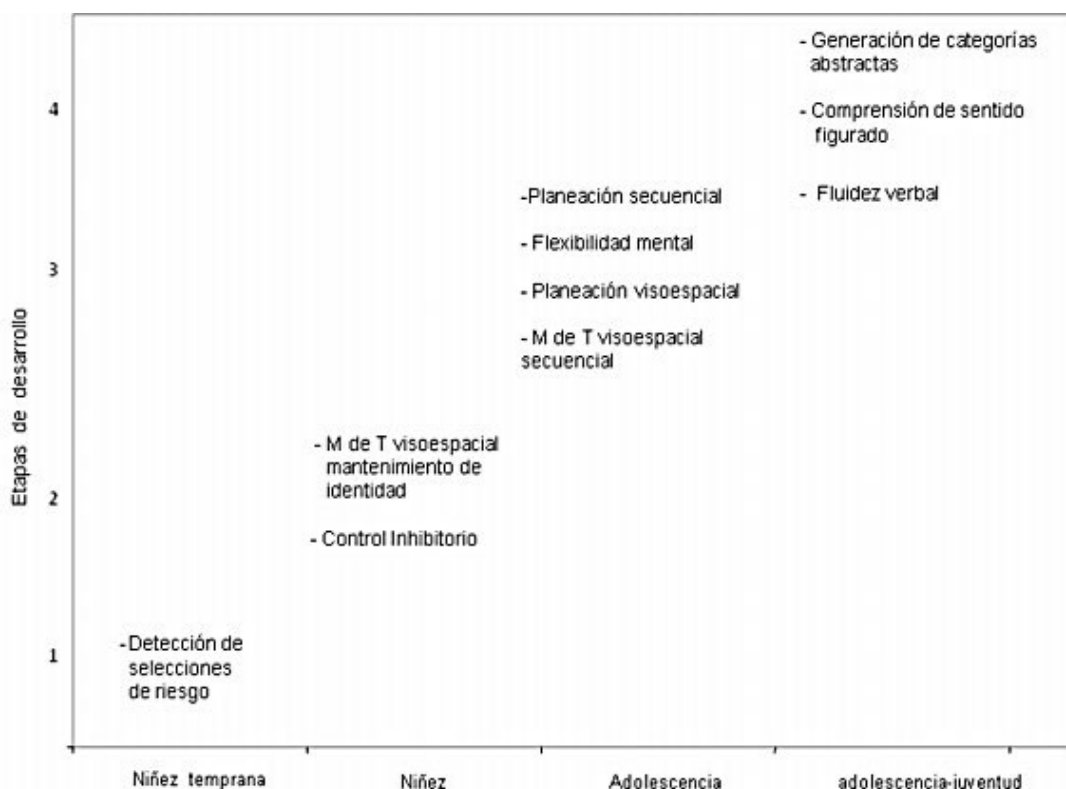


Figura 7: Secuencia general del desarrollo de FE (basado en Flores-Lázaro y Otrosky-Sheject, 2012). Recuperada de (Flores-Lázaro y Castillo-Preciado y Jiménez-Miramonte, 2014) Reproducida con permiso.

2. 3. Desarrollo de la metacognición

Respecto a la metacognición declarativa, éste es un proceso que se perfecciona con la edad. Los niños más pequeños tienen dificultades para utilizar estrategias adecuadas que les permitan procesar la información de forma que ésta sea fácilmente recuperable, como la categorización o asociación de palabras (Neimark, 1971) Los niños de 4-6 años por su parte, sobrestiman su capacidad de memoria e infraestiman el tiempo necesario de procesamiento de la información para su recuperación (Flavell, 1970)

Respecto a la metacognición o conocimiento sobre la exactitud del recuerdo, de lo que se sabe (introspección), aspecto que se ha relacionado con la inteligencia y el aprendizaje, existe una clara evolución desde aproximadamente 7 años a los 15 gracias a cambios neuroanatómicos que suceden en áreas prefrontales en el córtex ventromedial e insular (Fandakova et al., 2017). Según estos autores ello muestra un correlato entre el desarrollo del córtex frontal y el desarrollo de la metacognición. Esta habilidad se desarrolla de forma especial en la adolescencia, principalmente al final de la misma y culminando en la juventud (Weil et al., 2013). Esta introspección puede extenderse al conocimiento de lo que saben los otros, lo que se relaciona con la teoría de la mente (Efklides, 2009). Un ejemplo de ello sería la capacidad de valorar el conocimiento de los procesos de memoria y aprendizaje de los otros. Esta capacidad estimativa se desarrolla especialmente entre los 8-10 y 14-15 años (Paulus, Tsalas, Proust, y Sodian, 2014). Parece que la introspección respecto al conocimiento de uno mismo precede al conocimiento sobre lo que saben los demás (Goldman, 2006).

La memoria prospectiva (recordar qué tengo que hacer, indispensable para la planificación) nos permite recordar planes de acción y cuando deben realizarse (Kvavilashvili, Ellis, Brandimonte, Einstein, y McDaniel, 1996). Este proceso se desarrolla especialmente entre los 7 y los 8 años de edad (Yang, Chan, y Shum, 2011), estando mediado por las funciones ejecutivas (Roebers y Feurer, 2016) pero también por la metacognición (tanto declarativa como procedimental) (Cottini, Basso, y Palladino, 2018).

En cuanto a la metacognición procedimental, podemos mencionar entre otros, el desarrollo de las estrategias de orientación y de autorregulación. Una de ellas sería el lenguaje interno, esto es, las verbalizaciones mentales que realiza el niño para guiarse/orientarse en la realización de una tarea. El lenguaje interno evoluciona especialmente entre los 2 y 8 años, desde un habla más irrelevante a un habla dirigida a la tarea (Winsler, Fernyhough, y Montero, 2009a). Otra de las estrategias en este sentido, sería el uso de autoinstrucciones. Su desarrollo también varía durante el desarrollo del niño (Bjorklund y Harnishfeger, 1990; Vygotsky, Cole, John-Steiner, Scribner, y Soubelman, 1978) y en función del nivel de dificultad de la tarea (Fernyhough y Fradley, 2005). Es preciso destacar que este tipo de metacognición está especialmente influenciada por aspectos emocionales. Otra estrategia metacognitiva procedimental o de autorregulación sería la anticipación. Chevalier y Blaye (2016) mostraron a través de una

tarea computarizada de control ejecutivo en la que se facilita una estrategia de anticipación (antes de dar una respuesta, aparece en pantalla un punto donde fijar la mirada y una pista sobre el aspecto en el que deben prestar atención), que los niños más pequeños (6 años) tienen a estar menos preparados que los mayores (10 años), tardando más tiempo en responder y respondiendo antes de haber fijado la mirada. El hecho de haber fijado la mirada y de haberse preparado tiene una relación positiva con el desempeño en la tarea. Con la edad, los niños utilizan de forma más eficaz estrategias metacognitivas en tareas que requieren control ejecutivo. Los mismos autores sugieren que el control ejecutivo mejora con la edad mediado en buena parte por la metacognición (*metacognitive monitoring*). En general, la metacognición de autorregulación y las funciones ejecutivas comparten un desarrollo similar (Roebers y Feurer, 2016).

2.4. Conclusiones del apartado

Como conclusión sobre este apartado de desarrollo sobre los procesos en los que se fundamenta Nexxo, podemos decir que la atención es un requisito básico para el funcionamiento de otros procesos cognitivos más complejos (Amador, Forns, y Kirchner, 2006; McAvinue et al., 2012), es un proceso clave para que las personas emitan una respuesta adaptada (Howard, Johnson, y Pascual-Leone, 2014). Dicho de otra forma, “la atención se convierte en un proceso fundamental para el aprendizaje y el desarrollo ya que permite atender a los aspectos del entorno que son esenciales para la adquisición de nuevas competencias” (Perez-Hernandez, 2009). La atención, y, en particular la vigilancia, es requerida en diversas situaciones de la vida diaria, situaciones que requieren atención sostenida y atención dividida, requerida incluso en situaciones de riesgo, donde déficits en la misma podrían comprometer la integridad de la persona (Figueroa y Youmans, 2012). Siendo la atención un prerrequisito básico para otros procesos, ello nos permite sobreentender que la atención tiene un impacto sobre otras capacidades. El análisis que hemos realizado en nuestra muestra de 46 participantes de 6-8 años con desarrollo típico sobre el desempeño en el entrenamiento “Nexxo”, y las capacidades cognitivas, nos ha mostrado que aquellos participantes con resultados más altos en las tareas de vigilancia obtuvieron también puntuaciones más altas en inteligencia fluida y en flexibilidad cognitiva (Rossignoli- Palomeque, Quirós-Godoy, Perez-Hernandez, y González-Marqués, 2019). En la misma línea, se ha visto con anterioridad que el entrenamiento de la atención (basado en el modelo de Posner y Petersen (1990)) puede tener un impacto positivo en la inteligencia fluida (Rueda, Rothbart, McCandliss, Saccomanno, y Posner, 2005). En relación con la flexibilidad cognitiva, un estudio anterior sugiere que la flexibilidad cognitiva puede ser una herramienta útil en las tareas de vigilancia, ya que las diferencias individuales en flexibilidad cognitiva predicen mejores resultados en las tareas de vigilancia (Figueroa y Youmans, 2012). Cabe señalar, como hemos visto en apartados anteriores, la existencia de una estrecha relación entre la atención y las funciones ejecutivas.

Por su parte, las FFEE son cruciales para la adaptación del individuo en su contexto escolar, social, familiar y laboral (Bryck y Fisher, 2012), ya que, nos ayudan a dirigir nuestras actuaciones hacia una meta. Su desarrollo se ha relacionado con el desempeño académico y la inteligencia (Andersson, 2008; Conway y Gathercole, 2010; Karbach y Unger, 2014; Molfese et al., 2010), incluso se ha comprobado que las FFEE predicen mejor el rendimiento académico, la competencia matemática y lectora del niño que la propia inteligencia o cociente intelectual (Blair y Razza, 2007; Conway et al., 2003; Gathercole, Pickering, Ambridge, y Wearing, 2004). Un estudio reciente muestra que las funciones ejecutivas contribuyen de forma sustancial a la inteligencia fluida (Chen et al., 2019). Las áreas parietales y frontales (implicadas en atención y en funciones ejecutivas) se han relacionado con este tipo de inteligencia (Tschentscher, Mitchell, y Duncan, 2017; Yoon et al., 2017). Las FFEE no sólo se han relacionado con la inteligencia o con el rendimiento escolar (Illes y Sahakian, 2011), sino también con la capacidad del individuo a adaptarse de forma adecuada en su contexto social, inhibiendo comportamientos inadecuados (Bryck y Fisher, 2012; Crick y Dodge, 1994; Pérez-Edgar et al., 2010).

Finalmente, la aplicación de la metacognición se ha relacionado con un mejor desempeño en las funciones ejecutivas (Bewick, Raymond, Malia, y Bennett, 1995), una relación con la inteligencia (Fandakova et al., 2017) y en general con el aprendizaje y el rendimiento escolar (Blankson et al., 2017). Además de observar los beneficios de la atención sobre otros procesos, también podemos observar en qué situaciones se constatan sus carencias. En adultos, podemos decir que déficits de atención se producen con el envejecimiento, produciéndose un declive general con la edad de los aspectos básicos de atención (intensidad y selectividad) (McAvinue et al., 2012), especialmente en la atención ejecutiva o el control atencional (Reimers y Maylor, 2005). Por su parte, el daño cerebral, (especialmente frontal) deteriora los procesos atencionales y las funciones ejecutivas (Anderson, V. y Catroppa, 2005). Déficits de atención se observan en un repertorio de enfermedades neurológicas como traumatismos, demencias, heminegligencia y, en cuadros psiquiátricos como la esquizofrenia o la depresión (Estévez-González et al., 1997). Finalmente, el abuso de alcohol también deteriora el control atencional (Kaplan y Berman, 2010).

Como hemos visto anteriormente, la atención y las funciones ejecutivas están intrínsecamente relacionadas, así podemos observar que déficits en atención pueden afectar a las funciones ejecutivas y viceversa. Autores como Pérez-Edgar et al. (2010) han demostrado que niños con baja capacidad de atención sostenida tienen menor control inhibitorio en la infancia, lo que se relaciona con el ámbito social (relacionado la conducta inhibitoria) y con una menor resolución social en la adolescencia. En niños, se ha observado cómo fallos en vigilancia se ven reflejados en una menor capacidad de discriminación (apareciendo errores y omisiones) así como un declive en el tiempo de respuesta (Parasuraman y Giambra, 1991), es decir, en la velocidad de procesamiento. Esto tendrá un impacto en el día a día del niño con una baja capacidad de vigilancia o

atención sostenida, siendo más lento en la ejecución de las tareas y cometiendo más errores que otros niños. La capacidad de vigilancia o atención sostenida se ve comprometida en el Trastorno por Déficit de Atención e Hiperactividad (TDAH) (Huang-Pollock et al., 2012; Johnstone et al., 2012; Michelini et al., 2016), síndrome de la Tourette (Sukhodolsky, Landeros-Weisenberger, Scahill, Leckman, y Schultz, 2010), en trastornos de ansiedad (Price et al., 2013) y autismo (Christakou et al., 2013). Estudios anteriores, citados en Lovejoy y Rasmussen (1990) han mostrado dificultades en tareas de vigilancia, no sólo en niños con TDAH si no en casos de niños con riesgo de esquizofrenia (Nuechterlein, 1983), niños con dificultades de aprendizaje, discapacidad y niños con necesidades educativas especiales (Eliason y Richman, 1987; Keogh y Margolis, 1976). Por su parte Swanson y Cooney (1989) también señalaron esa relación entre baja inteligencia y pobres resultados en tareas de vigilancia. También se ha corroborado los déficits atencionales en niños con esquizofrenia (Sapir, Henik, Dobrusin, y Hochman, 2001), cardiopatía congénita (Miatton, De Wolf, François, Thiery, y Vingerhoets, 2007) y en daño cerebral (Galbiati et al., 2009). En general, también se pueden hallar déficits en la atención y en las funciones ejecutivas por factores ambientales, como en el caso del síndrome de alcohol fetal (Kodituwakku, 2009), o incluso en situaciones de maltrato infantil (Hart y Rubia, 2012). Por último, podemos considerar de especial relevancia estos procesos (la atención y las funciones ejecutivas), dado la proliferación de síntomas menores en población infantil, como en el caso de prematuridad, mostrando déficits en tales procesos al inicio en la etapa infantil (haciéndose más evidente en etapas educativas posteriores); éstas están mostrando una incidencia mayor en la actualidad que condiciones más graves (como la discapacidad intelectual o la parálisis cerebral) (Marret et al., 2013).

Respecto a las funciones ejecutivas, también se han relacionado sus carencias con ciertas dificultades en la vida diaria. Se observan dificultades en las funciones ejecutivas en trastornos del neurodesarrollo (Barkley, 1997) como el TDAH (Barkley, 1997; Beck, Hanson, Puffenberger, Benninger, y Benninger, 2010; Gau et al., 2010; Rebollo, M. Antonieta y Montiel, 2006; Stevens, Gaynor, Bessette, y Pearlson, 2016; Willcutt, Doyle, Nigg, Faraone, y Pennington, 2005), autismo (Ciesielski y Harris, 1997; Ozonoff y Jensen, 1999), el trastorno obsesivo-compulsivo (Enright y Beech, 1993; Ozonoff y Jensen, 1999), trastornos de conducta (Graziano y Hart, 2016; Rebollo, M. Antonieta y Montiel, 2006) o inadaptación social (Blair y Razza, 2007; Olson, 1989). En el caso de niños con TDAH y comorbilidad trastorno oposicionista desafiante (TOD), también se han encontrado afectación de las funciones ejecutivas, en especial flexibilidad cognitiva (Ter-Stepanian et al., 2017). También se ha encontrado afectación de las funciones ejecutivas en síndrome de la Tourette (Channon, Crawford, Vakili, y Robertson, 2003), en especial en la resolución de problemas, y en casos de Síndrome de Alcohol Fetal (Fuglestad et al., 2015; Kodituwakku, 2009; Rasmussen, Becker, McLennan, Urichuk, y Andrew, 2011), en especial en la inhibición, la atención, la capacidad intelectual y adaptación social. Por último, se han observado alteraciones en los procesos atencionales

y de las funciones ejecutivas en niños prematuros (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, y Oosterlaan, 2009; Grunewaldt, Kristine Hermansen, Skranes, Brubakk, y Låhaugen, 2016; van de Weijer-Bergsma, Wijnroks, y Jongmans, 2008), en trastornos específicos de aprendizaje (Dunning, Holmes, y Gathercole, 2013; Holmes, Joni et al., 2015), discapacidad intelectual (Bennett, Holmes, y Buckley, 2013; Soderqvist, Nutley, Ottersen, Grill, y Klingberg, 2012), daño cerebral (Hardy et al., 2015) y epilepsia (Fuentes y Kerr, 2017; Kerr y Blackwell, 2015).

En general, los déficits en las funciones ejecutivas causan diversas dificultades en el individuo. Anderson (2002) lo describe de la siguiente forma:

- Déficit en inhibición: las personas con dificultades en esta área tienen a ser impulsivas, con falta de autocontrol. Tienden a dejar sin terminar las tareas, cometer errores durante la ejecución, mostrar lapsos de atención, malinterpretar u olvidar las instrucciones y responder de forma inadecuada. Déficit en inhibición se han relacionado con dificultades de autorregulación (Rueda, Posner, y Rothbart, 2005), y en la teoría de la mente (Carlson, Moses, y Breton, 2002).
- Déficit en planificación: las personas con dificultades en planificación tendrán dificultades para resolver problemas por falta de planificación y organización. Presentarán dificultades en el desarrollo de nuevas estrategias eficaces (utilizando otras previas aprendidas), y un pobre razonamiento conceptual.
- Déficit en flexibilidad: las personas con falta de flexibilidad suelen mostrarse inflexibles, rígidos e incluso ritualistas, mostrando dificultades para adaptarse a los cambios. Pueden mostrar dificultades en la memoria de trabajo (para manipular mentalmente información o recordar información a corto plazo). Los déficits en flexibilidad se asocian a un comportamiento perseverativo, es decir, a repetir el mismo error por no ser capaz de cambiar de regla.

La tabla 2 resume los trastornos (no situaciones ambientales) en donde la atención y/o las funciones ejecutivas pueden estar alteradas.

Tabla 2.

Trastornos en la infancia donde pueden verse afectadas la atención y/o las funciones ejecutivas

Trastorno	Atención	Funciones Ejecutivas
TDAH	(Huang-Pollock et al., 2012; Michelini et al., 2016)	(Barkley, 1997; Barkley, 2011; Beck et al., 2010; Gau et al., 2010;

		Johnstone et al., 2012; Rebollo, y Montiel, 2006; Stevens et al., 2016; Willcutt et al., 2005)
Trastornos del Aprendizaje	(Eliason y Richman, 1987; Keogh y Margolis, 1976)	(Dunning et al., 2013; Holmes, Joni et al., 2015)
Discapacidad intelectual	(Eliason y Richman, 1987; Keogh y Margolis, 1976; Swanson y Cooney, 1989a)	(Bennett et al., 2013; Soderqvist et al., 2012)
Daño cerebral infantil	(Galbiati et al., 2009)	(Hardy et al., 2015)
Síndrome de la Tourette	(Sukhodolsky et al., 2010)	(Channon et al., 2003)
Síndrome de Alcohol Fetal	(Fuglestad et al., 2015; Kodituwakku, 2009; Rasmussen et al., 2011)	(Fuglestad et al., 2015; Kodituwakku, 2009; Rasmussen et al., 2011)
Prematuridad	(Aarnoudse-Moens et al., 2009; van de Weijer-Bergsma et al., 2008).	(Aarnoudse-Moens et al., 2009; Grunewaldt, Kristine Hermansen et al., 2016; van de Weijer-Bergsma et al., 2008).
Cardiopatía congénita	(Miatton et al., 2007)	
Ansiedad	(Price et al., 2013)	
Trastorno Obsesivo Compulsivo		(Enright y Beech, 1993; Ozonoff y Jensen, 1999)
Trastornos de conducta		(Graziano y Hart, 2016; Rebollo, M. Antonieta y Montiel, 2006; Ter-Stepanian et al., 2017)
Autismo	(Christakou et al., 2013)	(Ciesielski y Harris, 1997; Ozonoff y Jensen, 1999)

Epilepsia	(Fuentes y Kerr, 2017; Kerr, E. N. y Blackwell, 2015)
Esquizofrenia infantil	(Nuechterlein, 1983; Sapir et al., 2001)

Esta información nos parece relevante dado que la población a la que va dirigida este estudio es la población infantil, y la idea original proviene de la necesidad de entrenar estos procesos alterados en niños con TDAH. No obstante, podemos extender su uso a otro tipo de poblaciones en donde se hallan alterados los procesos atencionales y ejecutivos.

3. Presentación del entrenamiento “Nexxo”

El entrenamiento “Nexxo” es una idea original de la doctoranda, que surgió en el contexto clínico al trabajar con niños con TDAH. La idea inicial fue abordar el entrenamiento de la vigilancia y de la inhibición, aspectos deficitarios para estos pacientes en las reconocidas pruebas de ejecución continua como *Conners Continuous Performance Test II* (CPT-II) (Conners y Staff, 2000), *Conners Kiddie Continuous Performance Test* (K-CPT V.5) (Conners y Staff, 2001) o CSAT-R tarea de atención sostenida en la infancia revisada (Servera y Llabrés, 2015). Sin embargo, a raíz del análisis de los modelos atencionales y de funciones ejecutivas, el objetivo más general del entrenamiento se fijó en potenciar el **control atencional** (Anderson 2002, 2010), el **control ejecutivo** (Petersen y Posner, 2012; Posner y Petersen, 1990) y la **autorregulación** (Miyake et al., 2000). Debido a la misma revisión del estado de la cuestión, se consideró que además el programa debía contar con **estrategias metacognitivas** procedimentales para facilitar una mayor transferencia del aprendizaje (Chevalier y Blaye, 2016; Diamond et al., 2007; Riemer y Schrader, 2019) y su estrecha relación con las funciones ejecutivas (Roebbers y Feuer, 2016). Previamente se verificó que no existía en el mercado un entrenamiento similar (véase artículo de revisión en el capítulo 5.1.1), además se consultó información no publicada y se consultaron páginas webs para analizar otros entrenamientos de atención y funciones ejecutivas. De esto último la doctoranda realizó una revisión de los mismos, que continúa en la actualidad, dando a conocer tal información en un blog de creación propia: <https://neuroapp.wordpress.com/> (véase apartados de atención y funciones ejecutivas).

El siguiente esquema resume los elementos integrados en el programa de intervención “Nexxo”, donde el principal objetivo es potenciar el control atencional y la red ejecutiva.

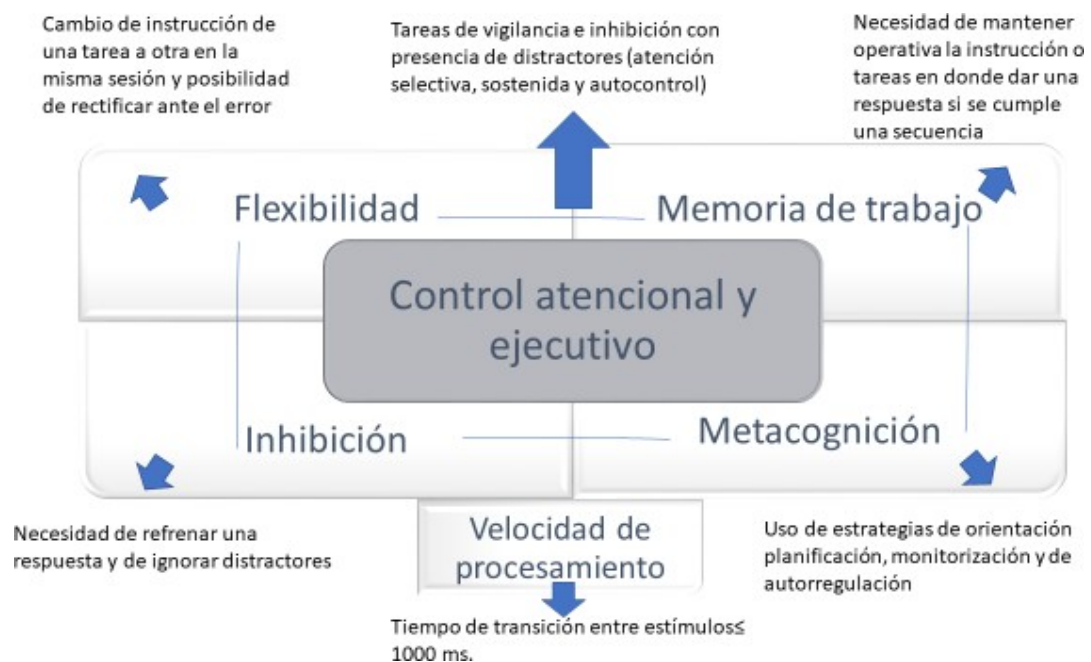


Figura 10: Integración de elementos en el diseño del programa de entrenamiento “Nexxo”.

El programa está diseñado para ser dirigido por un instructor (pe. psicólogos, psicopedagogos, neuropsicólogos etc.) ya que combina la repetición de una serie de juegos o ejercicios a través de la aplicación informática “Nexxo” en combinación con estrategias metacognitivas procedimentales que deben ser aplicadas y dirigidas por el instructor. El entrenamiento “Nexxo” combina el uso de la aplicación informática “Nexxo” (desarrollada por la doctoranda en colaboración con Marta Rincón Ortega y *Tapp-Mobile*), en donde se presentan tareas de inhibición y vigilancia, junto con estrategias metacognitivas procedimentales (diseñadas en colaboración con Elena Pérez-Hernández). Estas estrategias se dividen en: (1) *generales* (deben aplicarse en cada sesión) y (2) *estrategias compensatorias* (aplicadas en casos donde el participante muestra dificultad en la tarea). La figura 10 resume los componentes del entrenamiento:

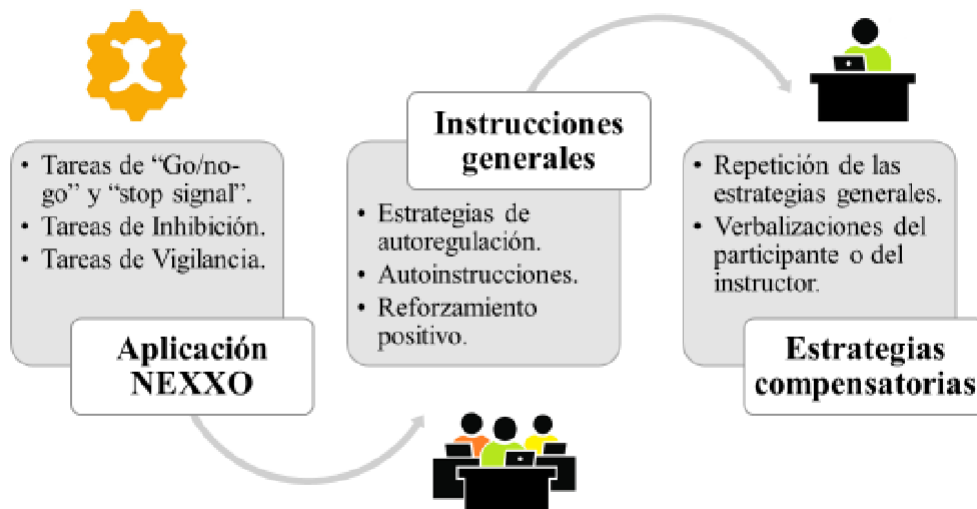


Figura 10: Descripción del entrenamiento “Nexxo”. Adaptada de “Schoolchildren’s Compensatory Strategies and Skills in Relation to Attention and Executive Function App Training” en Rossignoli-Palomeque et al.,2019. *Frontiers in Psychology*, (10), p.6.

El entrenamiento se distribuye a lo largo de 10 sesiones por nivel (existen dos niveles), de aproximadamente 15 minutos cada una, en las que se realizan 3-4 juegos (combinando los bloques de inhibición y vigilancia), que deben repetirse dos veces cada uno.

3.1. Descripción de la aplicación informática “Nexxo”

Como hemos dicho anteriormente, el entrenamiento se basa en modelos de atención y función ejecutiva reconocidos por la literatura científica (Anderson, Peter, 2002; Anderson, 2010; Miyake y Friedmand, 2012; Miyake, et al., 2000; Petersen y Posner, 2012; Posner y Petersen, 1990; Van Zomeren y Brouwer, 1994). Concretamente, las actividades que se realizan a través de la aplicación se basan en lo que se denomina tareas de *go/no-go* (hacer/no-hacer), *stop signal tasks* (tareas de parar ante una señal) (Logan, 1994; Shiffrin y Schneider, 1977) y *n-back*. Las tareas de *go/go-no* y *stop-signal* suponen suprimir una respuesta en marcha (en el bloque de inhibición) y mantener el estado de alerta (en el bloque de vigilancia), ya que en esas tareas la presencia del estímulo objetivo (*target*) es poco frecuente y por tanto los cambios han de ser detectados cuando hay baja frecuencia de aparición (Sturm, 2008). Además de ello, se ha diseñado la presencia de

distractores durante la tarea, dado que este aspecto es clave para favorecer la red ejecutiva (Anderson, 2002; Posner y Petersen, 1990). Las tareas *n-back*, presentes en menor medida en la aplicación, requieren retener a corto plazo, manipular y seleccionar la información (Tsujimoto, Kuwajima, y Sawaguchi, 2007) al decidir si dar o no una respuesta dependiendo si se completa o no una secuencia (memoria de trabajo).



Figura 11: Imágenes de la aplicación “Nexxo” (2016). Reproducidas con permiso de Tapp-Mobile.

La aplicación cuenta con dos bloques diferentes: (1) inhibición y (2) vigilancia. El mecanismo general consiste en pulsar la pantalla ante la presencia de un estímulo objetivo que se ha prefijado en una instrucción (por ejemplo: pulsa cuando aparezca algún alimento en la pantalla). En el bloque de vigilancia, el usuario debe pulsar la pantalla esporádicamente, respondiendo así a la presencia del estímulo objetivo (*target*), discriminado entre posibles distractores y manteniendo el estado de alerta. En el bloque de inhibición, el usuario debe pulsar de forma frecuente la pantalla (dado que el estímulo objetivo aparece frecuentemente) controlándose de pulsar ante estímulos que no son objetivo (*nontarget*), refrenando así una respuesta automática generada. A su vez, se ofrece una pauta general en cada bloque para que el usuario lo incorpore en su lenguaje interno. Para inhibición la pauta es “no pico en las trampas”, para vigilancia la pauta es “soy un gran observador”. La duración de los juegos no supera los dos minutos y el tiempo de transición es siempre igual o inferior a 1000ms. Los estímulos que aparecen pueden ser visuales o auditivos (tanto como *target*, *nontarget* y distractores). Ver las tablas 3 y 4.

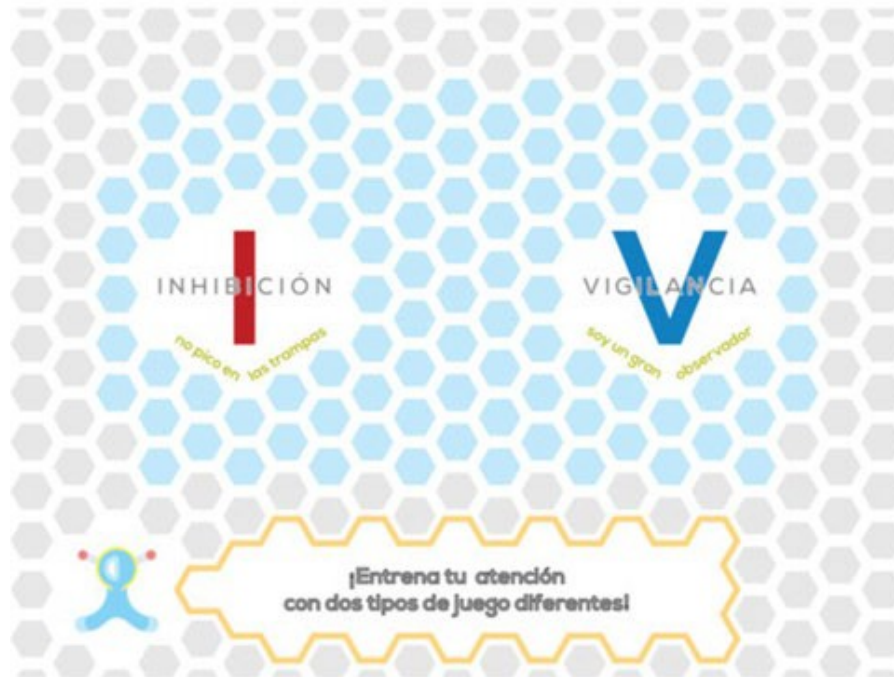


Figura 12: Imagen de la aplicación “Nexxo” (2016). Reproducidas con permiso de Tapp-Mobile.

En el bloque de vigilancia, la ratio de presencia del target es inferior al 30% (70% de probabilidad de no dar respuesta), mientras que en el de inhibición la presencia del target es superior al 70% (30% de probabilidad de no dar respuesta).

Las instrucciones y estímulos son diferentes para cada uno de los juegos. En la versión piloto de “Nexxo” (Tapp-Mobile, 2015) desarrollada para este estudio, la aplicación cuenta con dos niveles de dificultad y 15 juegos por cada bloque (vigilancia), 20 (nivel 1) 16 (nivel 2) de inhibición. El nivel tres que se diseñó para adolescentes y adultos no fue programado. Las figuras 14 y 15 muestran un ejemplo de una parte de dos de los juegos.

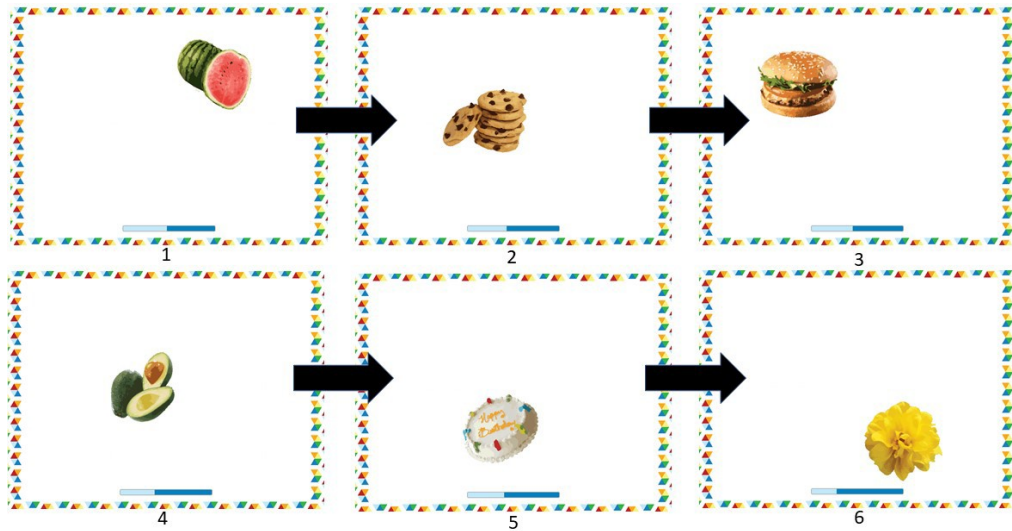


Figura 13: Recuperada de Rossignoli-Palomeque, T; Perez-Hernandez E. y González-Marqués, J. (en revisión en Acta Psychologica). “Nexxo” activity example. Screenshots from inhibition block. Instrucción: “pulsas cuando veas algún alimento”. El usuario debe pulsar todas las pantallas excepto la última. Transición entre pantallas 1000 ms. Reproducida con permiso.

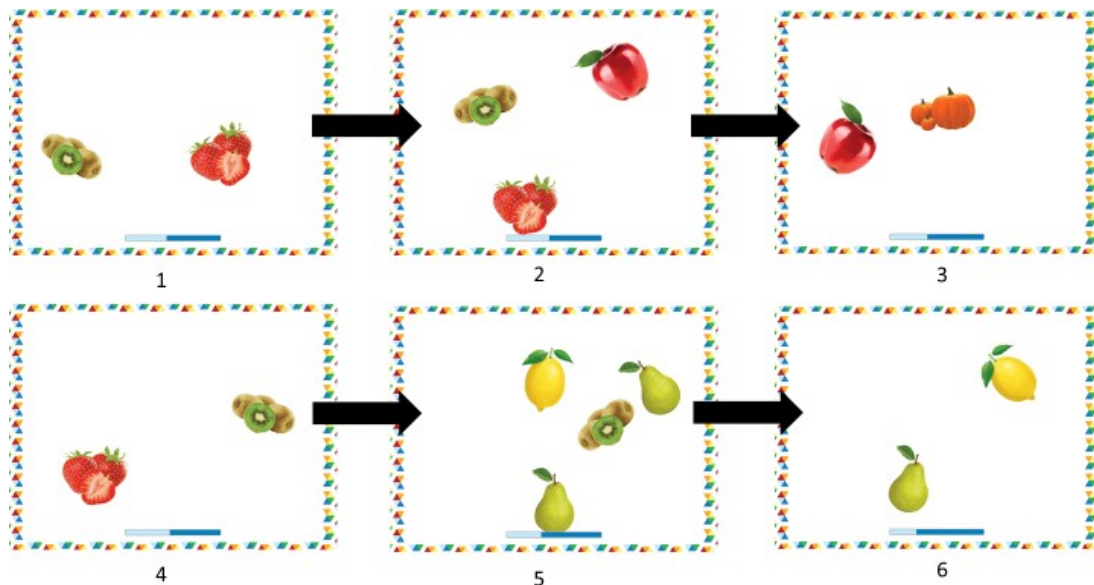


Figura 14: Imágenes del bloque de vigilancia. Instrucción: “pulsas cuando aparezca algún limón en pantalla”. El usuario sólo debe pulsar en las dos últimas. Transición entre pantallas 1000 ms. Reproducida con permiso de Tapp-Mobile.

La aplicación “Nexxo” requiere, además de control atencional y ejecutivo, la velocidad de procesamiento (al ser la transición entre un estímulo y otro igual o inferior a 1 segundo), y de procesamiento visual y auditivo dado que tanto los *targets* como *nontargets* pueden presentarse como imagen o sonido (p.e. “pulsas cuando escuches este sonido y aparezca un círculo”).

Por último, la aplicación proporciona diferentes feedback. De forma inmediata, cuando se acierta la pantalla se pone de color verde, mientras que si se falla se pone de color rojo. Ello da un feedback al usuario sobre si su ejecución es correcta. Por otro lado, la aplicación realiza un registro por sesión, registrando 2 tipos de errores: (1) errores de comisión (el usuario pulsó cuando no debía), y (2) errores de omisión (el usuario no pulsó cuando debía). Esta información se facilita por sesión (porcentaje de aciertos y errores en cada bloque) como de forma global (por sesiones). La figura 15 muestra un ejemplo del registro global por sesiones.

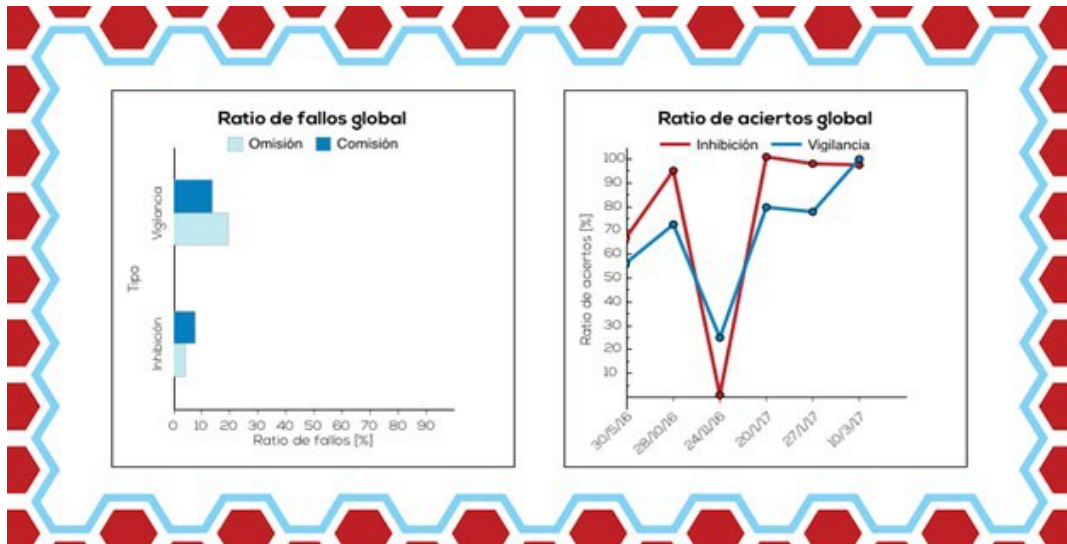


Figura 15: Ejemplo de ratio de fallos y aciertos a lo largo de 6 sesiones en la aplicación “Nexxo”. Reproducida con permiso de Tapp-Mobile.

De esta forma se puede valorar el tipo de ejecución del usuario y su evolución. En general, las personas con menor velocidad de procesamiento e inatención tenderán a cometer más errores de omisión, frente a las personas más impulsivas, que tenderán a cometer más errores de comisión (Connors y Staff, 2000; Connors y Staff, 2001).

Para más información sobre la aplicación, ésta se encuentra disponible en Apple Store: <https://itunes.apple.com/es/app/“Nexxo”/id979045960?mt=8>

A continuación, se presenta la información relevante de cada uno de los juegos según bloque y nivel (nivel 1, empleado en el estudio). Como hemos mencionado anteriormente, la aplicación dispone además de un nivel 2. El nivel 3 fue diseñado, pero no se ha desarrollado. Tanto las imágenes como los sonidos seleccionados para el entrenamiento son libres de derechos de autor.

Tabla 2. Descripción del nivel 1 del bloque de vigilancia

<i>Vigilancia_Nivel 1</i>					
Nombre del juego	Descripción (nº de estímulos/aparición del target)	Instrucción	Distractores (tipo y nº total)	Aclaración/comprensión de instrucciones	Feedback (nº estrellas 1-3/nº errores)

V.15	30/6	Pulsa cada vez que aparezca un osito en pantalla	Animales marrones (7)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿cualquier tipo de oso? (sí).	0: >3 1: 3 2: 2 3: 0-1
V.14	90/16	Pulsa la pantalla cada vez que veas la siguiente figura en el mismo color y en la misma posición	Misma forma/ Diferente color. -Misma forma/ Diferente posición. -Mismo color/ Diferente forma. (45)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si aparece la misma figura, pero en otro color? ¿o en otra posición? (entonces no debemos pulsar).	0: >5 1: 3-4 2: 2 3: 0-1
V.13	80/10	Pulsa cada vez que veas la siguiente figura con el mismo color junto al número 9	Mismo símbolo con número 6. -Número 9 con símbolo parecido. -Número 9 con mismo símbolo en diferente color. (15)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si aparece la misma figura, pero con un número que no es el 9 (por ejemplo, el 6)? ¿y si aparece el 9 pero la figura no es exactamente igual? (entonces no debemos pulsar).	0: >4 1: 3 2: 2 3: 0-1
V.12	50/8	Pulsa cada vez que veas una cruz	Formas parecidas a cruz (5) Sonidos distractores (11)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario).	0: >4 1: 3 2: 2 3: 0-1

				Aclaración: la cruz puede ser en cualquier color.	
V.11	30/8	Pulsa la pantalla cuando las dos imágenes sean exactamente iguales	Imágenes con una diferencia (color, parte incompleta, un elemento de más) (22)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si las dos imágenes son iguales, pero en distinto color o posición? (entonces no debemos pulsar).	0: >5 1: 3-4 2: 2 3: 0-1
V.10	30/5	Pulsa cada vez que veas un bebé en pantalla	-Niñas. -Familia con niña. -Mujeres. -Hombres. -Caras (de niña y mujer). (45)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si aparece un hombre o una mujer niños o adultos? (no debemos pulsar).	0: >3 1: 2 2: 1 3: 0
V.9	40/5	Pulsa cuando aparezca una figura de color rojo	-Sonidos distractores (8) -figuras naranjas y rosas. (5)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si por ejemplo aparece un animal rojo? (no debemos pulsar, porque no es una figura).	0: >3 1: 2 2: 1 3: 0

V.8	100/8 (tipo n-back)	Pulsa cada vez que veas en la pantalla un 6 y la pantalla anterior haya aparecido un 3	-Número 6 precedido de otro número. -Número 3 seguido de un número distinto del 6 (21).	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si sale el 6 pero el número anterior no era un 3? (no debemos pulsar).	0: >5 1: 3-4 2: 2 3: 0-1
V.7	45/12	Pulsa cada vez que veas un círculo amarillo y escuches este sonido	-Sonidos parecidos al target. (7)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si aparece el círculo amarillo con otro sonido? ¿y si es el mismo sonido, pero el círculo no es amarillo? (no debemos pulsar).	0: >4 1: 3 2: 2 3: 0-1
V.6	60/10	Pulsa cuando aparezca un limón en pantalla	-frutas amarillas: plátano, pera, calabaza. (39)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: si aparece uno o más limones debemos pulsar.	0: >4 1: 3 2: 2 3: 0-1
V.5	30/10	Pulsa cada vez que escuches este sonido	-Sonido muy parecido al target (5)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si el sonido se parece, pero no es el	0: >3 1: 2 2: 1 3: 0

				mismo? (no debemos pulsar).	
V.4	30/5	Pulsa cada vez que veas algo de color rojo	-Objetos naranjas y rosas (11).	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario).	0: >3 1: 2 2: 1 3: 0
				Aclaración: ¿y si aparece algo rosa o naranja? (no debemos pulsar).	
V.3	30/5	Pulsa cada vez que veas el número 1	-Aparición de muchos números en la misma pantalla. (25)	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario).	0: >3 1: 2 2: 1 3: 0
				Aclaración: ¿y si salen números, pero ninguno es el 1? (no debemos pulsar).	
V.2	50/11	Pulsa cada vez que veas el nombre de algo que no sea una fruta	-Nombres de alimentos (39)	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario).	0: >5 1: 3-4 2: 2 3: 0-1
				Aclaración: ¿y si sale el nombre de un alimento, por ejemplo, pollo? (no debemos pulsar).	
V.1	60/10	Pulsa cuando veas el siguiente símbolo en color azul	Sonidos (10) -3 -3" (en otro color) -3' (mismo color)	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario).	0: >4 1: 3 2: 2 3: 0-1

-3! (mismo color)
 -E” (mismo color)
 3´ (mismo color)
 (20)

Aclaración: ¿y si aparece el mismo símbolo, pero en otro color? (no debemos pulsar).

Tabla 3 Descripción del nivel 1 del bloque de inhibición

<i>Inhibición Nivel 1</i>					
Nombre del juego	Descripción (nº de estímulos/aparición del target)	Instrucción	Distractores (tipo y nº total)	Aclaración/comprensión de instrucciones	Feedback (nº estrellas 1-3/nº errores)
I.20	60/39	Pulsa cuando veas el número 5	Otros números (22)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si aparece un número, pero no es el 5? (no debemos pulsar).	0: >3 1: 2 2: 1 3: 0
I.19	40/33	Pulsa cada vez que aparezca un alimento en pantalla	-Oso panda -Flores -Cisne -Botón verde -Pelota (7)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si aparece algo que no se come? (entonces no debemos pulsar).	0: >3 1: 2 2: 1 3: 0-1
I.18	40/28	Pulsa cada vez que escuches este sonido	-Sonidos parecidos al target (18)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si suena un sonido parecido? (no debemos pulsar).	0: >3 1: 2 2: 1 3: 0
I.17	72/57	Pulsa cada vez que	-letra p -letra b (15)	Preguntar “¿Cuándo tenemos que pulsar?”	0: >3 1: 2 2: 1

		veas la letra d		(Esperar que dé la respuesta el usuario). Aclaración: fíjate bien en la letra d, mira hacia la izquierda, ¿si sale la b, la q o la p? (no debemos pulsar).	3: 0-1
I.16	60/39	Pulsa cada vez que veas la siguiente figura	- Formas parecidas: (21) - Sonidos distractores (19 veces).	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que de la respuesta el usuario). Aclaración: ¿y si sale la misma figura en otro color? ¿Y si es la misma figura, pero en distinta posición? (no debemos pulsar).	0: >3 1: 2 2: 1 3: 0
I.15	50/26	Pulsa cada vez que la palabra rojo esté escrita en color rojo	- Sonidos distractores (19 veces). - Palabra rojo escrito en otros colores -Otros colores escritos en rojo (15)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si aparece rojo pero escrito en otro color, como amarillo? ¿Y si aparece escrito otro color que no es rojo, pero en tinta roja? (no debemos pulsar).	0: >3 1: 2 2: 1 3: 0
I.14	40/32	Pulsa cuando las dos figuras sean iguales y estén en la misma posición	-Dos formas muy parecidas (10)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si son iguales, pero están en distinta	0: >3 1: 2 2: 1 3: 0-1

				posición? (no debemos pulsar).	
I.13	40/29	Pulsa cuando veas una letra que no sea la P	-Letra d -letra b (7)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: debo pulsar en todas las pantallas, pero si sale la p debo controlarme y no pulsar.	0: >3 1: 2 2: 1 3: 0
I.12	60/50	Pulsa cuando veas esta cara	-Caras parecidas: (p.e. misma cara con gafas, triste, sonrisa, susto, ups, extraterrestre) (11)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si aparece la misma cara, pero con diferente expresión? (no debemos pulsar).	0: >3 1: 2 2: 1 3: 0
I.11	50/39	Pulsa cuando aparezca un dibujo que no sea un animal	-Personas -Robot (6)	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: pulsamos en todas las pantallas, pero si aparece un animal nos controlamos y no pulsamos.	0: >3 1: 2 2: 1 3: 0
I.10	50/35	Pulsa cuando veas sólo una flecha roja en pantalla	-Dos flechas rojas en la pantalla (6).	Preguntar “¿Cuándo tenemos que pulsar?” (Esperar que dé la respuesta el usuario). Aclaración: ¿y si aparecen dos flechas rojas en la pantalla? (no debemos pulsar).	0: >4 1: 3-4 2: 2 3: 0-1

I.9	80/55	Pulsa cuando veas en pantalla la señal de stop	-Señal de ok verde (25)	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario). Aclaración: la señal de stop tiene que ser igual a la de la instrucción, ¿y si aparece una señal parecida? (no debemos pulsar).	0: >3 1: 2 2: 1 3: 0
I.8	40/30	Pulsa cuando veas en pantalla uno o más círculos	-Otras formas geométricas (10)	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario). Aclaración: hemos de pulsar cuando aparezca al menos un círculo.	0: >3 1: 2 2: 1 3: 0
I.7	50/35	Pulsa cuando veas un símbolo encima de la letra m	-M encima del símbolo -Símbolo al lado de la m -N con símbolo encima (18)	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario). Aclaración: ¿y si el símbolo aparece a un lado o debajo de la m? (no debemos pulsar).	0: >4 1: 3-4 2: 2 3: 0-1
I.6	50/40	Pulsa cada vez que veas una palabra que contenga la letra p	-Dibujos que contienen la letra p en presencia de palabras que no la contienen (18)	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario). Aclaración: fíjate en las palabras y no en las imágenes. Pulsamos si la palabra empieza o contiene la letra p.	0: >4 1: 3-4 2: 2 3: 0-1

I.5	60/46	Pulsa cada vez que los números coincidan	-Números que no coinciden (14)	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario). Aclaración: ¿y si los números no son iguales? (no debemos pulsar).	0: >3 1: 2 2: 1 3: 0
I.4	36/24	Pulsa cada vez que el sonido coincida con la imagen	-Imágenes que no coinciden con su sonido (9)	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario). Aclaración: ¿y si aparece por ejemplo un gato que ladra? (no debemos pulsar).	0: >3 1: 2 2: 1 3: 0
I.3	40/30	Pulsa cuando la imagen corresponda con la palabra	-Palabra escrita no coincide con la imagen (10)	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario). Aclaración: ¿y si la palabra es del mismo campo semántico que el dibujo, por ejemplo, pone pera pero la imagen es un plátano? (no debemos pulsar).	0: >4 1: 3-4 2: 2 3: 0-1
I.2	30/22	Pulsa cuando aparezca en pantalla una letra y escuches este sonido	- Número + sonido target. - Exclamación + sonido target (4)	Preguntar "¿Cuándo tenemos que pulsar?" (Esperar que dé la respuesta el usuario). Aclaración: ¿y si aparece el sonido, pero no una letra? (no debemos pulsar).	0: >4 1: 3 2: 2 3: 0-1
I.1	60/45	Pulsa cuando veas un	-Pantalla con color y sonido	Preguntar "¿Cuándo tenemos que pulsar?"	0: >3 1: 2 2: 1

dibujo en pantalla excepto si escuchas un sonido	(15)	(Esperar que dé la respuesta el usuario). Aclaración: hay que pulsar todas las pantallas menos en las que haya sonido.	3: 0
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3.2. Descripción de las estrategias metacognitivas

Como hemos comentado anteriormente, el entrenamiento conlleva una serie de estrategias denominadas “estrategias metacognitivas procedimentales”. Estas estrategias se engloban dentro de la metacognición de autorregulación y la autosupervisión. Las desarrolladas para este entrenamiento han sido inspiradas por Perez-Hernandez, Rabipour y Raz (2011), y siguiendo el modelo de estrategias metacognitivas propuesto por Efklides (2009). Las mismas han de ser dirigidas por el instructor y registradas para cada participante en cada sesión.

Estrategias generales (impartidas siempre, en cada sesión):

- a. Estrategias de orientación:
 - Señal de preparación para comenzar la sesión: el usuario debe poner las manos sobre dos pegatinas fijadas en la mesa cuando escuche “en posición” y esperar a las instrucciones del instructor.

- b. Estrategias de regulación:
 - Autoinstrucción visual (espero-veo-pulso): es un recordatorio visual que recuerda cómo ejercer las tareas, con el objetivo de no dar respuestas impulsivas.
 - Autoinstrucción verbal (“soy un gran observador”, “no pico en las trampas”). El objetivo es fomentar en el lenguaje interno una estrategia de autorregulación y control atencional. La figura 17 muestra la disposición de la tableta respecto a las pegatinas y el recordatorio visual de autorregulación.



Figura 16: disposición de la tableta, y las claves visuales. Tomado del script para instructores desarrollados para el entrenamiento “Nexxo”.

- c. Estrategias de planificación:
- Comprensión de instrucciones y autoinstrucciones: el instructor lee en voz alta la instrucción y pregunta al participante qué tiene que hacer (véase descripción de instrucciones y aclaraciones de la tabla 2 y 3). “¿Cuándo tenemos que pulsar?” (el participante responderá en voz alta). Se proporcionan además aclaraciones.
- d. Estrategias de Supervisión:
- Gracias al feedback proporcionado por la aplicación, el participante puede supervisar su propia ejecución. La pantalla se pone verde ante los aciertos y roja antes los errores.
- e. Estrategias de evaluación del resultado:
- Refuerzo positivo: el instructor dirá “muy bien” al finalizar si procede. La propia aplicación también aporta un feedback sobre el desempeño en el juego (0-3 estrellas según ejecución).

Estrategias compensatorias (facilitadas a los participantes que muestran dificultad durante el desempeño en la tarea).

- Repetición de la señal de comienzo.
- Repetición de la Autoinstrucción (espero-veo-pulso).
- Repetición de la comprensión de la instrucción y la Autoinstrucción.
- Verbalización por parte del niño: el niño debe decir en voz alta lo que aparece en la pantalla. Esta estrategia es una estrategia de autorregulación.

- Verbalización por parte del instructor: el instructor verbaliza los estímulos que aparecen en la pantalla para ayudar al participante en su control atencional y autorregulación.
- Refuerzo positivo a través de gestos o verbalizaciones como “muy bien” en voz alta.

En el *script* (guión) del entrenamiento “Nexxo”, se facilitan una serie de instrucciones para los instructores que impartieron el entrenamiento en los grupos reducidos. A continuación, mostramos una síntesis de las mismas:

Pautas para la primera sesión:

- Antes de entrar en la sala advertir de que deben sentarse donde se lo indique el monitor y que no deben jugar con las tabletas hasta que indique el monitor (cada tableta tiene el usuario de un participante/marcada por detrás con el nombre del mismo). “Vamos a entrar en una sala donde hay tabletas, os iréis sentando donde yo os diga, no se pueden tocar las tabletas hasta que yo lo ordene”.
- Colocación: Poner a los niños en fila por orden de cómo van a sentarse (participante 1-8)
- Presentarse: “me llamo x y voy a dirigir vuestro entrenamiento para ser súper observadores “Nexxo”” (para que se identifiquen en el grupo decirles: “somos el equipo “Nexxo”). Vamos a entrenarnos durante 10 sesiones, lo importante de cada sesión es hacerlo lo mejor que podáis”.
- Cada niño usa siempre la misma tableta: “Cada uno utilizaréis una tableta para realizar unos ejercicios. Os sentaréis siempre en el mismo sitio para utilizar siempre la misma tableta, fijaos en el color de vuestra funda, debe ser siempre el mismo”.
- “Os voy a explicar dos normas que utilizaremos siempre”: Explicar la norma de estar en posición y el recordatorio visual de actuación:
 - ¿Dónde tenemos que colocar las manos? Cada una en una pegatina.
 - ¿Cuándo hay que colocar las manos en la pegatina y mirar a la pantalla? Cuando yo diga “¡En posición, equipo “Nexxo”!”
- “En la mesa hay unos dibujos: un reloj, un ojo y una mano. Para ser “súper observadores “Nexxo”” tenemos que esperar, ver y pulsar. ¿Qué tenemos que hacer? (lo niños repiten a la vez que señalan o enseñan cada uno de los dibujos: esperar, ver pulsar.
- Indicar que el uso de los cascos cuando el monitor diga: “También tenéis unos cascos sobre la mesa, deberéis usarlos sólo cuando yo os lo indique”.

- “¡En posición, equipo “Nexxo”!”- Aplicar las estrategias metacognitivas procedimentales.

Pautas generales para cada sesión:

- 1) Una vez que los niños estén sentados decir: “En posición”. Asegurarse que todos los niños ponen las manos sobre la pegatina y miran la pantalla.
- 2) Indicar el bloque a pinchar (decir V o I) y después el juego que toca (p.e: “damos a V, ¿estamos todos? Ahora a v120 y esperamos). Si el niño no identifica el juego señalarlo.
- 3) Leer la instrucción en voz alta (“voy a leer lo que tenemos que hacer”).
- 4) Autoinstrucción: preguntar a los niños cuándo hay que tocar la pantalla para asegurarse de que han entendido la instrucción (“¿cuándo tenemos que tocar la pantalla?”) *mirar pautas concretas de comprensión de instrucciones de cada juego.
- 5) Recordarles: “¿qué significa que la pantalla se ponga verde? Que lo he hecho bien, ¿y qué significa que se ponga roja? Que me he equivocado y tengo que seguir intentándolo”.
- 6) En el caso de vigilancia, recordar que se trata de ser un gran observador, que no se me escape nada “recordar que soy un gran observador”. En el caso de inhibición recordar que se trata de no darle cuando no debo, esquivar una trampa “recordar que toco sólo cuando debo, no pico en las trampas”.
- 7) “Nos ponemos los cascos y cuando yo levante la mano darle al botón verde para empezar, cuando terminéis quitaros los cascos, si se os cae no pasa nada, seguid jugando. ¡En posición, equipo “Nexxo”!” (levantar la mano cuando todos los niños tengan los cascos puestos) “¡Adelante!”. Si se le cae decirle que continúe.
- 8) Una vez que terminen (y quiten los cascos): “esta primera vez es para entrenar, veamos una sola vez más si conseguimos que nos salga todavía mejor, esta vez le daremos a las flechas negras para volver a realizar el mismo juego. A mi señal podéis empezar, cuando terminéis quitaos los cascos”.
- 9) Al finalizar las dos repeticiones del mismo ejercicio indicar el cambio de bloque y/o de ejercicio (repetir los pasos anteriores).
- 10) Cuando finalice la sesión felicitarles y aplaudir: “¡muy bien! (aplaudir) ¡hemos entrenado nuestro cerebro! Ahora quedarán guardadas las estrellas que habéis conseguido, poco a poco veréis cómo conseguimos más, ¡hasta la próxima, Equipo...” Nexxo”! (dicen los niños)!

OBJETIVOS

Objetivos

A continuación, se exponen los objetivos de esta tesis doctoral:

- 1) Aportar una revisión actualizada sobre la eficacia de programas de entrenamiento de atención y funciones ejecutivas en la infancia y adolescencia a través de programas con soporte tecnológico (ordenador, tabletas o *smartphones*).
- 2) Desarrollar un programa de entrenamiento de la atención y las funciones ejecutivas (basado en modelos *go/no-go* y *stop signal*) para población escolar a través de una aplicación (“Nexxo” aplicación para Ipad) en combinación con estrategias metacognitivas, superando posibles hándicaps encontrados en programas anteriores.
- 3) Estudiar el impacto del entrenamiento en población de 6-7 y 8-9 años en relación a las siguientes variables: atención, funciones ejecutivas y supervisión; superando posibles limitaciones encontrados en estudios anteriores.
- 4) Establecer en qué momento evolutivo (antes o después de los 7 años) pudiera haber un mayor beneficio a través de un programa de entrenamiento cognitivo de la atención y funciones ejecutivas (“Nexxo”).
- 5) Estudiar el uso de estrategias complementarias por parte del grupo entrenado, así como variables cognitivas y/o de desarrollo que influyen en el desempeño de las tareas de vigilancia e inhibición.

PUBLICACIONES

4. Justificación de las publicaciones

Teniendo en cuenta los objetivos de la tesis, se realizaron tres publicaciones que se muestran en este apartado.

La primera publicación se trata de una revisión sobre la metodología de estudios previos en herramientas de *brain training* de atención y/o funciones ejecutivas en niños y adolescentes comercialmente disponibles, y sobre la eficacia de los mismos en términos de neuroplasticidad, transferencia (tanto en las áreas entrenadas como en las no directamente entrenadas), así como la durabilidad de los efectos. Esta revisión, nos sirvió para esclarecer el estado de la cuestión: qué herramientas existen en el mercado y si pudiera existir alguna similar a Nexxo, cuáles cuentan con validez científica, qué efectos producen; así como darnos pautas para el diseño de nuestra herramienta y nuestro diseño de estudio. De esta revisión de herramientas y estudios, observamos que el modelo aplicado en Nexxo es novedoso. También observamos limitaciones en cuanto al diseño metodológico, que procuramos superar en la medida de nuestras posibilidades en nuestro estudio, así como carencias en cuanto a los efectos.

La segunda publicación, es fruto del estudio de campo realizado en esta tesis. Con el objetivo de estudiar los efectos del entrenamiento Nexxo sobre la atención y las funciones ejecutivas en niños con desarrollo típico de 6-7 años y 8-9 años. La selección de estos grupos de edad se realizó para comparar cómo respondían a la intervención ambos grupos de edad con una diferencia clara en cuanto al desarrollo de las funciones entrenadas. Gracias a la revisión previa realizada, decidimos que fuera un estudio controlado, aleatorizado y que incluyese grupo de placebo. Pese a no ser estrictamente doble-ciego, los examinadores y los instructores de los talleres fueron personas diferentes para reducir la probabilidad de que los examinadores supieran la pertenencia de los participantes a los diferentes grupos (control, placebo o experimental). La incorporación de un grupo de placebo, reduce las posibilidades de detectar una mejora sólo por expectativas psicológicas de la intervención. El desarrollo de Nexxo fue realizado teniendo en cuenta una carencia en las herramientas analizadas, la falta de *far transfer* y de durabilidad. Por ello, decidimos incorporar estrategias metacognitivas procedimentales, dado que según la literatura científica pueden facilitar el aprendizaje. Ello fue incorporado en el estudio, gracias al uso de instructores durante la realización de los talleres (o grupos de entrenamiento Nexxo). Además, incorporamos herramientas de evaluación que mostrasen los efectos en la vida diaria de los niños, como son los cuestionarios obtenidos del entorno familiar. En esta publicación pueden consultarse los efectos producidos por el entrenamiento Nexxo.

Finalmente, decidimos analizar el uso de estrategias por parte del grupo experimental, la relación con el desempeño en las tareas y cuáles fueron más utilizadas. Además de ello, analizamos las variables cognitivas recogidas en una primera evaluación (inteligencia, atención, velocidad de procesamiento y funciones ejecutivas) en relación con el desempeño en las tareas de Nexxo. Este análisis dio lugar al tercer artículo, en donde pueden consultarse los resultados para ambos análisis (uso de estrategias compensatorias y relación de variables cognitivas con la ejecución en Nexxo).

4.1. Entrenamiento cognitivo de la atención y las funciones ejecutivas a través de nuevas tecnologías en niños y adolescentes

Se engloban dentro del concepto “entrenamiento cognitivo” programas o actividades que pretenden mejorar una habilidad o capacidad general a través de la repetición de tareas cognitivas durante un período de tiempo. Estas actividades deberían producir una serie de cambios en el comportamiento o en la cognición, a nivel neuroanatómico y funcional (Rabipour y Raz, 2012). El entrenamiento cognitivo, por tanto, se refiere a la práctica de habilidades cognitivas básicas con el objetivo de mejorar el rendimiento en otras tareas cognitivas o áreas (Simons et al., 2016). Comúnmente la mayoría de los programas de entrenamiento cognitivo son conocidos por la población general como *brain training* (entrenamiento cerebral). Existen programas de entrenamiento cognitivo, basados en la neurociencia, que permiten mejorar procesos básicos como la atención y las funciones ejecutivas y su transferencia incluso en la inteligencia fluida (Jaeggi, Buschkuehl, Jonides, y Shah, 2011).

El entrenamiento cognitivo está tomando formas cada vez más tecnológicas. En la actualidad, vivimos inmersos en un mundo tecnológico donde el acceso a las nuevas tecnologías o TICS desde temprana edad está siendo normalizado. Se entiende por tecnologías de la información y la comunicación (TIC) un amplio grupo de sistemas electrónicos que facilitan la adquisición y la transmisión de la información de manera fluida (Portellano, 2014). Se calcula que hay más de un billón de *smartphones* en todo el mundo (2014) y que esta cifra supera los dos billones en el 2015 (Brown et al., 2014). En cuanto al uso de tecnología móvil, entre las que se incluyen las aplicaciones o “apps”, se calcula que unas tres cuartas partes de la población mundial tiene acceso a esta tecnología (Bank, 2012). Particularmente, en el año 2012 se descargaron 30 billones de aplicaciones en todo el mundo.

Estas tecnologías están llegando a los más pequeños, en Estados Unidos los niños usan tecnología digital (redes sociales, mensajería móvil, juegos, aplicaciones etc.) en torno a 4 horas a día fuera de la escuela (Lai, Khaddage, y Knezek, 2013). Más allá del uso de las nuevas tecnologías (bien sea a través de móviles o tabletas) en el ámbito familiar, las aplicaciones son también utilizadas desde el ámbito escolar, por ejemplo, Apple vendió cerca de 2.5 millones de iPad a colegios en Estados Unidos en el año 2012 (McNaughton y Light, 2013). Sin embargo, el impacto que esta revolución digital pueda tener sobre los niños no suele ser considerado pese a estar tan inmersos en la era digital como los adolescentes y adultos que les rodean (Kress, 2003). Debido a esto, consideramos que los programas de entrenamiento cognitivo a través de las nuevas tecnologías que sean debidamente puestos a prueba pueden tener un importante calado en la sociedad. Debido a los datos reflejados, utilizar un soporte informático para el entrenamiento cognitivo “Nexxo” nos pareció lo más adecuado.

El uso de aplicaciones móviles para mejorar las funciones cognitivas, no sólo en adultos si no en niños, está creciendo en los últimos años. Debido a que el uso de tabletas

o aplicaciones móviles que resultan muy accesibles en la actualidad, resulta necesario fomentar los estudios científicos sobre aplicaciones de entrenamiento cognitivo. Sin embargo, son pocas las aplicaciones disponibles en el mercado que hayan demostrado su eficacia a nivel científico, formando parte de una corriente que debe tomarse con cautela. Existe una necesidad desde el mundo científico de impulsar la investigación sobre tales productos tecnológicos. En el campo de la estimulación cognitiva y de la intervención a través de plataformas o aplicaciones cobra mayor relevancia al ser estas más accesibles que otros medios. Según Portellano (2014): “dado que vivimos en una sociedad cada vez más informatizada, (...) la estimulación cognitiva de las personas sanas debe emplear recursos informáticos de manera creciente” (pg. 136). Estas vías deben ser diseñadas por especialistas y mostrar su eficacia a través de investigación empírica, dado que, de lo contrario, no sabremos si los usos de las aplicaciones disponibles en el mercado tienen alguna validez.

Pese a que el marketing del *brain training* se dirige a la población general, tiene un especial uso en niños y en personas mayores. A su vez, concretamente parece tener una relevancia especial para la psicopatología del desarrollo, siendo muy utilizado por ejemplo en trastornos de la atención como el TDAH (Rabipour y Raz, 2012). Como pudimos observar en nuestra revisión sobre productos de *brain training*, encontramos estudios especialmente dirigidos a niños con TDAH, pero también otras circunstancias como prematuridad, bajo nivel socio-económico, dificultades de aprendizaje, trastornos del lenguaje, discapacidad intelectual, trastornos de conducta, cáncer o epilepsia entre otros (Rossignoli-Palomeque, Perez-Hernandez, y González-Marqués, 2018)

La creación de este programa y la puesta en marcha de un estudio empírico sobre el mismo se efectúa no sin antes realizar un exhaustivo estado de la cuestión. Con el objeto de analizar los diferentes programas de entrenamiento cognitivo de la atención y funciones cognitivas en niños y adolescentes, realizamos una revisión que puede verse en el capítulo IV. En tal revisión se analizaron los diversos entrenamientos en términos de neuroplasticidad y transferencia, así como el diseño de los estudios (artículo 1: Rossignoli-Palomeque, T., Perez-Hernandez, E., y González Marqués, J. (2018). Brain training in children and adolescents: Is it scientifically valid? *Frontiers in Psychology*, 9, 565. doi:<https://doi.org/10.3389/fpsyg.2018.00565>). Analizando 70 trabajos, observamos que sólo 10 estudios (14.2%) proporcionaron resultados positivos en términos de neuroplasticidad, y, la mayoría de los desarrolladores de productos de *brain training* dicen basarse en este concepto sin aportar datos científicos que lo sustenten. 36 estudios (51.4%) mostraron *far transfer* (transferencia lejana) (7 de ellos no son estudios independientes), pero, en tan sólo 11 (15.7%) se mantienen los resultados en el seguimiento. Respecto a la metodología empleada en sus diseños, 40 estudios (68.2%) no fueron controlados ni aleatorizados; entre los estudios aleatorizados (27), tan sólo 9 (12.9%) fueron doble-ciego, y, tan sólo 13 (18.6%) incluyeron un grupo placebo en el diseño. Esta información fue utilizada para el diseño del estudio realizado sobre “Nexxo” (véanse los siguientes apartados).

4.1.1. Primera publicación: Brain Training in children and adolescents: Is it scientifically valid?



Brain Training in Children and Adolescents: Is It Scientifically Valid?

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Background: Brain training products are becoming increasingly popular for children and adolescents. Despite the marketing aimed at their use in the general population, these products may provide more benefits for specific neurologically impaired populations. A review of Brain Training (BT) products analyzing their efficacy while considering the methodological limitations of supporting research is required for practical applications.

Method: searches were made of the PubMed database (until March 2017) for studies including: (1) empirical data on the use of brain training for children or adolescents and any effects on near transfer (NT) and/or far transfer (FT) and/or neuroplasticity, (2) use of brain training for cognitive training purposes, (3) commercially available training applications, (4) computer-based programs for children developed since the 1990s, and (5) relevant printed and peer-reviewed material.

Results: Database searches yielded a total of 16,402 references, of which 70 met the inclusion criteria for the review. We classified programs in terms of neuroplasticity, near and far transfer, and long-term effects and their applied methodology. Regarding efficacy, only 10 studies (14.2%) have been found that support neuroplasticity, and the majority of brain training platforms claimed to be based on such concepts without providing any supporting scientific data. Thirty-six studies (51.4%) have shown far transfer (7 of them are non-independent) and only 11 (15.7%) maintained far transfer at follow-up. Considering the methodology, 40 studies (68.2%) were not randomized and controlled; for those randomized, only 9 studies (12.9%) were double-blind, and only 13 studies (18.6%) included active controls in their trials.

Conclusion: Overall, few independent studies have found far transfer and long-term effects. The majority of independent results found only near transfer. There is a lack of double-blind randomized trials which include an active control group as well as a passive control to properly control for contaminant variables. Based on our results, Brain Training Programs as commercially available products are not as effective as first expected or as they promise in their advertisements.

Keywords: cognitive training, brain training, computer-based intervention, children, adolescents

INTRODUCTION

The use of new technologies is increasingly accepted in society, not only in educational settings and the general population, but also in the clinical field. More specifically, some “brain training” (BT) platforms, BT applications and BT video game-like products are becoming very popular. A rigorous evaluation of such applications is merited because most commercially available BT products have not been tested (Rabiner et al., 2010) despite being widely used. Traditionally, BT programs have been used mainly for relaxation therapy, as a tool to encourage self-control in children, or to restore abilities following brain damage. Furthermore, it specifically seems to have a special relevance for developmental psychopathology, being widely used, in disorders such as Attention deficit hyperactivity disorder (ADHD) (Rabipour and Raz, 2012), and in the elderly with cognitive decline (Papp et al., 2009). Despite this tradition, since Nintendo launched the BT game “How old is your brain?” in 2006, there has been increased interest in the general population in commercially available BT programs to improve, for instance, intelligence. Currently, BT is used both by the general population with typical development as well as in populations with neuropsychological impairment (Rabipour and Raz, 2012). In other words, “as we live in an increasingly technological society, the cognitive stimulation of healthy people requires more and more computerized resources” (Portellano, 2014, p. 136). Nevertheless, although BT is increasingly being marketed and aimed at the general population, it has a special use in neurologically impaired children and the elderly.

For this review, we must distinguish between different domains of BT or what researchers refer to as computer-based interventions of “cognitive training” (CT). We must consider that the Eastern and European concepts differ; for instance, considering Tang and Posner (2009), we can classify attentional training (an example of CT) into two methods: the methods of the Asian tradition (for example mindfulness) and, the methods of the American or European tradition (such as BT programs). In the case of the first group, what is sought is to train a state of attention and self-regulation; while in the second, the aim is to alter specific brain processes related to cognitive tasks. In the case of American and European traditional methods, CT is based on the use of a repetition of exercises like those employed in cognitive psychology laboratories. This concept could be an extension of what we refer to as BT.

What is understood by “brain training?” BT is a program or activity which purports to improve a cognitive ability or general capacity by repeating certain cognitive tasks over a period of time. This is supposed to produce some changes in behavior, as well as at a neuroanatomical and functional level (Rabipour and Raz, 2012). Although this term is used mostly by companies rather than researchers (researchers commonly use “cognitive training”), BT refers to practicing core cognitive abilities with the goal of improving performance in other cognitive tasks (Simons et al., 2016). This model applies to computer-based programs as well as video game training or BT applications for touchscreens. Authors such as Nouchi et al. (2012) have researched the transfer effect of “video game training,” an issue

commonly discussed in BT research, or McNab et al. (2015) who studied human cognition while using a touchscreen BT game-like application. For the present review, we have considered BT products supported by online or computer-based platforms, videogame-like products or applications for touchscreens.

To provide a better understanding of most BT research and BT efficacy, we refer to two concepts upon which most programs claim to be based: transfer and neuroplasticity. Neuroplasticity is supposed to alter neural connections and be reflected in the performance of cognitive skills or behavior, which is known as transfer or the transfer effect. Most researchers explain transfer effects due to neuroplasticity, but provide little data to support this idea. Here we are going to clarify both concepts.

Transfer

Under this concept, authors such as Karbach and Unger (2014) distinguish between “near transfer” and “far transfer.” In the present review, we follow this distinction. The main goal of BT or CT should be not only to produce benefits in tasks similar to those directly trained or for the same construct, namely, near transfer (NT), but rather to benefit performance in other tasks that are different to those directly trained or for another construct: far transfer (FT). FT can have an impact on the user’s daily life, and is understood as the “ecological” outcome of BT interventions.

Cognitive training interventions have shown FT even in relevant skills such as general intelligence (Raz and Buhle, 2006). In this line, Tang and Posner’s (2009) study with adults seems to demonstrate that CT programs which target executive control or WM can benefit a wider variety of cognitive functions. In particular, in CT aimed at attention and WM, it seems that benefits could extend to fluid intelligence (Mackey et al., 2011). Klingberg (2010) explained this transfer as a result of the confluence of the prefrontal neural networks that support WM and fluid intelligence. Westerberg and Klingberg (2007) showed that practice in WM tasks gradually improved performance in WM tasks, and that the effect of practice also caused a general improvement in performance in a non-trained task such as a reasoning task. After training, WM-related brain activity was significantly increased in the middle and inferior frontal gyrus. According to this researcher, the changes could best be described by small increases in the extent of the activated cortex rather than activating additional areas. As we have seen, it is very common to justify transfer as a consequence of neuroplasticity. Strenziok et al. (2014) demonstrated FT of three cognitive training programs with healthy elderly people: (1) Brain Fitness (BF-auditory perception), (2) Space Fortress (SF-WM), (3) The Rise of Nations (RON-strategic reasoning). They found transfer of these trainings to other untrained areas (the first two), such as problem resolution of daily life and reasoning. The authors attributed their results to neuroplasticity, in that training produced changes in the integrity of gray matter in occipital-temporal areas (associated with improvement in problem solving of daily life), as well as in the ventral network. They hypothesized that this training produced changes in the attentional networks, leading to improvement in other processes. Some other studies in the adult population have tried to demonstrate the transfer effects of cognitive training through online platforms. Hardy et al. (2015)

in a randomized controlled trial with a considerable sample ($N = 4,715$ fully evaluable participants) divided into two groups: CT group (general cognitive training through 49 games of the Luminosity online platform) and active control group (they completed crosswords puzzles) showed transfer effects. After training conducted at home (15 min per day over 5 days per week for 10 weeks), the cognitive training group showed greater improvements than controls in speed of processing, short-term memory, WM, problem solving, and fluid reasoning assessments, and greater improvements in self-reported measures of cognitive functioning, particularly in concentration compared to the control group, which could be considered as an ecological benefit of training. Nevertheless, the results of Hardy et al.'s study must be considered carefully because instruments of cognitive assessments, while based on other known tests, are part of the Luminosity framework.

Studies on typically-developing children also support the idea of near and far transfer of CT. Karbach and Kray (2009) aim to dilute the effectiveness of training cognitive flexibility through shifting tasks and its transfer to another untrained area. For this purpose, they conducted a trial using children (aged 7 to 9) and elderly people. The results showed that with only four training sessions of shifting (flexibility) tasks, positive results in the two types of transfer, NT and FT, were found in the trained group in inhibition, verbal, and visual WM and reasoning. In 9-year-old, typically developed children, Jaeggi et al. (2008) suggested that the transfer of the training program (WM training over fluid intelligence) depends on the gains obtained in the training: those that improved their performance notably in the trained task (an n-back, WM task - giving a response to a given sequence in a go/no go task) obtained better scores on intelligence tests [Test of Nonverbal Intelligence (TONI) and Raven's Standard Progressive and Matrices (SPM)], which suggests that good performance in CT leads to FT. In adolescents, Zinke et al. (2012), conducted a randomized controlled study with children aged 10–14 years, comparing the effectiveness of CT (task switching based on that used by Karbach and Kray, 2009), with the addition of physical exercise. In addition to evaluating transfer in similar tasks, they observed transfer to other untrained areas (inhibition, WM, and processing speed), concluding that both groups throughout the sessions significantly reduced the cost of change (time it takes them to shift set), as well as the number of errors (NT). They also improved WM and processing speed (FT).

In children with special educational needs, another study has found FT and long-term effects in children with brain damage. Galbiati et al. (2009) conducted a controlled trial of 6–18-year-old patients with severe brain damage which produced attentional deficits. The experimental group received BT stimulation in laboratory conditions consisting of 45-min sessions, 4 times per week for 6 months using three BT programs targeting attention ("Tabletop," "Rehacom," and "Attenzione e Concentrazione"). The results demonstrated significant differences in the trained group compared to controls in sustained attention and selective attention (they maintained attention longer and produced fewer omissions). In parental reports, those who were trained showed improvement in communication, daily life skills, and social skills; and those results were maintained at follow-up (12 months

after intervention). In children with a low socioeconomic level (aged 7–8 years old), a combination of commercially available cognitive games and BT video game-like products (e.g., Rush hour, Professor Brainium's Games among others) have shown benefits in reasoning and processing speed (Mackey et al., 2011). In children with ADHD, many CT studies have been conducted, some of which seem to be effective in terms of NT and others in terms of FT. Kray et al. (2012), in a randomized trial, demonstrate that a relatively short cognitive training intervention (four training sessions in task shifting) on children aged 7–12 years with ADHD (medicated with methylphenidate), improved processes of inhibition and WM (components of executive function), but not fluid intelligence. Here we see lack of FT. In contrast, a randomized controlled trial (with children aged 6–18 years with ADHD) concluded that neurofeedback (NF), a type of CT, could be as effective as methylphenidate for treating the attentional and hyperactivity symptoms of ADHD, based on parental reports (Duric et al., 2012). According to Karbach and Unger (2014), the research on CT and ADHD seems to indicate that this training can compensate for deficits in executive functions (EF) and therefore improve school skills. Although this result has not been observed in all studies, this does not mean that the positive results are not encouraging. NF can be effective in relation to the improvement of EF, a key aspect of school performance (Illes and Sahakian, 2011).

Neuroplasticity

Most BT programs claim to be based on brain neuroplasticity: the capacity that neurons have to modify their synaptic structures and form new neural connections (Pressler et al., 2011). There are studies that connect the practice of a certain activity to an increase in gray matter volume in the areas related to this activity. In a study in which adult participants learned to juggle, Driemeyer et al. (2008) concluded that changes in the gray matter can occur even after 1 week of training in a task; similar results were found by Scholz et al. (2009). Focusing on our area, to study neuroplasticity due to CT, researchers have focused especially on gray matter and neural activity changes. Some researchers, and especially BT developers, often relate changes in cognitive skills to neuroplasticity. Rabipour and Raz (2012) claim that due to brain plasticity, BT can alter attentional networks in the brain, and thus improve certain skills. In our view, to properly justify an association between cognitive skill improvements after training and neuroplasticity, neuroimaging techniques should be included in the trials.

In adults, studies focused on working memory (WM) training, such as Takeuchi et al. (2011) using a randomized controlled trial with young adults, demonstrated that a BT intervention, intensive adaptive training of WM using mental calculations (IATWMMC) was associated with a decrease in regional gray matter volume in the bilateral frontoparietal regions and the left superior temporal gyrus (neuroplasticity), and also with cognitive performance improving verbal letter span and complex arithmetic ability (transfer effect). Another study also found gray matter differences after undertaking WM training: in their pseudorandomized controlled trial, Caeyenberghs et al. (2016) studied a typical sample aged between 19 and 40 years, divided

into two groups. The adaptive group trained WM at home using a Cogmed program (a computer-based program which aimed at WM and adjusted to user level, for 8 weeks with 45 min in each session, 40 sessions in total) vs. a non-adaptive group (training not adjusted to user level). Before and after training, cognitive assessment was applied, as well as white matter imaging techniques [diffusion tensor imaging (DTI)]. The results showed improvement in the adaptive group, not only in cognitive measures such as WM span, reasoning, and inhibition, but also changes in global integration based on white matter connectivity within a frontoparietal attention network. Another study with a similar design, related adaptive cognitive training to some changes in thickness of cortical structures (Metzler-Baddeley et al., 2016). In their pseudo-randomized study, an adult sample was divided into two groups: an active control group (who received training with no user-level adjustment) vs. adaptive training (for whom training was adapted to user-level performance); both groups trained using the Cogmed program. After training, neural changes were observed as increases in cortical thickness in some brain areas (right-lateralized executive regions) as well as reductions in others (such as the left pallidum). They related these changes in the brain to cognitive performance in near transfer assessment. These results support the idea of neuroplasticity due to a BT intervention. Apart from gray matter differences reflecting neuroplasticity due to CT, brain activity has been studied with the same purpose by means of the fMRI technique. Westerberg and Klingberg (2007) conducted a trial with three young healthy adults. Brain activity was measured on two separate days with fMRI: before practice and one day after practice of a WM task (Cogmed program). fMRI was also conducted during WM task performance. After training, WM-related brain activity was significantly increased in the middle and inferior frontal gyrus. Whereas this study provides data to support neuroplasticity, it lacks transfer evidence to other cognitive skills. With the same technique, fMRI, Clemens et al. (2013), through a randomized, controlled study of young adults and showed that some brain areas were commonly activated for alertness and focus attention training (participants trained attention through Cogniplus: four sessions of alertness or four sessions of focus attention training). Moreover, BT and assessment activated common neural areas described in the literature. These data support neuroplasticity, but there is no evidence of any transfer effect to other cognitions or behavior.

Having established a connection between neuroplasticity and BT in adults, we must question whether a similar result may also be found in children and adolescents, whose brain functioning differs due to developmental factors. In the following results section, we will mention certain studies that have proven neuroplasticity through brain activation changes in the following areas: dyslexia in which BT produces changes in language skills as well as changes in brain activation (observed by fMRI) in areas that are normally activated during performance of linguistic tasks, as well as in compensatory areas (Temple et al., 2003); cancer survivors, BT has also shown reduction in the activation of areas related to WM and attention apart from improvements in cognitive skills (Conklin et al., 2015) and increased brain activation in some areas of the prefrontal cortex

(Kesler et al., 2011a); using the same technique with ADHD children-teenagers, Stevens et al. (2016) found that, apart from effects on behavior, responsiveness of WM frontoparietal circuits and executive process-specific WM brain regions were altered by training. In Turner syndrome patients, apart from cognitive improvements, it seems that after treatment (Luminosity), bilateral parietal lobe activation increased and frontal-striatal and medial temporal activation decreased in the math task (Kesler et al., 2011b). Using MEG with typically-developing children, Barnes et al. (2016) showed how WM training (Cogmed) impacts networks in the brain related to this function (inferior temporal and frontoparietal cortex). The magnitude of task-related patterns of brain activity was significantly associated with previous findings observed in resting-state activity (Astle et al., 2015). Studies using EEG techniques, such as Johnstone et al. (2017) with children with ADHD, showed how neurofeedback (NF), a type of CT, can produce brain activity changes, indicating normalization of atypical EEG features with reduced delta and increased alpha activity after training. In adolescents with multiple sclerosis, Hubacher et al. (2015) found that performance gains after cognitive training (attention and WM training through the BrainStim program) were accompanied by increased activity in the WM network and changes in inter-network connectivity (fMRI). Taking this into account, we must ask ourselves what types of BT engender neuroplasticity and whether neuroplasticity produces some observational effects in cognition and behavior.

BT Current Limitations

Despite this background, other researchers highlight the lack of evidence of FT in many BT products (Cortese et al., 2015). Despite the increasing popularity of these training tools, Karbach and Unger (2014) claim that their results are neither robust nor consistent, and the transferability of training-induced performance improvements to untrained tasks seems limited. It must be considered that if learning is specific to the trained ability, as is often the case with BT programs, there is little generalization in relation to related tasks in new environments, limiting the practical impact of such learning. It may be the case that other activities, such as video games, music, and athletic training, show a more reasonable generalized effect (Green and Bavelier, 2008). What is essential for BT products is to establish clear cognitive targets that may have an impact on the user's daily live. Therefore, for many BT programs, FT is more difficult to prove than NT (Simons et al., 2016), not only in clinical populations, but also in a healthy or typically-developing populations. Supporting this concept, a large randomized controlled online study with 11,430 participants aged 18–69 years using a BT program (a BT tool designed by BBC Lab UK to improve reasoning, memory, planning, visuospatial skills, and attention) did not show any transfer effect in untrained tasks, even if they were parallel to the trained ones (Owen et al., 2010). These limitations are commonly found in research both with adults and with children. An example of these limitations may be seen in the study by Roberts et al. (2016). These authors studied the impact of WM training (Cogmed program) on WM skills and academic outcomes (reading, math, and spelling scores as

primary outcomes) in children aged 6–7 years with low WM. WM training had an impact on the 4 short-term and WM outcomes, but had no impact on academic outcome (FT), which means that only NT was found and that some of these training effect did not maintain benefits over time. Another study with children with low WM scores (Ang et al., 2015) showed that training, whether updating training or Cogmed training, did not have FT on math, and NT it was not lasting in the long term. Another limitation of computer-based interventions is that in the short term they often produce improvements in the trained processes (NT), however, there are difficulties in interpreting data because of study design limitations (e.g., lack of a control group), which restricts the possible interpretations of the results, and they usually do not show improvement maintenance beyond 6 months (Rabipour and Raz, 2012). In a review of 10 randomized controlled trials with older people, the authors concluded that apart from a limited transfer effect, there is a lack of sufficiently follow-up periods to validate long-term effects and a lack of active control groups in the research designs (Papp et al., 2009). Another common limitation seems to be sustainable effects. For these reasons, an updated review of BT research in children and adolescents is required, as well as a proper classification of available programs considering their scientific background for practical reasons. The objective of this paper is to classify BT products available for children and teenagers according to research found using BT as an independent variable and analyzing its effects in terms of neuroplasticity, NT, FT, and long-term effects.

METHOD

Inclusion Criteria

Studies from psychological sciences and neuroscience were reviewed and then included or rejected based on their relevance. First, a study was considered relevant for our research if it was based on empirical data from the use of a BT program (as an independent variable not combined with other BT products) with children or adolescents (4–17.9 years old) and its effects on NT and FT and/or neuroplasticity. Feasibility, compliance, acceptability, or factors to better benefit BT studies were not included. Second, the use of BT had to be for cognitive training purposes (motor skill training or emotional competence training were excluded). Third, the training described in the article must be commercially available. Fourth, this paper takes into consideration computer-based programs for children developed since the 1990s. Finally, the selection was limited to include only printed and peer-reviewed material, such as articles in journals, edited books, and research reports.

Search Terms and Databases

Searches were conducted from June 2015 until March 2017 with the filters: English, Humans, in the following electronic database: PubMed. Heading searches for the following areas were combined:

Search 1: 7648 results

- (1) Cognitive training

- (2) (or) Brain training

- (3) (and) Children

Search 2: 6,105 results

- (1) Cognitive training

- (2) (and) Working memory training

- (3) (or) Attention training

- (4) (and) Children

Search 3: 2,589 results

- (1) Cognitive training

- (2) (and) Language

- (3) (or) reasoning

- (4) (and) children

Search 4: 60 results

- (1) Neuroplasticity

- (2) (and) cognitive training

- (3) (and) children.

Searches on CT products websites were also conducted to screen commercially available products as well as to screen any other published research (available in Pubmed but not found in our database searches). Following the inclusion criteria, 70 articles were included in the results.

The selection flow diagram is shown in **Figure 1**.

Method of Analysis

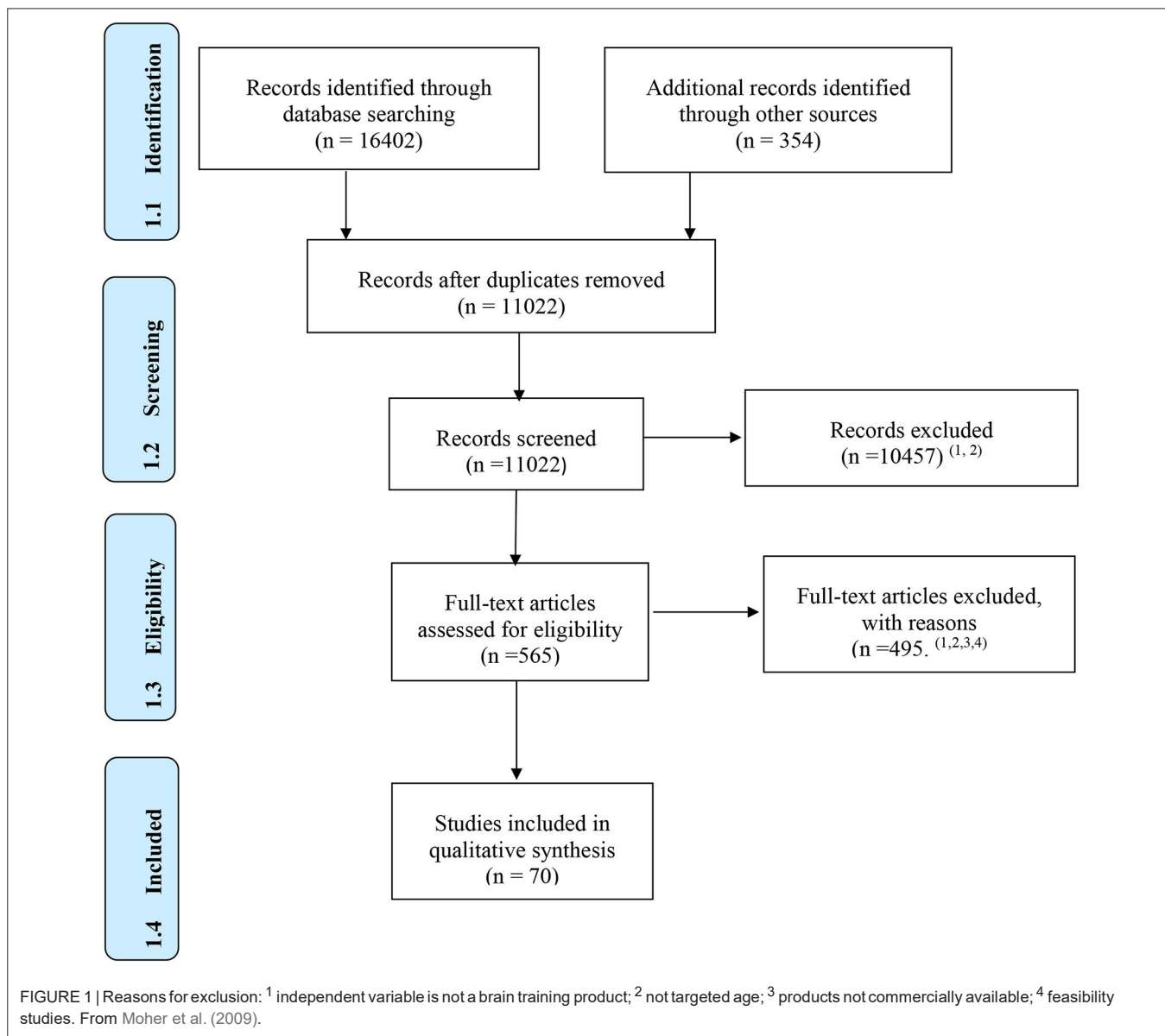
Qualitative analysis was performed in this review. We established the following parameters to properly classify programs: Neuroplasticity, NT and FT, long-term effects, and study design.

In a first step, the different articles were read in order to determine whether they contained relevant information and whether they fulfilled the inclusion criteria. In a second step, for each selected article, the following information was extracted and entered into a table: study design, population and results (see **Tables 1, 2**). The information provided by the different studies was compared in order to explore program efficacy (see **Table 3**) and gaps or the future direction of BT research was included in the discussion section.

RESULTS

After searching for results, we selected 70 articles which met with inclusion criteria. Then, we classified different commercially available BT programs for children according to their scientific background. **Tables 1, 2** summarizes the main research of programs selected for this article.

We have classified BT programs as follows: (1) products supported by neuroscience research: computer-based programs in which neuroimaging techniques, such as fMRI, MEG, EEG etc., have been applied to prove program impact in terms of neuroplasticity; (2) Products derived from experimental and quasi-experimental trials: computer-based programs in which psychometric tests have been applied to test program impact. Finally, to further clarify the scientific validity of the programs, we have taken into



account Mahncke and Merzenich's (2015) considerations about how to evaluate a BT program. This consideration includes questions related to program efficacy, study design, and long-term effects. Based on these criteria, **Table 3** summarizes the scientific validity of the programs mentioned in the present paper.

Products Supported by Neuroscience Research

In this section, we included computer-based programs aimed at research which use neuroimaging techniques such as fMRI, MEG, EEG, DNA analysis etc., to prove program impact under neuroplasticity parameters.

Table 1 shows a summary of characteristics of each research based on the aforementioned programs.

Fast ForWord® (FFW)

This program is supported by independent research based on neuroimaging techniques for dyslexia (Temple et al., 2003). These authors have shown that people with dyslexia show dysfunction in phonological processing. FFW was applied to children with dyslexia (divided into an experimental and control group); after an average of 27.9 training days (100 min in 5 sessions per week), participants showed improvements in reading and oral language, pseudo-word decoding and comprehension, as well as changes in brain activation (observed by fMRI) in areas that are normally activated during performance of phonological tasks as well as in compensatory areas (left temporoparietal regions, left frontal inferior rotation, right hemisphere temporal and frontal regions, and the anterior cingulate gyrus). This suggests that this program alleviates dysfunctions associated with phonological processing, as well as producing compensatory activation in other areas.

TABLE 1 | Products supported by neuroscience research.

Product name	Year release	Studies on children	Population	Design	Neuroimaging technique	Result	More information
The Fast for Words	1993	Temple et al., 2003	Children with dyslexia. <i>N</i> = 20 aged 8–12 years old	Randomized Controlled trial (experimental vs. passive control) Non-independent	fMRI	Neuroplasticity Near and far Transfer	www.scilearn.com/results/research-independent-reviews
Teach-The-Brain	1999	Rueda et al., 2005	Typical developed children. <i>N</i> = 73 aged 4–6 years old	Randomized controlled trial (experimental vs. passive control) Follow up (2 weeks after final session)	EEG	Neuroplasticity Far transfer	www.teach-the-brain.org/learn/attention/index.htm
Cogmed	2001	Söderqvist et al., 2012	Typical developed children. <i>N</i> = 96 aged 4.0–4.5 years old	Pseudorandomized controlled Non-independent	DNA genotypes	Neuroplasticity Near transfer	www.cogmed.com/published-research
		Astle et al., 2015	Typical developed children. <i>N</i> = 33 aged 8–11 years old	Randomized controlled trial (adaptive vs. non-adaptive training group)	MEG	Neuroplasticity Near transfer	
		Conklin et al., 2015	Children survivors of cancer <i>N</i> = 68 aged 8–16 years old	Randomized single-blind controlled Follow up (6 months)	fMRI	Neuroplasticity Near and far transfer	
		Barnes et al., 2016	Typical developed children. <i>N</i> = 33 aged 8–11 years old	Double-blind randomized controlled trial (adaptive vs. non-adaptive training group)	MEG	Neuroplasticity	
		Stevens et al., 2016	Children with ADHD <i>N</i> = 18 ADHD 18 non- ADHD controls aged 12–18 years old	Controlled trial	fMRI	Neuroplasticity Near and far transfer	
WinABC	2003	Penolazzi et al., 2010	Children with dyslexia <i>N</i> = 11	Interventional study	EEG	Neuroplasticity Near transfer	http://www.impararegiocando.it/WinABC50.htm
Luminosity	2007	Kesler et al., 2011a	Cancer survivors <i>N</i> = 23 aged 7–19 years old	A one-arm open trial pilot study	fMRI	Neuroplasticity Near transfer	www.luminosity.com/hcp/research/completed
		Kesler et al., 2011b	Turner Syndrome. <i>N</i> = 16 aged 7–14 years old	Case series study	fMRI	Neuroplasticity Near transfer	
Focus Pocus	2007	Johnstone et al., 2017	Children with ADHD <i>N</i> = 85 aged 7–12 years old	Randomized controlled trial Non-independent	EEG	Neuroplasticity Near and far transfer	www.focuspocushelp.weebly.com/focus-pocus.html

TABLE 2 | Products derived from experimental and quasi-experimental trials.

Product name	Year release	Studies on children	Population	Design	Result: type of transfer	More information
Brain train (Captain's log)	1989	Rabiner et al., 2010	Children with attention difficulties. N = 77 first grade students	Randomized controlled trial Follow up (6 months after intervention)	Near and far transfer	www.braintrain.com/cognitive-training-research/
		Steiner et al., 2011	Children with ADHD. N = 41 middle school	Randomized controlled trial Follow up (6 months after intervention)	Far transfer	
		La Marca and O'Connor, 2016	Children with ADHD N = 5 aged 9–10 years old	Multiple-baseline-across-participants single-case model Follow up (5 months after intervention)	Near transfer	
Cogmed	2001	Klingberg et al., 2002	Children with ADHD N = 14 aged 7–15 years old	Double-blind controlled (adaptive vs. non-adaptive training group). Non-independent	Near and far transfer	www.cogmed.com/published-research
		Klingberg et al., 2005	Children with ADHD N = 53 aged 7–12 years old	Randomized controlled trial Non-independent	Far transfer	
		Thorell et al., 2009	Typical developed children N = 65 aged 4–5 years old	Randomized controlled Non-independent	Near and far transfer	
		Holmes et al., 2009	Children low WM N = 37 aged 9–10 years old	Controlled (adaptive vs. non-adaptive training group) Follow up (6 months)	Near and far transfer	
		Holmes et al., 2010	Children with ADHD N = 25 aged 8–15 years old	Comparative study (not controlled not randomized) Follow up (6 months)	Far transfer Long-term effects	
		Beck et al., 2010	Children with ADHD N = 52 aged 7–17 years old	Controlled Follow up (4 months)	Far transfer Long-term effects	
		Mezzacappa and Buckner, 2010	Children low SES N = 9 Aged 8–10.5 years old	Pilot study single-group design with pre–post comparisons	Near and far transfer	
		Gibson et al., 2011	Adolescents with ADHD N = 47 aged 11–16 years old	Randomized controlled	Near transfer	
		Roughan and Hadwin, 2011	Children with behavioral difficulties N = 17 aged 11–13 years old	Randomized controlled Follow up (3 months)	Near transfer Long-term effects	
		Kronenberger et al., 2011	Children with cochlear implant N = 9 aged 7–15 years old	Pilot study. 2 periods: wait and training Follow up (6 months)	Far transfer Long-term effects	
		Løhaugen et al., 2011	Children preterm N = 46 aged 14–15 years old	Controlled trial	Near transfer Long-term effects	
		Bergman-Nutley et al., 2011	Typical developed children N = 101 aged 4 years old	Double-blind, randomized, controlled Non-independent	Near transfer	

(Continued)

TABLE 2 | Continued

Product name	Year release	Studies on children	Population	Design	Result: type of transfer	More information
		Dahlin, 2011	Children with special needs N = 57 aged 9–12 years old	Controlled trial Follow up (7 months)	Far transfer Long-term effects	
		Green et al., 2012	Children with ADHD N = 26 aged 7–14 years old	Double-blind randomized controlled (adaptive vs. non-adaptive training)	Near and far transfer	
		Soderqvist et al., 2012	Children with low IQ N = 41 aged 6–12 years old	Pseudorandomized Follow up (1 year) Non-independent	Slightly far transfer on girls	
		Gibson et al., 2012	Typical developed children N = 31 aged 9–16 years old	Randomized controlled trial	Near transfer	
		Soderqvist et al., 2012	Children with low IQ N = 41 aged 6–12 Years old	Pseudorandomized and controlled (adaptive vs. non-adaptive training group) Follow up (1 year after training) Non-independent	Slightly far transfer on girls	
		Egeland et al., 2013	Children with ADHD N = 67 aged 10–12 years old	Randomized controlled trial Follow up (8 months after intervention)	Near and far transfer Long-term effects	
		Hovik et al., 2013	Children with ADHD N = 67 aged 10–12 years old	Randomized controlled trial Follow up (8 months after intervention)	Near transfer Long-term effects	
		Dahlin, 2013	Children with attention difficulties. N = 57 aged 9–12 years old	Controlled trial Follow up (approximately 7 months after intervention)	Near and far transfer Long-term effects	
		Dunning et al., 2013	Children with low WM N = 47 aged 7–9 years old	Double-blind randomized controlled trial Follow up (6 and 12 months after intervention)	Near transfer Long-term effects	
		Hardy et al., 2013	Children survivors of cancer N = 20 aged 8–16 years old	Pilot study randomized Follow up (3 months)	Near and far transfer	
		Bennett et al., 2013	Children with down syndrome N = 21 aged 7–12 years old	Randomized controlled Follow up (4 months)	Near transfer Long-term effects	
		Grunewaldt et al., 2013	Children preterm N = 20 aged 5–6 years old	Stepped Wedge randomized trial design	Near and far transfer	
		Holmes and Gathercole, 2014	Children low WM N = 72 aged 8–11	Randomized controlled trial	Near and far transfer	

(Continued)

TABLE 2 | Continued

Product name	Year release	Studies on children	Population	Design	Result: type of transfer	More information
		Foy and Mann, 2014	Children from economically disadvantaged communities. N = 50 aged 4–5 years old	Randomized controlled trial	Near and far transfer	
		Bergman-Nutley and Klingberg, 2014	Typical developed children N = 304 aged 7–15 years old Children with ADHD N = 176 aged 7–15 years old	Controlled trial Non-independent	Far transfer	
		Chacko et al., 2014	Children with ADHD N = 85 aged 7–11 years old	Randomized controlled trial (adaptive vs. non-adaptive training)	Near transfer	
		Dongen-Boomsma et al., 2014	Children with ADHD N = 51 aged 7–12 years old	Triple-blind, randomized, placebo-controlled study (adaptive vs. non-adaptive training)	Near transfer	
		van der Donk et al., 2015	Children with ADHD (Children with comorbid learning disabilities (LDs) and/or oppositional defiant disorder (ODD) were also included. N = 100 aged 8–10 years old	Randomized controlled trial Follow up (6 months after intervention)	Near transfer Long-term effects	
		Holmes et al., 2015	Children with specific language impairment N = 179 aged 8–11 years	Not controlled trial	Near transfer	
		Söderqvist and Nutley, 2015	Typical developed children. N = 42 aged 9–11 years old	Controlled trial Follow up (2 years after intervention) Non-independent	Far transfer Long-term effects	
		Ang et al., 2015	Children with low WM N = 111 aged 7 years old	Controlled trial Follow up (1 year after training)	Near transfer	
		Partanen et al., 2015	Children with special needs n = 64 aged 8–9 years old	Randomized and controlled trial	Near transfer (better results in combination treatment)	
		Kerr and Blackwell, 2015	Children with epilepsy n=77 aged 5–15 years old	Randomized controlled trial	Near transfer	
		Phillips et al., 2016	Children with brain damage N = 23 aged 8–15 years old	Double-blind randomized controlled (adaptive vs. non-adaptive training) Randomized controlled trial Follow up (3 months)	Far transfer Long-term effects	
		Fälth et al., 2016	Typical developed children. N = 32 first grade of primary school	Controlled trial Follow up (7 months after intervention)	Far transfer	

(Continued)

TABLE 2 | Continued

Product name	Year release	Studies on children	Population	Design	Result: type of transfer	More information
		Grunewaldt et al., 2016	Children preterm <i>N</i> = 37 aged 5–6 years old	Pilot study Not controlled Follow up (1 year after training)	Near transfer Long-term effects	
		Eve et al., 2016	Children with brain damage <i>N</i> = 7 aged 10–16 years old	Randomized Follow up (6 months after training)	Near transfer	
		Graziano and Hart, 2016	Children with behavioral problems <i>N</i> = 45 pre-schoolers	Randomized trial Follow up (6 months)	Far transfer (better results in combination treatment)	
		Lee et al., 2016	Children preterm <i>N</i> = 12 preterm <i>N</i> = 10 term-born Aged 4–6 years old	Intervention study	Near transfer	
		Bigorra et al., 2016	Children with ADHD <i>N</i> = 66 aged 7–12 years old	Double-blind randomized controlled (adaptive vs. non-adaptive training) Follow up (6 months)	Near and far transfer Long-term effects	
		Hadwin and Richards, 2016	Adolescent with T-score > 50 on anxiety test <i>N</i> = 40 aged 11–14 years old	Randomized controlled Follow up (4 months)	Near and far transfer Long-term effect	
		Roberts et al., 2016	Children with low WM <i>N</i> = 452 aged 6–7 years old	Randomized controlled Follow up (1 year and 2 years)	Near transfer Long-term effects	
		Fuentes and Kerr, 2017	Children with epilepsy <i>N</i> = 28 aged 6–15 years old	Exploratory analysis Follow up (3 months)	Near transfer Long-term effects	
		Hitchcock and Westwell, 2017	Typical developed children <i>N</i> = 148 aged 12 years old	Cluster-randomized, controlled trial (adaptive vs. non-adaptive training vs. passive control) Follow up (3 months)	Near transfer (to similar task trained not to WM construct)	
		Conklin et al., 2017	Children survivors of cancer <i>N</i> = 68 aged 9–14 years old	Randomized, single-blind controlled Follow up (6 months)	Near and far transfer Long-term effects	
Focus Pocus (Neurocog)	2007	Johnstone et al., 2012	Children with ADHD <i>N</i> = 128	Randomized controlled trial Follow up (6 months after intervention) Non-independent	Far transfer Long-term effects	www.focuspocushelp.weebly.com/focus-pocus.html
Play Attention (recent version)	2010	Steiner et al., 2011	Children with ADHD <i>N</i> = 41 Aged 7–11 years old	Randomized controlled trial Follow up (6 months after intervention)	Far transfer	www.playattention.com
		Steiner et al., 2014	Children with ADHD <i>N</i> = 104 aged 7–11 years old	Randomized controlled trial Follow up (6 months after intervention)	Far transfer Long-term effects	
Braingame Brian	2010	Dovis et al., 2015	Children with ADHD <i>N</i> = 89 aged 8–12 years old	Double-blind Randomized Placebo controlled trial Follow up (3 months after intervention)	Near transfer	http://www.gamingandtraining.nl/beschrijving-braingame-brian/

(Continued)

TABLE 2 | Continued

Product name	Year release	Studies on children	Population	Design	Result: type of transfer	More information
ACTIVATE™	2011	Bikic et al., 2015	Children with ADHD N = 122 aged 6–13 years old	Randomized controlled trial Follow up (3 and 6 months after intervention)	Near transfer	http://www.c8home.com/
SIGUEME	2013	Vélez-Coto et al., 2017	Children with autism disorder N = 74 aged 3–16 years old	Controlled trial	Near transfer	http://www.proyectosigueme.com/
Tali Program	2017	Kirk et al., 2017	Children with intellectual and developmental disability N = 76 aged 4–11 years old	Randomized double-blind placebo controlled trial Follow up 3 (3 months after intervention). Non-independent	Improvements at 3 months but not significant	https://www.monash.edu/medicine/research/what-is-the-tali-attention-training-program

TABLE 3 | Scientific validity of Brain training programs for children based on Mahncke and Merzenich (2015).

	Has the product demonstrated transfer of training to other laboratory tasks that measure the same cognitive construct as the training task?	Has the product demonstrated transfer of training to relevant real-world tasks?	Has the product performance been evaluated using an active control group whose members have the same expectations of cognitive benefits as do members of the experimental group?	How long are the trained skills retained?	Have the purported benefits of the training product been replicated by research groups other than those selling the product?
Brain Train	Yes	Yes		6 months	Yes
The Fast for Words	Yes	Yes			
Teach-The-Brain	Yes	Yes		2 weeks follow up	yes
Cogmed	Yes	Yes	Yes, considering non-adaptive training as active control	2 years (follow up available 7–24 months)	Partially, it counts with non-independent research
WinABC	Yes				Yes
Luminosity	Yes	Yes			Yes
Focus Pocus	Yes	Yes		6 months	
Play Attention		Yes		6 months	
BrainGame Brian	Yes		Yes		Yes
ACTIVATE	Yes				Yes
Sigueme	Yes		Yes		Yes
Tali program	No				No

Teach-the-Brain

This program is based on independent research in neuroimaging techniques that measure brain activity through EEG (Rueda et al., 2005). It shows that 4–6-year-olds can improve EF and even intelligence quotient (IQ) after only 5 days of BT (with the aim of training the three attentional networks proposed by Posner and Petersen, 1990). They evaluate this evolution with EEG and psychologically-validated tests (Child ANT, Kaufman's brief intelligence test) and parent questionnaires, and conclude that, despite the genetic load on attention and executive functions, training produces improvements in these skills.

Cogmed

This program implements research based on neuroimaging techniques which measure brain activity in adults through fMRI (Westerberg and Klingberg, 2007), EEG (Liu et al., 2016), and DTI (Caeyenberghs et al., 2016). Specifically, for children, there are research studies that use neuroimaging techniques such as MEG (Astle et al., 2015; Barnes et al., 2016), fMRI (Conklin et al., 2015; Stevens et al., 2016), and DNA genotype (Söderqvist et al., 2012).

Astle et al. (2015) wanted to figure out whether WM training had an impact on brain connectivity at rest in those

areas typically associated with WM and controlled attention as well as in cognitive tests. Typically developed children, aged 8–11 years, completed 20 sessions of computerized WM training at home. Before and after the training, all of the children underwent a 9-min resting state (MEG) scan and completed standardized assessments of short-term and WM. The results showed that the adaptive group (in which the training was adapted to user execution) demonstrated significant improvements in standardized scores in the untrained short-term and WM assessments. Adaptive training enhanced resting functional connectivity: significant enhancement of connectivity was found in the bilateral frontoparietal network, superior parietal cortex, and a portion of inferior temporal cortex. Moreover, connectivity changes associated with training were greatest in those who displayed the greatest improvement in WM capacity.

Using MEG, Barnes et al. (2016), showed how this CT program impacted networks in the brain related to WM, specifically on frontoparietal and temporal brain structures. In this study on typically developed children, WM training involved at least 20 training sessions (35 min) for 4–6 weeks at home. WM task-related MEG data were collected before and after the training intervention. After the intervention, researchers identified “significantly increased cross-frequency phase amplitude coupling in children who completed training, specifically between the upper alpha rhythm (at 16 Hz), recorded in superior frontal and parietal cortex with high gamma activity (at ~90 Hz) in inferior temporal cortex” (Barnes et al., 2016 p. 1). Thus, it seems that BT can modulate brain waves. The authors associated this altered neural network activity with cognitive skill enhancement. Furthermore, the magnitude of task-related coupling found in this study (as a pattern of brain activity) is significantly associated with previous findings observed in resting-state activity (Astle et al., 2015). In addition, the results showed that changes in frontoparietal to inferior temporal phase amplitude coupling were significantly predictive of children’s improved performance in the WM task; in this case, there is evidence of a relationship between neuroplasticity and cognitive performance.

Through the fMRI technique, Stevens et al. (2016) conducted controlled trials comparing 18 children with ADHD to 18 control subjects aged 12–18 years. After training (standard Cogmed protocol: 5 weeks and 25 sessions with 30–40 min per session), the trained group showed some NT and FT (less ADHD clinical symptoms reported by parents). The responsiveness of both WM frontoparietal circuits and executive process-specific WM brain regions was altered by WM training. Within the same neuroimaging technique, Conklin et al. (2015), in a randomized controlled trial on children survivors of cancer, proved that Cogmed training affects cognition and brain activity (5–9 weeks with 25 sessions of 30–40 min at home). After training, NT was found in WM and FT (attention and processing speed) as well as brain activity changes: reduction in activation of left lateral prefrontal and bilateral medial frontal areas related to WM and attention.

Finally, we found a DNA genotype study (Söderqvist et al., 2012) which examined the effects of polymorphisms in five

genes involved in dopaminergic pathways after CT: WM training, Non-verbal reasoning training (NVR) or a combination, in preschoolers through a pseudorandomized controlled trial. They conducted 25 sessions of 15 min per day at home. WM training produced NT, and NVR produced gains in fluid intelligence. With regard to neuroplasticity, the authors found that polymorphisms of the DAT1 gene were associated with training effects: variation in the dopamine transporter gene (DAT1) influenced improvements in WM and fluid intelligence.

WinABC Program

WinABC is a computer-based program developed to improve literacy skills, supported by a study which supports NT and neuroplasticity in children with dyslexia (Penolazzi et al., 2010). In their study, 11 children with dyslexia aged 9–11 years received 6 months of phonological training at home (5 times a week for 10 min per day). Besides NT, the authors found that those children who had the greatest reading speed enhancement showed the largest left posterior EEG beta power increase in phonological task execution after the training sessions. Nevertheless, as this study is an intervention study (not controlled), the result must be considered with caution.

Luminosity

This program is based on research on neuroimaging techniques using fMRI in children with cancer or Turner syndrome (Kesler et al., 2011a,b), as well as EEG studies in adults (Schneider et al., 2013).

This program was found to be effective in training EF with children who have suffered cancer. Kesler et al. (2011a) designed a home cognitive training program (8 weeks of intervention/5 session per week/20 min per session). Not only cognitive assessment at baseline and post intervention were applied, but also fMRI measures were made. Following the cognitive intervention, participants showed a significant increase in processing speed, cognitive flexibility, verbal, and visual declarative memory scores, as well as a significant increase in pre-frontal cortex activation compared to the baseline (inferior, middle, and superior frontal gyrus activation). Nevertheless, in this study there was no correlation between cognitive scores at post-intervention and brain activation in fMRI.

Luminosity seems to be effective for children with Turner syndrome who have low math abilities. Kesler et al. (2011b) assess some mathematical skills and other involved mental processes (processing speed, attention, cognitive flexibility) as well as brain activation before and 1 week after training. The training consists of an adaptive BT program focused on number sense and general problem-solving skills (5 sessions/6 weeks/20 min per session, at home). After training, the participants significantly improved their basic math skills, including number sense and calculation, as well as processing speed, cognitive flexibility, and visual-spatial processing skills. In terms of brain activation, the participants showed significantly increased bilateral parietal lobe activation and decreased frontal-striatal and mesial temporal activation in math tasks. Nevertheless, it must be considered that a controlled randomized study in this field would contribute to contrasting

or supporting this study which lacks a randomized controlled design.

Focus Pocus

Focus Pocus is one of the BT programs based on neurofeedback (NF). NF is a process of learning in which the user is rewarded for positive brain activation modulation (Fox et al., 2005). The training consists in modulating brain waves to achieve a series of goals within a computer game. This program is based on empirical research using EEG records to demonstrate neuroplasticity due to training. Johnstone et al. (2017), in a controlled randomized study, showed how neurofeedback training (at home) can produce brain activity changes, indicating normalization of atypical EEG features with reduced delta and increased alpha activity after training in children with ADHD.

Products Derived From Experimental and Quasi-Experimental Trials

In this section, we include computer-based programs based on research using psychometric testing to evaluate program impact. Some of them have been included in the first section such as Cogmed.

Table 2 shows a summary of characteristics of each research project based on the different programs mentioned above.

BrainTrain

Some randomized controlled studies have also been conducted using BrainTrain products (such as Captain's Log) with ADHD children (Rabiner et al., 2010; Steiner et al., 2011, 2014).

A combination of CT with other techniques could also be of interest for children with ADHD symptoms (Rabiner et al., 2010). Cognitive training ("Captain's Log") and computer intervention that facilitates the understanding of instructions, or "Computer-assisted instruction," entails a decrease in ADHD symptoms in the classroom, especially for those who initially showed more symptoms of inattention, after 28 sessions of 75 min with first grade children. Steiner et al. (2011) showed the effectiveness of two neuroscientific interventions in children with ADHD; a neurofeedback program ("Play attention") and a computerized CT program ("Brain Train/Captain's Log"). After an average of 23.4 sessions in their schools, the parents reported a significantly greater improvement in symptoms associated with this disorder than in the control group. In subsequent studies, the same authors demonstrated that the effects were maintained at a 6-month follow-up (Steiner et al., 2014).

Finally, La Marca and O'Connor (2016) tried to determine whether neurofeedback training ("SmartMind Pro") is effective at improving not only attention and executive functions, but also reading comprehension and fluency in children with ADHD Inattentive Subtype. The participants followed 40 NF sessions in a school environment and three measurements of each were obtained: baseline, post-test, and 5-month follow-up. The results showed that following the intervention, improvements were observed in a continuous performance test and a shifting attention task. The results obtained from reading fluency tests revealed little change, although participants demonstrated gains in reading comprehension. In this case, it would be interesting to

conduct a randomized controlled trial that included attentional measures, in order to support their findings.

Cogmed

A study of typically-developing 4–5-year-old children was conducted by Thorell et al. (2009). The sample was divided into three groups: a group that received training in visuospatial WM (from Cogmed), another group that received inhibition training (through a go/no-go task), and a third, passive control group. After 5 weeks of training (they attended 15-min sessions each day), the children who received WM training improved significantly in non-trained visuospatial WM tasks, as well as in attention tasks (the children who were trained in inhibition did not display significant improvements in untrained tasks). In this case, Cogmed seemed to be effective for typically-developing children aged 4–5 years in terms of NT. In another study with typically developed children of the same age, Bergman-Nutley et al. (2011) demonstrated that Cogmed was effective for training WM in this population. First graders may also receive some benefits from CT (Fälth et al., 2016). In their study, children who received WM training (Cogmed standard protocol) showed significant improvements in a word decoding test compared to the control group. The implication is that there is a WM requirement for initial readers when the decoding process is not yet automatized, and the training was effective in improving this component. In another study with typically-developing children aged 9–11 years (Söderqvist and Nutley, 2015), it seems that WM training can have some FT on math and reading. An experimental group received 25 sessions for 20 min over 5 weeks at school, while a control group continued as usual. 12 months after training, the experimental group showed greater development in reading and math compared with a matched control group (maintained at a 2-year follow-up assessment). Furthermore, the progress in both math and reading in the trained group was directly related to the amount of improvement seen in the WM tasks. These results demonstrate transfer effects of training with a long-term effect. Nevertheless, these results must be considered with caution due to the non-independent nature of the study (the researchers have any kind of connection to the company or product). In children aged 9–16, Gibson et al. (2012) found that only the active maintenance of a limited amount of information in primary memory was improved by the program, however, no other WM components were improved. Finally, Hitchcock and Westwell (2017) compared WM training in children aged 12 years (adaptive vs. non-adaptive training) and passive control group, and did not find any transfer in task-related attention, reading, mathematics, or regulation of emotional, social, and behavioral challenges. It seems that studies on typically-developing children support evidence of NT (especially in preschoolers), yet there is no independent research to support FT for this population.

An early study of WM training effects on children with ADHD (Klingberg et al., 2002) showed that WM training produces improvements in trained capacities as well as reasoning, interference control and inhibition of motor skills after 5 weeks of training. Klingberg et al. (2005) showed that after training with the standard Cogmed protocol, the trained group

obtained better results compared to the active control group in verbal WM, inhibition and abstract reasoning. Transfer in both studies is not only NT but also FT. However, these initial studies are not independent and therefore must be considered with caution. Another attempt to prove the benefits of behavioral ADHD symptoms (FT) through WM training has been conducted by Beck et al. (2010). In this controlled trial, the experimental group improved in the areas of inattention, the overall number of ADHD symptoms, initiation, planning, and WM as rated by parents. Teacher ratings approached significance at posttreatment and at a 4-month follow-up in the area of initiative. Green et al. (2012), in a double-blind randomized controlled trial, showed that WM training through standard Cogmed protocol, reduced off-task ADHD associated behavior (distractions during performance of tasks). Other studies, such as Dahlin (2013), relate WM training to school performance in math for an experimental group that received the Cogmed standard protocol. Compared to controls, the experimental group improved significantly in WM tasks and in math results. However, because the sample was not randomized, the results should be taken with caution. Egeland et al. (2013) demonstrated the effectiveness of the Cogmed program in improving processing speed in children with ADHD as well as improvements in math and reading. The experimental group's scores (after undergoing Cogmed standard training) significantly increased compared to the control group in visual and auditory WM. A later study conducted by Bigorra et al. (2016) showed that an adaptive training group, compared to the non-adaptive training group, significantly improved in WM, EF (as rated by parents and teachers), reduced impulsivity and ADHD symptoms; and those gains were maintained at a 6-month follow-up. Holmes et al. (2010) compared medication treatment for ADHD with Cogmed training. The results demonstrated that WM training produced WM and central executive gains that were maintained 6 months after treatment; nevertheless, this is a comparative study (not controlled). Despite these results using the same program on children with ADHD, van der Donk et al. (2015), did not find FT. In their study, one group received 5 weeks of cognitive training and another received a "care in class" treatment developed for the research. They valued not only cognitive outcomes and academic performance but also behavioral aspects (including after 6 months of intervention). The authors concluded that CT produced improvements at a cognitive level (in the different tests), but not in academic performance or behavior. In the same way, Chacko et al. (2014) found that WM training (Cogmed) produced benefits in WM, but not in behavior and academic achievement (FT). Similar results were obtained by Dongen-Boomsma et al. (2014) who found only NT, and in this case, it did not survive correction for multiple testing. Gibson et al. (2011) found NT after WM training in adolescents with ADHD. They conceptualize WM in two aspects: (1) retention and maintenance of information during distractions, and, (2) recovering information from the secondary memory (SM). Likewise, in a later study (Gibson et al., 2012), after modifying the exercises included in the standard version of Cogmed-RM from simple span to complex span, they did not find benefits on SM which is typically impaired in children and

adolescents with ADHD. Their results showed WM training to be effective only for the first aspect of WM. In conclusion, there is some evidence to support Cogmed intervention in ADHD to obtain NT. FT results are controversial due to a lack of consistent findings, failures to replicate, and methodological limitations.

In children with low WM capability, Bergman-Nutley and Klingberg (2014) attempted to determine whether WM training (Cogmed standard protocol) could show FT on following instructions and arithmetic. They assessed WM (five times during and after training), following instructions and arithmetic using tests developed by Pearson and Cogmed. The training group improved significantly more than the control group in all three transfer tests. Using a regression model, transfer increased linearly with the amount of training time, and correlated with the amount of improvement on the trained tasks. It must be considered that this study is non-independent. Another study with low WM children aged 9–10 years was conducted by Holmes et al. (2009). The controlled trial results showed that adaptive WM training benefitted WM and mathematical reasoning, and those gains were maintained after 6 months. Holmes and Gathercole (2014), in a randomized controlled trial with children aged 8–11 with low academic achievement, showed that after WM training (Cogmed standard protocol conducted by teachers at school), WM, math and literacy improved. No follow-up was available. Along the same lines, Dunning et al. (2013) tried to demonstrate, through their randomized controlled study, the impact of CT (6 weeks of training) on WM, general intelligence, literacy and mathematics. The sample was divided in three groups (adaptive training, non-adaptive, and passive control group). The group who received adaptive training improved significantly in WM tests, maintaining this progress in visuospatial and verbal WM after 1 year. However, they did not obtain significant results in relation to the other groups in other cognitive areas (FT). In the same way, Ang et al. (2015) showed that training, whether updating training (seven computerized games were developed for the updating training: four games were based on the running span paradigm and three games were based on the keep track paradigm) or Cogmed training, did not show FT for math, and only NT which it was not maintained in the long term, beyond six months after training. Finally, the results of a study by Roberts et al. (2016) with low WM children demonstrated benefits in NT (only visuospatial short-term memory) which were maintained at 12 months. FT was not found in reading, spelling or math. In this population, robust findings supported NT and long-term effects (but not further than 6 months), while FT and longer-term effects were not replicated.

For children with low to moderate IQ, some partial benefits of training have been shown. A study with children with intellectual disability (IQ < 70), was conducted by Soderqvist et al. (2012): the sample was pseudorandomized in two groups (adaptive training vs. non-adaptive training) of WM (Cogmed standard protocol), and non-verbal training (NVR). 20 sessions were conducted at home (80% sample) or at school (20% sample). After training, the female participants showed improvement in instruction comprehension but not in other areas (reasoning, language, behavior rated by parents etc.) After a 1-year follow-up there were no significant improvements.

It seems that individual differences compromised results: only female participants without an additional diagnosis and with higher baseline performance showed greater progress. In this sense, a minimum cognitive capacity seems necessary for the training to be beneficial, and a greater training time is required to reach sustainable training effects. Similar results were found in a pseudorandomized trial with children with low IQ (Soderqvist et al., 2012). A randomized controlled study on children with Down syndrome conducted by Bennett (Bennett et al., 2013) showed that WM training (Cogmed 10–16-week period at school; three times a week for 25 min per session), produces NT and the effects were maintained at a 4-month follow-up. Partanen et al. (2015) demonstrated in a randomized controlled trial that WM training in combination with metacognitive techniques produced a significant difference in WM maintained at a 6-month follow-up. No transfer to arithmetic or reading and writing skills occurred in any of the two training conditions. In this population, only Dahlin (2011) has found FT; a controlled trial showed that children trained in WM Cogmed standard protocol at school increased scores in reading comprehension, and those gains were maintained at a 7-month follow-up. Some variables, such as cognitive level in lower IQ children, might influence WM training effects, but few transfer benefits in WM and reading comprehension were found.

Focusing on children with language learning disabilities, Holmes et al. (2015) compared children diagnosed with Specific Language Impairment (SLI) to children with typical language performance. There was no control group and both groups received intervention. They took part in 20 sessions of 45-min over 8 weeks in small groups at school. The results showed that both groups improved their visuospatial short-term memory. However, the SLI group improved significantly more in one of two verbal STM measures (digit span). Exploratory analyses across the sample established that low verbal IQ scores were strongly and highly-specifically associated with greater gains in verbal span-like WM tasks, and those children with higher verbal IQs made greater gains in visuospatial STM following training. In another study, children with cochlear implants received the standard Cogmed protocol (Kronenberger et al., 2011). The researchers compared scores during wait time and training. After training, children demonstrated a significant improvement in measures of verbal and nonverbal WM, sentence-repetition skills and parent-reported working memory behavior. Sentence repetition continued to show marked improvement at a 6-month follow-up. In this area, randomized controlled trials would be crucial to replicate results.

A number of studies using Cogmed have been conducted with a population at risk of learning disabilities. On the one hand, some studies have focused on low birthweight or preterm children. Grunewaldt et al. (2013) conducted a stepped-wedge randomized trial with children aged 5–6 years who were born preterm. They showed that WM training (Cogmed JM version: 10–15 min per session for 5 days per week over 5 weeks at home) benefitted WM and auditory attention, phonological awareness, facial memory, narrative memory, spatial span, and sentence repetitions. There were no effects on anxiety reduction. Later, Grunewaldt et al. (2016) also studied the effects of WM training on children with the same characteristics. An experimental group

received the standard Cogmed JM protocol at home. After training, some gains or equivalent scores as the control group were found in facial memory, narrative memory and spatial span, which remained at a 7-month follow-up. No group differences in performance gain were found for attention and behavior. It seems that FT to attention and behavior was not found in this case. A study conducted by Lee et al. (2016) on children aged 4–6 years did not find NT in preterm and normal-term children in WM after training (Cogmed JM version), and also found no FT to other domains such as attention and executive functions. Finally, a controlled trial on adolescents conducted by Løhaugen et al. (2011) showed that after training (standard Cogmed protocol) gains in WM were produced and maintained after 6 months, yet, no FT was evidenced. In this population, NT and FT in memory has been demonstrated, nevertheless there have been no findings so far for attention or behavior. On the other hand, children with a low sociocultural level (SES) are also at risk of potential learning difficulties. Foy and Mann (2014) carried out a study in an attempt to prevent learning difficulties. Through a sample of children aged 4–5 years (pre-readers) with a low socio-cultural level, they assessed whether WM training had some NT in WM, as well as FT on self-regulation and pre-literacy skills. For this purpose, one group received training in WM and another group did not receive any intervention. Their conclusions are that training favors the visuospatial memory of the trained children, as well as their self-regulation or executive control (assessed in inhibition tasks), but not on the prerequisites of literacy (e.g., phonological awareness or knowledge of letters). Another study on children with a low socioeconomic level was conducted by Mezzacappa and Buckner (2010). In this pilot study with a single group design, they compared WM and behavior (symptoms of ADHD before and after training as rated by teachers). After treatment, WM and behavior improved. Further research in this area is needed to provide more robust results.

Some researchers have focused on populations with different diseases such as cancer. Hardy et al. (2013) conducted a pilot study with child and teenage survivors of cancer. Immediately after treatment, the adaptive training group displayed significant improvements (not at follow-up) in their visual WM and in parent-rated learning problems, compared with those in the active control group. Conklin et al. (2017), in a randomized controlled trial with children aged 9–14 years, showed that after intervention, the trained group improved in WM, attention and processing speed. WM and processing speed gains were maintained at a 6-month follow-up. In this area, further research is required to better clarify the efficacy of Cogmed intervention. For children and adolescents with epilepsy, Kerr and Blackwell (2015) conducted a randomized controlled trial, the results of which showed that the trained group had significant post-interventive treatment effects for visual attention span, auditory WM, and visual-verbal WM (NT). Similar results were obtained by Fuentes and Kerr (2017), nevertheless FT (in fluid reasoning) was not observed. Indeed, further research is needed in this area to replicate results and to demonstrate the existence of any FT. Finally, in terms of brain damage, Eve et al. (2016) conducted a pilot study and a long-term follow-up with children who had suffered from an arterial ischemic stroke. They receive the standard Cogmed WM Training at

home, supervised by their parents. Measures of WM, attention, and mathematical achievement were conducted before and after intervention, and at a 1-year follow-up. The results indicated that a significant improvement in phonological-loop WM was produced, however, this improvement was not maintained after 12 months. No additional significant improvements on standardized psychometric outcome measures were seen either immediately or at the 12-month follow-up. Phillips et al. (2016) compared adaptive vs. non-adaptive training in children with brain damage. The results demonstrated a significant difference in favor of the adaptive training group in WM and reading (reading comprehension and reading accuracy); the latter was maintained at a 3-month follow-up. However, no benefits were found in math. This finding may not support WM training for these patients; thus, further randomized controlled trials with children with brain damage would help to clarify this issue.

Finally, some studies have been conducted on children and adolescents with behavioral problems. Regarding children with externalizing behavior problems, Graziano and Hart (2016) conducted a randomized trial on preschoolers. In this study, the participants completed an 8-week intervention. They were allocated to one of three programs (STP-PreK = summer treatment program for pre-kindergarteners which involved BT (Cogmed), PT = parent training (parents were trained in some parenting techniques), and STP-PreK Enhance (which involved additional social skills, self-regulation strategies). The results suggested that, although all groups improved in behavioral functioning groups at a similar magnitude, children in the STP-PreK Enhanced group experienced greater growth over time. This group and STT-PREK maintained improvements at a 6-month follow-up in academic achievement, emotional knowledge, emotion regulation, and executive functioning compared to children with PT only. In children with behavior problems aged 11–13 years, Roughan and Hadwin (2011), in a randomized controlled trial, showed that the group trained in Cogmed (standard protocol) had better post-training scores in measures of IQ, inhibition, test anxiety, teacher-reported behavior, attention and emotional symptoms, compared with a non-intervention passive group; differences in WM were also evident at a 3-month follow-up. In adolescents with high scores on anxiety questionnaires, Hadwin and Richards (2016), in a randomized controlled trial, compared WM training (Cogmed standard protocol) vs. CBT intervention (small group activities on feelings, thoughts, relaxation techniques, problem solving, and coping strategies in small groups). After treatment, the WM training group showed significant gains in WM. Both groups reported fewer anxiety symptoms, demonstrated increased inhibitory control and a reduction in attentional biases to threat post intervention, and these results were maintained after 4 months. In children with behavioral problems, the results are encouraging for better regulation of behavior through cognitive training of WM.

Focus Pocus

This program, mentioned in section 1, is also supported by a study using psychometric tests to improve training efficacy. Johnstone et al. (2012) showed, in children with

ADHD, that the combination of CT (Focus Pocus exercises) with and without neurofeedback, and compared to a passive control group, produced significant improvements in sustained attention, inhibition, WM, as well as a decrease in behavioral-type ADHD symptoms after 25 training sessions, as rated by parents. These results were maintained at follow-up (six months after intervention). As this is a non-independent research, the results must be considered with caution.

Play Attention

Steiner et al. (2011) demonstrated the effectiveness of two neuroscientific interventions for children with ADHD disorder: an NF training program (“Play attention”) and a computerized cognitive training program (“Brain Train/Captain’s Log”). After an average of 23.4 sessions in their schools, parents reported an improvement in symptoms associated with this disorder which was significantly higher than that reported for the control group. In later studies, the same authors demonstrated that the effects were maintained at 6-month follow-up (Steiner et al., 2014).

Braingame Brian

This online platform is designed to train EF and was endorsed by a randomized, double-blind, placebo-controlled trial on children with ADHD aged 8–12 years (Dovis et al., 2015). The experimental group received 25 sessions of 30–35 min each. After training, the trained group significantly improved in EF trained skills (NT). No FT on behavior or long-term effects were found.

ACTIVATE™

This online platform to train attention is supported by a study which tests NT (Bikic et al., 2015). In this randomized, controlled trial with children with ADHD (aged 6–13), the results showed that the trained group (40 min per day for 6 days per week over 8 weeks at home) displayed significant improvements in the primary outcome of attention. No long-term effect was confirmed.

SIGUEME Application

This application designed for autistic children is supported by a controlled study to test its efficacy. The study conducted by Véléz-Coto et al. (2017) involved the training of children using this application for 25 sessions of 10–15 min each. Following training, the results showed that the children improved in the areas of attention, association and categorization, and interaction (NT). Nevertheless, it must be considered that the assessment was designed by researchers.

TALI Attention Training Program

This program which aims to train attention is supported by a recent study on program efficacy in children with intellectual and developmental disabilities (Kirk et al., 2017). The children were randomly assigned to a training group or to a placebo control. The trained group received 25 sessions of 20 min. Although after training no significant effects were found, scores in numeracy increased at a 3-month follow-up. It must be considered that this study only assessed FT on academic achievement.

DISCUSSION

The present paper highlights and summarizes the current state of BT research focused on children in recent years. It also defines different commercially available BT programs for these children by type of method or research applied to test program efficacy. This summary should be particularly useful for psychologists, educators, and parents for practical purposes. A necessary consideration is that many BT programs are commercially available for children, yet the majority have not been endorsed by empirical research results. Here we attempt to provide a better understanding of which of these programs are supported by research, including their shortcomings and suggestions for future research.

BT or CT should attempt to produce some observable brain changes. As we have found, only a few BT products that are commercially available have empirical data that support evidence of neuroplasticity. Some BT programs have shown neuroplasticity using neuroimaging techniques such as FastForWord for children with dyslexia (Temple et al., 2003), Teach-The-Brain in typically-developing children (Rueda et al., 2005), Cogmed for typically-developing children (Söderqvist et al., 2012; Astle et al., 2015; Barnes et al., 2016), cancer survivors (Conklin et al., 2015), and for children with ADHD (Stevens et al., 2016), WinABC in children with dyslexia (Penolazzi et al., 2010), Luminosity in cancer survivors (Kesler et al., 2011b), and those with Turner syndrome (Kesler et al., 2011b), and Focus Pocus in children with ADHD (Johnstone et al., 2017). These suggestive neural changes are meant to reflect some improvement in cognition or behavior. Regarding FT, the results are more encouraging in the clinical population than for typically-developing children, however, due to the limitations of many of the studies, further research is required. Despite this, most BT programs claim to be based on neuroplasticity, yet, the majority are not supported by sufficient empirical research. Furthermore, confirming the existence of a relationship between neuroplasticity and transfer would provide more robust results in terms of program efficacy, because the relation between neural changes and improvements in cognition or behavior is still largely unexplored.

One of the challenges for BT is not only to produce NT (improvement in a task or skill similar to the one that was trained), but FT (improvement in an untrained task or skill which may produce some significant difference in the user's daily life). Several studies have shown transfer of different available programs and in different populations. Brain Train (Captain's Log) have shown NT in children with ADHD (La Marca and O'Connor, 2016) as well as FT for ADHD symptoms (Rabiner et al., 2010; Steiner et al., 2011), yet, no long-term effects have been found. Cogmed is supported by the largest number of research studies on children and BT. This program has been tested on typically-developing children, yet the ones showing positive NT and FT results in these populations are non-independent research: NT in Pre-schoolers (Thorell et al., 2009) FT in word-decoding (Bergman-Nutley et al., 2011) and math and reading for children aged 9–11 years with long-term effects at 2 years (Söderqvist and Nutley, 2015). Despite this, independent research has found inconclusive results in children aged 9–16

years related to WM (Gibson et al., 2012) and in 12-year-olds with no transfer effects and no long-term effects (Hitchcock and Westwell, 2017). In this case, we may ask ourselves why should this program be used with general population when there is a lack of consistent results. On the other hand, Cogmed seems to have some benefits in children with ADHD: Cogmed has shown NT in ADHD or children with attention difficulties, as well as low WM (Gibson et al., 2011; Dunning et al., 2013; Hovik et al., 2013; Chacko et al., 2014; Dongen-Boomsma et al., 2014; Ang et al., 2015; van der Donk et al., 2015; Roberts et al., 2016), FT over inhibition and reasoning through non-independent research (Klingberg et al., 2002, 2005) academic performance: math (Holmes et al., 2009; Dahlin, 2013; Holmes and Gathercole, 2014), math and reading (Egeland et al., 2013) on central EF (Holmes et al., 2010), EF (Bigorra et al., 2016), ADHD symptoms (Beck et al., 2010; Bigorra et al., 2016), and reduced off-task symptoms while performing tasks. (Green et al., 2012). Nevertheless, only a few of these studies have shown long-term effects on NT (Dunning et al., 2013; Hovik et al., 2013; van der Donk et al., 2015; Roberts et al., 2016), and on FT after 4 months (Beck et al., 2010), 6 months (Holmes et al., 2009; Bigorra et al., 2016), and 7–8 months (Dahlin, 2013; Egeland et al., 2013). It seems that the majority of studies do not demonstrate long-term effects of training. NT of Cogmed has been also shown in children with special needs (Partanen et al., 2015) with effects after 4 months (Bennett et al., 2013). Despite this, the authors of these studies did not find FT. Two studies have found FT on reading or instruction comprehension (Soderqvist et al., 2012) with long-term effects after 7 months (Dahlin, 2011). In children with language disabilities or hearing problems, there are two attempts to demonstrate the efficacy of Cogmed, however, the studies have not been properly randomized and controlled. NT has been shown to occur (Holmes et al., 2015) as well as some benefits over language skills related to WM, and was maintained at a 6-month follow-up (Kronenberger et al., 2011).

With regard to children at risk of developing learning difficulties, for children born preterm, a few studies have been conducted recently, especially on preschoolers, which showed NT and FT to some language skills related to WM (Grunewaldt et al., 2013) and FT to other domains related to WM, such as facial memory and narrative memory, which were preserved after 7 months of treatment (Grunewaldt et al., 2016). In the same population, Lee et al. (2016) only found the NT effect of Cogmed and no other effects on attention or behavior, mirroring the findings of previous authors. Finally, in adolescents, NT has been demonstrated and maintained after 7 months (Løhaugen et al., 2011), yet no FT has been provided. In children with low SES, there is evidence for NT (Mezzacappa and Buckner, 2010) as well as for FT on self-regulation and pre-literacy skills (Foy and Mann, 2014), yet no long-term effects were shown. Therefore, at this stage, the results for this at-risk group are inconclusive.

Diseases which may impact cognition have also come under the scope of WM training, such as cancer, epilepsy, and brain damage. The results for cancer patients seem to be inconclusive. Using samples within a wide age range from children to adolescents, NT was found by Conklin et al. (2015) as well as FT on processing speed and attention gains maintained at a 6-month follow-up; nevertheless, with

a similar sample, Hardy et al. (2013) found NT and parental reports of fewer learning problems, but the results were not maintained at a 3-month follow-up. Furthermore, a wide age range has been studied for children with epilepsy and only NT has been found (Kerr and Blackwell, 2015) with maintenance after 3 months (Fuentes and Kerr, 2017). Finally, in terms of brain damage, only a few NT effects have been demonstrated in preteens and teens, yet, these were not maintained at 1-year post-intervention (Eve et al., 2016). Adaptive training is more effective than non-adaptive (as in previous findings). In a study by Phillips et al. (2016), adaptive training was shown to produce some benefits in reading (but not math) and was maintained after 3 months. In this last study, a passive control group should be added to better interpret results.

Finally, encouraging results have been found for children with behavioral problems, especially for teenagers and in combination with other techniques. Some results have shown NT at maintenance and at a 3-month follow-up, however gains of FT on IQ, inhibition, anxiety, attention and emotional symptoms were not maintained at follow-up (Roughan and Hadwin, 2011). Treatment combinations have yielded better results and maintenance, for instance, on preschoolers; using Cogmed in combination with other techniques (social skills, self-regulation strategies) benefits WM (NT) as well as other FT (academic achievement, emotion knowledge, emotion regulation, and executive functioning) maintained at 6 months (Graziano and Hart, 2016). In this case, as Cogmed is part of a wider treatment, we cannot directly attribute improvement in dependent variables to the program. Finally, it seems that Cogmed may be as beneficial as traditional treatment for teenagers (with a focus on anxiety reduction and self-control improvement), and demonstrated maintenance at a 4-month follow-up (Hadwin and Richards, 2016). Focus Pocus, apart from its neuroplasticity results in ADHD children (Johnstone et al., 2017), has demonstrated efficacy in FT on ADHD symptoms maintained after a 6-month intervention (Johnstone et al., 2012); nevertheless, those studies are non-independent and the results need replication in independent research. In another NF intervention, Play Attention has shown some FT on ADHD symptoms (Steiner et al., 2011) and long-term effects (6 months) on children ADHD (Steiner et al., 2014). Braingame Brian has shown NT in children with ADHD (Dovis et al., 2015), but not FT or long-term effects. As this platform is quite new, future research will be needed to clarify its benefits. The same may be said about ACTIVATE™ where NT have been also found in ADHD children, but with no other results (Bikic et al., 2015). Finally, we have included two touchscreen intervention products: SIGUEME has shown positive results regarding NT with autistic children (Vélez-Coto et al., 2017). In contrast, for the TALI attention training program, another touchscreen intervention, the research provided only non-significant improvement in children with intellectual and developmental disability (Kirk et al., 2017).

A number of other programs have been supported by empirical research presented at professional conferences, and we hope to find further research and publications on these programs in future major scientific reviews. For instance, Arrowsmith, one

of the best-known computer-based interventions for children with special needs, is supported by an intervention trial conducted with children with learning disabilities, showing NT after treatment (Fitzer et al., 2014; Kubas et al., 2014). In this case, despite the fact that it has been on the market for several years, there is little evidence on its efficacy. Uno brain is supported by empirical research, presented in conferences, on an adult population (Fernández-Sánchez et al., 2013a,b) and on children with ADHD (Fernández-Sánchez et al., 2014). The results of this study seem encouraging because they report NT and FT over ADHD symptoms. Nevertheless, other well-known platforms and computer-based interventions, such as Cognifit, Brain Master, Happy Neuron, Neuron UP, Fit Brains, Sincrolab Kids, Gominis application, Beebrite Edu, Identifor, and the Nexxo application still lack published empirical research conducted with child populations. Independent randomized controlled trials with proper follow-ups will aid us to clarify the efficacy of these emerging computer-based interventions for children.

In general, we have found some limitations of commercially available BT products: (1) lack of scientific validity of many programs designed to train specific brain skills; (2) only 10 studies (14.2%) have been found to demonstrate neuroplasticity yet the majority of BT platforms claim to be based on these concepts without providing any scientific data; (3) only 36 of a total of 70 (51.4%) studies have shown FT, and, only 11 of them (15.7%) maintained FT at follow-up, which may lead to question the efficacy of BT products in the long term, and, finally, (4) lack of accessibility such as high prices, which make these products accessible to developed countries, but not worldwide.

Considering the methodological designs in the total of 70 published articles included in this review, we found: (1) fewer than half of them (30 or 42.8%) were randomized-controlled; (2) only 13 (18.6%) included an active control group and only 2 (2.9%) included 3 groups (experimental group/active control group/passive control group); (3) more than half of them, (38 or 54.3%) included follow-ups; (4) a double-blind design was not common, present in only 9 studies (12.9%); and finally (5), a minority of studies were non-independent (11 or 15.7%). Considering the research limitations discovered, we consider that further research is needed to scientifically validate the new BT programs available on the market, through double-blind randomized controlled trials, which include a passive control group and active control group, in addition to proper follow-up assessments. As we have seen, the majority of studies do not include an active control group and any follow-up beyond 6 months. Furthermore, a combination of neuroimaging techniques and psychometrical tools could be a robust method to demonstrate neuroplasticity and transfer effects to everyday life. For research designs we recommend that researchers review criteria proposed by the IoM report (Mahncke and Merzenich, 2015) about how to evaluate a BT program. It is necessary to consider some study limitations such as sample sizes, lack of tasks to evaluate transfer (Cortese et al., 2015), as well as the individual differences of the participants and their motivations. Thus, some authors propose different study designs to test programs including micro-trials and single-case studies (Granic et al., 2014).

Having seen the limitations of many BT programs to produce FT and long-lasting effects, together with the methodological research limitations, a combination of treatments might potentially be more profitable; i.e., using BT as part of a wider treatment. Thus, programs which involve not only BT but also other strategies, thereby offering a treatment combination, may be more beneficial for some populations, such as children with behavioral problems, and produce more sustainable effects, as suggested by Graziano and Hart (2016), or in children with special needs, as indicated by Partanen et al. (2015). These findings support the idea that a combination of methods may be more profitable to implement and maintain cognitive and behavioral improvements over time. Future research should aim to clarify whether a combination of strategy implementation and programs would have a more significant and sustainable effect.

Despite finding the benefits of BT or a treatment combination, some authors remain unconvinced by the difficulties BT programs reported here (e.g., reaching FT and long-lasting effects), and claim that other activities that form part of children's natural environment, such as video games, music, and sports, show a more reasonable and generalized effect (Green and Bavelier, 2008). These authors emphasize that these activities are natural forms of training in which several skills are practiced in parallel. If there are common activities that foster children's skills, should BT be incorporated for typically-developing children? Is it necessary to use a BT program to improve cognitive skills in typically-developing children while there are other activities in their everyday lives that seem to benefit them as well? Why should we aim to improve children's abilities beyond usual child development?

The results obtained for child populations are controversial because there is a large proportion of non-independent research. Regarding neuroplasticity, independent research has yielded positive results (Rueda et al., 2005; Astle et al., 2015; Barnes et al., 2016), and on NT (Gibson et al., 2012; Hitchcock and Westwell, 2017) and FT (Fälth et al., 2016). Non-independent research has produced better results in these populations regarding transfer or long-term effects (Temple et al., 2003; Thorell et al., 2009; Bergman-Nutley et al., 2011; Söderqvist et al., 2012; Bergman-Nutley and Klingberg, 2014; Söderqvist and Nutley, 2015). Despite the fact that BT marketing is aimed at the general population, considering the results, we believe that BT research should contribute to validate programs as treatment tools for neurologically impaired patients, such as children with ADHD, learning disabilities, and behavioral problems. Further research is required to test the efficacy of BT and to ascertain for which populations it may be suitable, and what strategies can foster the efficacy and long-term effects of CT.

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AUTHOR CONTRIBUTIONS

TR-P, EP-H, and JG-M: Conception and design of the review; TR-P: Searches, analysis, and data classification; EP-H and JG-M: Document review; TR-P: Writing of the paper.

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4.2. Efectos del entrenamiento “Nexxo” sobre la Atención y las funciones ejecutivas en niños de Primero y Tercero de Educación Primaria.

Procurando superar las limitaciones de estudios anteriores, se realizó un estudio donde poner a prueba el impacto del entrenamiento “Nexxo” en niños con desarrollo típico sobre los procesos de atención y funciones ejecutivas (artículo 2: Rossignoli-Palomeque, T., Perez-Hernandez, E., y González Marqués, J. (2019) *Training effects of attention and EF strategy-based training “Nexxo” in school-age students* (en revisión en Acta Psychologica).

Tras considerar el desarrollo de la atención y las funciones ejecutivas se decidió poner a prueba el entrenamiento en niños de 6-7 años y en niños de 8-9 años. Ello es así ante la hipótesis de que a los 7-8 años pudiera haber un cambio madurativo sustancial en inhibición y vigilancia y, por tanto, encontrarse resultados diferentes en ambos grupos de edad. Para ello se realizó un estudio aleatorio controlado que incluye un grupo placebo. Participaron 108 niños con desarrollo neurotípico: Primero de Primaria (N = 61, M = 6.46 años, SD = 0.35) y Tercero de Primaria (N = 47, M = 8.5 años, SD = 0.27), aleatoriamente asignados a los diferentes grupos: (1) experimental, (2) control activo o placebo y (3) control pasivo. Se realizó una media pre-intervención, post intervención y seguimiento a los dos meses. Las variables dependientes analizadas fueron relativas a la atención, funciones ejecutivas y supervisión valoradas desde el ámbito familiar a través del Sistema de Evaluación de Niños y Adolescentes (SENA) (Fernández-Pinto et al., 2015) y la versión española del *Behaviour Rating of Executive Functions-2* (BRIEF-2) (Gioia et al., 2000). La variable independiente fue el tipo de entrenamiento.

Este entrenamiento, como se ha explicado en apartados anteriores, combina el uso de la aplicación para Ipad “Nexxo”, una aplicación basada en tareas de *go/no-go* y *stop signal tasks*, junto con estrategias metacognitivas procedimentales (como el uso de autoinstrucciones, estrategias de autorregulación motora y verbal, y comprensión de instrucciones escritas) dirigidas por un instructor. Además de estas estrategias que fueron proporcionadas a todo el grupo experimental, en el diseño del programa incluimos una serie de estrategias compensatorias para aquellos participantes que mostraran dificultad durante los entrenamientos (p.e. repetir la instrucción, verbalizaciones por parte del niño o del instructor etc.). Los entrenamientos se realizaron en grupos de 8 participantes, 2 días a la semana durante 5 semanas. Las sesiones tuvieron una duración de 15 minutos, llevadas a cabo en horario escolar. Bajo las mismas condiciones, el grupo placebo entrenó a través de actividades lúdicas informáticas. El grupo de control pasivo no recibió ninguna intervención.

Los resultados mostraron que, en tercero de primaria, el grupo experimental redujo los problemas de atención en el seguimiento comparado con los dos grupos de control. Además, los problemas de funciones ejecutivas se redujeron en el seguimiento

en el grupo experimental. Este grupo mejoró también en cuanto a supervisión tanto en la evaluación post-intervención como en el seguimiento comparado con el grupo de control pasivo. En cuanto al grupo de primero de primaria no se encontraron resultados significativos. Pese a que los resultados son modestos, debe considerarse que el estudio incluye un grupo de placebo, y que los criterios de inclusión aplicados para garantizar que la muestra es típica son exhaustivos. Por otro lado, el tiempo de intervención es un período corto.

4.2.1. Publicación: Training effects of attention and EF strategy-based training “Nexxo” in school-age students

Training effects of attention and EF strategy-based training “Nexxo” in school-age students

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Abstract

Given the importance of attention and executive functions in children's behavior, programs directed to improve these processes are of interest. Nexxo-training combines the use of the Nexxo touchscreen application (go/no-go and stop signal tasks) with procedural metacognitive strategies. The present paper reports a test of Nexxo's impact on children aged 6-7 and 8-9 years. We conducted a randomized active-controlled trial involving 108 typically-developing children: 1st grade ($N = 61$, $M = 6.46$ years, $SD = 0.35$) and 3rd grade ($N = 47$, $M = 8.5$ years, $SD = 0.27$), randomly assigned to: (1) experimental, (2) active-control, or (3) passive-control groups. A 2-month follow-up was carried out after the intervention. *Results:* The 3rd grade experimental group displayed a significant reduction in attentional problems at follow-up compared to both control groups. Executive function problems were also reduced at follow-up in the experimental group. Participants in this group improved in supervision (self-monitoring) at post-intervention and follow-up compared to passive-controls. Although group effect was not significant at t1, it was significant at post measures in experimental group compared to passive-controls. Nexxo-training revealed a trend-level improvement in attention and executive functions for children in the 3rd grade. However, further research is needed.

Keywords: children; attention; executive functions; cognitive training; procedural metacognitive strategies.

1. Introduction

Attention is essential for fulfilling complex processes (Amador, Forns, y Kirchner, 2006; McAvinue et al., 2012), and fundamental for people to emit adaptive responses to stimuli. (Howard, Johnson, y Pascual-Leone, 2014). Executive functions (EF) are crucial for individual adaptation in school, labor, familiar, and social context (Bryck y Fisher, 2012; Crick y Dodge, 1994). Overall, attention and EF functions are related to behavior in class, academic achievement (Blair y Razza, 2007) and intelligence (Tschemtscher, Mitchell, y Duncan, 2017; Yoon et al., 2017; de Abreu, Conway, y Gathercole, 2010; Karbach y Unger, 2014). Our study examined whether cognitive training improves attention and executive function (EF) in healthy young students and whether this improvement is reflected in daily life.

Both attention and EF are relevant to children's lives. But the attentional process of vigilance is particularly relevant. Vigilance is the detection of changes when only a low rate of relevant stimuli exists (Hauke, Fimm, y Sturm, 2011). Vigilance is not only required in situations of sustained and divided attention in daily life but also in those situations where human lives are at risk (Figuroa y Youmans, 2012). Vigilance is one of the “intensity” processes of attention (Sturm, 2008), (Parasuraman y Giambra, 1991). Such attentional processes can be understood by considering the roles played by three interrelated mechanisms of attention: (1) the orienting network, (2) the executive network, and (3) the alerting network (Petersen y Posner, 2012; Posner y Petersen, 1990). The executive network is activated in situations that require decision-making, inhibitory control, or emotional self-regulation (Raz y Buhle, 2006). The executive network has also been related to error detection (Dehaene, Posner, y Tucker, 1994), as well as to the ability to resolve conflicts among default responses (Botvinick, Braver, Barch, Carter, y Cohen, 2001). These abilities

are fundamental to the development of self-control (Rothbart, Sheese, y Posner, 2007). Vigilance tasks require selective attention (identify *target* among *nontarget*), inhibition (holding response in *nontargets*) and sustained attention (as they require holding attention for a long period of time) (Parasuraman y Giambra, 1991). Failures in this process have been found in attention deficit hyperactivity disorder (ADHD) (Huang-Pollock, Karalunas, Tam, y Moore, 2012; Johnstone et al., 2012; Michelini et al., 2016), Tourette syndrome (Sukhodolsky, Landeros-Weisenberger, Scahill, Leckman, y Schultz, 2010), children with learning disabilities and educational needs (Eliason y Richman, 1987; Keogh y Margolis, 1976), anxiety (Price et al., 2013) autism (Christakou et al., 2013), children with schizophrenia (Sapir, Henik, Dobrusin, y Hochman, 2001), congenital heart disease (Miatton, De Wolf, François, Thiery, y Vingerhoets, 2007) and brain damage (Galbiati et al., 2009) among others.

The main factors of EF are (1) inhibition, (2) shifting, and (3) updating (Miyake et al., 2000; Miyake y Friedman 2012). In our study we focused on inhibition. Inhibition is not only the ability to suppress a dominant response but also the ability to select relevant stimuli when a distractor appears (Diamond, 2013). The prepotent response, inhibition, and resistance to distractor interference are connected (Friedman y Miyake, 2004). These distinctions among EF components have also been made in school-age children (McAuley y White, 2011; Rose, Feldman, y Jankowski, 2011). Inhibition is considered one of the first EF processes to develop and is responsible for the development of other, more complex EF components (Dempster, 1992). Inhibition seems to affect self-regulation (Rueda, Posner, y Rothbart, 2005), and theory of mind (Carlson, Moses, y Breton, 2002).

There is a strong relationship between attention and EF (Rebollo y Montiel, 2006). For instance, vigilance problems may be related to cognitive impulsivity (Lovejoy y

Rasmussen, 1990) and cognitive flexibility (Figuerola y Youmans, 2012). Also primary school children with higher levels of performance in vigilance tasks obtained higher scores in fluid intelligence and cognitive flexibility (Rossignoli-Palomeque, Quiros-Godoy, Perez-Hernandez, y González-Marqués, 2019). As we see, attention and EF converge. Thus, our view is that the combined training of attention (intensity processes) and self-control (inhibitory control) may produce more improvements in behavior than simply training attention alone.

We have focused our training on vigilance and inhibition because they are core factors for developing more complex components of attention and EF. According to Anderson (2002), people with difficulties in this area tend to be impulsive, showing a lack of self-control. They tend to leave tasks unfinished, making mistakes during execution. They show lapses of attention, misinterpret or forget instructions, and respond inappropriately. Failures in inhibitory processes have been found in disorders such as ADHD (Barkley, 1997; Beck, Hanson, Puffenberger, Benninger, y Benninger, 2010; Gau et al., 2010; Rebollo y Montiel, 2006; Stevens, Gaynor, Bessette, y Pearlson, 2016; Willcutt, Doyle, Nigg, Faraone, y Pennington, 2005), autism (Ciesielski y Harris, 1997; Ozonoff y Jensen, 1999), obsessive-compulsive disorder (Enright y Beech, 1993; Ozonoff y Jensen, 1999), behavioral disorders (Graziano y Hart, 2016; Rebollo y Montiel, 2006) or social maladjustment (Blair y Razza, 2007; Olson, S. L., 1989). For these reasons, studying the effects of attention and EF training in children seems to be important, not only to compensate for cognitive deficits but also to promote cognition and development in children (Karbach y Unger, 2014).

Since the nineties, Cognitive Training (CT) products have been increasingly used to improve attention or EF. Several CT products are becoming very popular. Nevertheless, most commercially available CT products have not been tested (Rabiner, Murray, Skinner, y

Malone, 2010). A few studies have shown the positive effects of CT using computer-based programs in typically-developing children, either in terms of attentional processes (Thorell, Lindqvist, Bergman Nutley, Bohlin, y Klingberg, 2009) or EF (Rueda, Posner, y Rothbart, 2005). Some authors have found that CT of attention span and working memory (WM) may produce some improvement in certain cognitive domains, such as fluid intelligence (Klingberg et al., 2005), academic performance: reading (Dahlin, 2011; Holmes y Gathercole, 2014) and mathematics (Dahlin, 2013). For typically developing children, Cogmed is supported by the largest number of research studies (near transfer (Thorell, Lindqvist, Bergman Nutley, Bohlin, y Klingberg, 2009) far transfer (Bergman Nutley et al., 2011), and long-term effects at two years (Söderqvist y Nutley, 2015). Despite this, independent research has found inconclusive results in terms of transfer effects (Gibson et al., 2012) and lack of long-term effects (Hitchcock y Westwell, 2017). Specifically, regarding inhibition training, a previous study of a go/no-go task though a touchscreen application with preschoolers showed a trend-level improvement in reasoning and neural changes in the experimental group after 3 hours of training (Liu, Zhu, Ziegler, y Shi, 2015). These findings are consistent with the idea that attention and EF are related to academic performance and cognition. Nevertheless, these studies have limitations. For example, many of them lack an active control group in the trial design and they lack single and double-masked trials.

Therefore, further studies must be carried out to bridge the research gap generated by these methodological limitations. In this review, cognitive training products were analyzed in terms of neuroplasticity and transfer, as well as the design of the studies. Analyzing 70 results, 36 studies (51.4%) showed far transfer (7 of them were not independent studies), but only 11 (15.7%) of them maintained results at follow-up. Regarding the methodology used in their designs, 40 studies (68.2%) were neither controlled nor randomized; among the randomized studies (27), only 9 (12.9%) were double-blind, and only 13 (18.6%) included a placebo

group in the design (Rossignoli-Palomeque, Pérez-Hernández, y González Marqués, 2018). Studies on attention and EF training in typically-developing children with valid data and less bias are scarce, and there are even fewer that include CT interventions using touchscreen devices (Nexxo training requires a touchscreen. Those that do tend to focus on children with specific learning problems (Kirk, Gray, Ellis, Taffe, y Cornish, 2017) or conditions such as autism (Vélez-Coto et al., 2017). This is an important consideration as the accessibility of touchscreen devices for young children has been increasing in recent years (Marsh et al., 2005). Around three-quarters of the world population has access to this technology (Bank, 2012). In 2012 alone, 30 billion applications were downloaded worldwide. On the one hand, applications are appealing for children; in the United States, children use digital technology around 4 hours a day outside of school (Lai, Khaddage, y Knezek, 2013). On the other hand, untested applications for CT can be accessed by typically-developing children, yet there is no evidence of their transfer to children's skills or behavior. New CT of attention and EF should be properly tested for practical psychological intervention.

The aim of an EF training should be the generalization of the training into children's daily lives (Simons et al., 2016) This may be termed "far transfer" (Korbin y Unger, 2014). As mentioned above, an extended number of previous studies of EF training efficacy lacks this type of transfer result (Rossignoli-Palomeque et al., 2018). We consider that the lack of far transfer in many CT interventions may be explained by the fact that those interventions follow a training model that targets specific skills rather than general domains. To overcome this limitation of traditional "process-based training," where the training consists of the repetition of a task, "strategy-based training" provides (in addition to the task) instructions for users to enhance strategies involved in those tasks (Jolles y Crone, 2012; Morrison y Chein, 2011). These are metacognitive strategies which promote better performance in the EF tasks (Bewick et al., 1995) and facilitates learning (Blankson et al., 2017). One example of

this can be scaffolding or metacognitive strategies designed in combination with the training (Pozuelos et al., 2018). In this study children in the metacognitive group not only showed larger gains in intelligence compared to the process-based training group but also significant increases in conflict processing measured through electrophysiological techniques. This is a new finding, and further research of attention and EF should focus on strategy-based trainings to improve task performance and far transfer. In this sense, our training involves not only the repetition of a task (vigilance and inhibition tasks) but procedural metacognitive strategies to enhance strategies involved in those tasks. Furthermore, our training provides these general strategies for the whole group and also compensatory strategies for those participants with more difficulties during the training.

Drawing from the assertion that intensity and inhibition are core factors in developing more complex components of attention and EF, our team developed a strategy-based training. Previous studies have shown that procedural metacognitive strategies, such as telling oneself out loud what one should do or how one should do something, may foster better results in inhibition tasks, and, therefore, EF development in children (Diamond et al., 2007). Prior research has shown that young children exhibit enhanced self-control strategies not only when they use verbal strategies provided through adult instructions, but also spontaneous verbalizations or motor behavior to exercise self-control in inhibition tasks (Manfra et al., 2014). These types of strategies are considered as “procedural metacognitive” strategies. The training used in this analysis includes procedural metacognitive strategies, which consist of the combination of self-regulation strategies (motor and verbal strategies) in combination with instructions comprehension and self-instructions, as appropriate for the participant’s age. These three are considered metacognitive strategies that can be applied in self-regulated learning (Dina y Efklides, 2009). In our view, combining training of vigilance, inhibition,

and procedural metacognitive strategies would be beneficial for children's learning and generalization of training.

Finally, we have taken into consideration the development of attention (vigilance) and EF (inhibition and procedural metacognitive strategies) to establish an optimal? Age range to test Nexxo-training. There is a crucial developmental period based on neural changes in the neural network that supports attention control between the ages of 3 and 7 years (Diamond, Barnett, Thomas, y Munro, 2007). In addition to this, from 7 to 9 years, there is a sudden increase in the activity of the frontal regions, as well as the integration of long-distance connections in the right hemisphere (Perez-Hernandez y Capilla, 2011) which means that this period is sensitive for our attentional training. We consider that younger participants would not be prepared for the proposed tasks. As we have mentioned, attention requires inhibitory control. Although this process develops especially from 5 to 10 years old (Urban, van der Linden, y Barisnikov, 2011), a previous study, using go/no-go tasks, shows a significant improvement in this ability between 6 and 8 years old (Becker, Isaac, y Hynd, 1987), (Urban et al., 2011) (Becker et al., 1987) which makes this period relevant. EF and procedural metacognition share developmental paths (Roebbers y Feurer, 2016). Orientation and self-regulation strategies are part of these strategies; one of them would be the internal language. Internal language evolved, from more irrelevant speech to task-directed speech especially between ages 2 and 8, (Winsler, Fernyhough, y Montero, 2009). Eight years old seems a crucial moment in the use of this strategy. Finally, another metacognitive strategy would be anticipation. Chevalier y Blaye (2016) showed, using a computerized executive control task in which an anticipation strategy was provided, that younger children (6 years) showed less anticipation than older children (10 years). For the youngest participants, it took longer to respond, and they responded before they had fixed their eyes. Having a fixed glance and being prepared had a positive relationship with the performance in the task. With age,

children use more effective metacognitive strategies in tasks that require executive control. The same authors identify that executive control improves with age, largely mediated by metacognition. Based on this literature, as metacognitive strategies mediate this training, we hypothesize that results in the different age groups may differ. In contrast to other studies, we analyzed training in two different age groups to understand training effects in different developmental periods. Taking into account this information, we have chosen participants aged 6-7 and 8-9 years old for the training. It is plausible to suggest that training cognitive skills without establishing the appropriate developmental level can be a waste of time and resources. With the application of metacognitive strategies, we hypothesize that training will have far transfer effects on children's daily life.

The purpose of this paper is to test the effectiveness of “Nexxo-training” in attention and EF in typically-developing children. If positive results are found, does age moderate the efficacy of the intervention on far transfer? In the present study, we have the following objectives: (1) to develop an attention and EF training through an application (Nexxo) in combination with procedural metacognitive strategies (2) to test Nexxo-training efficacy in typically-developing children aged 6-7 years old with respect to attention and EF, and (3) to test Nexxo-training efficacy in typically-developing children aged 8-9 years old with respect to attention and EF. We assume that effects may be different in the 6-7-year-old group compared to the 8-9-year-old group due to developmental factors.

2. Method

2. 1. Participants

One hundred seventy students from ordinary schools consented to participate, and 103 typically-developing children were selected based on inclusion criteria. The selected children were in the 1st grade ($N = 61$, $M = 6.46$ years, $SD = 0.35$) or the 3rd grade of primary

education ($N = 47$, $M = 8.5$ years, $SD = 0.27$). The parents' professional range displayed a Mdn of 3.00 (IQR=2.00) (0=low, 1=medium-low, 2=medium, 3=medium-high, and 4=high) according to "National Institute of Professional Range" (Spain). Table 1 shows the participants' sociodemographic descriptions, and Figure 1 shows the participant's flow diagram.

Table 1

<i>Sociodemographic Characteristics of Participants</i>				
		RIST	Gender G/B	Age
1st grade of primary	Experimental group	103.81 (13.44)	10/11	77.71 (3.93)
	Active-control group	100.33 (12.31)	10/9	77.00 (4.51)
	Passive-control group	97.62 (14.56)	11/10	77.76 (4.60)
	<i>F</i> (2,51)	1.081 (<i>p</i> = .347)		.137 (<i>p</i> = .873)
3rd grade of primary	Experimental group	108.43 (12.91)	9/7	101.79 (2.99)
	Active-control group	106.90 (14.13)	8/7	103.30 (2.79)
	Passive-control group	104.80 (12.04)	9/7	101.47 (3.56)
	<i>F</i> (2,36)	.289		1.073

($p = .751$)

($p = .353$)

Table 1 legend: G=girls; B=boys. RIST: Reynolds Intellectual Screening Test. Age= participants' age in terms of months.

The inclusion criteria were: (1) between the ages of 6-7 and 8-9 years; (2) no previous diagnosis of diseases or disorders related to developmental delays; (3) no psychological or speech therapy treatment required at the time of the study or earlier; (4) Spanish-speaking monolingual; (5) no diagnosis of learning difficulties or course repetition; (6) schooled in ordinary schools, and (7) not scoring more than 2 standard deviations above at pretest in behavioral problems, EF, and attentional problems scale from Evaluation System of Children and Adolescent, SENA (Fernández-Pinto, Santamaría, Sánchez-Sánchez, Carrasco, y Del Barrio, 2015) and/or in cognitive scores of the Reynolds Intellectual Screening Test, RIST (Reynolds y Kamphaus, 2003). Criteria 1-6 were obtained through a parent's questionnaire. Different schools were contacted to participated in the study, finally 2 of them agreed to participate. There we no economic benefits for participation.

Sample size was estimated by using 'Epidat 4.1'. The sample size calculation was based on the assumption that enrollment of 90 participants (30 children in passive-control, 30 in active-control, and 30 in Nexxo - training group) would provide the trial with 95% power to detect an absolute difference of at least 5.00 units.

2. 2. Materials and Procedure

In accordance with the Declaration of Helsinki, written informed parental consent was obtained from the parent of each participant. This study was approved by the ethics committee of the San Carlos Hospital (n° 15/315-E) in June 2015.

A pilot version of the Nexxo application was developed for the study in October 2015 (Tapp-mobile, 2015). After obtaining the parents' informed consent, the participants underwent intelligence and behavioural assessments. The baseline included one individual test and questionnaires filled out by parents. The participants were assessed at baseline (t1), at post-intervention (t2) and at a 2-month follow up (t3). The experimental group received a 5-week intervention, the active-control group received intervention through game-like applications over the same time-period, and the passive-control group had no training at all.

The dependent variables were the following: Attention and Executive Functions. These domains were assessed using the SENA (Fernández-Pinto et al., 2015: index of EF problems, index of Attention problems, and the BRIEF-2 (Gioia, Isquith, Guy, y Kenworthy, 2000): index of Supervision, and Global index of EF.

The Nexxo-training was the independent variable: Nexxo app (go/no-go and stop-signal tasks) + procedural metacognitive strategies.

Overview of assessments instruments

1. The RIST (Reynold et al., 2009), used for inclusion criteria, is a screening intelligence test which determines a general index of intelligence ($M=100$, $SD = 15$). To evaluate the transfer effects of Nexxo-training, we assessed children's behavior rated by parents at t1, t2, and t3. We have chosen this type of assessment to overcome the difficulties of the previous assessments which use "lab" tests to measure attention and EF in terms of "verisimilitude" (the degree to which an assessment task is similar to the those in real life and) and "veracity" (predictability value of cognitive assessment in the participant's life) (Chaytor y Schmitter-Edgecombe, 2003; Franzen y Wilhelm, 1996; Olson, K., Jacobson, y Van Oot, 2013). Questionnaires seem to be a

good solution as measures of the processes and behaviors in the child's "real life" (Chaytor y Schmitter-Edgecombe, 2003).

2. The SENA (Fernández-Pinto et al., 2015) is a standardized questionnaire based on DSM-5, the standard classification of mental disorders with 3 reports (teacher, parents and self-report), which allows us to assess emotional or behavioral problems in children aged 3 to 18 years old. Regarding Attention, EF and Hyperactivity-impulsivity, higher scores indicate problems in those constructs (T, typical scale $M = 50$, $SD = 10$), reliability is based on Cronbach's alpha $\geq .70$ for all scales. SENA was used at pretest, post-test and follow up.
3. The BRIEF-2 (Gioia, Isquith, Guy, y Kenworthy, 2000), is a standardized test for 5 to 18-year-olds focusing on the assessment of EF with 2 reports (teachers and parents). For the study, we used the Spanish adaptation. It provides different index scores, such as inhibition, flexibility, supervision, etc. It provides a global EF score. Higher scores mean problems in those constructs (T, typical scale $M = 50$, $SD = 10$), reliability is based on Cronbach's alpha $M = .86$. BRIEF was used at pretest, post-test and follow up.

Overview of interventions

The Nexxo intervention (N=36) was applied by instructors through a special training script. Nexxo-training combines the repetition of EF and attentional task plus strategies to enhance the task. We refer to those strategies as "procedural metacognitive strategies." In addition to general strategies to the whole group, we provide compensatory strategies to those participants who experience higher difficulties while training. The Nexxo-training occurred over a 5-week intervention period (2 sessions per week/15 minutes each). Figure 2 shows the Nexxo-training description.

Figure 2.

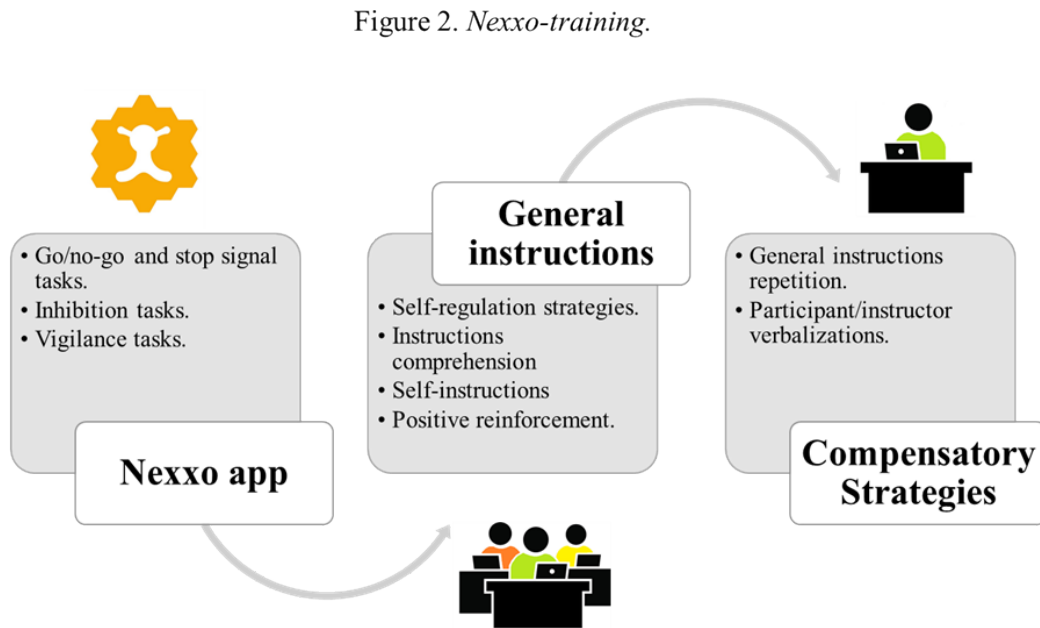


Figure 2. Nexxo-training description. Nexxo 2016. Reproduced with permission from tap-mobile.

Nexxo-training intervention is based on models of attention and EF (Anderson, Peter, 2002; Anderson, Peter J., 2010; Miyake, Akira et al., 2000; Petersen y Posner, 2012; Posner y Petersen, 1990; Van Zomeren y Brouwer, 1994) and metacognition (Efklides, 2009; Favell, 1979; Perez-Hernandez et al., 2011). Concretely, The Nexxo application is based on neuropsychological models known as "go/no-go" and "stop signal" tasks (Logan, 1994; Shiffrin y Schneider, 1977). These tasks involve suppression of an on-going response (inhibition), and alertness by training vigilance, in which changes were to be detected when only a low rate of relevant stimuli was presented (Sturm, W., 2008). The game had two different blocks. In the vigilance block, the user had to tap the screen sporadically (discriminating between possible distractors and thus maintaining a state of alertness, known as "vigilance") In the inhibition block, the user must tap very frequently (holding back an automatic response, known as "inhibition or self-control"). The mechanics of the game

included requirements to press the screen in the presence of a specific stimulus, for example: "tap when you see something edible".

In the vigilance block, the rate of target presence was less than 30% (70% no-go probability), whereas, in the inhibition block, the rate of target presence was more than 70% (30% no-go probability). The instructions and stimuli were changed from game to game. Figure 3 shows an example.

Figure 3.

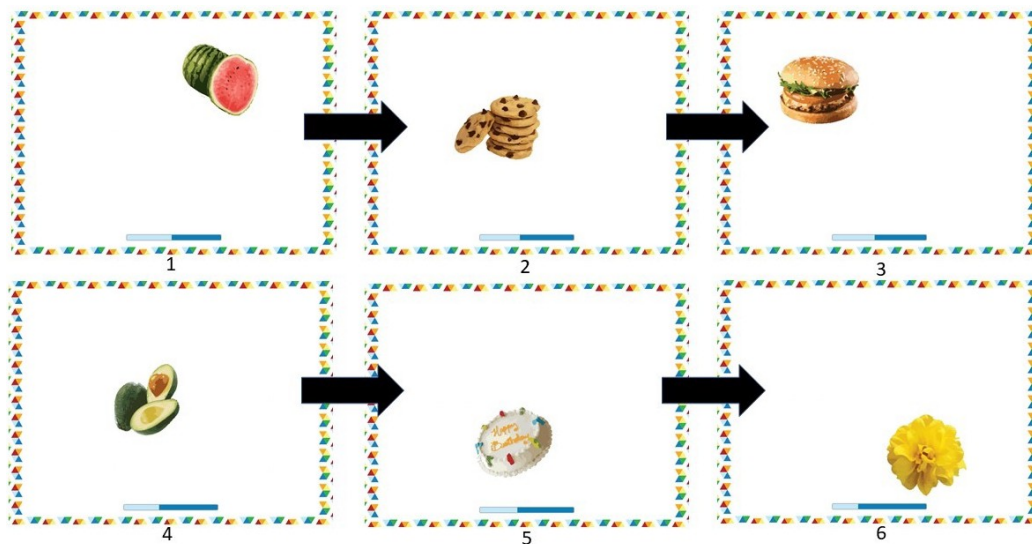


Figure 3. Nexxo activity example. Screenshots from inhibition block.

Instruction: "tap when you see something edible". The user must tap in all screens except in the last one when the hold response is required. Nexxo 2016. Reproduced with permission from tap-mobile.

The whole Nexxo-training nature and structure (tasks), administration and dose/duration details can be seen in **Supplemental Material**.

The participants played 30 games distributed over two different blocks in the first level. The Nexxo app involves processing speed (as the screen transition was 1 second), stimulus processing and decision to tap or not tap required perceptual-motor agility; and visual and auditory discrimination given the presence of both types of stimuli. Finally, the Nexxo app registers the two types of errors: commission errors (the user tapped the screen when a

response should have been withheld) and omission errors (the user did not tap when a response was required). For more information:

<https://neuroapp.wordpress.com/2017/03/02/nexxo-2/>. See more information about Nexxo-training in the supplementary information.

The intervention also involved procedural metacognitive strategies inspired by Perez-Hernandez et al., (2011) and Efklides (2009) carried out by the instructor and recorded for each participant in each session in a register, as follows:

(1) *general instructions (provided to the whole group)*: (a) signal to prepare for the start of the session (participants had to put their hands over two fixed stickers when they heard the cue “get into position” and wait until the instructor gave further instructions), (b) “visual self-instruction” (wait-see-tap), a visual reminder of how to perform the games in order to foster self-control, and (c) verbal self-instructions: “I am a good observer, I will not fall for any tricks”, (d) instructions comprehension: the instructor reads the instructions of the game out loud and asks the participants to say when they have to tap in each game through fixed questions (e.g., “when do we have to tap?”), and, (e) verbal reinforcement after games (e.g., “very good”).

(2) *compensatory strategies (provided to participants with higher difficulties while training)*: individual reinforcement if required (a) repeating the signal for starting, (b) repeating self-instruction, (c) repeating instructions, (d) child verbalizations through the game (say out loud what appears on the screen), or in the last case, (e) instructor verbalizations (say out loud what appears on the screen), and (f) positive reinforcement through gestures or saying “well done” out loud. More information about strategies applied can be found in Rossignoli-Palomeque, T; Quiros-Godoy, M; Perez-Hernandez, E y González-Marqués, J (in press).

Additionally, after each game, the participants were shown how many stars they received on the screen as a reinforcement (0-3 depending on the level of performance).

Active-control intervention (N=36): this group spent the same time as the experimental group and under the same conditions. The children were asked to play 3 different games: “Lego Star Wars”, a video-game like application, “Chocolapps” an application for drawing, and “Boo” an app that contains different games and pet care activities. The children were allowed to play the three apps indiscriminately, and the instructor noted which games were played by each participant in every session. Games are not intended as CT but as ludic games.

Both interventions were applied using iPad Mini 2 devices in groups of 8 students seated in a u-shaped table disposition, during school time.

The passive-control group (N=36) received no intervention and continued as usual.

Randomized active-controlled trial design

Participants were randomly assigned to one of three groups: (1) an experimental group, (2) an active-control group, and (3) a passive-control group. Children were assigned to different groups based on the criteria of Higgins y Green (2006) using a computerized random number generator. To oversee the placebo effect, we included an active control group.

Families and participants were informed of the existence of 3 groups, in which two consisted of computer activities. In this way, they were not able to know the children’s allocation.

To assess the impact of Nexxo-training, the participants and examiners were blind to the participants’ assignment. Examiners and instructors were psychologists. All agents (10) partook in a 5-hour training program. In order to avoid bias, examiners and instructors were not the same. Examiners conducted the assessments, whereas instructors applied the training (experimental and active control group). All the instructors followed the same script to

conduct Nexxo-training. Children in the experimental and active-control group knew that other groups were also doing computer-like games activities. Although our study is not a double-blind study, we applied these measures to avoid bias. Finally, fidelity to the conditions of the training was ensured as interventions took part at school.

Data Analysis

This study was conducted to evaluate the effects of the Nexxo-training on attention and EF in typically developing children. The pre- and post-training scores in these functions were presented in Table 2

First, we conducted an analysis at t1 in both groups of age (normality test, one-factor ANOVA, average, and variance homogeneity). This was done to exclude the possibility that any pre-existing difference between the groups affected the results of each measure. To test objectives 2 and 3, we analyzed 1st grade and 3rd grade separately. It would not be possible to detect different effects of the training in the different age groups if we joined both age groups, even if we controlled for age.

The data analysis was carried out through a repeated-measures mixed ANOVA, where two factors were included: time (3 measurements: t1, t2, t3), and group (experimental/active-control/passive-control). The main effects and inter-group effects were analyzed. We applied Bonferroni post hoc tests, and the effect size estimates were calculated using eta square (η^2), where $|\eta^2 \geq 0.01$ is regarded as a small effect, $|\eta^2 \geq 0.06$ as a medium effect, and $|\eta^2 \geq 0.14$ as a large effect. This is considered as a descriptive index of the strength of association between an experimental factor (main effect or interaction effect) and a dependent variable (Nouchi et al., 2013). Regarding p -value, it ranges from 0-1. Higher values indicate less probability of committing a type II error. The level of significance was set at $p < .05$.

Missing data were imputed using Missing Value Analysis in the Statistical Package for the Social Sciences (SPSS). The analyses were conducted using IBM SPSS statistics 22.

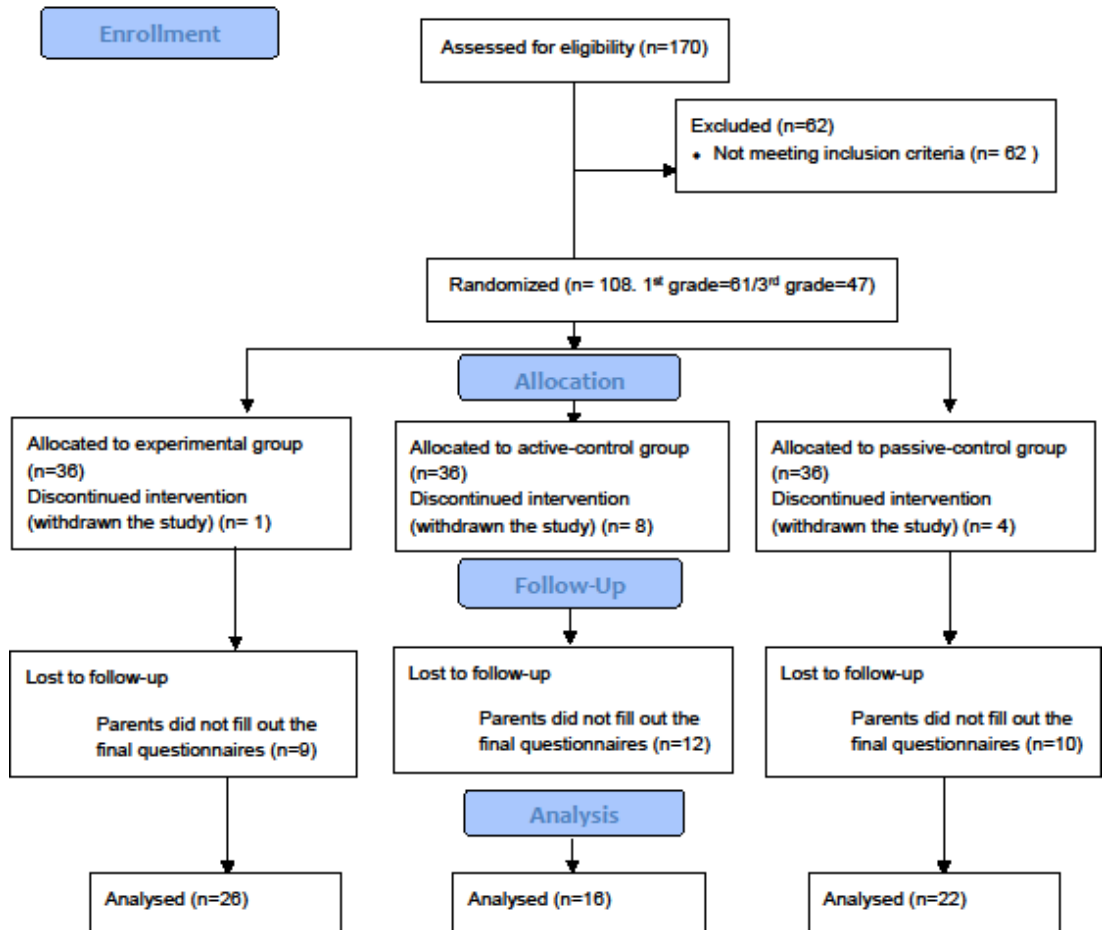
3.

Results

Figure 1 show participant's flow diagram

Figure 1.

Figure 1. Participant's Flow Diagram



CONSORT flow diagram for randomized, controlled trials. The inclusion criteria were: (1) between the ages of 6-7 and 8-9 years; (2) no previous diagnosis of diseases or disorders related to developmental delays (3) no psychological or speech therapy treatment required at the time of the study or earlier; (4) Spanish-speaking monolingual; (5) no diagnosis of learning difficulties or course repetition (6) schooled in ordinary schools, and (7) not scoring more than 2 standard deviations above the baseline in behavioral problems, EF and attentional problems scales from Evaluation System of Children and Adolescent, SENA (Fernández-Pinto, Santamaría, Sánchez-Sánchez, Carrasco, & Del Barrio, 2015) or in cognitive scores of the Reynolds Intellectual Screening Test, RIST (Reynolds & Kamphaus, 2003).

Table 2 shows the descriptive statistics of the groups at t1, t2, and t3 of each dependent variable as well as ANOVA t1 and the (3x3) ANOVAs results.

Table 2

<i>Average and standard deviation of behavioral assessment of groups (t1, t2, and t3).</i>								
		Experimental	Active-control	Passive-control	ANOVA t1 p-value	Results of the (3x3) ANOVAs p-value/ effect size (f^2)		
		1st Grade Primary Family report				Time	Group	Time*group
SENA Executive Functions problems	t1	48.11 (6.05)	51.30 (7.77)	45.33 (7.43)	.104	.091/.088	.163/.130	.998/.001
	t2	48.14 (9.67)	49.62 (7.73)	43.00 (9.07)				
	t3	44.57 (10.13)	49.56 (8.08)	43.87 (6.71)				
SENA Attention problems	t1	49.61 (7.17)	50.50 (7.07)	47.94 (7.42)	.635	.872/.005	.654/.032	.991/.005
	t2	50.00 (9.88)	50.12 (7.36)	46.29 (6.79)				

	t3	45.93 (8.54)	51.22 (9.66)	48.37 (5.58)				
	t1	46.60 (6.38)	46.44 (6.63)	45.57 (7.47)	.914			
BRIEF Executive Functions index	t2	47.27 (10.48)	47.75 (4.83)	46.14 (7.09)		.061/ .110	.974/ .002	.982/ .008
	t3	45.67 (9.19)	45.50 (6.91)	44.00 (6.54)				
	t1	46.33 (7.59)	45.00 (6.84)	47.28 (9.01)	.800			
BRIEF Supervision	t2	46.27 (9.38)	47.12 (6.40)	45.93 (9.56)		.045/ .121	.659/ .034	.836/ .029
	t3	42.00 (10.93)	45.37 (8.76)	41.75 (6.85)				
3rd Grade Primary Family report								
	t1	45.08 (10.04)	46.83 (8.20)	48.67 (6.94)	.517			
SENA Executive Functions problems	t2	45.17 (11.53)	46.74 (8.62)	47.33 (7.08)		.388/ .031	.493/ .046	.068/ .133
	t3	41.54 (10.68)	45.61(8.42)	47.00 (5.49)				

SENA Attention problems	t1	45.58 (7.29)	48.68 (7.80)	52.20 (8.00)	.062	.169/ .057	.065/ .167	.051/ .144
	t2	46.42 (6.92)	49.97 (7.99)	52.47 (8.51)				
	t3	42.73 (6.50)	48.36 (7.99)	51.21 (6.93)				
BRIEF Executive Functions index	t1	45.85 (8.87)	44.33 (4.58)	48.07 (5.31)	.422	.228/ .045	.228/ .088	.047/ .138
	t2	44.33 (8.05)	46.56 (6.11)	48.36 (6.23)				
	t3	41.85 (6.52)	45.89 (5.53)	48.00 (5.24)				
BRIEF Supervision	t1	44.54 (7.88)	42.78 (8.57)	47.93 (5.01)	.179	.185/ .051	.027/ .202	.098/ .114
	t2	40.58 (5.60)	43.44 (7.11)	47.92 (6.44)				
	t3	38.92 (7.75)	43.89 (8.31)	47.27 (7.32)				

Table 2. post hoc: a) Differences Experimental-active control b) Differences Experimental-passive-control c) active-control-passive control. Significance: $p \leq .05$ (*). SENA: system of evaluation for children and teenagers BRIEF: Behavior rating inventory of executive functions.

In the 1st grade children, the ANOVA t1 scores showed no significant differences between the groups in all dependent variables. The (3x3) ANOVAs showed no significant differences, with the exception of BRIEF Supervision time effect ($F(2,27) = 3.300, p = .045, \eta^2 = .144, P = .599$). Post hoc contrast showed a significant difference between t2 and t3 ($p = .041$).

In the 3rd grade children, the ANOVA t1 scores showed no significant differences between the groups in all dependent variables. Results for third graders are the followings:

SENA Attention problems

In SENA Attention problems scale, neither group nor time effect were significant, group ($F(2,32) = 3.001, p = .065$), time ($F(2,32) = 1.829, p = .169$). Nevertheless, there was a marginal significant effect in time * group interaction ($F(2,32) = 2.517, p = .051, \eta^2 = .144, P = .680$). Post hoc contrasts showed that the experimental group significantly reduced the score of SENA attention problems at t3 compared to both control groups, experimental vs active-control ($p = .050$) and experimental vs passive-control ($p = .018$).

SENA Executive Functions Problems

In SENA Executive Functions Problems, neither group nor time effect were significant, group ($F(2,32) = .724, p = .493$), time ($F(2,32) = .962, p = .388$). Nevertheless, there was a marginal significant effect in time * group interaction ($F(2,32) = 2.307, p = .068, \eta^2 = .133, P = .637$). Post Hoc contrasts showed that the experimental group significantly reduced the score from t1-t3 ($p = .032$) and from t2-t3 ($p = .035$). These results were not found in the control groups.

BRIEF Global Index of Executive Functions Problems

In the BRIEF Executive Functions Problems scale, neither group nor time effect were significant, group ($F_{(2,34)} = 1.549, p = .228$), time ($F_{(2,34)} = 1.512, p = .228$). There was a significant effect in time * group interaction ($F_{(2,34)} = 2.554, p = .047, \eta^2 = .138; P = .690$). Post Hoc contrasts showed that the experimental group significantly reduced the score compared to passive control group at t3 ($p = .028$). The experimental group significantly reduced the score from t1-t3 ($p = .012$).

BRIEF Supervision

In the BRIEF Supervision, although ANOVA results showed there were no significant differences at t1 ($F_{(2,34)} = 1.691, p = .199$), group effect was significant at post measures ($F_{(2,34)} = 4.061, p = .027, \eta^2 = .202; P = .691$). Post hoc contrast showed a significant difference between the experimental and passive-control group ($p = .025$). The experimental group scored lower at t2 ($p = .018$) and t3 ($p = .014$). Time effect was not significant ($F_{(2,34)} = 1.735, p = .185$). Effect in time * group interaction was not significant ($F_{(2,34)} = 2.051, p = .098$).

Figure 4 shows 3rd graders' evolution in significant variables.

Figure 4.

3rd graders significant results.

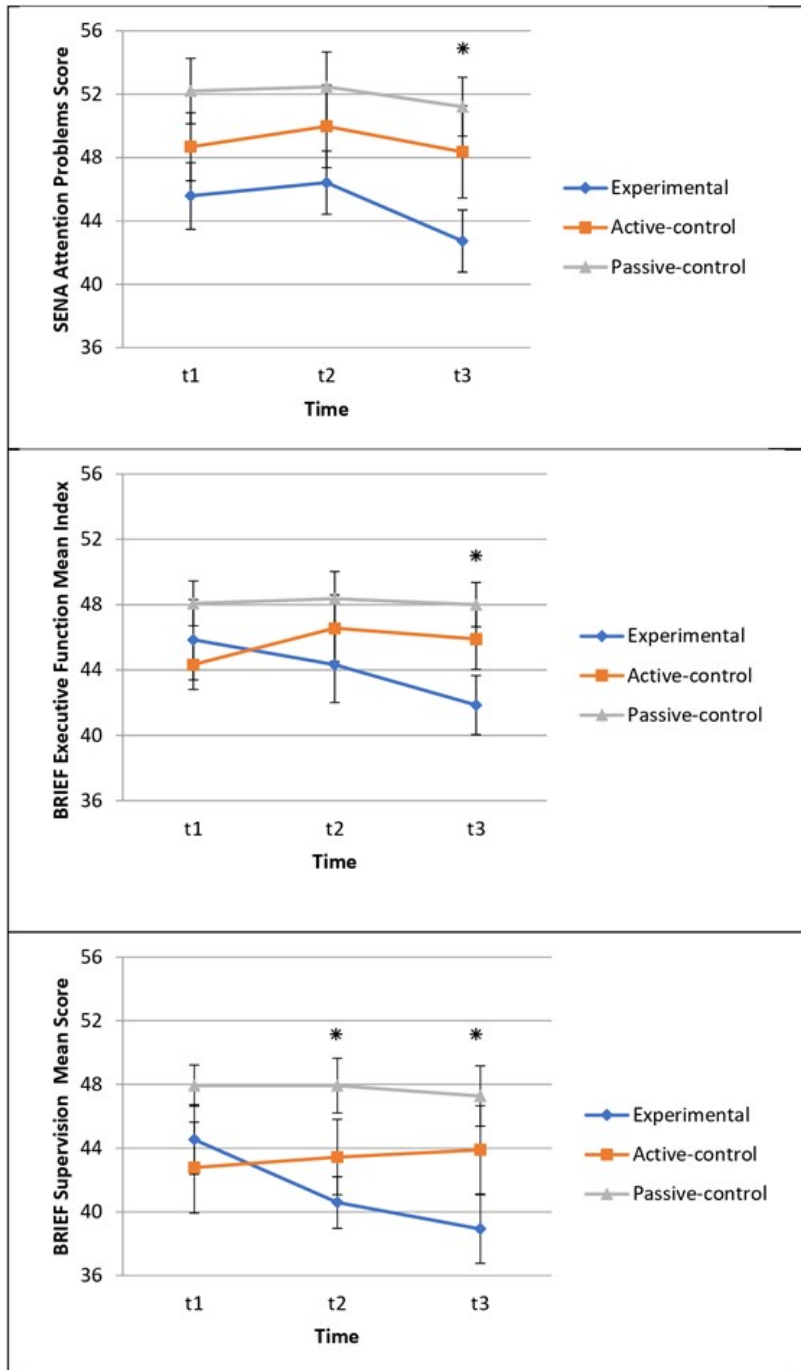


Fig.4. SENA: the system of evaluation for children and teenagers. BRIEF: Behaviour rating inventory of executive functions. Standardized mean scores in the function of the group. * $p < 0.05$. SENA attention problems: differences experimental-passive and active control group. BRIEF Executive Functions: differences experimental-passive control group. BRIEF Supervision: differences experimental-passive control group.

4. Discussion

The Nexxo app has been designed based on well-known attention and EF models in the scientific literature (Anderson, Peter, 2002; Anderson, Peter J., 2010; Miyake, Akira et al., 2000; Petersen y Posner, 2012; Posner y Petersen, 1990; Van Zomeren y Brouwer, 1994) and was combined with strategies to improve procedural metacognition (Efklides, 2009; Favell, 1979; Perez-Hernandez et al., 2011). Based on our knowledge, this is the first training that integrates strategies and CT through an application. Nexxo-training has been tested in the developmental period in which these processes normally develop (Lange- Küttner, 2010; Perez-Hernandez y Capilla, 2011; Reck y Hund, 2011; Urban, Van der Linden, y Barisnikov, 2011). Nexxo-training is a “strategy-based” training that, apart from the repetition of attention and EF tasks, provides general instructions (based on developmental theories) along with compensatory strategies for those who experienced higher difficulties during the training. As seen in the Spearman correlations of a previous study (Rossignoli-Palomeque, Quiros-Godoy, Perez-Hernandez y González-Marqués, 2019) those strategies are needed more for those who experienced difficulties while training (difficulties in orientation and anticipation, understanding instructions, controlling response when not required, and maintaining attention). This gives us an idea of the importance of the compensatory strategies. Moreover, 80.38% of participants in the training group required some compensatory strategies at some point. The most important present finding was that the Nexxo-training revealed a trend-level improvement in 3rd grade participants in supervision, as reported by the family in the home environment. This means that this improvement is reflected in the children’s behavior and remains after the post-intervention period. Attention and EF problems were also reduced at follow up for the experimental group. Taking into account the fact that we did not find significant results in post-training in those variables, we

hypothesize that this is due to the short period of time between pre and post-assessments. Although the results are moderately significant, this trial is extremely rigorous as it includes: (1) an active-control group, (most studies of CT do not feature this design), (2) examiners and parents were blind to the group assignment of participants, and, (3) rigorous control in inclusion criteria to ensure a typically-developing sample.

Regarding the lack of effects for 1st graders, we hypothesize that this is due to two reasons: One is that there is a significant increase in the development of the trained cognitive processes after the 1st grade (Becker et al., 1987; Chevalier y Blaye, 2016; Perez-Hernandez y Capilla, 2011). The other is due to developmental factors; the use of strategies requires a higher level of cognitive demands for 1st graders than for 3rd graders (Miller, 1990). We cannot statistically support the suitability of training up to or after 7 years of age. Nevertheless, there is a tendency to reach a higher number of significant results in 3rd-grade students. In this sense, further research is needed.

The current study presents several strengths. First, it is a study about a touchscreen intervention in combination with procedural metacognitive strategies in typically-developing children. While previous studies yielded better results in combined trainings, or “strategy-based training” (Graziano y Hart, 2016; Partanen, Jansson, Lisspers, y Sundin, 2015) ours is an innovative approach for cognitive training, which shows potential for further research. Furthermore, it contributes scientific data of a commercially available application based on scientific background. As we have found positive results in typically-developing children in which the inclusion criteria have been carefully controlled, we expect to find more encouraging results in children with some difficulties in attention and EF. While we do not have many significant results, for the significant results we do have, most effect sizes and observed power values are large. This means that the probability that the significant results

would be caused randomly is quite small, and the effect of the training in the sample is relevant. Secondly, unlike previous studies of CT with touchscreens and children (Kirk et al., 2017; Vélez-Coto et al., 2017), we used a randomized, active-controlled trial. Most CT studies do not include active-control (Rossignoli-Palomeque, T., Pérez-Hernández, y González Marqués, 2018). The randomized active-controlled trial provides an excellent means to test the effectiveness of CT controlling the test-retest effects (Nouchi et al., 2013) and bias due to the psychological expectations of interventions (Turner, Deyo, Loeser, Von Korff, y Fordyce, 1994). As shown in the results, the act of playing with a touchscreen application by itself (active-control group) does not provide positive results. Finally, in our view, computer-based interventions must be directed by a specialist and reinforced with complementary strategies.

It is also important to consider the limitations of this study. First, some transfer effects may be non-tested due to the limited intervention time. The minimum CT time with positive results in typically-developing children was shown by Rueda et al., (2005) to be a total of 5 hours. Secondly, we have no teachers' reports included. The teachers did not fill out the teacher version because the number of participants and the short duration of the intervention, would have imposed a work overload for them and would not have guaranteed the validity of the assessment. Thirdly, our sample size is smaller than calculated because of the rigorous control in inclusion criteria to ensure a typically-developing sample, and the fact that several parents did not fill out the final questionnaires. This has reduced the sample analyzed. Fourthly we did not test near transfer effects (effects in the task directly trained), because our objective was to test Nexxo-training effects on attention and EF in daily life (far transfer), and for this objective questionnaires seem to be suitable tools (Chaytor y Schmitter-Edgecombe, 2003). Far transfer is the main objective of cognitive trainings (Simons et al., 2016). Finally, Nexxo-training is non-adaptive. Previous studies in children suggest that

training that adjusts to the user's level, is more effective for improving cognitive functions (Chacko et al., 2014; Dongen-Boomsma, Vollebregt, Buitelaar, y Slaats-Willemse, 2014; Green et al., 2012; Holmes, Gathercole, y Dunning, 2009; Klingberg, Forssberg, y Westerberg, 2002). Nevertheless, we have offset this by using "compensatory strategies". The Nexxo - training adapts to user execution through procedural metacognitive strategies during the training process. Moreover, these strategies are meant to improve participants' performance in real-life contexts. This is the main strength of this "strategy-based" training.

4. 1. Conclusions

Nexxo-training revealed a trend-level improvement in attention and executive functions for children in the 3rd grade. The 3rd grade experimental group displayed a significant reduction in attentional problems at follow-up compared to both control groups. Executive function problems were also reduced at follow-up in the experimental group. Participants in this group improved in supervision (self-monitoring) at post-intervention and follow-up compared to passive-controls. Although group effect was not significant at t1, it was significant at post measures in the experimental group compared to passive-controls.

Conflict of Interest

TRP has the original idea of Nexxo application and participated in Nexxo games design. The Nexxo application for iPad is a commercially available app (a free-to-install app with in-app purchases). TRP is part of the developer's team of the Nexxo application for iPad. EPH, JGM does not have any competing interests.

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Author Contributions

Conceived Application: TRP, conceive and designed the experiments: TRP, EPH and JGM. Coordinated the experiments: TRP, EPH. Analyzed the data: TRP, EPH, JGM. Wrote the paper: TRP. Reviewed the paper: EPH, JGM

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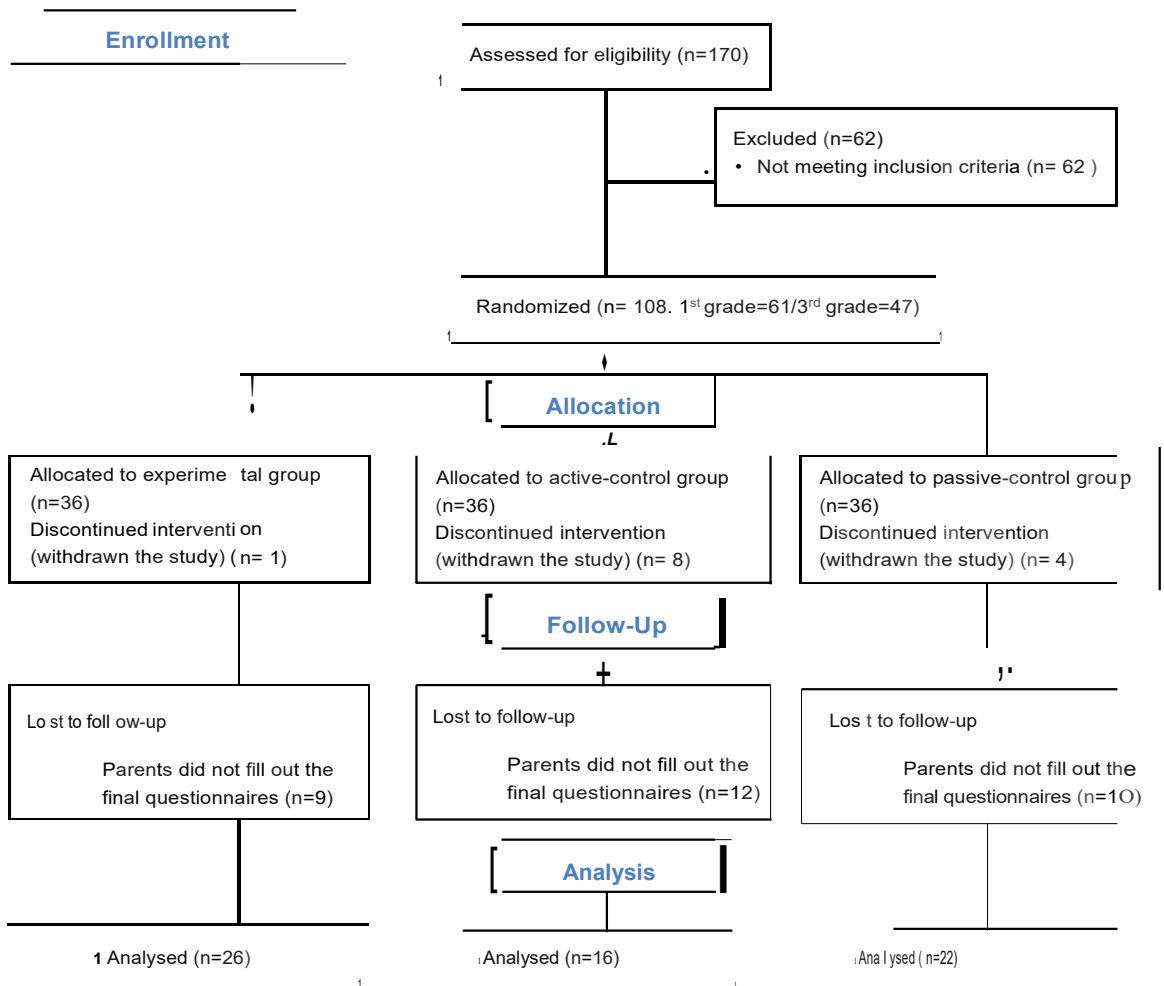
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CONSORT flow diagram for randomized, controlled trials. The inclusion criteria were: (1) between the ages of 5-7 and 8-9 years; (2) no previous diagnosis of diseases or disorders related to developmental delays (3) no psychological or speech therapy treatment required at the time of the study or earlier; (4) Spanish-speaking monolingual; (5) no diagnosis of learning difficulties or course repetition (6) schooled in ordinary schools, and (7) not scoring more than 2 standard deviations above the baseline in behavioral problems, EF and attentional problems scales from Evaluation System of Children and Adolescent, SENA (Fernández-Pinto, Santamaría, Sánchez-Sánchez, Carrasco, y Del Barrio, 2015) or in cognitive scores of the Reynolds Intellectual Screening Test, RIST (Reynolds y Kamphaus, 2003).

Figure 2. *Nexxo-training*.

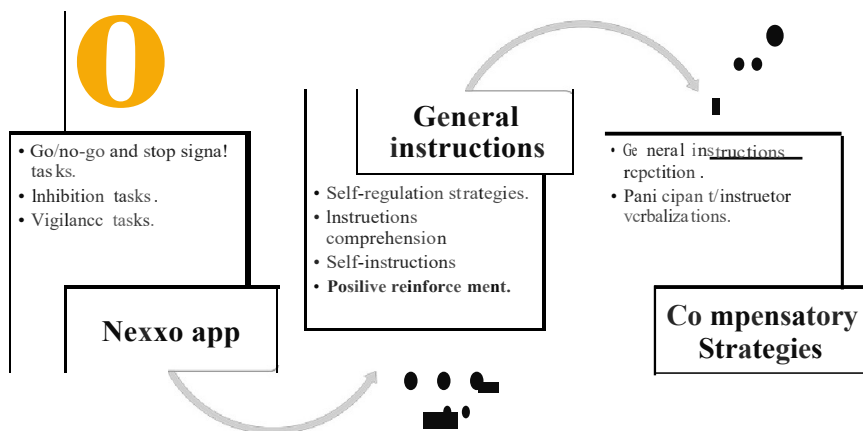


Figure 2. Nexxo-training description. Nexxo 2016. Reproduced with permission from tap-mobile.

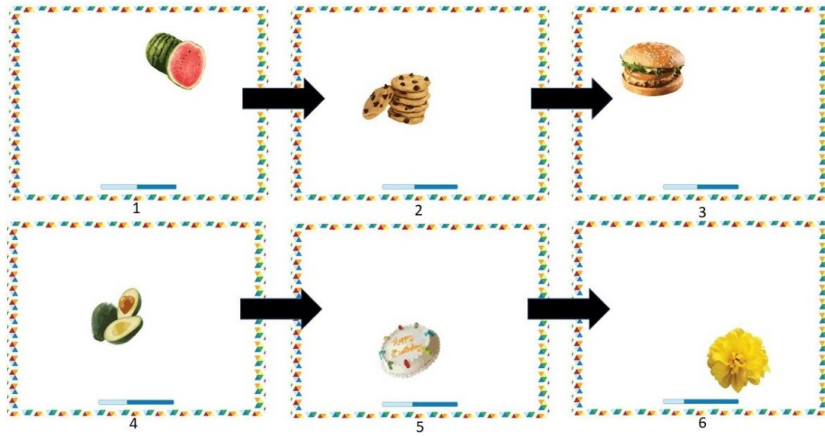


Figure 3. Nexxo activity example. Screenshots from inhibition block.
Instruction: "tap when you see something edible". The user must tap in all screens except in the last one when the hold response is required. Nexxo 2016. Reproduced with permission from tap-mobile.

3rd graders significant results.

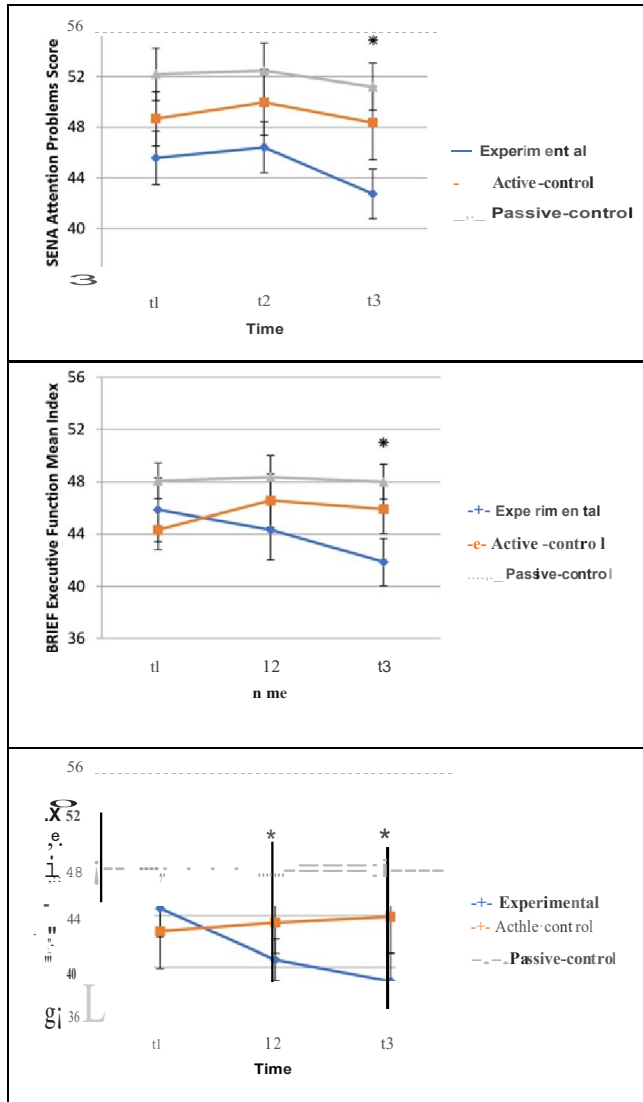


Fig.4. SENA: system of evaluation for children and teenagers. BRIEF: Behaviour rating inventory of executive functions. Standardized mean scores in function of group. * $p < 0.05$. SENA attention problems: differences experimental-passive and active control group. BRIEF Executive Functions: differences experimental-passive control group. BRIEF Supervision: differences experimental-passive control group.

Table 1

<i>Sociodemographic Characteristics of Participants</i>				
		RIST	Gender G/B	Age
1st grade of primary	Experimental group	103.81 (13.44)	10/11	77.71 (3.93)
	Active-control group	100.33 (12.31)	10/9	77.00 (4.51)
	Passive-control group	97.62 (14.56)	11/10	77.76 (4.60)
	<i>F</i> (2,51)	1.081 (<i>p</i> = .347)		.137 (<i>p</i> = .873)
3rd grade of primary	Experimental group	108.43 (12.91)	9/7	101.79 (2.99)
	Active-control group	106.90 (14.13)	8/7	103.30 (2.79)
	Passive-control group	104.80 (12.04)	9/7	101.47 (3.56)
	<i>F</i> (2,36)	.289 (<i>p</i> = .751)		1.073 (<i>p</i> = .353)

Table 1 legend: G=girls; B=boys. RIST: Reynolds Intellectual Screening Test.

Table 2

<i>Average and standard deviation of behavioural assessment of groups (t1, t2 and t3).</i>									
		Experimental	Active-control	Passive-control	ANOVA t1 p-value	Results of the (3x3) ANOVAs p-value/ effect size (η^2)			
		1st Grade Primary Family report				Time	Group	Time*group	
SENA Executive Functions problems	t1	48.11 (6.05)	51.30 (7.77)	45.33 (7.43)	.104	.091/ .088	.163/ .130	.998/ .001	
	t2	48.14 (9.67)	49.62 (7.73)	43.00 (9.07)					
	t3	44.57 (10.13)	49.56 (8.08)	43.87 (6.71)					
SENA Attention problems	t1	49.61 (7.17)	50.50 (7.07)	47.94 (7.42)	.635	.872/ .005	.654/ .032	.991/ .005	
	t2	50.00 (9.88)	50.12 (7.36)	46.29 (6.79)					
	t3	45.93 (8.54)	51.22 (9.66)	48.37 (5.58)					
	t1	46.60 (6.38)	46.44 (6.63)	45.57 (7.47)	.914				

BRIEF Executive Functions index	t2	47.27 (10.48)	47.75 (4.83)	46.14 (7.09)		.061/ .110	.974/ .002	.982/ .008
	t3	45.67 (9.19)	45.50 (6.91)	44.00 (6.54)				
BRIEF Supervision	t1	46.33 (7.59)	45.00 (6.84)	47.28 (9.01)	.800			
	t2	46.27 (9.38)	47.12 (6.40)	45.93 (9.56)		.045/ .121	.659/ .034	.836/ .029
	t3	42.00 (10.93)	45.37 (8.76)	41.75 (6.85)				
3rd Grade Primary Family report								
SENA Executive Functions problems	t1	45.08 (10.04)	46.83 (8.20)	48.67 (6.94)	.517			
	t2	45.17 (11.53)	46.74 (8.62)	47.33 (7.08)		.388/ .031	.493/ .046	.068/ .133
	t3	41.54 (10.68)	45.61(8.42)	47.00 (5.49)				
SENA Attention problems	t1	45.58 (7.29)	48.68 (7.80)	52.20 (8.00)	.062	.169/ .057	.065/ .167	.051/ .144
	t2	46.42 (6.92)	49.97 (7.99)	52.47 (8.51)				
	t3	42.73 (6.50)	48.36 (7.99)	51.21 (6.93)				

BRIEF Executive Functions index	t1	45.85 (8.87)	44.33 (4.58)	48.07 (5.31)	.422	.228/ .045	.228/ .088	.047/ .138
	t2	44.33 (8.05)	46.56 (6.11)	48.36 (6.23)				
	t3	41.85 (6.52)	45.89 (5.53)	48.00 (5.24)				
BRIEF Supervision	t1	44.54 (7.88)	42.78 (8.57)	47.93 (5.01)	.179	.185/ .051	.027/ .202	.098/ .114
	t2	40.58 (5.60)	43.44 (7.11)	47.92 (6.44)				
	t3	38.92 (7.75)	43.89 (8.31)	47.27 (7.32)				

Table 2. post hoc: a) Differences Experimental-active control b) Differences Experimental-passive-control c) active-control-passive control. Significance: $p \leq .05$ (*). SENA: system of evaluation for children and teenagers BRIEF: Behavior rating inventory of executive functions.

Table 3.

Spearman correlation between level of performance in the Nexxo application and compensatory strategies needed

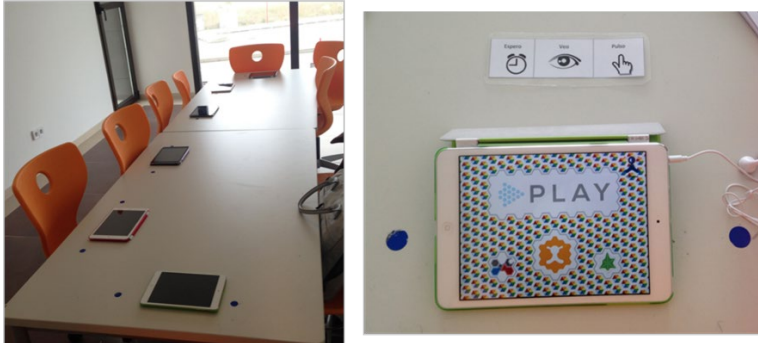
	Total score of Inhibition	Total score of Vigilance
Repeating the Signal for starting	-0.562**	-0.498**
Repeating Self-instructions	-0.381*	-0.345*
Repeating Instructions	-0.660**	-0.523**
Child verbalisations	-0.243	-0.310
Instructor verbalisations	-0.226	-0.226
Reinforcement through gestures	-0.39	-0.210
Total of compensatory strategies	-0.564**	-0.506**

Table 3: **Significant correlations at two-tailed test (p value= $p \leq 0.01$) *Significant correlations at one-tailed test (p value= $p \leq 0.05$).

Supplementary Material

Figure 1.

Example of Nexxo-training placement.



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Table 1

Supplementary data: Nexxo-training games descriptions

Session/games	Games description	Game's command (read by instructor)	Instructor's specific command clarification
1. V15(x2) I20 (x2) I19 (x2)	V15: number of stimulus_50/appearance of target_12	Tap each time a bear appears on the screen.	When do we have to tap? (children "when we see a bear"); and if any other animal appears? (children: "then we shouldn't tap".)
	I20: number of stimulus_60/appearance of target_39	Tap when you see the number 5.	When do we have to tap? (Children: "when the number 5 appears"). If another number appears, but it's not the number 5, we shouldn't tap.
	I19: number of stimulus_40/appearance of target_33	Tap every time you see something edible.	When do we have to tap? (children: "when something edible appears"), and if something that is not edible appears? (children: "then, we shouldn't tap").

2. V14 (x2) I18 (x2) I17(x2)	V14: number of stimulus_90/appearance of target_16	Tap each time you see the following image (with the same color and position).	When do we have to tap? (children: “when this figure appears on the screen”); and if it appears in a different color? (children: “then we shouldn’t tap”); and if it appears in the opposite direction or in any other direction? (children: “then, we shouldn’t tap”). It has to appear with the same color and position as the one you see in the instructions.
	I18: number of stimulus_40/appearance of target_28	Tap every time you hear this sound.	When do he have to tap? (children: “each time we hear this sound” (press the sound symbol)). Instructor reproduces it twice.
	I17: number of stimulus_72/appearance of target_57	Tap every time you see the letter <i>d</i> .	When do we have to tap? (children: “when we see the letter <i>d</i> ”); and if we see a letter that is similar to <i>d</i> but is not <i>d</i> ? (children: “we shouldn’t tap, only when we see <i>d</i> ”).
3. V13(x2) V12(x2) I16(x2)	V13: number of stimulus_80/appearance of target_10	Tap when you see this symbol appear with the number 9.	When do we have to tap? (children: “when we see this symbol and the number 9 at the same time”); and if we see this figure but not the number 9? (Children: “we shouldn’t tap”). And if the number 9 appears, but not this figure or the same but in another color or position? Then, we shouldn’t tap. Number 9 could appear in any color and would be correct.
	V12: number of stimulus_50/appearance of target_8	Tap each time you see a cross.	When do we have to tap? (children: “when we see a cross”). The cross’ color doesn’t matter; each time we see a cross, we have to tap.

	I16: number of stimulus_72/appearance of target_57	Tap every time you see the following figure.	When do we have to tap? (children: “when we see this figure”). And if it appears in a different color? (children: “then, we shouldn’t tap”).
4. V11(x2) I14(x2) I13(x2)	V11: number of stimulus_30/appearance of target_8	Tap when both pictures on the screen are exactly the same.	When do we have to tap? (children: “when both pictures are the same”). Both pictures have to be exactly the same: same shape, size and color.
	I14: number of stimulus_40/appearance of target_32	Tap when you see that both figures are the same (in the same position).	When do we have to tap? (children: “when both figures are the same”). And if both figures are the same, but they appear in a different positions? Then, we shouldn’t tap.
	I13: number of stimulus_40/appearance of target_29	Tap when you see any letter except <i>P</i> .	When do we have to tap? (children: “when we see a letter except <i>P</i> ”). We only have to tap when the letter is not <i>P</i> .
5. V10(x2) V9(x2) I12(x2)	V10: number of stimulus_30/appearance of target_5	Tap each time you see a baby on the screen.	When do we have to tap? (Children: “when we see a baby on the screen”) An if there is a man or a woman? Then we shouldn’t tap, only when there is a baby, regardless the baby’s sex.
	V9: number of stimulus_40/appearance of target_5	Tap when you see a red shape.	When do we have to tap? (children: “when we see a red shape”). And what if a red animal appears? In this case we shouldn’t tap because it is not a figure.
	I12: number of stimulus_40/appearance of target_5	Tap when you see this face.	When do we have to tap? (children: “when we see this face”). And if the face looks the same, but with a different expression? (children: then, we

			shouldn't tap).
6.V7(x2) I11(x2) I10(x2)	V7: number of stimulus_45/appearance of target_12	Tap each time you see a yellow circle with this sound.	When do we have to tap? (children: "when we see a yellow circle and hear this sound"). And if the yellow circle appears, but with a different sound? (children: "then, we shouldn't tap") And if the sound is the same, but the circle is not yellow? (children: "then, we shouldn't tap").
	I11: number of stimulus_50/appearance of target_39	Tap any picture except when it is a picture of animals.	When do we have to tap? (children: any picture that isn't a picture of animals"). And when an animal appears? (children: "then, we shouldn't tap).
	I10: number of stimulus_50/appearance of target_35	Tap when you see one red arrow.	When do we have to tap? (children: "when we see a red arrow"). And if two red arrows appear? Then, we shouldn't tap.
7. V6(x2) I9(x2) I8(x2)	V6: number of stimulus_50/appearance of target_35	Tap when you see a lemon or more on the screen.	When do we have to tap? (children: "when one or more lemons appear on the screen"). If one or more than one lemon appears, we should tap.
	I9: number of stimulus_80/appearance of target_55	Tap when you see a stop signal	When do we have to tap? (children: "when we see a stop signal"). Stop signal has to be the same as in the instructions, so do we have to tap if a different stop signal appears? (children: "no, we don't").
	I8: number of stimulus_40/appearance	Tap when you see one or more circles	When do we have to tap? (children: when one or more circles appear") We have to tap

	of target_30	on the screen.	when we see at least one circle on the screen.
8.V5(x2) I7(x2) I5(x2)	V5: number of stimulus_30/appearance of target_10	Tap each time you hear this sound.	When do we have to tap? (children: “when we hear this sound”). Instructor reproduces it twice. What if we hear a similar sound that is not the same? (children: “then, we shouldn’t tap”).
	I7: number of stimulus_50/appearance of target_35	Tap every time you see a symbol over the letter <i>m</i> .	When do we have to tap? (children: “when we see the letter <i>M</i> with a symbol above it”) And if the symbols appear on the side or under the letter <i>m</i> ? (children: “then, we shouldn’t tap”).
	I5: number of stimulus_60/appearance of target_46	You should tap each time you see equal numbers on the screen.	When do we have to tap? (children: “when we see equal numbers on the same screen”). And what if the numbers are not the same? (children: “then we shouldn’t tap”).
9.V4(x2) V3(x2) I4(x2)	V4: number of stimulus_30/appearance of target_5	Tap when something red appears.	When do we have to tap? (children: “when something red appears”). And if something pink or orange appears? Then we shouldn’t tap, only when something red appears.
	V3: number of stimulus_30/appearance of target_5	Tap each time you see the number 1 on the screen.	When do we have to tap? (children: “when the number 1 appears”). And if a different number appears? Then we shouldn’t tap, only when the number 1 appears.
	I4: number of stimulus_36/appearance of target_24	Tap each time the sound matches the	When do we have to tap? (children: each time the sound matches the picture). What if a cat that barks appears?

		picture.	(children: “then, we should tap”).
10. V1(x2) I2(x2) I1(x2)	V1: number of stimulus_60/appearance of target_10	Tap each time you see this symbol in blue: 3”.	When do we have to tap? (children: “when we see this symbol”). And if the symbol appears in a different color? (children: then, we shouldn’t tap).
	I2: number of stimulus_30/appearance of target_22	Tap each time you see a letter and hear this sound at the same time.	When do we have to tap? (children: “when we see a letter and hear this sound”). Instructor reproduces the sound twice. What if a number appears with this sound? (children: then, we shouldn’t tap). We shouldn’t tap because it is not a letter, and what if we hear this sound, but there is no letter? (children: “then, we shouldn’t tap”).
	I1: number of stimulus_60/appearance of target_45	Tap every time you see an image; if you hear a sound, you shouldn’t tap.	When do we have to tap? (children: “when we see an image without a sound”). What happens if we hear a sound? (children: “in that case, we shouldn’t tap”).

Note. Level A of Nexxo application for Ipad. V=vigilance block, I=inhibition block. x2=Each game was applied twice. Medium speed from stimulus to stimulus appearance ranges from 0-1 sg. Total duration of each session:15 minutes approximately.

4.3. Análisis de las estrategias compensatorias empleadas en el entrenamiento “Nexxo” y su relación con la ejecución en la aplicación. Análisis de variables de desarrollo y cognitivas en el desempeño del programa de entrenamiento “Nexxo”.

Tras el estudio anterior, se analizaron las estrategias, así como las variables cognitivas que pudieran predecir un mayor o menor desempeño en inhibición y vigilancia (artículo 3: Rossignoli-Palomeque, Quiros-Godoy, M; T., Perez-Hernandez, E., y González Marqués, J. *Schoolchildren's compensatory strategies and skills in relation to Attention and Executive Function App training*. Esto es relevante dado que aporta información sobre la utilidad de las estrategias, y, por otro lado, aporta datos sobre qué aspectos cognitivos puedan estar relacionados con el desempeño en este tipo de tareas.

Para este estudio se analizó una muestra de 46 participantes del grupo experimental (del estudio anterior) Primero de Primaria (n =28, \bar{x} = 78.32 \pm 4.037 meses) y Tercero de Primaria (n =18, \bar{x} =102.11 \pm 3.445). Se valoraron las funciones ejecutivas, atención e inteligencia a través de pruebas neuropsicológicas efectuadas antes de la intervención y después de la misma. Las pruebas empleadas fueron el test de discriminación simple de árboles-R (DIVISA-R) (Santacreu, Shih, y Quiroga, 2010), el test de inteligencia breve de Reynolds (RIST) (Reynolds, C. y Kamphaus, 2003), el test de los cinco dígitos (FDT) (Sedó, 2007) y la subpruebas de memoria de trabajo y velocidad de procesamiento de la escala de inteligencia Wechsler para niños-cuarta edición (WISC-IV) (Wechsler, 2003). También se recogió información sobre el desempeño por parte de los participantes en inhibición y vigilancia (recogido por la aplicación), así como el uso de estrategias compensatorias requeridas durante la intervención (recogido por los instructores).

Los resultados mostraron que el 80.43% de los participantes precisaron estrategias compensatorias en algún momento del entrenamiento. En cuanto a las estrategias compensatorias se observó que aquellos con puntuaciones más bajas en inhibición y vigilancia (en el desempeño del entrenamiento) necesitaron más estrategias compensatorias, en concreto la estrategia de comprensión de instrucciones ($r = -.561$, $p < .001$ para tarea de inhibición; $r = -.342$, $p < .001$ para tareas de vigilancia). En cuanto a los factores de desarrollo, la edad predice un mejor desempeño en ambas tareas ($\beta = .613$, $p < .001$ para inhibición; $\beta = .706$, $p < .001$ para vigilancia). En cuanto a la ejecución de las tareas, aquellos con mejor desempeño en inhibición tuvieron también mejor desempeño en vigilancia ($r = .72$, $p < .001$). Por último, en cuanto a las habilidades cognitivas, aquellos participantes con niveles más altos en inteligencia fluida (Q1, n=12) tuvieron puntuaciones más altas ($U = 14.5$, $p < .05$) en vigilancia respecto al grupo con puntuaciones más bajas (Q4, n=11). Además, considerando todo el grupo respecto a la puntuación en vigilancia, aquellos con puntuaciones más altas e inteligencia fluida ($\beta = .389$, $p = .002$), más bajas en omisiones según la prueba de atención individual aplicada

($\beta=-.479$, $p<.001$) y flexibilidad cognitiva ($\beta=-.279$, $p=.02$), obtuvieron un mejor desempeño en vigilancia.

En conclusión, según los resultados obtenidos podemos decir que la inhibición y la vigilancia son procesos relacionados. En cuanto al uso de estrategias compensatorias, éstas fueron más necesarias para aquellos que presentaron más dificultades durante el entrenamiento (puntuaciones más bajas en inhibición y vigilancia). En cuanto al análisis de estrategias, parece que la estrategia de comprensión de instrucciones y autoinstrucciones fueron las estrategias más útiles para los que mostraron dificultades durante el entrenamiento. En cuanto al desarrollo, tal y como cabía esperar, la edad modera el desempeño en inhibición y vigilancia. Por último, respecto a habilidades cognitivas, la inteligencia fluida y la flexibilidad cognitiva predicen mejores resultados en vigilancia.

4.3.1 Publicación: *Schoolchildren's Compensatory Strategies and Skills in Relation to Attention and Executive Function App Training*



Schoolchildren's Compensatory Strategies and Skills in Relation to Attention and Executive Function App Training

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Background: Given the importance of attention and executive functions (EF) in children's behavior, programs aimed at improving these processes are of special interest. Nexxo-training combines the use of the Nexxo touchscreen application (inhibition and vigilance tasks) with procedural metacognitive strategies (imparted by an instructor) for all the individuals using the app, regardless of their level of ability, plus compensatory strategies based on individual child performance. This study presents an analysis of the compensatory strategies that schoolchildren (aged 6–8 years old) receive when experiencing difficulties with EF tasks, in addition to an analysis of the developmental factors and cognitive skills that may modulate EF task performance.

Methods: For this study, we use data from a previous randomized active-controlled study (under review), in which forty-six typically developing children aged between 6 and 8 years old (24 girls/22 boys) were enrolled in the training group. The selected children were in the 1st grade ($n = 28$, $\bar{x} = 78.32 \pm 4.037$ months) and 3rd grade of primary education ($n = 18$, $\bar{x} = 102.11 \pm 3.445$). We collected data on EF training performance, compensatory strategies needed and neuropsychological assessments.

Results: A total of 80.43% participants required some form of compensatory strategy during training. Regarding required compensatory strategies, those who had lower scores in EF training needed more compensatory strategies, in particular, instructional comprehension ($r = -0.561$, $p < 0.001$ for inhibition-tasks; $r = -0.342$, $p < 0.001$ for vigilance-tasks). Concerning developmental factors, age significantly predicted better performance in both EF tasks ($\beta = 0.613$, $p < 0.001$ for inhibition; $\beta = 0.706$, $p < 0.001$ for attention). As regards task performance, those with better performance in inhibition tasks also had better performance in vigilance tasks ($r = 0.72$, $p < 0.001$). Finally, regarding cognitive skills, participants with higher performance in fluid intelligence (Q1, $n = 12$) had higher scores ($U = 14.5$, $p < 0.05$) than the group with the lowest performance (Q4, $n = 11$) in vigilance.

Conclusion: As previous literature suggests, inhibition is one of the core processes of EF. Therefore, we should focus training on the core EF processes. Inhibition and vigilance are closely related processes. In terms of the use of compensatory strategies, these are more needed for participants with lower levels of performance in inhibition or vigilance. Regarding strategy analysis, instructional comprehension and self-instruction (goal setting and planning) seem to be the most useful strategies for those with difficulties in inhibitory and vigilance task performance. Regarding development, as expected, age moderates task performance in inhibition and attention. Finally, cognitive skills, such as fluid intelligence and cognitive flexibility, predicted better results in attention. EF training using not only an app, but also compensatory strategies based on user performance, is a new research direction offering more opportunities to generalize EF training in everyday life.

Keywords: inhibition, vigilance, procedural metacognition, application, children, attention, executive functions, cognitive training

INTRODUCTION

Executive Functions (EF) can be understood as a variety of interrelated processes that help to direct and control mental abilities to accomplish a task or goal (Reck and Hund, 2011). Miyake et al. (2000) propose a hierarchical model in which EF is considered as a unitary construct with three main components: (1) inhibition, (2) updating, and (3) shifting. Inhibition is the ability to suppress one automatic or prepotent response in favor of another, or to suppress the response altogether, known as response inhibition. Another aspect of inhibition is interference control, which is required to select relevant stimuli when a distractor appears (Miyake et al., 2000; Diamond, 2013; van der Ven et al., 2013; Tamm and Nakonezny, 2015). This process is one of the first stages to develop and is thought to be responsible for changes in other EF components (Dempster, 1992; Gandolfi et al., 2014). Updating is the ability to retain and manipulate information during a short period of time (Miyake et al., 2000; Klingberg et al., 2002). This ability is essential for learning (Conway et al., 2003). Finally, shifting is the ability to change from “one mental set” to another (Miyake et al., 2000). These components are involved in several everyday activities (Diamond, 2013).

Previous studies have found a relation between EF and intelligence (Andersson, 2008; Molfese et al., 2010; Karbach and Unger, 2014); however, EF is even more predictive of academic success than IQ (Gathercole et al., 2004; Blair and Razza, 2007). Apart from academic success, EF also seems to have an impact on social adjustment (Bryck and Fisher, 2012). “Social adjustment is defined as the degree to which children get along with their peers; the degree to which they engage in adaptive, competent social behavior; and the extent to which they inhibit aversive, incompetent behavior” (Crick and Dodge, 1994, p.82). Difficulties in EF are present in social maladjustment (Olson, 1989; Blair and Razza, 2007). EF components are impaired in various childhood disorders (Barkley, 1997), such as ADHD (Rebollo and Montiel, 2006; Gau et al., 2010), autism (Ciesielski and Harris, 1997), obsessive-compulsive disorder (Enright and Beech, 1993),

and behavioral disorders (Rebollo and Montiel, 2006). For these reasons, studies on EF interventions in children and the mechanisms involved in their development are relevant. This knowledge can be applied to EF programs aimed at school settings for typically developing children as a protective factor or in clinical contexts for those with EF difficulties as part of the intervention.

If inhibition is one of the core components of EF, the intensity domain of attention is the core component of attention (Sturm, 2008). The intensity domain involves alertness, sustained attention and vigilance as the basis of attention (Hauke et al., 2011). Tonic alertness is thought of as a top-down control function of the arousal system without the influence of external stimuli, whereas phasic alertness is the capability to respond following a warning stimulus (Sturm and Willmes, 2001). Sustained attention involves the detection of changes over a long period with a high rate of relevant stimuli. In contrast, vigilance, a state of sustained alertness, involves the detection of changes when only a low rate of relevant stimuli exists (Hauke et al., 2011). Some aspects of attention overlap with certain components of EF (Rueda et al., 2012), which explains the high degree of interaction between attention and EF. The core processes of attention and EF are related; for instance, inhibition is fundamental for attentional maintenance (Pontifex et al., 2012). Furthermore, previous research has found that children with higher levels of sustained attention present high levels of inhibitory control (Reck and Hund, 2011). Sustained attention and behavioral inhibition interact throughout child development. A longitudinal study (testing attention at 9 months and studying behavioral inhibition until adolescence) demonstrated that sustained attention is related to inhibitory control. Individuals with lower levels of sustained attention presented increased levels of behavioral inhibition during childhood and social discomfort during adolescence (Pérez-Edgar et al., 2010). Apart from sustained attention, vigilance and inhibitory control are closely related (Lovejoy and Rasmussen, 1990).

Studying the attentional element involved in EF tasks, procedural metacognitive strategies (including self-regulatory

strategies) and related skills may help us to design EF training strategies and interventions based on scientific data. Attention is strongly needed in EF tasks, and EF and self-regulation share resources (Kaplan and Berman, 2010). Some attention training has shown benefits in EF tasks. One study demonstrated how attention training in children with ADHD not only reduced symptoms of inattentiveness, but also enhanced EF, specifically, by shifting attention (La Marca and O'Connor, 2016). Studies on attention span and working memory have shown how training benefits participants with ADHD with regard to EF (Klingberg et al., 2002, 2005; Beck et al., 2010). In our view, due to the interaction between attention, EF and self-regulation, training that combines these processes may produce more transfer effects than just training EF alone. Following this hypothesis, our team developed Nexxo-training, which aims to improve vigilance, inhibition and procedural metacognitive strategies in typically developing children.

Most cognitive training can be classified into two categories: process-based training and strategy-based training (Morrison and Chein, 2011; Jolles and Crone, 2012). Both approaches involve practice or intentional instruction to improve cognitive skills. The main difference is that strategy-based training uses more explicit task instructions than process-based training (Jolles and Crone, 2012). Regarding attention and EF training, a few process-based training methods have shown positive effects in typically developing children, either in terms of attention (Thorell et al., 2009) executive attention (Rueda et al., 2005), fluid intelligence (Klingberg et al., 2005; Liu et al., 2015), or academic performance (Dahlin, 2011, 2013; Holmes and Gathercole, 2014). Nevertheless, the limitations of process-based training have been found in the far transfer or generalization of the training in the user's everyday life. Similarly, limitations have been found in long-term effects (Rossignoli-Palomeque et al., 2018). The aim of EF training should be the generalization of the training in children's daily life, in cognitive skills, academic performance, and social adjustment, which are considered "far transfer." A significant number of previous studies on EF training efficacy fail to find or examine these types of transfer results (Rossignoli-Palomeque et al., 2018). To overcome this limitation of traditional process-based training, strategy-based training provides guidance with the tasks which help users to identify the strategies needed to perform those tasks. An example of this kind of guidance is scaffolding, or metacognitive strategies, designed in combination with the training (Pozuelos et al., 2018). Indeed, strategy-based training has yielded positive results. Pozuelos et al. (2018) compared two groups with executive attention training in typically developing children with an active control group. One of the training groups followed traditional attention and EF protocol, whereas the other underwent metacognitive strategies. The children in the metacognitive group showed not only greater gains in intelligence, but also significant increases in conflict processing, measured through electrophysiological techniques. In addition, changes in brain activity regarding conflict processing predicted gains in intelligence in this group. The EF and attention intervention program that we analyze, called Nexxo-training, combines inhibition and vigilance training through a touchscreen application with strategies of "procedural

metacognition" directed by a single instructor. This strategy-based training consists of repeating a task in combination with strategies to improve performance tasks. The unique feature of this specific strategy-based training is that the training provides not only procedural metacognitive strategies (i.e., general strategies for the whole group), but also compensatory strategies for participants who experience greater difficulty during the training. In this way, the developmental processes involved in the attention and EF training task can be easily improved and generalized. A previous study of Nexxo-training, a randomized-controlled study, showed far transfer after training in supervision, attention and EF as reported by parents (Rossignoli-Palomeque et al., submitted). Far transfer occurs when training effects are produced in tasks or constructs that have not been directly trained. By contrast, near transfer occurs when the effects are reflected in similar tasks to those that have been directly trained (Karbach and Unger, 2014). Further research on this type of training is crucial as it offers a new direction for cognitive training interventions.

In addition, to plan any form of attention and EF intervention, developmental factors must also be considered. In general, the initial manifestations of EF occur during the 1st year of life, with accelerated development in childhood (Carlson and White, 2013). EF development may be a pyramidal process. Certain basic components, such as inhibition, will later support the development of other more complex processes, such as flexibility (Flores-Lázaro et al., 2014). Nevertheless, other components, such as planning, do not reach adult levels until approximately the age of 12 years old while others, such as abstraction, will continue to develop into adulthood (Zelazo and Müller, 2002) reaching peak performance at around 20–30 years of age (Blakemore and Choudhury, 2006). Regarding attention, conscious control of attention increases between 2 and 6 years of age (Rothbart and Posner, 2001; Diamond et al., 2007). There is a second significant improvement in cognitive control of attention at around 9–12 years of age (Pozuelos et al., 2014). Meanwhile, sustained attention improves significantly between the ages of 3 and 5 years old (Garon et al., 2008) and continues to develop progressively throughout a child's school years. There are significant changes in sustained attention from 6 to 7 years of age in comparison with 10- to 11-year-olds (Lewis et al., 2017b). Inhibition and attention are relevant cognitive abilities. In terms of development, go/no-go tasks have demonstrated a significant improvement in response inhibition and sustained attention between the ages of 6 and 8 years old, while these changes are more subtle from 8 to 11 years of age (Lewis et al., 2017a). Previous studies, using go/no-go tasks for assessment, support the same idea that there is an improvement in response inhibition abilities between the ages of 6 and 8 years (Becker et al., 1987). Inhibition is a process that develops particularly between the ages of 5 and 10 years (Urban et al., 2011).

Apart from the relation between attention, EF and developmental factors, it is also worth considering what other skills and strategies may be involved in performing attention and EF tasks successfully. Previous studies have shown that inhibition training in preschoolers produced a trend-level improvement in reasoning and neural changes in the experimental group

(Liu et al., 2015). Other authors suggest that students with a high IQ also perform well in EF tasks, specifically in inhibition and flexibility (Sastre-Riba and Viana-Sáenz, 2016). On the other hand, lower vigilance performance has been linked to a lower IQ in children who are at risk of learning disabilities (Swanson and Cooney, 1989). Therefore, if attention, EF and intelligence are related, which specific cognitive abilities are involved, and which are better at predicting attention and EF performance? These crucial questions must be addressed by attention and EF training developers.

Regarding schoolchildren's use of procedural metacognitive strategies in inhibitory tasks, it seems that verbal strategies (e.g., verbalizations of what to do/not do) and motor strategies (e.g., moving away, shaking their heads, covering their mouths, etc.) are used by preschoolers to inhibit themselves (Fatzer and Roebers, 2013). The combination of both types of strategies seems to produce better inhibitory results (Manfra et al., 2014). The development of these strategies depends on the child's age. For instance, verbalizations and inner speech evolve between 2 and 8 years of age, from irrelevant speech to self-directed verbalizations, both of which are relevant to the task (Winsler et al., 2009). Another type of strategy, which seems to promote better results in EF tasks in older students and adults, are self-instructions (e.g., saying out loud what to do, how to do it, etc.) (Karbach and Kray, 2009). The development of these strategies varies throughout child development (Vygotsky et al., 1978; Bjorklund and Harnishfeger, 1990) and is also based on the level of task difficulty (Ferryhough and Fradley, 2005). Nexxo-training strategies consist of procedural metacognitive strategies. These strategies involve self-regulation (motor and verbal strategies), instructional comprehension, and self-instruction strategies, according to the participant's development. Self-instruction and instructional comprehension involve three phases: (1) forethought (establish goals, "what do I have to do?"), (2) performance/volitional control (planning, monitoring and controlling cognition, "how am I going to do it?") and, (3) self-reflection (self-evaluation and cognitive flexibility to make adjustments if required). These three phases are metacognitive strategies that can be applied in self-regulated learning (Dina and Efklides, 2009). EF and procedural metacognition (such as the strategies mentioned above) share common theoretical characteristics, developmental paths, and even brain regions. Therefore, the student's control of their own learning is crucial (Roebers and Feurer, 2016). To our knowledge, this is the first EF training that offers these strategies for school-aged students. The primary focus of this study was to analyze the strategies that students (aged 6–8 years old) use when confronted with challenging strategy-based EF and attention training ("Nexxo-training"). This training, delivered through an online application, combines inhibition and vigilance training with procedural metacognitive strategies. The study also analyzes the cognitive skills and developmental factors that may modulate task performance.

The study objectives are as follows: (1) to determine whether procedural metacognitive strategies have an impact on task performance and which ones are relevant; (2) to ascertain whether age moderates the use of strategies and task

performance; (3) to identify which cognitive skills are related to task performance as possible predictors; and (4) if cognitive skills are predictive of task performance, the final objective is to test whether this relation is sustainable when the lowest and highest levels of performance are compared.

This information is crucial to the scientific development of new training technologies for EF and attention interventions.

MATERIALS AND METHODS

Ethics Statement

In accordance with the Declaration of Helsinki, written informed consent was obtained from each parent's participant. This study was approved by the ethics committee of the San Carlos Hospital (n° 15/315-E) in June 2015.

Participants

The study participants were recruited from two schools after receiving their parents' consent. Forty-six typically developing children aged between 6 and 8 years old (24 girls and 22 boys) participated in the study. The selected children were in the 1st grade ($n = 28$, $\bar{x} = 78.32 \pm 4.037$ months) or 3rd grade of primary education ($n = 18$; $\bar{x} = 102.11 \pm 3.445$). The parents' average professional range was $\bar{x} = 2.59 \pm 0.53$ (0 = low level, 1 = medium-low, 2 = medium, 3 = medium-high, and 4 = high) according to the "National Institute of Professional Range" (Spain). The inclusion criteria were as follows: (1) between the ages of 5–7 and 8–9 years; (2) no previous diagnosis of diseases or disorders related to developmental delays; (3) no psychological or speech therapy treatment required at the time of the study or earlier; (4) Spanish-speaking (monolingual); and (5) no diagnosis of learning difficulties or repetition of school year. Criteria 1–5 were obtained through a parents' questionnaire. **Table 1** shows the sociodemographic description of the participants.

Assessments

Standardized Tests Were Used to Assess the Following Dimensions:

Cognitive skills through individual cognitive assessments (40–45 min): attention using the DIVISA-R "Trees Simple Visual Discrimination Test - Revised" (Santacreu et al., 2010), intelligence using the Reynolds Intellectual Screening Test (RIST) (Reynolds and Kamphaus, 2003), the Five Digit Test (FDT) (Sedó, 2007) to measure inhibition and cognitive flexibility, and,

TABLE 1 | Sociodemographic description of participants.

	Female (n = 24)				Male (n = 22)				Total (n = 46)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Age	7.04	1.06	6	9	6.62	0.973	5	8	6.85	1.03	5	9
IQ	104	13.9	79	131	106	16.1	78	130	105	14.8	78	131

SD = standard deviation; IQ = intelligence quotient measured by Reynolds Intellectual Screening Test (RIST); Min = minimum; Max = maximum.

processing speed assessment through the Wechsler Intelligence Scale for Children-fourth edition (WISC-IV) (Wechsler, 2005).

The DIVISA-R (Santacreu et al., 2010) is a computer-based test in which the participant is required to tap the same trees as the model as quickly as possible. It takes approximately 15 min and is suitable for children aged 6–12 years. It provides five main indexes: distraction-precipitation, commission errors, omission errors, processing speed, and a global attention score. The reliability is based on Cronbach's $\alpha = 0.77$ for all scales.

The RIST (Reynolds and Kamphaus, 2003) is a screening intelligence test. It contains two subscales: "guess what," to assess verbal intelligence, and "odd-item-out," to assess non-verbal intelligence. The sum of both subscales determines a general index of intelligence ($M = 100 \pm 15$). The reliability based on Cronbach's α is 0.91.

The FDT (Sedó, 2007) is a test to measure certain aspects of EF (inhibition and cognitive flexibility). It contains four subscales: decoding, counting, election and alternative. It provides measures of inhibition and flexibility. In the inhibition subscale, the participant is required to count the numbers in a box instead of reading the numbers (automatic response). In the flexibility subscale, the participant must change strategy (from counting the numbers in a box to reading the number seen in the box), indicated by boxes in a blue frame. The Spearman-Brown coefficient ranges between 0.92 and 0.95.

The WISC-IV (Wechsler, 2005) implemented in this study included the Index of processing speed PSI (Coding and symbols searching). In coding, the participant is required to transcribe a digit-symbol code as quickly as possible for 2 min. In symbol searching, the participant is asked to decide whether target symbols appear in a row of symbols or not. These subscales were used to assess processing speed. The average internal consistency coefficient for PSI is 0.88.

Inhibition and vigilance through go/no-go and stop signal task performance: the Nexxo application provides a score of task performance for inhibition and vigilance for each session according to the number of errors (omissions and commissions) and successes. At the end of the training, the scores for each session in the different blocks are added up to obtain an overall score for the intervention, which is used to as a measure of task performance in inhibition and vigilance for each participant.

Task

Go/No-Go and Stop Signal Tasks

The Nexxo application is based on neuropsychological models known as "go/no-go" and "stop signal" tasks (Shiffrin and Schneider, 1977; Logan, 1994), which involve a suppression of an ongoing response (inhibition), "n-back," a typical task involving the temporary storage, manipulation, and selection of information (Tsujiimoto et al., 2007) by deciding whether to make a response or not depending on whether a sequence is fulfilled (working memory), and, vigilance, in which changes are to be detected when only a low rate of relevant stimuli are presented (Sturm, 2008). As there is a low presence of these types of games (n-back) in level 1 of the Nexxo app (i.e., the one used in the study), we excluded them to focus on

inhibition and vigilance processes. The game had two different blocks: vigilance vs. inhibition. In the vigilance block, the user had to tap the screen sporadically (differentiating between possible distractors and thus maintaining a state of alertness, also known as "vigilance"), whereas in the inhibition block, the user had to tap very frequently (holding back an automatic response, which is known as "inhibition or self-control"). The mechanics of the game included requirements to touch the screen when a specific stimulus was present, for example: "tap when you see that the figures on the screen are the same." The screen turned green when the user tapped correctly and red when the user tapped incorrectly. The instructor applied compensatory strategies if the user displayed difficulties in carrying out the task.

Figure 1 shows an example of a Nexxo activity.

Each game has a different command and stimulus presentation. In the vigilance block, the rate of target presence was less than 30% (70% no-go probability), whereas in the inhibition block the rate of target presence was over 70% (30% no-go probability). After each game, the participants were shown on the screen how many stars they had received as a reinforcement (0–3 depending on the level of performance). The participants played 30 games divided into two different blocks (15 vigilance games and 15 inhibition games) in the first level. There were 15 sessions in total (three games per session/each game was done twice) with each session lasting approximately 15 min. Additionally, Nexxo was developed to train processing speed (as the screen transition was set at one second, stimulus processing and the decision to tap or not tap required perceptual-motor agility). The Nexxo application also requires visual and auditory discrimination skills due to the presence of both types of stimuli in the form of targets and distractors (e.g., game V7 level 1 instruction: "tap each time you see a yellow circle with this sound"). Finally, Nexxo records the types of errors committed by the user: commission errors (the user tapped the screen when a response should have been withheld) and omission errors (the user did not tap when a response was required).

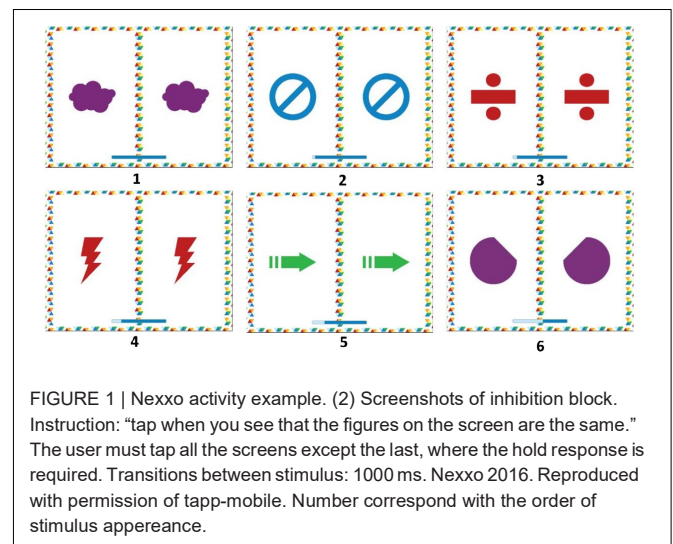


FIGURE 1 | Nexxo activity example. (2) Screenshots of inhibition block. Instruction: "tap when you see that the figures on the screen are the same." The user must tap all the screens except the last, where the hold response is required. Transitions between stimulus: 1000 ms. Nexxo 2016. Reproduced with permission of tapp-mobile. Number correspond with the order of stimulus appearance.

Procedural Metacognitive Strategies

The training also involved self-regulatory and self-monitoring strategies inspired by Perez-Hernandez and Capilla (2008), which were directed by the instructor and recorded for each participant in each session, as follows: (1) general instructions (for all participants): an instruction to get ready for the session (the participants had to put their hands over two fixed stickers when they heard “in position” and wait for the instructor to give further instructions), “visual self-instruction” (wait-see-tap), a visual reminder of how to perform the games in order to foster self-control, and verbal self-instructions: “I am a good observer, I do not fall into traps,” instructional comprehension/self-instruction (goal setting and planning): the instructor reads the instructions of the game out loud and asks the participants to say when and how they have to tap in each game through fixed questions (e.g., “when do we have to tap?” (the instructor) “we have to tap when. . .” (the participants) “how are we going to do it?” (the instructor) “we have to wait, see and tap”), and, verbal reinforcement after the games (e.g., “very good”); and (2) compensatory strategies (for participants who presented difficulties while performing the task): individual reinforcement if required (repeating the instruction to get ready, repeating self-instruction, repeating instructions, child verbalizations during the game (saying out loud what appears on the screen), or, in the latter case, instructor verbalizations (saying out loud what appears on the screen), and positive reinforcement through gestures (saying “well done” out loud).

More information about strategies applied can be seen in **Supplementary Material**.

Procedures

The Nexxo-training intervention combines the repetition of EF and attentional tasks in addition to strategies to enhance the

tasks. We refer to these strategies as “procedural metacognitive strategies.” In addition to general strategies aimed at the whole group, Nexxo-training provides compensatory strategies to individual participants who experience greater difficulties during training. The Nexxo application (go/no-go and stop signal tasks) was designed between 2012 and 2014, and a pilot version was developed for the study in October 2015 (Tapp-Mobile, 2015). Written informed parental consent was obtained from each participant. The participants underwent a neuropsychological assessment conducted by an examiner, which included individual tests to measure intelligence, attention, inhibition and flexibility, working memory, and processing speed. The examiners were trained psychologist who participated in the data collection. The group received a 5-week intervention conducted by a psychologist (groups of eight participants) using a special training script provided by each instructor. The Nexxo intervention was carried out over a 5-week intervention period (two sessions per week/15 min each/three games repeated twice in each session). Regarding inhibition training, a previous study of a go/no go task using a touchscreen application with preschoolers showed a trend-level improvement in reasoning and neural changes in the experimental group after 3 h of training (Liu et al., 2015). This is the reason why we decided to set the Nexxo-training duration at 3 h. The complementary strategies aimed at procedural metacognitive strategies were inspired by Perez-Hernandez and Capilla (2008). The complementary strategies were implemented by an instructor and recorded for each participant. **Figure 2** shows a description of the Nexxo-training.

Data Analysis

Statistical analyses were performed using IBM SPSS Statistics 23. **Table 2** shows the frequency of participants with whom compensatory strategies were used at some point during the

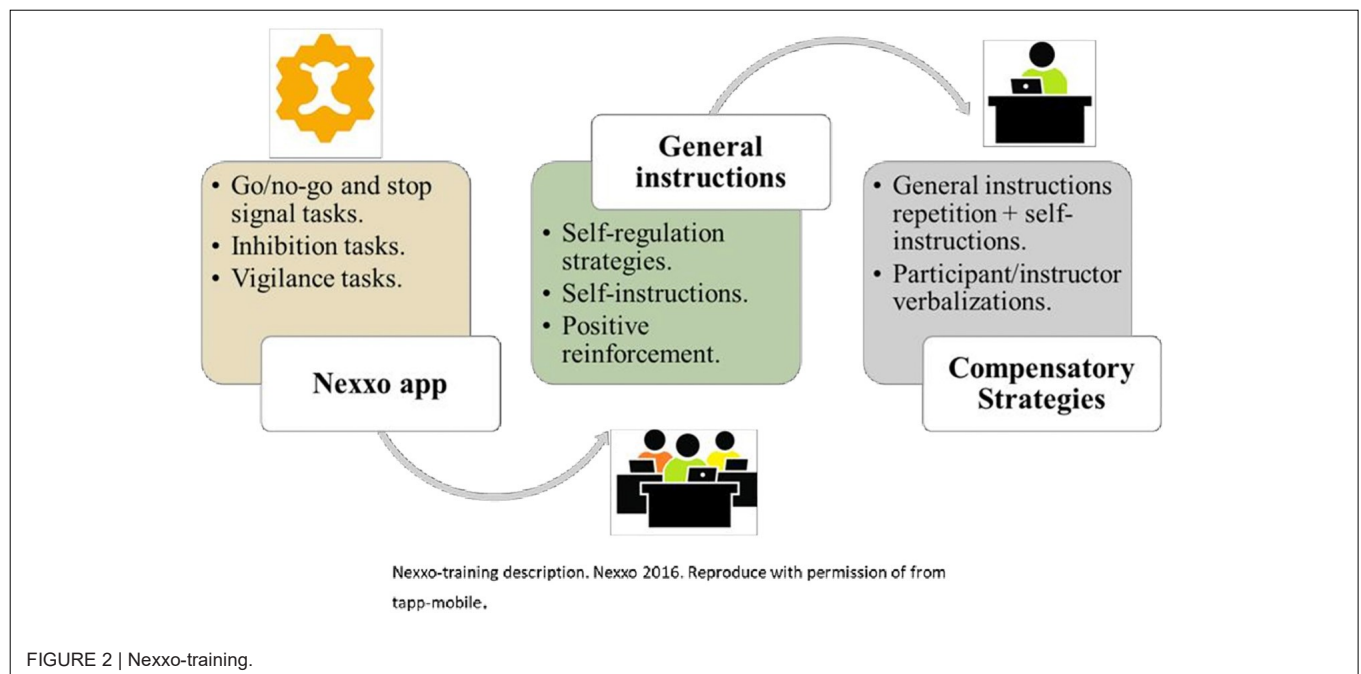


TABLE 2 | Frequency of participants with whom compensatory strategies were used at some point during the training.

	Total N (%)	1st grade n (%)	3rd grade n (%)
Repeat warning to get ready	21 (45.65)	19 (67.86)	2 (11.11)
Repeat self-instructions	13 (28.26)	12 (42.86)	1 (5.56)
Instructional comprehension	35 (76.09)	25 (89.29)	10 (55.56)
Positive reinforcement	2 (4.35)	2 (7.14)	0 (0)
Child verbalizations	26 (56.52)	19 (67.86)	7 (38.89)
Instructor verbalizations	16 (34.78)	11 (39.29)	5 (27.78)
Total set of compensatory strategies	37 (80.43)	26 (92.86)	11 (61.11)

% = percentage.

training. The “positive reinforcement” strategy was excluded from the following analyses because only two used it once.

Table 3 shows the scores in inhibition and vigilance tasks recorded by the Nexxo App, the number of total compensatory strategies applied and recorded by the instructor for children who experienced difficulties during the tasks, and the number of strategies applied of each subtype. These scores were reported for the total sample and, also, separately for the 1st and 3rd grade groups.

For cognitive skills, we used T-scores provided by the instruments, with the exception of FDT since part of our sample was younger than the norm-based scores provided by the instrument. In this case, we calculated T-scores for our sample (1st graders and 3rd graders, separately); the higher the T-score, the lower the FDT performance.

For all the statistical analyses, the significance threshold was set at 0.05. In linear regressions, standardized β and adjusted R^2 are reported.

RESULTS

Compensatory Strategies and Task Performance

We used partial correlation analysis to detect the possible relation between performance and compensatory strategies, controlling for age (in months) to eliminate possible moderation due to development. After controlling for age, there was a significant correlation between inhibition and vigilance performance: the participants with a higher level of performance in inhibition games also demonstrated a higher level in vigilance games ($r = 0.517, p < 0.001$).

The correlations between performance in both types of tasks and compensatory strategies were significantly negative for “repeat self-instructions” and “instructional comprehension” (see Table 4), meanwhile they were marginally significant between performance in “vigilance” and “instructor verbalizations” ($r = -0.29, p = 0.053$). Those who obtained lower scores in the tasks (either inhibition or vigilance) required more compensatory strategies. Table 4 shows the correlations between inhibition and vigilance performance and compensatory strategies.

TABLE 3 | Indicators of performance in inhibition and vigilance, and compensatory strategies.

	Mean	SD	Minimum	Maximum
Inhibition				
Total	92.5	5.93	79	100
1st grade	89.82	5.88	79	100
3rd grade	96.78	2.67	91	100
Vigilance				
Total	69.7	14.3	38	97
1st grade	61.79	10.73	38	85
3rd grade	82.11	9.45	60	97
Repeat warning to get ready				
Total	0.674	0.871	0	3
1st grade	1	0.9	0	3
3rd grade	0.17	0.51	0	2
Repeat self-instructions				
Total	0.609	1.42	0	8
1st grade	0.96	1.73	0	7
3rd grade	0.06	0.24	0	1
Instructional comprehension				
Total	2.59	2.29	0	7
1st grade	3.43	2.33	0	8
3rd grade	1.28	1.49	0	4
Child verbalizations				
Total	0.891	1.1	0	5
1st grade	1.18	1.25	0	5
3rd grade	0.44	0.62	0	2
Instructor verbalizations				
Total	0.609	1.11	0	5
1st grade	0.79	1.32	0	5
3rd grade	0.33	0.59	0	2
Total set of compensatory strategies				
Total	5.43	5.39	0	26
1st grade	7.46	5.81	0	26
3rd grade	2.28	2.42	0	8

SD = standard deviation.

Compensatory Strategies and Task Performance in Relation to Age

Using the participants’ age in months as an independent variable in a linear regression showed that age predicts better performance in both inhibition ($\beta = 0.613, p < 0.001$, adjusted $R^2 = 0.361$) and vigilance ($\beta = 0.706, p < 0.001$, adjusted $R^2 = 0.487$), with a steeper slope for vigilance: older participants have better results (see Figure 3).

Regarding the relation between age (in months) and compensatory strategies, statistically negative correlations were found with the total set of compensatory strategies, and the subtypes “repeat the warning for starting,” “instructional comprehension,” and “child verbalization” (see Table 5).

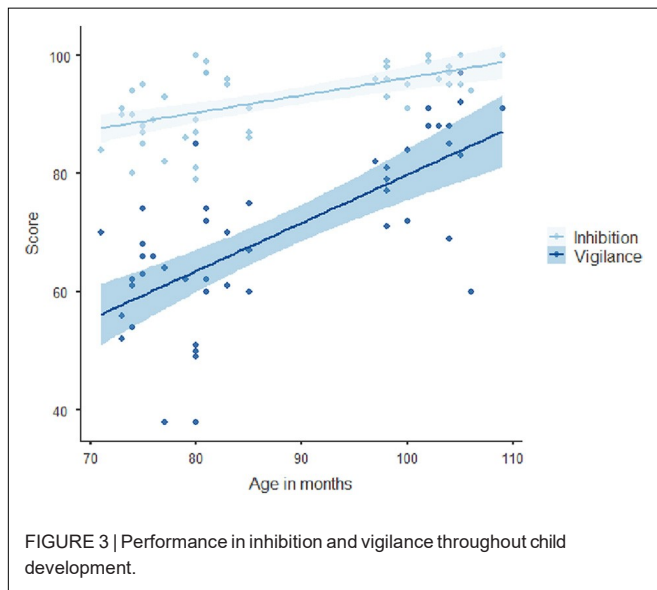
Cognitive Skills and Task Performance

Stepwise multiple linear regression analysis was used to identify which cognitive skills scales (DIVISA, RIST, WISC and FDT indexes) (independent variables) better predict performance

TABLE 4 | Partial correlation, controlling for age in months, between performance in inhibition and vigilance, and compensatory strategies.

		Repeat warning to get ready	Repeat self-instructions	Instructional comprehension	Child verbalizations	Instructor verbalizations	Total set of compensatory strategies
Inhibition	Pearson's r	-0.229	-0.354*	-0.561***	-0.110	-0.256	-0.475**
	p-value	0.130	0.017	<0.001	0.472	0.090	0.001
Vigilance	Pearson's r	-0.196	-0.362*	-0.342*	-0.073	-0.290	-0.387**
	p-value	0.197	0.014	0.022	0.635	0.053	0.009

* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.



in inhibition and vigilance tasks (dependent variables). For inhibition tasks, all the independent variables were non-significant. For vigilance tasks, the results showed that higher scores in odd-item-out from RIST ($\beta = 0.389, p = 0.002$) and lower scores in omissions from DIVISA ($\beta = 0.479, p < 0.001$) and flexibility from FDT ($\beta = -0.279, p = 0.02$) predicted better performance. **Table 6** shows the complete regression model.

To ascertain if this relation is present when comparing children with low and high performance in inhibition and vigilance tasks, the sample was divided into four groups using quartiles. The groups with the best performance (Q1, superior quartile) and worst performance (Q4, inferior quartile) for each task were selected for the analysis (see data in **Table 7**).

Because the sample size of the groups was small, and the normality assumption was not met, a non-parametric Mann-Whitney U test was carried out to compare the differences between the Q1 and Q4 groups. **Tables 8, 9** show the results for Inhibition and Vigilance, respectively.

Concerning inhibition tasks, no differences were found between the Q1 and Q4 groups in any of the skills assessed. Nevertheless, for vigilance tasks, the scores were significantly higher for Q1 in distraction from DIVISA ($U = 18, p = 0.008$), odd-item-out subtest ($U = 14.5, p = 0.002$) and general index

($U = 29.5, p = 0.024$) from RIST, and lower in omissions from DIVISA ($U = 22.5, p = 0.021$) and flexibility from FDT ($U = 33, p = 0.042$).

DISCUSSION

Nexxo-training is an innovative strategy-based training for attention and EF. Strategy-based training combines the repetition of a task with strategies (e.g., scaffolding or metacognitive strategies) to improve performance (Morrison and Chein, 2011; Jolles and Crone, 2012). In this study, the Nexxo-training involved computer-based training through “go/no-go” and “stop signal” tasks, in combination with procedural metacognitive strategies for the whole group, adapted to the participants’ developmental stage, as well as compensatory strategies for those who presented greater difficulties during the training. The tasks were developed using an application (“Nexxo” iPad application). As touchscreens and applications are appealing to children (Lai et al., 2013), this approach can motivate them to participate in the training. This new training approach has demonstrated positive results in school-age students in terms of attention and EF (Rossignoli-Palomeque et al., unpublished). To our knowledge, this is the first (strategy-based) cognitive training that provides compensatory strategies for participants who experience greater difficulties. Considering the proportion of participants who required compensatory strategies at some point in the training period (80.43%), it seems that compensatory strategies are relevant over the course of the training process. The most commonly used compensatory strategy was instructional comprehension (76.05%), followed by child verbalizations (56.52%), repeating warning for starting (45.65%), instructor verbalizations (34.78%), repeating of self-instructions (28.26%), and gestures reinforcement (4.35%). Instructional comprehension (i.e., verbalizations of what to do) was the strategy most commonly required by both 1st-grade and 3rd-grade participants. This strategy is fundamental in self-regulated learning (Dina and Efklides, 2009). As shown in **Table 2**, the younger participants displayed a greater need for repeating instructions to get ready (67.86% in 1st grade vs. 11.11% in 3rd grade), child verbalizations (67.86% in 1st grade vs. 38.89% in 3rd grade), and self-instructions (42.86% in 1st grade vs. 5.56% in 3rd grade). These results may be due to a greater development of attentional control and inner speech around the 3rd grade. As suggested by Winsler et al. (2009), inner speech evolves from irrelevant speech to self-directed verbalizations

TABLE 5 | Correlations between age in months and compensatory strategies.

		Repeat warning to get ready	Repeat self-instructions	Instructional comprehension	Child verbalizations	Instructor verbalizations	Total set of compensatory strategies
Age (in months)	Pearson's r	-0.510***	-0.276	-0.484***	-0.329*	-0.174	-0.473***
	p-value	<0.001	0.063	<0.001	0.026	0.248	<0.001

* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

TABLE 6 | Regression model predicting performance in vigilance.

	Unstandardized coefficients		Standardized coefficient	
	B	SE	β	t
Intercept	79.367	11.072	-	7.168***
DIVISA-R: omissions	-0.199	0.048	-0.479	-4.417***
RIST: odd-item-out	0.46	0.137	0.389	3.356**
FDT flexibility	-0.407	0.167	-0.279	-2.431*

$F(3,38) = 13.11***$, adjusted $R^2 = 0.47$

* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. DIVISA-R = test of simple visual discrimination of trees – revised; RIST = reynold intellectual screening test; FDT = five digit test.

TABLE 7 | Data from Q1 and Q4 groups for Inhibition and Vigilance performance.

	n	Mean age (months)	SD age (months)	Score	Mean score	SD score
Inhibition Q1	14 (7 M; 7 F)	95.07	11.38	≥ 97	98.6	1.28
Q4	11 (5 M; 6 F)	78.27	4.41	≤ 87	84	3
Vigilance Q1	12 (6 M; 6 F)	101.33	7.34	≥ 82	87.8	4.37
Q4	11 (4 M; 7 F)	80.82	9.15	≤ 60	51.6	7.85

M = Males; F = Females; SD = standard deviation.

that are relevant for the task. Strategy-based attention and EF training with compensatory strategies is a new direction, and further research on attention and EF training should focus on strategies that are more likely to improve task performance and far transfer. Indeed, it is crucial to conduct this type of training research on strategies used by students while performing attention and EF tasks.

Cognitive training should be designed based on neuropsychological models. The Nexxo application is founded on well-known attention and EF paradigms (Shiffrin and Schneider, 1977; Logan, 1994). In addition, the strategies, self-regulation strategies (motor and verbal strategies), instructional comprehension, and self-instruction have been designed considering developmental factors (Vygotsky et al., 1978; Bjorklund and Harnishfeger, 1990). As reviewed in scientific literature, verbal and motor strategies are used by preschoolers to inhibit themselves (Fatzer and Roebers, 2013; Manfra et al., 2014), and internal verbalizations evolve from irrelevant speech (at 2 years of age) to self-directed instructions that are relevant to the tasks (at 8 years of age) (Winsler et al., 2009). Thus, it seems reasonable to use self-directed instructions

as a verbal strategy in school-age students in combination with motor strategies for self-control. Finally, Nexxo-training also involves procedural metacognitive strategies, such as self-instruction and instructional comprehension strategies, to promote self-control and attention. As cognition and self-regulation are viewed as an integral unit (Vygotsky et al., 1978), by combining computer-based training in attention and EF with procedural metacognitive strategies selected for the appropriate developmental period, the training will help to improve these processes as they develop naturally. This should be the criteria when selecting the training strategies. Teaching children to control their own behavior can lead to more durable behavioral changes and less dependency on adult supervision (O'Leary and Dubey, 1979). The student's use of procedural metacognitive strategies, such as selection, monitoring, and control of their learning activities, is crucial for their achievement in all learning situations (Zimmerman, 2011). This can be justified by the theoretical overlap between EF and procedural metacognition (Roebers and Feurer, 2016). For this reason, we consider that analyzing strategy-based training is relevant for the increased likelihood of transference and long-term effects. Finally, cognitive training researchers should consider studying strategies that can be applied in attention and EF training at different developmental stages.

In this study, we analyzed the compensatory strategies used by participants experiencing difficulties in EF and attention tasks. In addition, we analyzed the developmental factors and cognitive skills that may modulate EF and attention task performance. This is relevant for the future of attention and EF cognitive training design. First, we found a positive correlation between inhibition and vigilance. This result is supported by previous findings suggesting a relation between the two elements (Lovejoy and Rasmussen, 1990; Corbetta and Shulman, 2002; Friedman and Miyake, 2004; Rebollo and Montiel, 2006; Tirapu Ustároz, 2012). As inhibition is central to EF (Dempster, 1992), and vigilance is central to attention (Hauke et al., 2011), we believe that the combination of both processes may help to improve more complex subcomponents of attention and EF. The results are consistent with previous findings that connect attention and EF (Lovejoy and Rasmussen, 1990; Pérez-Edgar et al., 2010).

Regarding the procedural metacognitive strategies used during task performance, our analysis showed that those who obtained lower scores in task performance (either inhibition or vigilance) required more compensatory strategies. Compensatory strategies provide a way for participants to adapt to the training. Specifically, the participants with lower inhibition and

TABLE 8 | Mann–Whitney U test in inhibition.

	Q1 Mdn	Q4 Mdn	Mann–Whitney U	p-Value
DIVISA-R				
General attention index	3	5	44.5	0.345
Commissions	85	75	55.5	0.841
Omissions	45	85	43	0.299
Organization	50	25	49	0.523
Distraction	15	10	36.5	0.131
RIST				
Guess what	55.5	53	51	0.153
Odd-item-out	54.5	51	70.5	0.721
General intelligence index	107.5	100	62.5	0.427
WISC-IV				
Symbol search	10.5	11	67	0.579
Coding	9.5	10	72.5	0.8
Digit span	12	10	54	0.201
Digit forward	11	11	56	0.229
Digit backward	12.5	12	68.5	0.639
Processing speed index	104.5	104	67.5	0.602
FDT				
Inhibition	45.17	53.30	52	0.171
Flexibility	45.61	50.96	49	0.134

* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. Mnd = median; DIVISA-R = test of simple visual discrimination of trees – revised; RIST = reynold intellectual screening test; WISC-IV = wechsler intelligence scale IV; FDT = five digit test.

TABLE 9 | Mann–Whitney U test in vigilance.

	Q1 Mdn	Q4 Mdn	Mann–Whitney U	p-Value
DIVISA-R				
General attention index	10	2.5	28.5	0.058
Commissions	85	88	50	0.723
Omissions	20	89	22.5	0.021*
Organization	35	35	46.5	0.547
Distraction	15	5	18	0.008**
RIST				
Guess what	53	50	57	0.578
Odd-item-out	60	41	14.5	0.002**
General intelligence index	113.5	91	29.5	0.024*
WISC-IV				
Symbol search	10	8	45.5	0.201
Coding	9.5	9	49	0.283
Digit span	12	10	51	0.350
Digit forward	11	11	63	0.847
Digit backward	13	12	46.5	0.226
Processing speed index	106	96	38.5	0.09
FDT				
Inhibition	45.57	54.97	40	0.109
Flexibility	44.49	50.96	33	0.042*

* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. Mnd = median; DIVISA-R = test of simple visual discrimination of trees – revised; RIST = reynold intellectual screening test; WISC-IV = wechsler intelligence scale IV; FDT = five digit test.

vigilance scores in the application required more instructional comprehension as a compensatory strategy. Similarly, those with lower task performance and a higher number of omissions in

the DIVISA-R test (Santacreu et al., 2010), which is related to inattention, depended more on the instructional comprehension strategy. As mentioned above, instructional comprehension and self-instruction strategy can help participants to establish a goal, plan and monitor task performance (Dina and Efklides, 2009). Moreover, repeating instructions helps to overcome difficulties in working memory (Baddeley, 1992). This finding is robust considering the effectiveness that self-instruction has shown in students with difficulties in attention and EF, such as ADHD (Harris et al., 2004; Gawrilow and Gollwitzer, 2008). For these participants, repeating instructions using self-instruction and goal setting was fundamental. Future strategy-based training designs for attention and EF should consider these findings.

One of the objectives of the study was to analyze the influence of age in task performance in order to identify the appropriate age for Nexxo-training. As hypothesized, the older participants obtained better results in inhibition and vigilance tasks; therefore, age moderates task performance. This may be due to neuropsychological changes that occur during child development (Duncan and Owen, 2000; Collette et al., 2005). In terms of inhibition performance using go/no-go tasks for assessment, it seems that there is an improvement in response inhibition abilities moderated by age (Becker et al., 1987; Lewis et al., 2017a), which makes this period relevant. In this regard, our finding is consistent with previous scientific literature. Furthermore, age moderates the use of strategies, as statically negative correlations were found with the total set of compensatory strategies, and the subtypes (“repeat the warning for starting,” “comprehension instructions,” and “child verbalization”). This finding is consistent with the progressive development of verbal strategies and self-instruction (Vygotsky et al., 1978; Bjorklund and Harnishfeger, 1990). According to these findings, and, consistent with our results, using this type of training with children up to the age of 8 years old seems ideal.

Regarding cognitive skills and task performance, our results shows that higher scores in RIST odd-item-out (fluid intelligence), and lower levels of Omissions in DIVISA (attention test) and in FDT flexibility (cognitive flexibility) predicts better results in vigilance tasks. Recent research shows that working memory, inhibition and shifting, the main components of EF, contribute substantially to general intellectual ability, especially fluid intelligence (Chen et al., 2019). Meanwhile, the parietal and frontal areas involved in EF have also been related to fluid intelligence (Tschentscher et al., 2017; Yoon et al., 2017). Consequently, based on this idea, we analyzed the relation between inhibition and vigilance task performance with fluid intelligence. Our results show that fluid intelligence predicts better results in vigilance. Vigilance tasks require attentional control which is related to inhibitory control. We also found that participants with higher levels of performance in vigilance also obtained higher scores in fluid intelligence. Previous findings have suggested a relation between vigilance and intelligence in children at risk of learning disabilities (Swanson and Cooney, 1989). In this sense, we must add that intelligence benefits vigilance performance. In terms of attention, our results show that the participants with fewer omissions and a lower level

of distractibility in neuropsychological tests had better results in vigilance task (after training). As demonstrated in previous studies, omissions and distractibility can be predictors of go/no-go performance (Lewis et al., 2017b). In our view, the fact that lower levels of omissions in the DIVISA-R test is related to better performance in vigilance, is a result which provides validity to the training. Finally, as regards the relation between cognitive flexibility and attention, we consider that cognitive flexibility has a positive influence on vigilance tasks as the instructions change for each game. The transition from one rule (e.g., “tap each time a bear appears on the screen) to another (e.g., “tap when you see the number 5”) involves not only an alteration in the type of instructions (target and distractors) but also a change from vigilance tasks to inhibition tasks, as both types of games are played in each session. We hypothesize that individuals with higher cognitive flexibility may better adjust their cognitive resources to these changes. A previous study suggested that cognitive flexibility may become a useful tool for vigilance training strategies, as individual differences in cognitive flexibility predicts better results in vigilance tasks (Figueroa and Youmans, 2012). Another possible explanation refers to the idea of flexibility as a predictor of response speed (Deák and Wiseheart, 2015). Go/no-go tasks involve response speed, i.e., a participant with a low response speed may produce a high number of omissions in the task and, as a result, obtain lower levels of vigilance performance. All these examples demonstrate how cognitive processes are interrelated, and, therefore, how training may have a simultaneous impact on multiple processes.

This study has several key strengths. Firstly, it examines a type of strategy-based training in attention and EF functions that provides compensatory strategies adapted to the participant’s needs. This is an innovative approach for cognitive training with potential for further research. Secondly, the cognitive training tasks presented in the Nexxo app are based on neuropsychological models (Shiffrin and Schneider, 1977; Logan, 1994). Furthermore, the implemented strategies are based on previous research and have been designed according to the developmental stage at which the training is applied. In this regard, it is important for future strategy-based training designs to consider child developmental factors. In our view, this approach can overcome the limitations of previous cognitive training designs in attention and EF, in terms of generalization and long-term effects (Rossignoli-Palomeque et al., 2018). Thirdly, this analysis has helped to clarify the relevance of instructional comprehension and self-instruction as compensatory strategies. This finding should also be taken into consideration for future training designs. This study reveals that child development moderates inhibition and vigilance performance. In addition, this paper demonstrates that there is a relation between fluid intelligence and vigilance. This finding raises the question of whether intelligence can be improved by training vigilance. However, further research is needed in this area. In addition, our paper shows a relation between inhibition and vigilance. Nevertheless, this study also had certain limitations. For example, as the study did not involve groups of older participants, we could not analyze the feasibility of the strategies in different age groups. In addition, due to a technical

limitation, we were unable to include processing speed as a variable in our analysis. Therefore, it would be advantageous to include this variable in future training designs.

Finally, we focused on Nexxo-training with typically developing children. Further research on Nexxo-training should focus on atypically developing children in terms of attention and EF, such as ADHD.

CONCLUSION

Nexxo-training is a specific form of strategy-based training that provides not only general procedural metacognitive strategies for the whole group, but also compensatory strategies for individual participants who experience greater difficulties during the training. Considering the proportion of participants who required compensatory strategies at some point in the training period (80.43%), it seems that compensatory strategies are relevant over the course of the training process. Regarding strategy analysis, instructional comprehension and self-instruction (e.g., goal setting and planning) seem to be the most useful strategies for participants with difficulties in inhibitory and vigilance task performance. Finally, developmental factors moderate task performance, while fluid intelligence and cognitive flexibility is related to vigilance performance.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the manuscript/**Supplementary Files**.

ETHICS STATEMENT

In accordance with the Declaration of Helsinki, written informed parental consent was obtained from each participant. This study was approved by the Ethics Committee of the San Carlos Hospital (*n*°186; 15/315-E) in June 2015.

AUTHOR CONTRIBUTIONS

TR-P conceived the application. TR-P, EP-H, and JG-M conceived, design, and coordinated the experiment. MQ-G involved in the data analysis. TR-P and MQ-G wrote the manuscript. EP-H reviewed the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02332/full#supplementary-material>

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Conflict of Interest: TR-P owns the original idea for the Nexxo application and participated in the design of the Nexxo games. The Nexxo application for iPad is a commercially available app (a free-to-install app with in-app purchases). TR-P is part of the development team for the Nexxo application for iPad.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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DISCUSIÓN

La realización de esta tesis parte de la propia creación de un programa de entrenamiento cognitivo, “Nexxo”, para entrenar la atención y las funciones ejecutivas (objetivo 2 de esta tesis). Como se ha comentado a lo largo de este trabajo, la idea surgió en el ámbito clínico al tratar pacientes con Trastorno por Déficit de Atención e Hiperactividad (TDAH), ante la necesidad de potenciar la atención y las funciones ejecutivas. La atención y las funciones ejecutivas (FFEE) son de vital importancia. La atención facilita la adquisición de otros procesos de orden superior (Amador et al., 2006; McAvinue et al., 2012), como la inteligencia (Rueda et al., 2005) y es clave para la vida diaria (Figuera y Youmans, 2012). Respecto a las funciones ejecutivas, su desarrollo se ha relacionado con el desempeño académico y la inteligencia (Andersson, 2008; Chen et al., 2019; de Abreu et al., 2010; Karbach y Unger, 2014; Molfese et al., 2010). Así mismo, las áreas parietales y frontales (implicadas en atención y en funciones ejecutivas) se han relacionado con la inteligencia fluida (Tschantz et al., 2017; Yoon et al., 2017), por lo que ambos procesos tienen un impacto en esta capacidad. Por último, Las FFEE no sólo se han relacionado con la inteligencia o con el rendimiento escolar (Illes y Sahakian, 2011), sino también con la capacidad del individuo para adaptarse de forma adecuada en su contexto social, inhibiendo comportamientos inadecuados (Bryck y Fisher, 2012; Crick y Dodge, 1994; Pérez-Edgar et al., 2010). Por todos estos motivos, la atención y las FFEE se consideran de vital relevancia para el individuo, y, por tanto, programas dirigidos a tal fin son de especial consideración.

Para el diseño del programa “Nexxo”, se consideraron previamente otros productos y programas existentes en el mercado dirigidos a los procesos mencionados, que fueron debidamente analizados a través de un artículo de revisión (artículo 1: Rossignoli-Palomeque, T., Perez-Hernandez, E., y González Marqués, J. (2018). *Brain training in children and adolescents: Is it scientifically valid? Frontiers in Psychology, 9, 565*), formando parte del plan de investigación de la doctoranda (objetivo 1: revisión actualizada sobre la eficacia de programas de entrenamiento de atención y funciones ejecutivas en la infancia y adolescencia a través de programas con soporte tecnológico (ordenador, tabletas o smartphones). Adicionalmente, se consultaron otras fuentes y recursos no publicados en revistas científicas para comprobar si la idea original de este entrenamiento pudiera existir previamente en el mercado. Tanto para el diseño de Nexxo como para el diseño del estudio sobre el mismo, tuvimos en cuenta los resultados obtenidos de la revisión realizada (artículo 1), especialmente gracias a las limitaciones encontradas. Esta revisión destaca y resume el estado actual de la investigación sobre entrenamiento cognitivo de la atención y/o las funciones ejecutivas a través de tecnologías informatizadas, durante los últimos años, en niños y adolescentes. Este fue el punto de partida o el estado de la cuestión sobre el que partimos para el desarrollo de Nexxo y de las investigaciones sobre el mismo. Esta revisión proporciona una mejor comprensión de cuáles de estos programas están respaldados por la investigación, incluyendo sus deficiencias y sugerencias para futuras investigaciones, incluyendo nuestra investigación sobre “Nexxo”. De esta revisión analizamos las limitaciones en cuanto los efectos producidos por el entrenamiento y respecto al diseño metodológico de los estudios.

En cuanto a los efectos de los entrenamientos, estos productos deberían producir algunos cambios cerebrales observables (neuroplasticidad). La investigación independiente ha arrojado algunos resultados positivos (Astle et al., 2015; Barnes et al., 2016; Rueda et al., 2005), además de NT (Gibson et al., 2012; Hitchcock y Westwell,

2017) y FT (Fälth, Jaensson, y Johansson, 2016). Algunos programas de BT han demostrado neuroplasticidad utilizando especialmente técnicas de neuroimagen, siendo poco numerosos los estudios y en pocas de las herramientas analizadas (“FastForWord”, “Teach-The-Brain”, “Cogmed”, “WinABC”, “Luminosity” y “Focus Pocus”), por lo que la mayoría de productos de entrenamiento cognitivo no demuestran neuroplasticidad, aunque digan basarse en este concepto. Según los estudios revisados, sólo unos pocos productos BT que están comercialmente disponibles cuentan con datos empíricos que respalden la evidencia de la neuroplasticidad. Proporcionar la existencia de una relación entre la neuroplasticidad y la transferencia proporcionaría resultados más sólidos en términos de eficacia del programa ya que la relación entre los cambios neuronales y las mejoras en la cognición o el comportamiento todavía está en gran parte inexplorada.

Otro de los desafíos para BT no es sólo producir NT (*near transfer*) o mejora en una tarea o habilidad similar a la que se entrenó), aspecto que se encuentra en la mayoría de los estudios, sino FT (*far transfer*) o mejora en una tarea o habilidad que no ha sido directamente entrenada y que puede producir alguna diferencia significativa en la vida diaria del usuario. Aproximadamente la mitad de los estudios demostraron este tipo de transferencia en las siguientes herramientas: “Brain Train (Captain's Log)”, “Cogmed” (herramienta que cuenta con el respaldo del mayor número de estudios de investigación en niños y BT, en población típica y en población clínica), “Focus Pocus” y “Play Attention”. Pese a estos resultados encontrados en escasas herramientas analizadas, los efectos a largo plazo son muy limitados. Además, es la investigación no independiente la que ha producido mejores resultados respecto a la transferencia o los efectos a largo plazo (Bergman-Nutley et al., 2011; Bergman-Nutley y Klingberg, 2014; Söderqvist, Bergman-Nutley, Ottersen, Grill, y Klingberg, 2012; Söderqvist y Bergman-Nutley, 2015; Temple et al., 2003; Thorell et al., 2009), lo cual genera cierta controversia. Se requiere más investigación para evaluar la eficacia de la BT y determinar para qué poblaciones puede ser adecuada, y qué estrategias pueden fomentar la eficacia y los efectos a largo plazo de los mismos. Procurando superar las limitaciones encontradas en cuanto a transferencia del entrenamiento en la vida diaria y durabilidad de los efectos, decidimos incorporar estrategias metacognitivas procedimentales en el programa “Nexxo”.

En cuanto a las limitaciones metodológicas de los diseños de los estudios de investigación, nos encontramos con que existe una carencia de estudios doble-ciego y de estudios aleatorizados que incluyan grupo placebo y grupo de control para controlar variables contaminantes. Teniendo en cuenta estas limitaciones, consideramos que se necesitan más estudios para validar científicamente los nuevos programas de BT disponibles en el mercado, a través de ensayos controlados aleatorios doble ciego, que incluyan un grupo de control pasivo y un grupo de control activo, además de un adecuado seguimiento. Estos criterios coinciden con los recomendados por el informe de IoM (Mahncke, y Merzenich, 2015) sobre cómo evaluar un programa de BT. Es por ello que, en nuestro diseño, incorporamos estos tres grupos (control, control activo y experimental), aleatorizando los grupos y proporcionando un seguimiento. Como hemos visto, la mayoría de los estudios no incluyen un grupo de control activo ni seguimiento más allá de los 6 meses. Por último, es necesario tener en cuenta otras limitaciones de los estudios, como el tamaño de las muestras, la falta de tareas para evaluar la transferencia (Cortese et al., 2015), así como las diferencias individuales de los participantes y sus

motivaciones. Para superar esto, algunos autores proponen diferentes diseños de estudio para probar programas que incluyen micro-ensayos y estudios de casos únicos (Granic, Lobel, y Engels, 2014) aspecto que podríamos explorar en el futuro en poblaciones clínicas.

Habiendo analizado las limitaciones de muchos programas de BT para producir FT y efectos duraderos, junto con las limitaciones de la investigación metodológica, pensamos que una combinación de tratamientos podría ser potencialmente más eficaz; es decir, usar BT como parte de un tratamiento más amplio. Es decir, programas que involucren no sólo BT sino también otras estrategias (tratamiento combinado) pueden ser más beneficiosos para algunas poblaciones, como sugieren Graziano y Hart (2016) en niños con problemas de conducta; o en niños con necesidades especiales, como indican Partanen et al. (2015). La investigación futura debería aclarar si una combinación de estrategias y programas tendría un efecto más significativo y sostenible que en ausencia de estrategias. Es por ello que nuestro entrenamiento será de tipo combinado (incorpora estrategias además el programa de BT). A pesar de encontrar beneficios de BT o una combinación de tratamiento, algunos autores no están convencidos sobre los programas de BT (por ejemplo, por las dificultades de alcanzar FT y efectos duraderos), y afirman que otras actividades que forman parte del entorno natural de los niños, como los video juegos, música y deportes, muestran un efecto más razonable y generalizado (Green y Bavelier, 2008). Estos autores enfatizan que estas actividades son formas naturales de entrenamiento en las cuales se practican varias habilidades en paralelo. Entonces, si hay actividades cotidianas que fomentan las habilidades de los niños, ¿es necesario utilizar un programa de BT para mejorar las habilidades cognitivas en niños con desarrollo típico? ¿Por qué debemos pretender mejorar las habilidades de los niños más allá del desarrollo infantil habitual? Considerando los resultados y las muestras en las que se centran la mayoría de los estudios, creemos que la investigación de BT debería contribuir a validar programas como herramientas de tratamiento para pacientes con trastornos del neurodesarrollo, como niños con TDAH, trastornos de aprendizaje y problemas de conducta, a pesar del hecho de que el marketing de BT esté dirigido a la población general. Nuestro enfoque es que estos programas deben ir dirigidos a población con déficits neuropsicológicos y no a la población general.

Constatando la originalidad de la idea del entrenamiento “Nexxo”, se procedió al diseño del programa basándonos en modelos neuropsicológicos sobre la atención y las funciones ejecutivas (Anderson, 2002; Anderson, 2010; Miyake y Friedman, 2012; Miyake et al., 2000; Petersen y Posner, 2012; Posner y Petersen, 1990; Van Zomeren y Brouwer, 1994) y la metacognición (Flavell, 1979), concretamente estrategias metacognitivas inspiradas por Perez-Hernandez, Rabipour y Raz (2011), y, el modelo de estrategias metacognitivas propuesto por Efklides (2009). Estas estrategias fueron implementadas con el objetivo de facilitar una mayor transferencia del aprendizaje, tal y como apunta la literatura científica (Blankson et al., 2017; Chevalier y Blaye, 2016; Diamond et al., 2007; Riemer y Schrader, 2019), y, porque éstas promueven un mejor desempeño en las FFEE (Bewick et al., 1995). El principal objetivo del programa de entrenamiento cognitivo “Nexxo” es potenciar la atención y las FFEE mediado a través de estrategias metacognitivas, reflejándose en la vida diaria. El programa aquí propuesto es un *strategy-based training* (entrenamiento basado en estrategias), un enfoque novedoso, con, desde nuestro punto de vista, un gran potencial para futuras investigaciones. Como hemos comentado anteriormente, el uso de estrategias

metacognitivas facilita la transferencia del aprendizaje (Chevalier y Blaye, 2016; Diamond et al., 2007; Riemer y Schrader, 2019), aspecto crucial entre los objetivos de los programas de entrenamiento (Rossignoli-Palomeque et al., 2018).

Tras la revisión sobre el estado de la cuestión y diseño del programa de entrenamiento se procedió a la realización del trabajo de campo por parte de la investigadora y los colaboradores, con los objetivos de estudiar el impacto del entrenamiento “Nexxo” en población de 6-7 y 8-9 años en relación a las siguientes variables: atención, funciones ejecutivas y supervisión; superando posibles hándicaps encontrados en estudios anteriores (objetivo 3), así como establecer en qué momento evolutivo (antes o después de los 7 años) pudiera haber un mayor beneficio a través de un programa de entrenamiento cognitivo de la atención y funciones ejecutivas (“Nexxo”) (objetivo 4). Los resultados han sido reflejados en el artículo 2: Rossignoli-Palomeque, T., Perez-Hernandez, E., y González Marqués, J. (2019) Training effects of attention and EF strategy-based training “Nexxo” in school-age students (en revisión en *Acta Psychologica*). El diseño de este estudio procuró superar limitaciones encontradas en estudios anteriores sobre otros programas de entrenamiento, por ello, incluye dos grupos de control (incluyendo placebo) es aleatorizado, se han controlado rigurosamente los criterios de inclusión, incluido medida de efectos a medio plazo y controlado el conocimiento por parte de los evaluadores y de las familias la pertenencia al grupo concreto por parte de los participantes. Para superar las limitaciones de transferencia y durabilidad, se incorporaron estrategias metacognitivas procedimentales en el entrenamiento. Hasta donde alcanza nuestro conocimiento, este es el primer entrenamiento cognitivo de la atención y las FFEE a través de una aplicación informática, que integra estrategias metacognitivas. El entrenamiento se ha probado en un momento evolutivo donde se desarrollan estos procesos (Lange-Küttner, 2010; Perez-Hernandez y Capilla, 2011; Reck y Hund, 2011; Urben, Van der Linden y Barisnikov, 2011). El entrenamiento “Nexxo” es un entrenamiento "basado en estrategias" (*strategy-based*) que, además de la repetición de tareas de atención y FFEE, proporciona instrucciones generales (basadas en teorías del desarrollo) junto con estrategias compensatorias para aquellos que experimentan mayores dificultades durante el entrenamiento. Como se ve a través de las correlaciones de Spearman, esas estrategias fueron más necesarias para aquellos que experimentaron más dificultades durante el entrenamiento, lo que da una idea de la idoneidad de las estrategias compensatorias.

El hallazgo más importante fue que el entrenamiento de “Nexxo” reveló una tendencia de mejora para los alumnos de Tercero de Primaria en atención, tal y como informó el entorno familiar, lo que significa que esta mejora se refleja en su comportamiento y, además, permanece después del período posterior a la intervención. Los problemas de supervisión y de FFEE también se redujeron en el seguimiento para el grupo experimental. Respecto al hecho de no haber encontrado resultados significativos en la evaluación post intervención en esas variables, planteamos la hipótesis de que esto se debe al corto período de tiempo entre las evaluaciones. Aunque los resultados son moderadamente significativos, se debe considerar que este estudio es extremadamente riguroso ya que incluye: (1) un grupo de control activo, (la mayoría de los estudios de CT no presentan este diseño), (2) los examinadores y los padres desconocían la asignación de los participantes en los distintos grupos, y (3) el control riguroso en los criterios de

inclusión para asegurar una muestra de desarrollo típico. Respecto a la falta de efectos significativos en los participantes de Primero de Primaria, planteamos la hipótesis de que esto se debe a dos razones: una es que hay un aumento significativo en el desarrollo de los procesos cognitivos entrenados después de Tercero de Primaria. La otra explicación se sustenta en factores de desarrollo, ya que el uso de estrategias requiere un mayor nivel de demandas cognitivas para los alumnos de primero que para los de tercero (Miller, 1990). No podemos respaldar estadísticamente la idoneidad del entrenamiento antes o después de los 7 años de edad, sin embargo, existe una tendencia a alcanzar un mayor número de resultados significativos en los participantes de tercero. En este sentido, se necesita más investigación.

Por otro lado, este estudio presenta varias fortalezas. En primer lugar, es un estudio sobre un entrenamiento cognitivo (soportado en pantalla táctil en combinación con estrategias metacognitivas procedimentales) en niños con desarrollo típico. Estudios anteriores mostraron mejores resultados en entrenamientos combinados, o "entrenamientos basado en estrategias" (Graziano y Hart, 2016; Partanen et al., 2015). Este es un enfoque innovador para el entrenamiento cognitivo, que muestra potencial para futuras investigaciones. Como hemos encontrado resultados positivos en niños con desarrollo típico donde los criterios de inclusión se han controlado cuidadosamente, esperamos encontrar resultados alentadores en niños con dificultades de atención y de FFEE. En cuanto a los resultados significativos, se debe considerar que la mayoría de los tamaños de efecto y los valores de potencia observados son altos. Esto significa que la probabilidad de que los resultados significativos se produzcan aleatoriamente es bastante pequeña y el efecto del entrenamiento en la muestra es relevante. En segundo lugar, a diferencia de los estudios previos de CT con pantallas táctiles en niños (Kirk, Gray, Ellis, Taffe, y Cornish, 2017; Vélez-Coto et al., 2017), utilizamos un ensayo clínico aleatorizado, controlado y con control activo o placebo. La mayoría de los estudios de CT no incluyen el control activo (Rossignoli-Palomeque et al., 2018). Los diseños aleatorizados, controlados y con control activo proporcionan un medio excelente para evaluar la efectividad del entrenamiento controlando los efectos test-retest (Nouchi et al., 2013) y sesgo debido a las expectativas psicológicas por el hecho de recibir una intervención (Turner, Deyo, Loeser, Von Korff, y Fordyce, 1994). Desde nuestro punto de vista, las intervenciones informáticas deben ser dirigidas por un especialista, y ser reforzadas con estrategias complementarias. Como hemos visto, el simple hecho de jugar con una aplicación de pantalla táctil (grupo de control activo) no proporciona resultados positivos.

También es importante tener en cuenta las limitaciones de este estudio. En primer lugar, algunos efectos de transferencia pueden no haberse podido constatar debido al tiempo de intervención limitado. Hasta donde alcanza nuestro conocimiento, el tiempo mínimo de intervención con resultados positivos es el mostrado en el estudio de Rueda et al. (2005) donde se encontraron resultados positivos en niños con desarrollo típico tras 5 horas de intervención. En segundo lugar, no hemos podido incluir la versión de los cuestionarios para maestros. Los maestros no completaron la versión del maestro debido al gran número de participantes y a la corta duración de la intervención, lo que les habría impuesto una sobrecarga de trabajo, sin poder garantizar la validez de la evaluación. En tercer lugar, nuestro tamaño de muestra es menor que el calculado debido al control riguroso de los criterios de inclusión (para garantizar una muestra de desarrollo típico) y

al hecho de que varios padres no completaron los cuestionarios finales. Esto ha reducido la muestra analizada. Finalmente, el entrenamiento “Nexxo” no es adaptativo. Estudios anteriores en niños sugieren que el entrenamiento que se ajusta al nivel del usuario es más efectivo para mejorar las funciones cognitivas (Chacko et al., 2014; Dongen-Boomsma, Vollebregt, Buitelaar, y Slaats-Willemse, 2014; Green et al., 2012; Holmes, Gathercole, y Dunning, 2009; Klingberg et al., 2002). Sin embargo, hemos compensado esta carencia mediante el uso de "estrategias compensatorias" (estrategias facilitadas para los que mostraron mayores dificultades durante la tarea). El entrenamiento “Nexxo” se adapta a la ejecución del usuario a través de estrategias metacognitivas procedimentales. Además, estas estrategias están destinadas a mejorar el rendimiento de los participantes en contextos de la vida real. Esta es la principal fortaleza de este "entrenamiento cognitivo basado en estrategias". Por último, aunque el estudio cuenta con un seguimiento (a los dos meses), lo más adecuado sería incluir un seguimiento más espaciado en el tiempo (p.e. a los seis meses).

Finalmente, se realizaron análisis complementarios sobre el grupo experimental para estudiar el uso de estrategias complementarias por parte del grupo entrenado, así como variables cognitivas y/o de desarrollo que influyen en el desempeño de las tareas de vigilancia e inhibición (objetivo 5), resultados reflejados en el artículo 3: Rossignoli- Palomeque, Quiros-Godoy, M; T., Perez-Hernandez, E., y González Marqués, J (2019). Schoolchildren’s compensatory strategies and skills in relation to Attention and Executive Function App training. *Frontiers in Psychology, 10*, 2332. Las publicaciones sobre las que hemos realizado esta discusión están completamente relacionadas entre sí. La revisión nos sirvió como estado de la cuestión para, el diseño del programa y el diseño metodológico de la investigación. La segunda publicación refleja el estudio de campo llevado a cabo en esta tesis, y finalmente el tercer artículo aporta información complementaria que debemos considerar para potenciales mejoras de nuestro entrenamiento u otros dirigidos a la atención y a las funciones ejecutivas en edad escolar. Tal información es valiosa para posibles mejoras en el diseño del entrenamiento “Nexxo”, y para el diseño de futuros programas de intervención que, como este, se consideren entrenamientos basados en estrategias (más allá de la tarea). Como hemos mencionado anteriormente, hasta donde alcanza nuestro conocimiento, el entrenamiento “Nexxo” es el primer entrenamiento cognitivo basado en estrategias que proporciona además de estrategias generales (estrategias metacognitivas), estrategias compensatorias para aquellos que experimentan dificultades durante el entrenamiento. Respecto a las estrategias, las estrategias de autorregulación (estrategias motoras y verbales), la comprensión de instrucciones y las autoinstrucciones, se han diseñado teniendo en cuenta los factores de desarrollo (Bjorklund y Harnishfeger, 1990; Vygotsky et al., 1978). Como se revisó en la literatura científica, los niños en educación infantil utilizan estrategias verbales y motoras para inhibirse (Fatzer y Roebbers, 2013; Manfra et al., 2014), y las verbalizaciones internas evolucionan a partir del discurso irrelevante para la tarea (a los 2 años de edad) a instrucciones autodirigidas que son relevantes (a los 8 años de edad) (Winsler, Fernyhough, y Montero, 2009). Por lo tanto, parece razonable utilizar instrucciones autodirigidas como estrategia verbal en participantes en edad escolar en combinación con estrategias motoras para el autocontrol. El entrenamiento “Nexxo” involucra estrategias metacognitivas procedimentales, como son las estrategias de

autoinstrucciones y comprensión de instrucciones, para promover el autocontrol y la atención. Como la cognición y la autorregulación son una unidad integral (Vygotsky et al., 1978), al combinar el entrenamiento cognitivo informatizado de la atención y FFEE con estrategias metacognitivas procedimentales (seleccionadas para el período de desarrollo apropiado), creemos que el entrenamiento ayudará a mejorar estos procesos al desarrollarlos de forma más natural. Este debería ser el criterio al seleccionar las estrategias. Enseñar a los niños a controlar su propio comportamiento puede producir cambios más duraderos y con menor dependencia de la supervisión de un adulto (O'Leary y Dubey, 1979). El uso por parte del niño/a de estrategias metacognitivas procedimentales, como la selección, la supervisión y el control de sus actividades de aprendizaje, es crucial para el desempeño en todas las situaciones de aprendizaje (Zimmerman, 2011). Esto puede justificarse por la superposición teórica existente entre FFEE y la metacognición procedimental o de autorregulación (Roebbers y Feuer, 2016). Por esta razón, consideramos que analizar el entrenamiento basado en estrategias es relevante para dilucidar si existe una mayor probabilidad de transferencia y efectos a largo plazo. Finalmente, los investigadores del entrenamiento cognitivo deberían considerar estudiar estrategias que puedan aplicarse en los entrenamientos de atención y FFEE en las diferentes etapas de desarrollo.

En primer lugar, encontramos una correlación positiva entre inhibición y vigilancia. Este resultado está respaldado por hallazgos anteriores que sugieren una relación entre ambos constructos (Corbetta y Shulman, 2002; Friedman y Miyake, 2004; Lovejoy y Rasmussen, 1990; Rebollo y Montiel, 2006; Tirapu Ustároz, 2012). Como la inhibición es uno de los elementos centrales de las FFEE (Dempster, 1992; Miyake y Friedman, 2012) y la vigilancia uno de los centrales para la atención (Hauke et al., 2011), creemos que la combinación de ambos procesos puede ayudar a mejorar subcomponentes más complejos de atención y FFEE. Los resultados son consistentes con hallazgos previos que conectan o relacionan la atención y las FFEE (Lovejoy y Rasmussen, 1990; Pérez-Edgar et al., 2010).

Respecto a las estrategias metacognitivas procedimentales utilizadas durante el desempeño de la tarea, nuestro análisis mostró que aquellos que obtuvieron puntuaciones más bajas en el desempeño de la tarea (ya sea inhibición o vigilancia) requirieron más estrategias compensatorias. Las estrategias compensatorias proporcionan una forma de adaptación del programa al participante. Específicamente, los participantes con puntuaciones de inhibición y vigilancia más bajas requirieron especialmente la estrategia de comprensión de instrucciones como estrategia compensatoria. Del mismo modo, aquellos con menor rendimiento de la tarea y un mayor número de omisiones en la prueba DIVISA-R (Santacreu, Shih, y Quiroga, 2010) (lo que se relaciona con falta de atención), dependían más de la estrategia de comprensión de instrucciones. Como se mencionó anteriormente, la comprensión de instrucciones y las autoinstrucciones pueden ayudar a los participantes a establecer una meta, planificar y monitorear el desempeño de la tarea (Dina y Efklides, 2009). Además, repetir las instrucciones ayuda a superar las dificultades en la memoria de trabajo (Baddeley, 1992). Este hallazgo es sólido considerando la efectividad que las autoinstrucciones han demostrado en estudiantes con dificultades de atención y FFEE, como el TDAH (Gawrilow y Gollwitzer, 2008; Harris, Reid, y Graham, 2004). Para los participantes, fue fundamental repetir las instrucciones

utilizando las autoinstrucciones y el establecimiento de objetivos. Los futuros diseños de entrenamiento cognitivo de la atención y FFEE deberían considerar estos hallazgos.

Uno de los objetivos del estudio fue analizar la influencia de la edad en el desempeño de la tarea para identificar la edad apropiada para el entrenamiento "Nexxo". Según los resultados, los participantes mayores obtuvieron mejores resultados en las tareas de inhibición y vigilancia; por lo tanto, la edad modera el rendimiento de la tarea. Esto puede deberse a los cambios neuropsicológicos que ocurren durante el desarrollo del niño (Collette et al., 2005; Duncan y Owen, 2000). En términos de rendimiento en inhibición, utilizando tareas de *go/no-go* para la evaluación, parece que hay una mejora en las habilidades de inhibición de la respuesta moderadas por la edad (Becker et al., 1987; Lewis et al., 2017a). En este sentido, nuestro hallazgo es consistente con la literatura científica previa. Además, la edad modera el uso de estrategias, ya que se encontraron correlaciones estadísticamente negativas con el conjunto total de estrategias compensatorias y las diferentes estrategias ("repetir la advertencia para comenzar", "comprensión de instrucciones" y "verbalizaciones por parte del niño/a"). Este hallazgo es consistente con el desarrollo progresivo de estrategias verbales y autoinstrucciones (Bjorklund y Harnishfeger, 1990; Vygotsky et al., 1978). Según estos hallazgos y, de acuerdo con nuestros resultados, utilizar este tipo de entrenamiento con niños a partir de 8 años parece idóneo.

Respecto a las habilidades cognitivas y el rendimiento de la tarea, nuestros resultados muestran que las puntuaciones más altas en RIST categorías (inteligencia fluida), niveles más bajos de omisiones en DIVISA (prueba de atención) y en flexibilidad FDT (flexibilidad cognitiva) predicen mejores resultados en tareas de vigilancia. Investigaciones recientes muestran que la memoria de trabajo, la inhibición y la flexibilidad, los componentes principales de FFEE, contribuyen sustancialmente a la capacidad intelectual general, especialmente a la inteligencia fluida (Chen et al., 2019). De hecho, las áreas parietales y frontales involucradas en la atención y en las FFEE también se han relacionado con la inteligencia fluida (Tschentscher et al., 2017; Yoon et al., 2017). En consecuencia, basándonos en esta idea, analizamos la relación entre el desempeño en inhibición y vigilancia con inteligencia fluida. Nuestros resultados muestran que la inteligencia fluida predice mejores resultados en la vigilancia. Las tareas de vigilancia requieren un control atencional que está relacionado con el control inhibitorio. También encontramos que los participantes con niveles más altos en vigilancia también obtuvieron puntuaciones más altas en inteligencia fluida. Hallazgos previos han sugerido una relación entre vigilancia e inteligencia en niños en riesgo de dificultades de aprendizaje (Swanson y Cooney, 1989). En este sentido, debemos mencionar que la inteligencia beneficia el desempeño de la vigilancia. En términos de atención, nuestros resultados muestran que los participantes con menos omisiones y un menor nivel de distracción en las pruebas neuropsicológicas tuvieron mejores resultados en la tarea de vigilancia. Como se demostró en estudios anteriores, las omisiones y la distracción pueden ser predictores del rendimiento en tareas de *go/no-go* (Lewis et al., 2017b). Desde nuestro punto de vista, el hecho de que los niveles más bajos de omisiones en la prueba DIVISA-R se relacionen con un mejor desempeño en la vigilancia, es un resultado que aporta validez al entrenamiento. Finalmente, en lo que respecta a la relación entre flexibilidad cognitiva y atención, consideramos que la flexibilidad cognitiva tiene una influencia positiva en las tareas de vigilancia, ya que cambian las instrucciones para

cada juego. La transición de una regla (por ejemplo, "toca cada vez que aparece un oso en la pantalla) a otra (por ejemplo, " toca cuando veas el número 5 ") implica no sólo una alteración en el tipo de instrucciones (objetivo y distractores) sino también un cambio de tareas de vigilancia a tareas de inhibición, ya que ambos tipos de juegos se practican en cada sesión. Presuponemos que las personas con mayor flexibilidad cognitiva pueden ajustar mejor sus recursos cognitivos a estos cambios. Un estudio anterior sugirió que la flexibilidad cognitiva puede convertirse en una herramienta útil para las estrategias de entrenamiento de vigilancia, ya que las diferencias individuales en la flexibilidad cognitiva predicen mejores resultados en las tareas de vigilancia (Figuroa y Youmans, 2012). Otra posible explicación se refiere a la idea de que la flexibilidad puede ser un predictor de la velocidad de procesamiento (Deák y Wiseheart, 2015). Las tareas de *go/no-go* implican velocidad de procesamiento, es decir, un participante con una velocidad de procesamiento baja puede cometer un alto número de omisiones en la tarea y, como resultado, obtener niveles más bajos de rendimiento de vigilancia. Todos estos ejemplos demuestran cómo los procesos cognitivos están interrelacionados y, por lo tanto, cómo el entrenamiento puede tener un impacto simultáneo en múltiples procesos.

Este estudio tiene varias fortalezas. En primer lugar, examina un tipo de entrenamiento (*strategy-based*) de atención y FFEE, que, además, proporciona estrategias compensatorias adaptadas a las necesidades del participante. Este es un enfoque innovador para el entrenamiento cognitivo con potencial para futuras investigaciones. Además, las estrategias implementadas se basan en investigaciones previas y se han diseñado de acuerdo con la etapa de desarrollo en la que se aplica el entrenamiento. En este sentido, es importante que los futuros diseños de entrenamientos basados en estrategias consideren los factores de desarrollo evolutivo. En nuestra opinión, este enfoque puede superar las limitaciones de los diseños previos de entrenamiento cognitivo en atención y FFEE, en términos de generalización o transferencia y efectos a largo plazo (Rossignoli et al., 2018). En tercer lugar, este análisis ha ayudado a aclarar la relevancia de la comprensión de instrucciones y las autoinstrucciones como estrategias compensatorias. Este hallazgo también debe tenerse en cuenta para futuros diseños de entrenamientos cognitivos y las mejoras que realicemos en nuestro programa. Este estudio revela que el desarrollo infantil modera el desempeño de inhibición y vigilancia. Además, también demuestra que existe una relación entre la inteligencia fluida y la vigilancia. Este hallazgo plantea la cuestión de si la inteligencia se puede mejorar mediante el entrenamiento de la vigilancia; se necesita más investigación en este sentido. Además, nuestro artículo muestra una relación entre inhibición y vigilancia. Por otro lado, este estudio también presenta ciertas limitaciones. Por ejemplo, como el estudio no incluyó grupos de participantes de más edad, no pudimos analizar la viabilidad de las estrategias en diferentes grupos de edad. Además, debido a una limitación técnica, no pudimos incluir la velocidad de procesamiento como una variable en nuestro análisis. Sería muy útil incluir esta variable en el futuro.

Finalmente, nos hemos centrado en el entrenamiento de "Nexxo" con niños con desarrollo típico. La investigación futura sobre el entrenamiento "Nexxo" debería centrarse en poblaciones con desarrollo atípico en términos de atención y FFEE, como el TDAH, dado que nuestro enfoque es que estas herramientas sean utilizadas en población clínica y que su diseño se realizó para esta población. Querríamos duplicar el tiempo de intervención y añadir seguimientos más extensos. Además, nos gustaría incorporar una

medida de tiempo de reacción o velocidad de procesamiento dentro de la propia aplicación. Además, en esta línea futura, querríamos incorporar herramientas para comprobar, además de la transferencia del entrenamiento, la neuroplasticidad que pudiera potenciar el mismo. Por otro lado, para estudiar el impacto que tienen las estrategias, quisiéramos comparar un grupo que realizara la intervención (strategy-based) con otro grupo que recibiera la intervención, pero sin el uso de estrategias. Ello nos ayudaría a demostrar el potencial que pueden tener las estrategias en combinación con el programa. Por último, sería conveniente ampliar los grupos de edad para probar los efectos del entrenamiento en grupos de edad superiores (de 8 a 12 años).

CONCLUSIONES

1. En relación al diseño metodológico de los estudios sobre productos de brain training de atención y/o funciones ejecutivas en niños y adolescentes, se encuentran importantes limitaciones metodológicas en la mayoría de ellos. Existe una carencia de estudios doble-ciego aleatorizados que incluyan grupo de control activo y grupo de control pasivo para controlar variables contaminantes.
2. En relación a los efectos de los entrenamientos:
 - a. La mayoría de productos de entrenamiento cognitivo no tienen estudios sobre neuroplasticidad.
 - b. Aunque aproximadamente la mitad de ellos producen efectos en áreas que no son directamente entrenadas (*far transfer*), el mantenimiento de los mismos a largo plazo es limitado.
 - c. Los productos comercializados de *brain training* no parecen tan efectivos como pudiera esperarse según el marketing derivado de los mismos.
3. Considerando los resultados y las muestras en las que se centran la mayoría de los estudios, creemos que la investigación de BT debería contribuir a validar programas para población con déficits neuropsicológicos y no ser dirigidos a la población general.
4. Nuestro enfoque parte de modelos neuropsicológicos de la atención, las funciones ejecutivas y metacognición. El entrenamiento cognitivo basado en estrategias facilita la transferencia del aprendizaje. Además de facilitar estrategias generales, proporciona estrategias complementarias a aquellos participantes que mostraron dificultades durante el entrenamiento. Este es un enfoque novedoso con potencial para futuras investigaciones.
5. El estudio realizado sobre el impacto de Nexxo es riguroso metodológicamente hablando dado que es controlado, aleatorizado e incluye grupo de placebo. Los criterios de inclusión han sido revisados escrupulosamente para garantizar la normalidad de la muestra.
 - a. En 3º de primaria, el grupo experimental redujo significativamente las puntuaciones en problemas atencionales en el seguimiento en comparación con ambos grupos de control. Ello supone una evidencia de “*far transfer*” respecto a la atención y de mantenimiento a medio plazo de los efectos (3 meses después).
 - b. Se encuentran otros resultados positivos sobre el grupo experimental en comparación con el grupo de control pasivo. Éstos son de menor consideración al no darse respecto a los dos grupos de control.
6. En cuanto al grupo de primero de primaria no se encontraron resultados significativos.

7. No podemos respaldar estadísticamente la idoneidad del entrenamiento antes o después de los 7 años de edad, sin embargo, existe una tendencia a alcanzar un mayor número de resultados significativos en los participantes de tercero de primaria.
8. En relación al uso de estrategias compensatorias, éstas fueron más necesarias para aquellos que presentaron más dificultades durante el entrenamiento.
9. En cuanto al análisis de estrategias, parece que las estrategias de comprensión de instrucciones y autoinstrucciones fueron las estrategias más útiles para los que mostraron dificultades durante el entrenamiento.
10. Respecto al análisis de variables cognitivas de desarrollo y desempeño en tareas de inhibición y vigilancia:
 - a. La inhibición y la vigilancia son procesos relacionados.
 - b. La edad modera el desempeño en inhibición y vigilancia.
 - c. La inteligencia fluida y la flexibilidad cognitiva predicen mejores resultados en vigilancia.

Futuras líneas de investigación:

1. Comprobar la eficacia del entrenamiento a partir de los 8 años, aumentando la duración de la intervención (aplicando no solo el nivel uno del programa si no también el nivel 2).
2. Comprobar la eficacia del programa en poblaciones clínica donde la atención y las FFEE estén afectadas como en el caso del TDAH.
3. Incorporar una medida de velocidad de procesamiento respecto a la ejecución del participante en la aplicación.
4. Comprobar los efectos que produce el entrenamiento en términos de neuroplasticidad, aplicando medidas de evaluación neurofisiológicas o de neuroimagen.
5. Comparar los efectos de la intervención con estrategias con intervención sin estrategias, para conocer la influencia que las estrategias tienen en el *far transfer*.

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