Universidad de Oviedo

Evaluación de los Problemas de Atención con o sin Dificultades de Aprendizaje

Assessment of Attentional Problems with or without Learning Disabilities

Programa de Doctorado en Psicología y Educación regulado por el Real Decreto 99/2011

Tesis Doctoral

Autora: Débora Areces Martínez

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Directores: Paloma González Castro
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RESUMEN DEL CONTENIDO DE TESIS DOCTORAL

1.- Título de la Tesis	
Español/Otro Idioma: Evaluación de los Problemas de Atención con o sin Dificultades de Aprendizaje	Inglés: Assessment of Attentional Problems with or without Leaning Disabilities

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RESUMEN (en español)

La presente tesis doctoral cuenta con tres grandes objetivos generales, cuyo propósito final es conseguir una evaluación válida y fiable para el diagnóstico del TDAH.

El primer objetivo, trata de elaborar un modelo de evaluación del TDAH que considere las relaciones existentes entre variables de diferente tipología (en concreto, entre el rendimiento en tareas de ejecución y la activación cortical en áreas prefrontales). Para ello, se llevaron a cabo dos estudios: el primer estudio ya se encuentra publicado en la revista *Frontiers in Psychology*, mientras que el segundo se encuentra en proceso de revisión en la revista *JOVE* (trabajo complementario). Los resultados generales de ambos estudios revelaron que: (1) la relación entre el rendimiento en las tareas de ejecución y los niveles de activación y oxigenación cortical (tomados en las regiones Fp1 y Cz/Fpz) fue mayor en estudiantes con TDAH que en aquellos estudiantes que no presentaban dicho trastorno; (2) dentro de la muestra de estudiantes con TDAH, se observó un comportamiento diferencial del modelo en función del tipo de presentación: concretamente, la sintomatología impulsiva e hiperactiva se asoció con una baja activación y oxigenación sanguínea en área Fp1, y un mayor número de comisiones; mientras que la sintomatología de inatención, se relacionó con una baja activación y oxigenación sanguínea en la región Fpz/Cz, y un mayor número de omisiones. De este modo, dadas las implicaciones prácticas derivadas de los presentes hallazgos, posteriormente se diseñó un protocolo de evaluación del TDAH en el que se consideraban las relaciones evidenciadas por el anterior modelo de evaluación comentado.

Por su parte, el segundo de los objetivos, pretende analizar si la incorporación de la realidad virtual a los test de ejecución continua (CPT) supone o no un avance en la evaluación de la sintomatología TDAH. Este objetivo general, se concretó a través de dos estudios: el primero de ellos se encuentra publicado online en la revista *Journal of Attention Disorders*, y el segundo está bajo proceso de revisión en la revista *PlosOne* (trabajo complementario). Tales trabajos, permitieron extraer las siguientes conclusiones generales: (1) cuando se analiza la información obtenida por el CPT de realidad virtual (en este caso, Aula Nesplora) en función de las distintas condiciones ofrecidas por la prueba (concretamente tres condiciones: presencia Vs. ausencia de distractores, canal visual Vs. canal auditivo, tarea go Vs. tarea no-go), el test permitió discriminar entre los diferentes tipos de presentación de TDAH; (2) el número de errores por omisión obtenido a través de un CPT con realidad virtual, el rendimiento en

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memoria de trabajo procedente de la escala Weschler, y la edad de los estudiantes, han resultado ser las tres variables más relevantes para predecir la pertenencia al grupo (TDAH Vs. No TDAH), esto sugiere que un mal rendimiento en tareas de atención puede ser debido no sólo a problemas de inatención, sino también a problemas en la memoria de trabajo; (3) El CPT con realidad virtual estudiado, al igual que ocurre con otros CPTs tradicionales, mostró mayores niveles de sensibilidad que de especificidad.

Finalmente, en tercer lugar, el último objetivo trata de comprobar cómo se relaciona el rendimiento en las tareas de denominación con los problemas de atención y/o de lectura. Este último objetivo, se llevó a cabo a través de dos estudios, que se encuentran publicados en la revista *Anales de Psicología* y en la revista *Child Neuropsychology*. En este sentido, los resultados más significativos procedentes de tales trabajos son los siguientes: (1) si bien el rendimiento en las tareas de denominación (obtenido a través de la prueba RAN/RAS) se ve influido por variables de distinta naturaleza (edad cronológica, errores de lectoescritura y variables de ejecución), tales variables tienen un efecto diferencial en función del grupo diagnóstico analizado (esto es, en función de la presencia o ausencia de problemas atencionales y/o dificultades lectoras); (2) la prueba RAN/RAS (en concreto la tarea de denominación compuesta por colores) predice mejor la pertenencia al grupo (Grupo Control, Grupo con TDAH, Grupo con Dificultades y Grupo Comórbido) a edades tempranas (cuando los estudiantes tienen edades comprendidas entre los 5 y los 9 años); (3) para predecir correctamente la pertenencia al grupo con TDAH es necesario considerar los tiempos de denominación junto con la información relativa a los síntomas presentes en cada caso (contenida en el DSM-5).

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RESUMEN (en Inglés)

The present PhD. thesis presents three general objectives, aiming at a valid and reliable evaluation for the diagnosis of ADHD.

The first objective is to elaborate a model of evaluation for ADHD that considers the relations existing among variables of different types (particularly, between performance in execution tasks and cortical activation in prefrontal areas). To this aim, two research studies were carried out. The first of these has been published in *Frontiers in Psychology,* whereas the second is under reviewing for publication by the journal *JOVE* (supplementary work). The general results obtained in these studies showed that (1) the relationship between performance in execution tasks and activation and cortical oxygenation levels (taken in Fp1 and Cz/Fpz regions) was greater in students with ADHD than in those without this condition; (2) within the sample of students with ADHD a differential performance was observed depending on the model: thus, symptoms of impulsiveness and hyperactivity were associated to low activation and blood oxygenation in the Fp1 area and a larger number of commissions, whereas symptoms of inattention were related to low activation and blood oxygenation in the Fpz/Cz region and a larger number of omissions. Thus, due to the practical implications deriving from such results, a protocol for the evaluation of ADHD was later elaborated in which the areas to be evaluated for a valid and reliable diagnosis of ADHD taking into consideration the relationships found in the previous model.

As for the second objective, this is to analyse whether incorporating virtual reality to continuous performance tests (CPT) renders an advance in the evaluation of ADHD

symptoms. This general objective was tackled in two research studies, the first of which has been published in the online journal *Journal of Attention Disorders* and the second is under reviewing for publication by the journal *PlosOne* (supplementary work). These papers led to the following general conclusions: (1) when analysing the information obtained from a virtual reality CPT (in this case, Aula Nesplora) according to the conditions set by the test (namely three: presence vs. absence of distractors; visual channel vs. auditory channel; go-task vs. non-go-task) the test allowed for a discrimination among the different forms of occurrence of ADHD; (2) the number of omission errors obtained through a virtual reality CPT, the performance in working memory under the Weschler scale and the age of the students have been the most relevant variables in predicting group associations (ADHD vs. non-ADHD), which suggests that low performance in attention tasks may be due not only to inattention problems, but also to problems in working memory; (3) the virtual reality CPT under analysis, as is the case with other traditional CPTs, showed higher levels of sensibility than those of specifity.

Finally, the third and last objective is to verify how performance in naming tasks relates to attention and/or reading problems. This last objective was pursued in two research studies, both published in the journals: *Anales de Psicología* and *Child Neuropsychology*. The most significant results from these papers are: (1) although performance in naming tasks (through the RAN/RAS test) is under influence of different kinds of variables (chronological age, reading-writing errors and execution variables), such variables have differential effect according to the diagnostic group under analysis (that is, depending on the presence or absence of attentional problems and/or reading difficulties); (2) the RAN/RAS test (the colour-naming task in particular) is better at predicting group belonging at early ages (ages 5 to 9); (3) in order to adequately predict the belonging to the ADHD group naming times must be considered together with information concerning the symptoms present in each case of (contained in the DSM.

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Debora Areces PhD letter of support

To whom it may concern:

I am writing to support the application of Debora Areces to receive the international Ph.D. thesis to complete the doctoral program of study. The Ph.D. thesis resulted in a series of publications regarding the interaction between brain activation variables and executive functioning with Attention-Deficit Hyperactivity Disorder (ADHD) Specifically, the studies consisted of analyzing the diagnostic effectiveness of the AULA Nesplora test to discriminate the different ADHD presentations (inattentive, I/H, and combined), analyze the explanatory power of reading (type of reading error), and attentional (commission, omission, and D´ as given by TOVA) variables on naming speed by diagnostic attentional condition (ADHD, RLD, ADHD+RLD, control group), describe and compare naming speed abilities in children diagnosed with either Reading Learning Difficulties (RLD) or Attention Deficit/Hyperactivity Disorder (ADHD) or comorbidity for both (ADHD+RLD), and finally, to develop a complete procedure/model of assessment of patterns of cortical activation and executive control to provide a more objective diagnosis of ADHD than is currently utilized.

Of the five studies conducted, two are currently published and two are in press in various journals (e.g., Anales de Psicología, Frontiers in Psychology, Child Neuropsychology, Journal of Attention Disorders). I have read the studies (in English) and believe that they were methodologically sound and of very high quality.

I fully support the application of Debora Areces to receive the Ph.D. thesis with international recognition. Please let me know if you have any questions or require any additional information.

Sincerely,

Bruce Saddler, Ph.D.
Associate Professor
Associate Dean for Academic Advancement
School of Education
Department of Educational and Counseling Psychology
Division of Special Education
University at Albany
ED 210
1400 Washington Ave. Albany, New York, USA 12222
(518-442-4988)

Boston Children's Hospital Harvard Medical School

October 30h, 2017

To whom it may concern,

I am writing in support of the application of Debora Areces to receive the international Ph.D. thesis title at the completion of her doctoral program of study. The Ph.D. thesis resulted in a series of publications regarding the diagnosis of ADHD using executive functioning or the use of a measure that utilizes virtual reality and clinical information, or the utilization of speed of processing variables including RAN and naming speed constructs. Specifically, the studies consisted of developing and analyzing the contribution of various theoretically driven assessment tools, for the identification of ADHD children.

Of the six studies conducted, four are currently published (e.g., Child Neuropsychology, Anales de Psicología) and two are in press in various journals. I have read four of the studies (in English) and believe that they met well the criteria of rigorous research, they were methodologically sound and of high quality as I expected based on the novelty of the topic. The ADHD population has been studied well but issues related to identification and classification are still under scrutiny due to the high comorbidity levels between the ADHD population and other populations such as those of children with learning disabilities, dyslexia, etc. Thus, the general topic was very important and was approached with great theoretical clarity. Overall, I believe that these studies greatly broadened our understanding of ADHD individuals.

I support the application of Debora Areces to receive her Ph.D. thesis with international recognition. Please let me know if you have any questions or require additional information.

Sincerely,

Georgios D. Sideridis, Ph.D.
Assistant Professor of Pediatrics and Senior Survey Methodologist
Harvard Medical School/Boston Children's Hospital
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Debora Areces Martinez

This is confirm that Debora was enrolled as a visiting research student in the Department of Psychology and Human Development at the Institute of Education, UCL during the months of May, June and July 2016. During this time she worked in the Language and Literacy research centre under my guidance. She worked on developing publications, attended a special module on Behaviour and Social Development and made a special presentation to the department.

With Kind Regards,

Professor Julie Dockrell FrCSLT, FaSS
Director Language and Literacy Research Centre
Psychology and Human Development, IOE UCL

IOE
LONDON

Esta Tesis Doctoral se ha llevado a cabo gracias a una beca predoctoral perteneciente al Programa Severo Ochoa de la Fundación para el Fomento en Asturias de la Investigación Científica Aplicada y la Tecnología-Ficyt (Ref. BP14-030).

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Agradecimientos

Terminar una tesis doctoral significa que han sido muchas las personas que, de una forma u otra te han guiado, apoyado y dado fuerzas cuando lo necesitabas.

En primer lugar, debo a agradecer al profesor Luis Álvarez el haberme abierto las puertas al campo de la investigación. Gracias a él he tenido la posibilidad de iniciarme y conocer a un equipo de investigación que, a día de hoy, es un referente para mí.

Gracias a mis directores de tesis, Julio Antonio González García y Paloma González Castro. Gracias Julio, por confiar en mí para lleva a cabo estos años de trabajo y formación. Gracias Paloma, por creer en mí y darme energía cuando lo necesito.

Mi especial agradecimiento a cada uno de los miembros del equipo ADIR, quienes me han hecho sentir una profesional más del equipo y han hecho que estos años sean inolvidables. Gracias al profesor Celestino Rodríguez, por apoyarme y ponerme las cosas tan fáciles. Has sido y serás un referente en lo profesional y en lo personal. Gracias a Trinidad, por enseñarme lo importante que es luchar y trabajar para poder obtener resultados reforzantes como este. Gracias a Marisol, por mostrarte siempre dispuesta a ayudarme y solventar mis dudas.

Gracias a mi familia (abuela, tíos, primos) por hacerme sentir siempre tan arropada. A mi madre por enseñarme a no perder la sonrisa y ser positiva en todo momento. A mi padre por haberme mostrado lo importante que es el esfuerzo y no rendirse para conseguir las cosas que quieres. A mi abuelo, por mostrarse siempre orgulloso de cada cosa que hago.

Gracias a Nel, uno de mis mayores apoyos durante todos estos años, gracias por tu implicación en este proyecto y por convertirte en un experto de todos y cada uno de los temas que componen esta tesis.

Finalmente, agradecer la excelente labor de los centros educativos y las familias que, con su consentimiento, permitieron que todos estos estudios se llevaran a cabo.

Listado de trabajos

Publicaciones:

Rodríguez, C., González-Castro, P., Cueli, M., Areces, D., & González-Pienda, J.A. (2016). Attention Deficit/Hyperactivity Disorder (ADHD) diagnosis: an activation-executive model. *Frontiers in Psychology*, *7*. Doi: 10.3389/fpsyg.2016.01406

Areces, D., Rodríguez, C., García, T., Cueli, M., & González-Castro, P. (In press). Efficacy of a continuous performance test based on virtual reality in the diagnosis of ADHD and its clinical presentations. *Journal of attention disorders*. Doi: 10.1177/1087054716629711

Areces, D., Pérez, C. R., Gonzalez-Castro, P., García, T., & Cueli, M. (2017). Naming Speed and its effect on attentional variables and reading errors depending on the diagnosis. *Anales de Psicología*, *33*(2), 301-310. Doi: 10.6018/analesps.33.2.239091

Areces, D., García, T., Álvarez, D., González-Castro, P., & Rodríguez, C. (In press). Naming Speed as a Predictive Diagnostic Measure in Reading and Attentional Problems. *Child Neuropsychology*. Doi: 10.1080/09297049.2017.1391191.

Trabajos complementarios:

Areces, D., Cueli, M., García, T., González-Castro, P., & Rodríguez, C. Using brain activation (nir-HEG/Q-EEG) and execution measures (CPTs) in a ADHD assessment protocol. Under review in *Journal JOVE*

Areces, D., Dockrell, J., García, T., González-Castro, P., & Rodríguez, C. Analysis of cognitive and attentional profiles in children with and without ADHD using an innovative virtual reality tool. Under review in *PlosOne*

Índice

Resumen

El Trastorno por Déficit de Atención e Hiperactividad (TDAH) se caracteriza por la presencia de un patrón persistente de conductas de inatención, impulsividad e hiperactividad, las cuáles afectan de forma negativa a los diferentes contextos del desarrollo de los niños/as. Esta sintomatología frecuentemente se inicia en la infancia, y persiste en la adolescencia y en la vida adulta. Sus tasas de prevalencia oscilan entre el 3% y el 7% de la población escolar, lo que genera la necesidad de que los profesionales dispongan de instrumentos válidos y fiables para poder detectar el trastorno, y de este modo prevenir complicaciones futuras.

En la presente tesis doctoral se plantearon tres objetivos generales, cuyo propósito final es conseguir una evaluación válida y fiable para el diagnóstico del TDAH. El primer objetivo trata de elaborar un modelo de evaluación del TDAH que considere las relaciones existentes entre variables de diferente tipología (en concreto, entre el rendimiento en tareas de ejecución y la activación cortical en áreas prefrontales). Por su parte, el segundo de los objetivos, pretende analizar si la incorporación de la realidad virtual a los test de ejecución continua (CPT) supone o no un avance en la evaluación de la sintomatología TDAH. Finalmente, en tercer lugar, el último objetivo trata de comprobar cómo se relaciona el rendimiento en las tareas de denominación con los problemas de atención y/o de lectura.

Para alcanzar el primero de los objetivos, se utilizó una muestra de 499 estudiantes con edades comprendidas entre los 8 y los 16 años. 256 estudiantes contaban con el diagnóstico previo de TDAH, mientras que 243 pertenecía al Grupo Control. Para la consecución de dicho objetivo, fue diseñado un modelo de ecuaciones estructurales, el cual

incluyó, por un lado, variables de ejecución, las cuales se obtuvieron a través de un test de ejecución continua (tales como omisiones, comisiones, tiempo de respuesta, variabilidad…); y, por otro lado, variables relacionadas con la activación y la oxigenación sanguínea en las áreas prefrontales tomadas con el QEEG y el nir-HEG respectivamente.

Los análisis del este modelo mostraron los siguientes resultados generales: (1) la relación entre el rendimiento en las tareas de ejecución y los niveles de activación y oxigenación cortical tomados en las regiones Fp1 y Cz/Fpz fue mayor en estudiantes con TDAH que en estudiantes sin TDAH; (2) dentro de la muestra de estudiantes con TDAH, se observó un comportamiento diferencial del modelo en función del tipo de presentación: de este modo, la sintomatología impulsiva e hiperactiva se asoció con una baja activación y oxigenación sanguínea en área Fp1, y un mayor número de comisiones; mientras que la sintomatología de inatención, se relacionó con una baja activación y oxigenación sanguínea en la región Fpz/Cz, y un mayor número de omisiones. De este modo, dada las implicaciones prácticas derivadas de tales resultados, y de acuerdo con el primero de los objetivos, se elaboró un protocolo de evaluación en el que se describieron las áreas a evaluar para realizar un diagnóstico válido y fiable del TDAH (información personal/autobiográfica relevante, perfil cognitivo, análisis de la ejecución, la activación y oxigenación cortical), así como los pasos a seguir para evaluar de forma precisa cada una de las mismas.

Por otro lado, de acuerdo con el segundo de los objetivos, el propósito del primer trabajo consistía en comprobar si un CPT que utilice realidad virtual (Aula Nesplora) es capaz de diferenciar entre los tres tipos de presentación de TDAH. Para ello, se utilizó una submuestra de 117 estudiantes de entre 5 y 16 años, y se llevó a cabo un Análisis

Multivariado de la Covarianza (MANCOVA). Las medidas procedentes de este CPT fueron analizadas inicialmente de forma global, y posteriormente, considerando las distintas condiciones ofrecidas por la propia prueba (concretamente tres condiciones: presencia Vs. ausencia de distractores, canal visual Vs. canal auditivo, tarea go Vs. tarea no-go).

Los resultados mostraron que la información global ofrecida por el CPT de realidad virtual permitió discriminar entre la presentación impulsiva-hiperactiva y la combinada con respecto al grupo control, así como entre presentación impulsiva e hiperactiva y la presentación inatenta. Sin embargo, la diferenciación entre la presentación combinada e inatenta, o entre la presentación impulsiva-hiperactiva y la combinada, solo se evidenciaron cuando los resultados de la prueba son analizados en función del canal sensorial (auditiva y visual).

En este sentido, la incorporación de la realidad virtual a un CPT ha mostrado ser eficaz para discriminar entre los tres tipos de presentaciones de TDAH, siempre y cuando, se realice un análisis de los resultados tanto de forma global como de forma específica, considerando las diferentes condiciones ofrecidas por la prueba (especialmente, toma especial relevancia el análisis de los resultados obtenidos según el canal sensorial utilizado).

Continuando con el segundo de los objetivos, el siguiente estudio trató de comprobar la capacidad discriminativa de un CPT que utiliza la realidad virtual para diferenciar entre casos con y sin TDAH. Con esta finalidad, se utilizó una submuestra de 88 estudiantes con edades comprendidas entre los 6 y los 16 años. De este modo, se llevó a cabo un Análisis Discriminante, en el que se introdujeron variables ofrecidas por el CPT (omisiones, comisiones, tiempo de respuesta …) junto con variables cognitivas (memoria de trabajo y velocidad de procesamiento tomadas de la escala Weschler) y la edad de los sujetos.

Los resultados revelaron que las variables que tienen un mayor poder explicativo para predecir la pertenencia al grupo fueron: el número de omisiones, el rendimiento en memoria de trabajo y la edad. Tales resultados, sugieren que el mal desempeño en las tareas de atención puede ser debido no sólo a problemas de inatención, sino también a problemas en la memoria de trabajo.

En cuanto a los niveles de especificidad y sensibilidad del CPT con realidad virtual, al igual que ocurre con otros CPTs tradicionales, los resultados mostraron mayores niveles de sensibilidad que de especificidad.

Finalmente, de acuerdo con el tercero de los objetivos de la presente tesis doctoral, el primer trabajo enmarcado en este último objetivo general, trató de comprobar el poder explicativo de determinadas variables relacionadas con la atención (en concreto, variables de ejecución ofrecidas por un CPT) y la lectura (errores lectores) sobre la velocidad de denominación. Para ello, se utilizó una submuestra compuesta de 132 estudiantes de entre 5 y 16 años, los cuáles fueron divididos en cuatro grupos (Grupo Control, Grupo con Dificultades Lectoras, Grupo con TDAH, y Grupo comórbido: TDAH + Dificultades Lectoras).

De este modo, de acuerdo con la finalidad de dicho estudio, se llevaron a cabo diferentes análisis de regresión simple de tipo jerárquica (uno para cada grupo diagnóstico), cuyos resultados mostraron que: 1) en ausencia de dificultades, la velocidad de denominación es explicada por el CI, la edad y el género; 2) ante dificultades lectoras, las variables con mayor poder predictivo son los errores de lectura; 3) ante dificultades atencionales, son las variables ofrecidas por el CPT las que muestran una mayor significatividad. La conclusión general, por tanto, es que si bien las tareas de denominación (a través de la prueba RAN/RAS) se ven influidas por variables de distinta naturaleza (edad cronológica, errores de lectoescritura y variables de ejecución), tales variables tienen un efecto diferencial en función del grupo diagnóstico analizado.

Por último, el último trabajo enmarcado en el tercero de los objetivos, trataba de comprobar en qué medida el rendimiento de la prueba RAN/RAS permite predecir la pertenencia al grupo (Grupo Control, Grupo con Dificultades Lectoras, Grupo con TDAH y Grupo Comórbido). Con esta finalidad, el estudio utilizó una submuestra de 101 estudiantes con edades comprendidas entre los 5 y 16 años. Los resultados procedentes de los análisis discriminantes, evidenciaron que: (1) la prueba RAN/RAS (en concreto la tarea de denominación de colores) predice mejor la pertenencia al grupo a edades tempranas (edades comprendidas entre los 5 y los 9 años); y (2) para predecir adecuadamente la pertenencia al grupo con TDAH, es necesario considerar los tiempos de denominación junto con la información relativa a los síntomas presentes en cada caso de TDAH (contenida en el DSM-5).

Summary

The Attention Deficit Hyperactivity Disorder (ADHD) is characterized by the presence of a persistent pattern of inattention, impulsivity, and hyperactivity, which negatively affect different contexts in child development. These symptoms often start at childhood and persist in adolescence and adult age. Prevalence rates range between 3% y el 7% of the population at school age, generating a need for professionals to have valid and reliable assessment instruments in order to detect the disorder, thus preventing future complications.

The present thesis sets three general objectives, aiming at a valid and reliable evaluation for the diagnosis of ADHD. The first objective is trying to elaborate a model of evaluation for ADHD that considers the relations existing among variables of different types (particularly, between performance in execution tasks and cortical activation in prefrontal areas). On the other hand, the second objective aims at analyzing whether incorporating virtual reality to Continuous Performance Test (CPT) renders an advance in the evaluation of ADHD symptoms. As for the third and last objective aims at verifying how performance in naming tasks relates to attention and/or problems.

In order to tackle the first objective, a sample was used consisting of 499 students, aged 8 to 16. 256 students had previously been diagnosed with ADHD, whereas 243 did not present ADHD. To reach the objective, a structural equation model was devised, including, on the one hand, execution variables, obtained through a continuous execution test (such as omissions, commissions, response time, variability…) and, on the other hand, variables related to activation and blood oxygenation in the prefrontal areas, respectively obtained through the QEEG test and the nir-HEG.

Analyses of the model showed the following general results: (1) the relationship between performance in execution tasks and activation and cortical oxygenation levels taken in Fpl and Cz/Fpz regions was greater in students with ADHD than in those without it; (2) within the sample of students with ADHD a differential performance was observed depending on the model: thus, symptoms of impulsiveness and hyperactivity were associated to low activation and blood oxygenation in the Fp1 area and a larger number of commissions, whereas symptoms of inattention were related to low activation and blood oxygenation in the Fpz/Cz region and a larger number of omissions. Subsequently, due to the practical implications deriving from such results, and according to the first objective, an evaluation protocol was elaborated in which the areas to be evaluated for a valid and reliable diagnosis of ADHD were described (relevant personal/autobiographical information, cognitive profile, analysis of execution, activation and cortical oxygenation), along with the steps to be taken in precisely evaluating each of those.

On the other hand, and in accordance with the second objective, the first paper aims at testing whether a CPT using virtual reality (Aula NESPLORA) can differentiate the three forms of occurrence ADHD. To this aim, a subsample of 117 students, aged 5 to 16 was used and a multivariate analysis of covariance (MANCOVA) was carried out. Results obtained from this CPT were first analyzed globally and then considering the different conditions set by the test itself (presence vs. absence of distracters, visual channel vs. auditory channel, go-task vs. non-go-task).

Results showed that the global information provided by the virtual reality CPT allowed for a discrimination between the impulsive-hyperactive occurrence and the combined one with respect to the control group, and also between impulsive and hyperactive occurrence and the inattentive type. However, differentiations between the combined and the inattentive presentation or between the impulsive-hyperactive presentation ant the combined one were only observed when test results were analyzed considering the sensory channel (auditory and visual).

In this sense, incorporating virtual reality to a CPT has proved effective in discriminating among the three types of occurrence of ADHD, provided an analysis of results, both globally and specifically, is carried out considering the different conditions of the test (it is particularly relevant to analyze the results obtained depending on the Taking the second objective into consideration, the second study aimed at testing the discriminating capacity of a CPT that makes use of virtual reality in differentiating cases with and without ADHD. To this aim, a subsample of 88 students, aged 6 to 16, was used. A Discriminant Analysis was carried out, introducing variables offered by the CPT (omissions, commissions, response time…) together with cognitive variables (working memory and processing speed, taken from the Weschler scale) and age. The results revealed that that the variables with a greater explanatory power in predicting group membership were: the number of omissions, working memory performance and age. Such results suggest that poor performance in attention tasks may be due, not only to inattention problems, but also to problems in working memory. As for specificity and sensitivity levels of the CPT with virtual reality, along with other traditional CPTs, the results showed higher levels of sensibility than those of specifity.

Finally, and in accordance with the third objective of this thesis, a first work pursuing it aimed at testing the explanatory power of some variables related to attention (particularly execution variables offered by a CPT) and reading (reading errors) on naming speed. To this aim, a subsample of 132 students, aged 5 to 16, was used. Students were divided into four groups (Control Group, Group with Reading Difficulties, Group with ADHD and Co-morbid Group: ADHD + Reading Difficulties). Subsequently, and according to the aim of the study, different simple regression hierarchical analyses were carried out (one for each diagnostic group). The results showed that: 1) difficulties being absent, naming speed is explained by IQ, age and gender; 2) given reading difficulties, the variables with the highest predictive power are reading errors; 3) given attentional difficulties, the variables shown by the CPT are the most significant ones.

The general conclusion is therefore that, although naming tasks (through the RAN/RAS test) are influenced by variables of different kinds (chronological age, reading-writing errors and execution variables), such variables have differential effect according to the diagnostic group under analysis.

Finally, the last work framed by the third objective aimed at testing to what extent achievement in the RAN/RAS test allows for a prediction as to belonging to a group (Control Group, Group with Reading Difficulties, Group with ADHD and Co-morbid Group). To this aim, a subsample of 101 students, aged 5 to 16 was used. The results obtained from discriminant analyses showed that: 1) the RAN/RAS test (the colour-naming task in particular) is better at predicting group belonging at early ages (ages 5 to 9); and 2) in order to adequately predict the belonging to the ADHD group naming times must be considered together with information concerning the symptoms present in each case of (contained in the DSM-5).

Introducción

El Trastorno por Déficit de Atención e Hiperactividad (TDAH) frecuentemente se inicia en la infancia, y persiste en la adolescencia y en la vida adulta. Estudios de carácter nacional e internacional señalan unas tasas de prevalencia que oscilan entre un 3% y un 7% de la población en edad escolar (Catalá et al., 2012; Polanczyk, Willcutt, Salum, Kieling, & Rohde, 2014; Steinau, 2013), diagnosticándose tres veces más en niños que en niñas.

Este trastorno se caracteriza por la presencia de un patrón persistente de conductas de inatención, impulsividad e hiperactividad, las cuáles afectan de forma negativa a los diferentes contextos del desarrollo de los niños/as (Presentación, Siegenthaler, & Miranda, 2010). De este modo, esta triada sintomatológica presente en el TDAH da lugar a tres tipos de presentaciones de TDAH, tal y como señala el DSM-5 (APA, 2013): a) presentación predominantemente inatenta, b) presentación predominantemente hiperactiva, y c) presentación combinada.

Cuestionarios y pruebas más utilizadas en la evaluación del TDAH

Dado el carácter heterogéneo de la sintomatología presente en el TDAH, resulta compleja la evaluación temprana del mismo. En este sentido, los profesionales necesitan disponer de instrumentos válidos y fiables para poder detectar el trastorno, y de este modo prevenir complicaciones futuras.

Actualmente, uno de los instrumentos más utilizados en el diagnóstico del TDAH junto con la entrevista, son los cuestionarios de observación de la conducta. Ente ellos destacan: la Escala de Evaluación del TDAH (EDAH; Farré & Narbona, 2001), el Sistema de Evaluación de la Conducta de Niños y Adolescentes (BASC; Reynolds & Kamphaus, 2004), el Inventario de Comportamientos Infantiles (Behavior Checklist-CBCL; Achenbach, 1991), y la Escala de Conners (Conners, 1997). Este tipo de cuestionarios se basan en medir la frecuencia de una serie de conductas relacionadas de forma directa con los síntomas claves y característicos del TDAH (déficit de atención, impulsividad e hiperactividad). Sin embargo, a pesar de que todos ellos son ampliamente utilizados para evaluar la sintomatología TDAH, tales instrumentos presentan una limitación importante que consiste en la influencia subjetiva por parte del observador y del informante (García, González-Castro, Areces, Cueli, & Rodríguez, 2014).

Otras pruebas ampliamente utilizadas en la evaluación del TDAH son los conocidos "Test de Cancelación". Se trata de pruebas clásicas de papel y lápiz que requieren poner en marcha la búsqueda visual, la activación de objetivos, inhibir elementos distractores, una adecuada coordinación visuo-motora, así como una rapidez en el análisis del input y en la ejecución de la respuesta (Leclercq & Zimmerman, 2002). Son pruebas útiles para diferenciar entre el procesamiento automático y el procesamiento controlado. Un ejemplo de este tipo de pruebas sería el Test d2 (Brickenkamp, 2002) y el test Caras- R (Thurstone, Yela, & Luque, 2012). Ambas pruebas han mostrado ser válidas y fiables en la evaluación de la atención selectiva, si bien su duración es demasiado corta (entre 3 y 8 minutos) como para poder obtener un indicador fiable de la concentración del niño/a en tareas más largas.

Del mismo modo, los conocidos "Continuous Performance Test" (CPT) o "Test de Ejecución Continua", son también muy utilizados por los profesionales en el diagnóstico el TDAH. Los CPTs son pruebas objetivas administradas para evaluar la atención, velocidad de respuesta, resistencia a las distracciones y capacidad de inhibición durante la ejecución de una tarea (cuya duración oscila entre los 15 y los 20 minutos). Dichas variables son evaluadas a través de diferentes indicadores tales como el número de respuestas correctas, omisiones, comisiones y el tiempo de respuesta. El número de respuestas correctas refleja la precisión general, los errores de omisión están típicamente asociados con falta de atención y los errores de comisión con la impulsividad e hiperactividad (Albrecht, Sandersleben, Wiedmann & Rothenberger, 2015). Entre los CPTs más utilizados, destacan el CPT-II (Conners, 2004), el TOVA (Test of Variables of Attention; Greenberg, 1993), el CSAT (the Children Sustained Attention Task; Servera & Llabres, 2004) o el IVA (the Integrated Visual and Auditory Test; Tinius, 2003).

Medidas de Activación Cortical en la evaluación del TDAH

Con la publicación del actual DSM-5 (APA, 2013), a pesar de que éste no plantea cambios significativos en lo que respecta a los síntomas característicos del trastorno, el TDAH pasa a ser clasificado como un trastorno del neurodesarrollo. Este cambio plantea dos cuestiones; la primera cuestión, hace referencia a si los tres tipos de presentación del TDAH (presentación predominantemente inatenta, presentación predominantemente hiperactiva y presentación combinada) son diferentes desde un punto de vista evolutivo y epidemiológico (Willcutt et al., 2012); mientras que la segunda cuestión se plantea si las distintas comorbilidades presentes en el TDAH dependen del tipo de presentación (Sciberras et al., 2014). Dicho de otro modo, en términos generales, se cuestiona acerca de si las presentaciones del TDAH se podrían considerar categorías diagnósticas diferenciales (González-Castro, Álvarez, Núñez, González-Pienda, Álvarez, & Muñiz, 2010). Para estudiar este tipo de cuestiones, no es suficiente hacer una evaluación de la ejecución, sino que es preciso contrastar tales resultados con pruebas de activación cortical. Además, de este modo, se disminuiría el porcentaje de falsos positivos, el cual se ha incrementado de forma significativa en los últimos años (Moreno, Lora & Sánchez, 2011)

En la actualidad son varias las investigaciones de neuroimagen que han contribuido al desarrollo de la evaluación electroencefalográfica en este trastorno, aumentando el conocimiento sobre la neurobiología del TDAH. En este sentido, se han encontrado evidencias que relacionan el retraso en la maduración cerebral, en regiones que maduran con la edad, sugiriendo un perfil inmaduro de activación funcional (Rodillo, 2015). Diferentes variables electroencefalográficas han sido asociadas con el TDAH (Chabot, di Michele & Prichep, 2005), observándose un patrón muy peculiar en las ondas cerebrales beta y theta principalmente (Moreno y Lora, 2008).

Concretamente, varios estudios sostienen que el TDAH presenta bajos niveles de activación cortical regulados por los sistemas de neurotransmisión noradrenérgico y dopaminérgico (Brown, 2006). El sistema noradrenérgico está relacionado principalmente con la modulación de la atención selectiva y el nivel de activación general del sujeto para atender (Parasuraman, Warm, y See, 1998). El dopaminérgico, por su parte, se asocia con la capacidad de control del comportamiento (Brown, 2006), tanto a nivel ejecutivo como motivacional, puesto que está íntimamente relacionado con el sistema límbico. De este modo, cuando hay una disminución de la activación dopaminérgica, decae la capacidad de autorregulación y control inhibitorio (Álvarez, González-Castro, Núñez, González-Pienda, & Bernardo, 2008).

En este sentido, el QEEG (EEG cuantitativo) ha jugado un rol importante en la evaluación del funcionamiento neural en niños con TDAH. Estudios previos (Cueli, Rodríguez, González-Castro, Álvarez & Álvarez, 2012) han comprobado que los niños/as con TDAH presentan una activación cortical significativamente más baja que sus iguales en las zonas centrales (Cz) y prefrontales (Fp1). Concretamente, cuando la ratio beta/theta es baja en la región Cz se asocia con un déficit de atención, mientras que si la activación cortical es baja en la región Fp1 se relaciona con problemas en el control inhibitorio (González-Castro, Rodríguez, López, Cueli, & Álvarez, 2013).

Del mismo modo, otra alternativa para medir la activación cortical en niños/as con TDAH sería el nir-HEG (Toomin et al., 2004). El nir-HEG permite la evaluación e intervención del trastorno a través de la medición del flujo sanguíneo, concretamente registra la oxigenación sanguínea en zonas expresamente seleccionadas (en este caso, en las regiones Fpz y Fp1), y presenta una gran ventaja frente al QEEG, ya que la tensión muscular y el movimiento de los ojos, no afecta a la medida de activación (Toomin et al., 2004).

Por todo ello, considerando las distintas herramientas utilizadas para el diagnóstico del TDAH, así como los diferentes tipos de variables recogidas con ellas, resultaría relevante elaborar un modelo diagnóstico que permita detectar las relaciones entre las diferentes medidas recogidas. Por ejemplo, la relación existente entre el número de errores por omisiones y comisiones cometidas en un CPT con el nivel de activación cortical de las regiones Fp1 y Cz/Fpz tomadas del QEEG y el nir-HEG. Además, esto permitiría elaborar un protocolo de evaluación del TDAH basado en una evaluación precisa y objetiva, que permita diferenciar sujetos con sintomatología TDAH que no presentan TDAH (puesto que tales síntomas son explicados por otras casuísticas) de aquellos cuya sintomatología es debida a la presencia TDAH (Skounti, Philatithis, & Galanakis, 2007).

La importancia de la validez ecológica en la evaluación del TDAH

Otro aspecto relevante en la evaluación del TDAH es la validez ecológica de las pruebas o test utilizados para su diagnóstico. Los CPTs a los que previamente se ha hecho alusión, a pesar de que han demostrado su utilidad en el diagnóstico de dicho trastorno, estos han sido criticados por presentar una baja validez ecológica (Gioia, Kenworthy & Isquith, 2010). Es decir, el contexto y el método utilizado por este tipo de pruebas no es similar al entorno diario al que se enfrentan los niños/as evaluados.

A este respecto, el uso de la realidad virtual en los CPTs supone un avance en la evaluación del TDAH, puesto que aumenta la validez ecológica de este tipo de pruebas al permitir al sujeto sumergirse en un entorno más realista (Bioulac et al., 2012). De este modo, es relevante estudiar la eficacia de CPTs que utilicen la realidad virtual.

Un ejemplo de CPT que utilice la realidad virtual es Aula Nesplora (Climent, Banterla, & Iriarte, 2011). Esta herramienta evalúa la atención, impulsividad, velocidad de procesamiento y actividad motora en sujetos de entre 6 y 16 años. Para ello, presenta dos tipos de tareas basados en el paradigma go/no go en un entorno de realidad virtual mostrado a través de unas gafas 3D dotadas de sensores de movimiento y auriculares. De este modo, la perspectiva del evaluado se sitúa en uno de los pupitres, mirando hacia la pizarra, de tal forma que los movimientos de la cabeza son capturados por las gafas y el software actualiza el ángulo de visión, dando la sensación al sujeto de encontrarse en una clase virtual. Además, esta herramienta presenta otra ventaja, ya que si bien el tipo de medidas proporcionadas es similar al resto de CPTs: omisiones, comisiones, tiempo de respuestas…En este caso diferencia el rendimiento de tales variables según el canal sensorial (visual o auditivo), tipo de tarea (tarea go o tarea no go) y según la presencia o ausencia de distractores. Esta diferenciación es útil no solo de cara a la propia evaluación sino también en el momento de la intervención posterior.

El TDAH y las Dificultades de Aprendizaje en la Lectura (DAL)

Un dato curioso, que debe de tenerse en cuenta de cara al diagnóstico del TDAH, es que entre el 25 % y el 40% de los individuos con dislexia o TDAH cumple también los criterios para el otro trastorno (Willcutt y Pennington, 2000). La explicación de esta elevada comorbilidad consistiría en que la corteza prefrontal activa el sistema lector dorsal y, como consecuencia, la lectura se ve facilitada o interferida por las capacidades atencionales (Nakamura, Dehaene, Jobert, Le Bihan & Koudier, 2005). Concretamente, Pennington (2006) sugiere el *modelo de déficit múltiple*, según el cual los dos trastornos comparten bases cognitivas y estructuras neuroanatómicas, lo que favorece la comorbilidad y explicaría el extenso espectro fenotípico que suelen mostrar. En este sentido, diferentes estudios mostraron que las dificultades lectoras y atencionales comparten determinados síntomas, como son: la baja velocidad de procesamiento (Shanahan et al., 2006) o la presencia de problemas en el procesamiento semántico (Tannock, Banaschewski, & Gold, 2006), que pueden influir en los resultados de las tareas de denominación. Más específicamente, Purvis y Tannock (2000) informan en ambos trastornos de un déficit en el procesamiento fonológico y en la velocidad de denominación.

La mayoría de estas investigaciones han utilizado la prueba Rapid Automatizad Naming and Rapid Automatized Stimulus-RAN/RAS-(Wolf & Denckla, 2005), compuesta por seis tareas de denominación de estímulos visuales (cuatro tareas de denominación compuestas por estímulos de una misma tipología: figuras, colores, letras y números; y dos tareas compuestas por estímulos de distinta tipología: una de ellas compuesta por letras y números, y otra compuesta por letras, números y colores que se presentan de forma alternante), cuyas puntuaciones directas se basan en el tiempo (en segundos) invertido en realizar cada una de ellas.

De esta forma, se ha visto que el RAN alfanumérico (es decir, las tareas de denominación compuestas por letras o números) está más estrechamente asociado con la lectura (Rodríguez, van den Boer, Jiménez, & de Jong, 2015), mientras que el RAN no alfanumérico (es decir, las tareas de denominación compuestas por colores u objetos) se asocia con los procesos de atencionales (Whipple, & Nelson, 2016).

La mayoría de estos estudios se han llevado a cabo en lengua opacas (como el inglés) lo que dificulta conocer la eficacia de esta herramienta en lenguas transparentes como el castellano. De esta forma, resultaría relevante analizar la prueba RAN/RAS en lengua castellana para conocer el tipo de relación entre variables lectoras, atencionales y de denominación, así como para comprobar la capacidad discriminativa para la existencia de problemas lectores y/o de atención.

Una de las principales implicaciones prácticas que se desprenden de la utilización de la prueba RAN/RAS es que ésta permite una evaluación temprana, puesto que es posible aplicar esta prueba en población que aún no tienen automatizadas las habilidades lectoras.

De este modo, considerando los diferentes estudios e investigaciones llevadas a cabo previamente comentados, conviene preguntarse las siguientes cuestiones:

1. ¿Es posible elaborar un protocolo de evaluación de TDAH que considere las relaciones existentes entre variables de distinta naturaleza?

2. ¿Los test de ejecución continua que utilizan la realidad virtual suponen un avance en la evaluación de procesos atencionales?
3. ¿El rendimiento en las tareas de denominación tiene algún tipo de relación con los problemas de atención con o sin dificultades lectoras?

Objetivos

De acuerdo con las cuestiones previamente planteadas a continuación, se detallan los objetivos generales de la presente tesis doctoral acompañados de los objetivos específicos correspondientes para la consecución de cada uno de ellos:

1. Elaborar un modelo de evaluación que considere las relaciones existentes entre variables de diferente tipología (variables de ejecución y variables de activación cortical). Este objetivo general se ha podido llevar a cabo a través de dos objetivos específicos:
    A. Analizar la interacción entre las variables de activación cortical relacionadas con la atención (fundamentalmente en las áreas Fp1 y Cz/Fpz) recogidas con el nir-HEG y el QEEG con las variables de ejecución tomadas con el test TOVA (Test of Variables of Attention). Este objetivo se llevó a cabo en el primero de los estudios titulado: "Attention Deficit/Hyperactivity Disorder (ADHD) Diagnosis: An Activation-Executive Model" ["Diagnóstico del Trastorno por Déficit de Atención e Hiperactividad (TDAH): Un modelo de Activación-Ejecución"], el cual ha sido publicado en el año 2016 en la revista *Frontiers in Psychology*.
    B. Elaborar un protocolo de evaluación para el TDAH basado en modelo diagnóstico que tome en especialmente consideración la relación entre las medidas de ejecución y activación cortical. Este objetivo forma parte del primero de los trabajos complementarios titulado: "Using brain activation (nir-HEG/Q-EEG) and execution measures (CPTs) in a ADHD assessment protocol" ["La utilización de las medidas de activación cortical y de

ejecución en un protocolo de evaluación del TDAH”]. Dicho Trabajo se encuentra a la espera de su aceptación definitiva en la Revista *JOVE.*

2. Analizar la eficacia de la realidad virtual en los test de ejecución continua para evaluar la sintomatología TDAH.
   - *A.* Comprobar la capacidad discriminativa de un test de ejecución continua que utiliza la realidad virtual (en concreto, la prueba Aula Nesplora) para detectar los diferentes tipos de presentación del TDAH. Esta investigación forma parte del segundo de los artículos aceptado y publicado online en la Revista *Journal of Attention Disorders.*
   - B. Comparar el poder explicativo de variables cognitivas afectadas en el TDAH (memoria de trabajo y velocidad de procesamiento) con las variables proporcionadas por un CPT de realidad virtual (Aula Nesplora). Este estudio se ha llevado a cabo en el segundo trabajo complementario, el cuál encuentra actualmente en proceso de revisión en la revista *PlosOne.*
3. Analizar la relación existente entre la velocidad de denominación y los procesos lectores y atencionales.
   - A. Comprobar cómo variables de ejecución relacionadas con la atención (omisiones, comisiones, …) y variables asociadas a la lectura (tipología de errores presentes en la lectoescritura: errores por omisión, por sustitución, por adicción…) predicen el rendimiento en tareas de denominación. Este objetivo se ha llevado a cabo en un estudio publicado en la revista *Anales de la Psicología*.

B. Analizar cómo la velocidad de denominación predice la presencia de dificultades lectoras y/o atencionales. Dicho trabajo forma parte del cuarto trabajo aceptado en la revista *Child Neuropsychology*.

Publicaciones

Estudio 1

First study published in *Frontiers in Psychology* [Primer estudio publicado en la revista *Frontiers in Psychology*]:

Attention Deficit/Hyperactivity Disorder (ADHD) diagnosis: an activation-executive model

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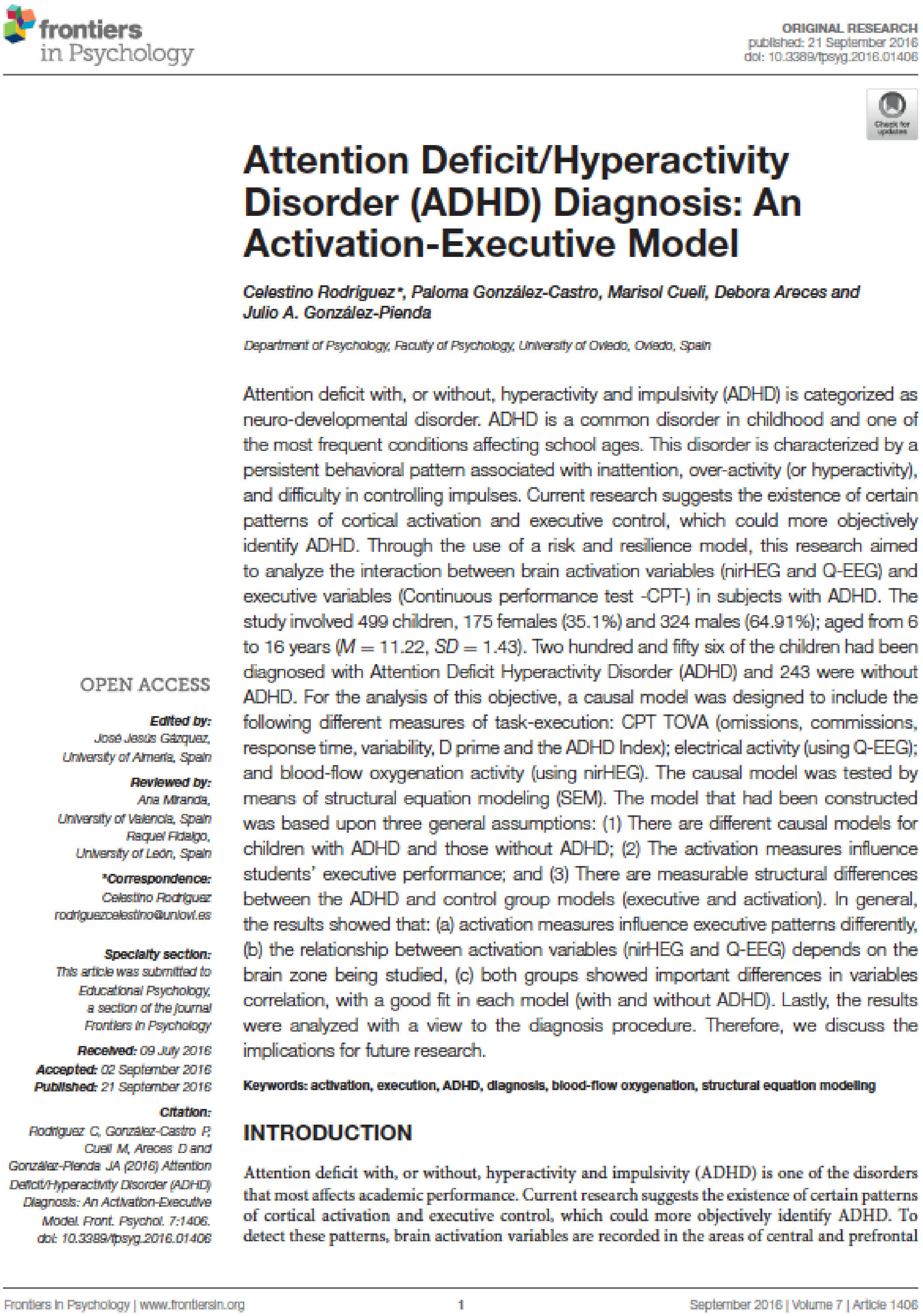

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Attention Deficit/Hyperactivity Disorder (ADHD) Diagnosis: An Activation-Executive Model

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Attention deficit with, or without, hyperactivity and impulsivity (ADHD) is categorized as neuro-developmental disorder. ADHD is a common disorder in childhood and one of the most frequent conditions affecting school ages. This disorder is characterized by a persistent behavioral pattern associated with inattention, over-activity (or hyperactivity), and difficulty in controlling impulses. Current research suggests the existence of certain patterns of cortical activation and executive control, which could more objectively identify ADHD. Through the use of a risk and resilience model, this research aimed to analyze the interaction between brain activation variables (nirHEG and Q-EEG) and executive variables (Continuous performance test -CPT-) in subjects with ADHD. The study involved 499 children, 175 females (35.1%) and 324 males (64.91%); aged from 6 to 16 years (*M* = 11.22, *SD* = 1.43). Two hundred and fifty six of the children had been diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) and 243 were without ADHD. For the analysis of this objective, a causal model was designed to include the following different measures of task-execution: CPT TOVA (omissions, commissions, response time, variability, D prime and the ADHD Index); electrical activity (using Q-EEG); and blood-flow oxygenation activity (using nirHEG). The causal model was tested by means of structural equation modeling (SEM). The model that had been constructed was based upon three general assumptions: (1) There are different causal models for children with ADHD and those without ADHD; (2) The activation measures influence students' executive performance; and (3) There are measurable structural differences between the ADHD and control group models (executive and activation). In general, the results showed that: (a) activation measures influence executive patterns differently, (b) the relationship between activation variables (nirHEG and Q-EEG) depends on the brain zone being studied, (c) both groups showed important differences in variables correlation, with a good fit in each model (with and without ADHD). Lastly, the results were analyzed with a view to the diagnosis procedure. Therefore, we discuss the implications for future research.

Keywords: activation, execution, ADHD, diagnosis, blood-flow oxygenation, structural equation modeling

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INTRODUCTION

Attention deficit with, or without, hyperactivity and impulsivity (ADHD) is one of the disorders that most affects academic performance. Current research suggests the existence of certain patterns of cortical activation and executive control, which could more objectively identify ADHD. To detect these patterns, brain activation variables are recorded in the areas of central and prefrontal

Abstract

Attention deficit with, or without, hyperactivity and impulsivity (ADHD) is categorized as neuro-developmental disorder. ADHD is a common disorder in childhood and one of the most frequent conditions affecting school ages. This disorder is characterized by a persistent behavioral pattern associated with inattention, over-activity (or hyperactivity), and difficulty in controlling impulses. Current research suggests the existence of certain patterns of cortical activation and executive control, which could more objectively identify ADHD. Through the use of a risk and resilience model, this research aimed to analyze the interaction between brain activation variables (nirHEG and Q-EEG) and executive variables (Continuous performance test -CPT-) in subjects with ADHD. The study involved 499 children, 175 females (35.1%) and 324 males (64.91%); aged from 6 to 16 years (*M* = 11.22, *SD* = 1.43). 256 of the children had been diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) and 243 were without ADHD. For the analysis of this objective, a causal model was designed to include the following different measures of task-execution: CPT TOVA (omissions, commissions, response time, variability, D-prime and the ADHD Index); electrical activity (using Q-EEG); and blood-flow oxygenation activity (using nirHEG). The causal model was tested by means of structural equation modeling (SEM). The model that had been constructed was based upon three general assumptions: 1) There are different causal models for children with ADHD and those without ADHD; 2) The activation measures influence students' executive performance; and 3) There are measurable structural differences between the ADHD and control group models (executive and activation). In general, the results showed that: a) activation measures influence executive patterns differently, b) the relationship between activation variables (nirHEG and Q-EEG) depends on the brain zone being studied, c) both groups showed important differences in variables correlation, with a good fit in each model (with and without ADHD). Lastly, the results were analyzed with a view to the diagnosis procedure. Therefore, we discuss the implications for future research.

Keywords: activation, execution, ADHD, diagnosis, blood-flow oxygenation, structural equation modeling

Introduction

Attention deficit with, or without, hyperactivity and impulsivity (ADHD) is one of the disorders that most affects academic performance. Current research suggests the existence of certain patterns of cortical activation and executive control, which could more objectively identify ADHD. To detect these patterns, brain activation variables are recorded in the areas of central and prefrontal cortex through electro-encephalographic techniques such as quantified EEG (Q-EEG) to measure beta-theta electrical activity ratios (González-Castro, Rodríguez, López, Cueli, & Álvarez, 2013), as well as oxygenated blood-flow in the brain (hemo-encephalography: nirHEG) (Toomim et al., 2005; Toomin & Jeffrey, 2009). In addition, executive control is evaluated with tests to verify levels of cortical activation by measuring performance during a lengthy repetitive task known as the Continuous Performance Test (CPT).

On the other hand, with the publication of the new DSM-5 classification manual (American Psychiatry Association, APA, 2013), ADHD is now categorized as neuro-developmental disorder. While there were no significant changes in terms of the main symptoms of the disorder, with respect to classification there are now three types of presentations (instead of subtypes) of ADHD: predominantly hyperactive/impulsive; predominantly inattentive; and combined presentation. However, regardless of the names used for classification, much research has investigated if ADHD subtypes (or types of presentation) differ in their development or in their epidemiology (Willcutt et al., 2012), and also whether different comorbidities generally associated with the disorders are dependent upon the subtype (Sciberras et al., 2014).

ADHD, cortical activation and execution

Although there is a substantial body of symptom-based evidence highlighting the neurologic nature the disorder, the primary causal factors underlying this problem remain unclear to date (Congdon et al., 2014; Rubia et al., 2011; Tsujimoto et al., 2013).

Within this context, some investigations point to a delay in myelination formation during brain development (Sowell et al., 2003), or insufficient white matter in the frontal lobe (Mostofsky, Cooper, Kates, Denckla, & Kaufman, 2002). A further potential factor may be early dysfunctions in executive functions associated with fronto-thalamic circuits (Brown, 2006), which have a direct impact on cortical activation levels (Álvarez, Gonzalez-Castro, Núñez, González-Pienda, & Bernardo, 2008; Cortese et al., 2012; Lubar, Swartwood, Swartwood, & O'Donnell, 1995; Orinstein & Stevens, 2014).

From a general perspective, ADHD has been associated with a dysfunction in the central nervous system, characterized by a developmental delay and cortical hypo-activation related to a deficit in the dopaminergic and noradrenergic systems (Bledsoe, Semrud-Clikeman, & Pliszka, 2011). The noradrenergic system is primarily responsible for the modulation of selective attention and the levels of general activation that an individual needs to perform a task (Brown, 2006). The dopaminergic system, in turn, is associated with the ability to control one´s behavior, both at an executive and motivational level. Thus, this low cortical activation associated with dopaminergic and noradrenergic systems would at least partially explain the inhibitory and attentional deficits that characterize ADHD (Cubillo, Halari, Smith, Taylor, & Rubia, 2012). Furthermore, the investigation of González-Castro, Rodríguez, López, Cueli and Álvarez (2013) showed that the low activation in prefrontal areas was reflected in different patterns of executive control measured in a continuous performance test.

The above hypothesis is supported by neo-connectionist learning models, which have also linked cortical activation (measured by means of frequency fields) with the cortical areas involved in ADHD (Congedo & Lubar 2003; Mazaheri et al., 2014; Orinstein & Stevens, 2014; Orlando & Rivera, 2004). When the subject is distracted, frequency fields are characterized by delta or theta waves, with a frequency of 0.5 to 4 Hz and 4 to 8 Hz, respectively. When the subject is relaxed with scattered attention, brain theta waves have values between 8-12 Hz. Finally, when the subject is in an alert state, beta waves with frequency ranges from 15 to 35 Hz are dominant. These waves are produced by brain metabolism and blood flow, as shown by Lubar et al. (1995). In this sense, an increase in theta activity would be accompanied by decreases in blood flow and brain metabolism. Hence, high frequencies of theta activity are commonly observed in brain areas with low activation (Álvarez et al., 2008).

Concerning ADHD, a differential pattern of electro-cortical activity has been observed in a state of rest, and it is characterized by increased theta -and decreased beta-activity (Lansbergen, Arns, Van Dongen-Boomsma, Spronk, & Buitelaar, 2011). This profile has been reflected in different studies with a low cortical activity associated with decreased beta activity in central and prefrontal brain regions in students with ADHD (Ernst at al., 2003). The detection of this pattern of cortical hypo-activation has been made using different neuro-imaging techniques, such as functional magnetic resonance imaging (fMRI) (Logothetis & Wandell, 2004; Solanto, Schulz, Fan, Tang, & Newcorn, 2009), electro-encephalography (EEG) (Mazaheri et al., 2014), or hemo-encephalography (HEG) (Schecklmann et al., 2009).

On the other hand, increasing cortical activation has been observed in students with ADHD who have had positive responses to intervention, and this has led to a decrease in inattention, impulsivity and hyperactivity according to previous research (Arns, De Ridder, Strehl, Breteler, & Coenen, 2009; Kropotov et al., 2007; Monastra et al., 2005). For example, a study conducted by Thompson and Thompson (1998) involving 111 subjects (children and adults) with ADHD observed significant improvements in cortical activation (measured by Q-EEG) and symptomatology (measured by CPT), following an intervention involving neurofeedback techniques.

Other studies have also found that, by increasing cortical activation with neurofeedback techniques or pharmacological support, individuals with ADHD significantly improved their performance in attention tasks, apparently as a consequence of a decrease in the core symptoms of the disorder (Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser, 2003; Othmer, Othmer, & Kaiser, 2000; Rossiter, 2004). Also, Monastra et al. (2005), in a review, analyzed the empirical evidence of the intervention with neurofeedback, according to the Association of Applied Psychophysiology and Biofeedback and the International Society for Neuronal Regulation. They concluded that neurofeedback is "probably an efficacious instrument" for treatment of ADHD, as clinically significant improvement is observed in approximately 75% of the cases analyzed.

In sum, previous research supports the relationship between ADHD symptoms and decreased cortical activation. Nevertheless, although it has been argued that low activation occurs in prefrontal and frontal areas, the specific areas involved in these processes have not been adequately defined (Orinstein & Stevens, 2014). The most frequently reported areas in this case have been in the pre-frontal (e.g. Fp1, Fp2, Fp3) and central (e.g. Cz) regions (González-Castro, Rodríguez, López, Cueli, & Álvarez, 2013; Hale, Bookheimer, McGough, Phillips, & McCracken, 2007).

The difficulties in the detection of specific brain areas have been associated with the presence of differential profiles or presentations in the disorder (Nikolas & Burt, 2010; Willcutt, et al., 2012). Thus, the relevance of these areas would be dependent on the presence of inattentive or hyperactive/impulsive symptomatology (Depue et al., 2010; Mazaheri et al., 2014). Considering the different presentations of ADHD, previous studies have shown that while the hyperactive/impulsive presentation is related to poor activation in left prefrontal areas, the inattentive presentation is commonly accompanied by less activation in central and central-prefrontal areas (Gonzalez et al., 2013). Similarly, it has been observed that students with low levels of activation in left prefrontal areas show more commission errors and higher variability in continuous performance tests, while students with low central activation show more omissions and slower response time than the other group.

The empirical evidence concerning the different categories of symptomatology in ADHD, and their new conceptualization in DSM-5 (APA, 2013), makes it necessary to define the relationship among the levels of activation in specific brain areas, executive functions, and diagnosis-related variables (i.e. distinction between ADHD and controls, and among different ADHD presentations).

It is important to consider that this disorder not only leads to impairments in the academic context (Barnard-Brak, Sulak, & Fearon, 2011; Frazier, Youngstrom, Gluntting, & Watkins, 2007), but also in the social and familiar contexts (Anastopoulos, Sommer, & Schatz, 2009; Schroeder & Kelley, 2009). It is therefore crucial to have appropriate evaluation strategies that are able to minimize error in the diagnosis process (Skounti, Philalithis, & Galanakis, 2007). This particular aspect was the key stimulus for the present study. Although the exact cause of the disease has not yet been identified, it is thought to be caused by a complex interaction between the neuro-anatomical system and neuro-biochemistry rather than a single cause. Overall, an increased number of findings suggest that ADHD is a disease of the brain (Swanson & Castellanos, 2002). Thus, genetic factors, neuro-developmental factors, psychosocial factors, and neuro-physiological factors all have an influence on behavior, activity and task-execution.

By using a risk and resilience model, this research aims to analyze the interaction between brain activation variables and executive function in students with ADHD. For the analysis of this objective, a causal model (relationship between pre-frontal cortex activation and task-execution) was formulated in which different measures were included (CPT-TOVA, Q-EEG and nirHEG; Toomim et al., 2005.

Purposes of this Study

By means of a structured equation model (SEM) we expect to deepen our knowledge of the relationship between activation measures and executive function measures. The SEM designed was fit using two samples of data (control group without ADHD and ADHD group). The first sample (without ADHD) was utilized to fit the model, and the second sample (with ADHD) to analyze the consistency of the data with predictive differences. We also performed multi-group analysis to verify the consistency of the results from both samples, to know which variables differentiate subjects with and without ADHD.

Considering the data provided by literature findings, the causal model was tested using structural equation modeling (SEM). This model was built based on three general assumptions (see Figure 1):

1) There are different causal models for children with ADHD and those without ADHD.
2) The activation measures influence a student's executive performance. Specifically, certain task-execution variables will be related to activation in the left pre-frontal cortex, and others with central zone pre-frontal cortex activation.
3) There are important structural differences between the models for the ADHD and control groups.

When estimating the dependent variables of the model (latent variables), we also assume that the measured errors are not inter-correlated in the model, and that there is no relationship between the types of errors committed. Lastly, although previous research indicates reciprocal relationships among the dependent variables measured in this model (omissions, commission, response time -RT-, variability and D-prime), in the current investigation it is theoretically unacceptable to expect that reciprocal relationships between causal measures have been observed at a single temporal moment.

Our model has two parts: one of measurement, which corresponds to the relationship between the latent variables and their respective observed variables (activation), and a structural part, which involves the relationship between the independent and the dependent variables of the model (execution). The effects of the independent on the dependent variables are indicated with gamma (γ), whereas the relationships among the dependent variables are represented as beta (β).

Method

Participants

The participants included in the study comprised 499 students aged between 8 and 16 years (M = 11.22, SD = 1.43). There were 324 males (64.9%) and 175 females (35.1%).

As one of the goals of this research was the cross-validation of the study-model developed, the final calibration sample was split into two subgroups [243 (48.7%) in the Control Group, and 256 (51.3%) in the ADHD group]. All participants had an IQ higher than 80 (WISC-IV; Weschler, 2004), were attending public and subsidized schools in northern Spain. Statistical analysis revealed no significant between-group differences concerning IQ, though there were slight differences in mean ages and gender ratios (Table 1).

Table 1. Means (M) and standard deviations (SD) of IQ scores, age in months, and EDAH percentile scores of the two groups in the sample (Control and ADHD group)

		Control group	**ADHD group**	***Total sample***	
N		243	256	499	
IQ *M (SD)*		98.30 (10.28)	98.95 (10.15)	98.64 (10.21)	F (1, 497) = .496, p = .481, η^2 = .001
Age (months) *M(SD)*		136.67 (17.51)	132.88 (16.77)	134.72 (17.22)	F (1, 497) = 6.102, p = .014, η^2 = .012
Sex (male/female)		146/97	178/78	324/175	χ^2 (1) = 4.888, p = .027
EDAH scores	*ADHD-I*	73.84 (10.71)	90.96 (5.44)	82.62 (12.01)	F (1, 497) = 514.33, p = .000, η^2 = .509
	ADHD-HI	74.49 (10.59)	92.05 (5.20)	83.50 (12.06)	F (1, 497) = 561.34, p = .000, η^2 = .530
	ADHD-C	75.77 (9.90)	91.46 (6.17)	83.82 (11.34)	F (1, 497) = 456.27, p = .000, η^2 = .479

Note. (ADHD-I) subtype with predominance of attention deficit; (ADHD-HI) subtype with predominance of hyperactivity–impulsivity; and (ADHD-C) combined subtype, with predominance both of inattention and hyperactivity-impulsivity.

Inclusion criteria

For ADHD, the diagnosis involved: (a) clinical diagnosis of Attention Deficit Disorder with Hyperactivity according to the Diagnostic and Statistical Manual of Mental Disorders-IV-R (APA, 2002); (b) symptom duration of more than one year; (c) the problem began before the age of 7 years; and, (d) the children had no associated disorders. Subjects who presented with a cognitive deficit, Asperger's syndrome, Guilles de la Tourette syndrome or extensive anxious depressive disorders were excluded from the study, (e) to confirm the diagnosis and rule out other associated disorders, all students underwent a semi-structured interview for parents Diagnostic Interview Schedule for Children DISC-IV (Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000), and (f) were administered the WISC-IV (Wechsler Intelligence Scale for Children-IV; Wechsler, 2005) to evaluate the presence of specific (or other) cognitive deficits.

All healthy controls underwent the same diagnostic assessment to rule out any psychiatric disorders. To ensure the correct assignment of the students to their respective groups, Farré and Narbona's (1997) Spanish Scale or the adaptation by Sánchez, Ramos, Diaz and Simón (2010) for ADHD (EDAH) was administered to the participants' parents.

Instruments and Measures

The variables included in the hypothesized model were grouped into two categories: activation measures (nirHEG Fp1, nirHEG FpZ, Q-EEG Fp1 and Q-EEG Cz), and executive measures (omissions, commissions, variability, RT, D prime and ADHD Index).

Activation measures

The nirHEG (Toomim et al., 2005) is a tool used to measure blood oxygenation in expressly selected areas. The nirHEG employs the translucent properties of biological tissue, and low-frequency red and infrared light from light emitting diodes (LEDs). The source of light and the light receptor (optode) are mounted on a headband 3 centimeters apart. The band should be carefully placed so that no external light enters. It is important to highlight that, in contrast with the EEG method, low muscular tension or small subject movements do not affect nirHEG measurements. Other possible sources of error were researched and were found to be minimal (Toomim et al., 2005). Only around 5 to 10% of nirHEG readings come from the skull skin or tissue because these regions of the body have little blood flow in comparison with brain tissue. The depth of effective penetration in the highly vascular cortical tissue is approximately 1.5 cm below the midpoint between the light source and the receptor optode. The entrance and exit light areas are 0.052 cm2 at the skin surface. The light entrance and exit points and the refractive and scattering qualities of the tissue form a banana-shaped light field.

The lights are emitted alternately onto the surface of the skin. The emitted light penetrates these tissues and is scattered, refracted, and reflected. A small amount of light modified by absorption of the tissue returns to the surface and is measured. The ratio is calculated by comparing the red light (at 660 nm wavelength), which is not absorbed as much by oxygenated hemoglobin, with infrared light (at 850 nm wavelength), which is less affected by oxygenation (Toomim et al., 2005). Capillary oxygenation is barely affected by peripheral blood pressure and is mainly controlled by tissue demand for energy. The concentration of oxygenated hemoglobin is therefore a useful measurement of local blood flow. Thus, mathematically, the formula for the nirHEG ratio is as follows: nirHEG Ratio = Red light (variable)/infrared light (less affected by oxygenation).

The nirHEG Ratio or proportion between red and infrared light has a useful property. The numerator and denominator in the relationship are influenced in the same way by attenuation of the skin, the skull, and the length of the path. In this relationship, these variables are therefore discarded. The standardized reference value was established at 100 (*SD* = 20) and used to calibrate all new spectrophotometers (Toomim et al., 2005).

In addition to this measure, nirHEG provides an Attention Index (AI), indicating malfunctioning of the ability to increase the nirHEG ratio; that is, the participant is incapable of increasing the ratio and, thereby, brain activation. This apparently indicates a lapse in the attentional process, which, according to Toomin et al. (2005), is equivalent to a measure of sustained attention or concentration capacity.

Q-EEG (quantified electroencephalogram), Biocomp 2010 (Developed by The Biofeedback Institute of Los Angeles; www.biocompresench.org) was used to record electrical activity. Q-EEG (quantified electroencephalogram) is a computerized EEG system, adapted by Toomin (2005), which provides levels of cortical activation through the beta/theta ratio. It measures attention in general, independently of the task to be performed. For this purpose, an electrode is placed on the subject's corresponding cortical area (Cz, Fp1) to record the beta/theta ratio, and two more control electrodes are placed on the subject's left and right earlobe. The Q-EEG is administered to each participant, with open eyes, for a maximum duration of 10 min and after receiving instructions of smooth and steady abdominal breathing, in order to to carry out the test under the best possible performance conditions. Lastly, an EMG system is placed on the right forearm to identify the degree of movement. Once the electrodes are in place, participants are asked to remain relaxed, without moving, breathing slowly and evenly, concentrating exclusively on the computer screen on which the theta and beta waves emitted by them are displayed successively. After assessment, the results obtained are interpreted. When the beta/theta ratio is lower than 50% at Cz, there is an associated deficit of sustained attention and if the ratio is also lower at Fp1, then the attentional deficit is associated with a lack of executive control, attributable to hyperactivity (González-Castro et al., 2013).

Latent variables (pre- frontal cortex activation)

Activation left cortex was estimated as a latent variable in the SEM from two indicators of activation measures. One of the indicators was nirHEG in Fp1 and the other was Q-EEG in Fp1. Thus, our latent variable takes into account the commonalities between these two ratio-index measures of the of the student's cortical activation.

Activation central cortex was estimated as a latent variable. One of the indicators was nirHEG in FpZ and the other was Q-EEG in Cz. So, our latent variable subsumes the communalities between this two ratio measures indexes of the students' activation.

Executive functioning variables

Test of Variables of Attention (TOVA; Greenberg, 1996) is a continuous performance test that presents two simple images. The first one presents the stimulus at the top of the screen and the second one at the bottom of the screen. The subject is given a push-button that should only be pressed when the first image appears. Subjects are trained for 3 minutes before testing, and the test lasts between 20 and 24 minutes. The following profile is obtained: omissions, RT, commissions, variability, D prime (performance and/or concentration quality during the test, based on the number of errors) and ADHD Index. In the current study, the Cronbach's alpha for this executive factor was .877.

Procedure

The identification of the participants was carried out according to the DSM-IV-TR criteria in the Hospital Pediatric Service by a neurologist with experience in ADHD diagnosis. It was confirmed by the EDAH with parent-teacher agreement equal to or higher than 90% following previous studies (González-Castro et al., 2015). Once the ADHD group was established, we proceeded to select the students who made up the group without

ADHD, so that the groups would be as equivalent as possible. For this purpose, all the participants completed the WISC-IV (Wechsler, 2005), and their age was also taken into account. Once identified, if their IQ was equal or higher than 80, they completed the TOVA. Both tests (WISC-IV and TOVA) were interpreted according to their corresponding instruction manuals. Participants were not undergoing pharmacological treatment during the study. It was withdrawn 48 hours to perform the tests.

After psychological assessment and the appraisal of executive control, the level of cortical activation was identified by means of the Q-EEG analysis, using the Biocomp 2010. The surface electrodes were placed at points Fp1 and Cz. To control participants' movement, an Electromyogram (EMG) electrode was placed on the right fore-arm and the reference electrodes were placed on the ear lobes. The recording was carried out in a sound-proof and electrically-isolated room with low illumination, and the test always at the same time of day (between 4 p.m. and 6 p.m). The Q-EEG was administered to each participant (with their eyes open), and for a maximum duration of 10 min. The nirHEG was administered in the same circumstances of Q-EEG. With a measurement of 35 seconds in Fp1 and FpZ duly counterbalancing the order with the characteristics of the band measurement described above. The TOVA measures were standardized, interpreting scores lower than 1.2 standard deviations as negative measures. Lastly, a general executive control index showing recorded readings lower than -1.80 was interpreted as ADHD. For the partial correlations, we took age into account because activation and executive control both tend to decrease with age.

The study was conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki), which reflects the ethical principles for research involving humans (Williams, 2008). All subjects and their parents gave written informed consent after receiving a comprehensive description of the study protocol. Participants had volunteered to be involved in this study and they were not given any incentive to take part in it. The participants came from families of medium socio-economic status and were Caucasian.

Data analysis

The adequacy of the model was analyzed with SEM, using the AMOS.22 program (Arbuckle, 2009). Firstly, the data matrix (control group and ADHD group samples) was analyzed to determine whether there were any values that violated any of the assumptions required for the use of SEM (e.g., multivariate normality, linear relations among variables, absence of multi-collinearity), or simply whether there were any missing data or outliers. Subsequently, the fit of the model was examined utilizing the control group sample and, although the hypothesized model fitted well, potential areas of misfit in the model were scrutinized (by examining the standardized residuals and the modification indexes). Secondly, we followed an invariance-testing strategy to test the structural paths across groups to determine whether the models of the Control Group and of the ADHD Group were equivalent. In order to cross-validate our data-analysis, we fitted the model to an independent clinical sample of students (the ADHD sample).

Results

Initial data screening

Table 1 shows the descriptive data as well as the two Pearson correlations matrixes corresponding to the Control Group and the ADHD group. Before conducting the statistical analyses, we examined the matrixes with regard to missing data, the presence of outliers, linearity and normality of the data. We examined the data to determine whether any of the variables or subjects presented a significant amount of missing values. Considering the variables with respect to Kline’s (2013) suggestions, the number of absences was found to be less than 1.4% in all cases, which was not significant.

One of the important assumptions of SEM is that the variables taken must follow a normal distribution. As maximum likelihood (ML) can produce biases when this assumption is violated (West, Finch, & Curran, 1995), we examined the distribution of the variables (i.e., kurtosis and skewness). Following the criteria of Finney and DiStefano (2006), the allowable values for skewness and kurtosis are ±2 and ±7 respectively (outside of which, ML should not be used). All the variables in this study respected those criteria (see Table 2). Therefore, with normality conditions being met, we decided to fit the model using ML.

Table 2. Correlation matrix corresponding to the variables included in the model (Control group and ADHD group) and descriptive data (means, standard deviation, skewness and kurtosis)

	1	2	3	4	5	6	7	8	9	10
1	—	.499**	.594**	.330**	.306**	.435**	.514**	.213**	.213**	.222**
2	.441**	—	.315**	.743**	.471**	.258**	.304**	.366*	.183*	.218**
3	.848**	.303**	—	.376**	.238**	.290**	.330**	.125	.108	.090
4	.428**	.842**	.387**	—	.447**	.193**	.203**	.380**	.122	.159*
5	.456**	.757**	.371**	.795**	—	.342**	.449**	.667**	.389**	.447**
6	.720**	.378**	.660**	.398**	.453**	—	.505**	.132*	.428**	.358**
7	.811**	.309**	.816**	.356**	.425**	.722**	—	.428**	.380**	.458**
8	.411**	.731**	.339**	.753**	.852**	.441**	.409**	—	.339**	.479**
9	.698**	.475**	.703**	.559**	.571**	.678**	.725**	.525**	—	.813**
10	.644**	.492**	.670**	.580**	.631**	.614**	.750**	.596**	.874**	—
Control group										
M	101.64	105.50	.58	.59	98.76	100.90	97.44	99.37	.49	1.51
SD	12.40	17.45	.07	.07	8.01	10.09	8.65	10.45	1.05	2.29

Skewness	.970	1.192	1.181	.909	.216	.097	.708	.506	.572	.461
Kurtosis	.926	1.158	4.314	1.331	-.150	1.024	.913	1.839	-.089	-.238
ADHD group										
M	78.52	79.82	.43	.43	77.05	82.83	76.55	77.67	-1.49	-3.39
SD	10.71	12.04	.07	.07	10.82	10.82	10.13	10.06	.89	1.89
Skewness	.501	1.138	-.070	-.033	-.017	-.052	-.058	.528	-.207	-.548
Kurtosis	2.399	4.048	.118	.457	1.469	1.321	.544	2.702	.008	-.097

Note. In the correlation matrix, the upper matrix corresponds to the without ADHD sample and the lower matrix to the ADHD group sample.1, nirHEG-Fp1;2, nirHEG-FpZ; 3, Q-EEG-Fp1; 4, Q-EEG-CZ; 5, TOVA omissions; 6, TOVA commissions; 7, TOVA variability; 8, TOVA response time; 9, TOVA D prime; 10, TOVA ADHD index.
$p < 0.05$; $p < 0.001$.

Another important aspect in the initial analysis of the data matrix is to verify that the variables are significantly correlated, although such correlations should not be excessively high ($r > .85$). The pattern of correlations (e.g. size; + tendency) was similar both groups.

Testing and adjusting model (Control Group)

In a first assessment of the model (Figure 1), the estimated parameters did not show the expected magnitudes and mathematical sign (consistent with the theory underlying the model), and excessive standard errors were observed (Bentler, 1995). The data provided by the analyses performed with AMOS.22 indicated that the fit of the hypothesized model to the data matrix was not acceptable, $\chi2(28) = 81.11$, $\chi2/df = 2.89$, $p < .001$, GFI = .939, AGFI = .881, TLI = .928, CFI = .928, RMSEA = .089 (.066-.111), $p = .003$.

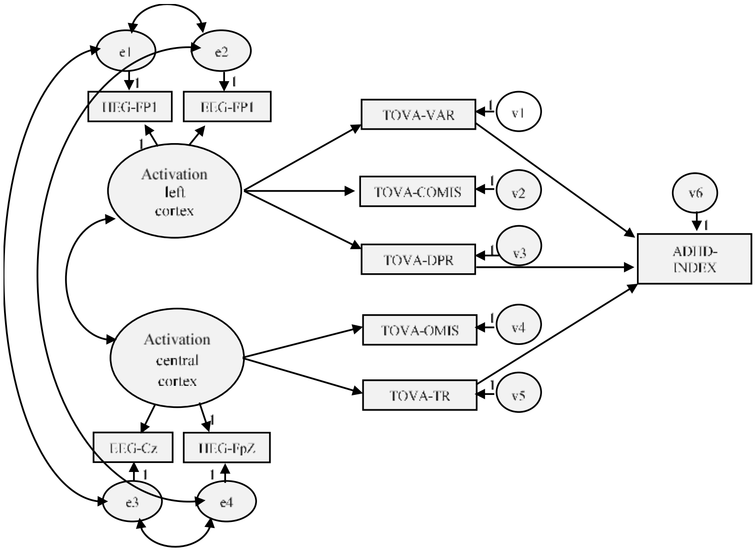

Figure 1. Hypothetical model of activation and executive function.

Variables in the model: HEG-Fp1 (nirHEG ratio: left pre-frontal cortex); HEG-FpZ (nirHEG ratio: central zone pre-frontal cortex); Q-EEG-Fp1 (beta-theta ratio: left pre-frontal cortex); Q-EEG-CZ (beta-theta ratio: central cortex); TOVA-OMIS (CPT: omissions); TOVA-COMIS (CPT commissions); TOVA-VAR (CPT: variability); TOVA-TR (CPT: response time); TOVA-DPR (CPT: D-prime); ADHD-INDEX (CPT: ADHD index).

Re-specification of the model

After examining the residuals and modification index (although the hypothesized model did not show a good fit), we considered the possibility of including covariance effect between Commissions and RT in the TOVA test (leaving the parameter free) as well as the indirect effect contained in the initially hypothesized model. At the theoretical level, this effect is negative, indicating that a higher number of commissions the response time will be less in TOVA.

The results indicated that the fit of the re-specified model was good, [$\chi2(27) = 57.924$; $\chi2/df = 2.145$; $p \leq .001$; GFI = .954; AGFI =.907; CFI = .974; TLI =.956; RMSEA = .069(.044-.093), $p = .098$], and the improvement over the initial model was statistically significant ($\Delta\chi2(1) = 23.192$). As expected, the new estimated parameter was statistically significant and negative ($r = -.39$). Neither the residuals nor the modification indices recommended carrying out more changes in the model (Figure 2).

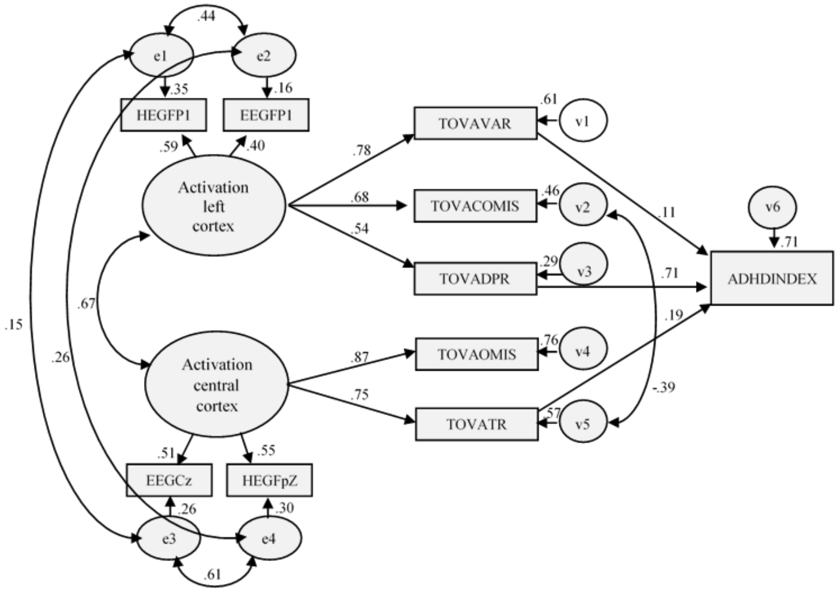

Figure 2. Re-specified model (Control Group): structural and measurement coefficients

Table 3 shows the coefficients of the relationships in the measurement model and the structural model, as well as their corresponding estimation errors, critical ratios, and associated probabilities.

Table 3. Results of testing the re-specified model (sample without ADHD).

	Standardized Coefficients	SE[1]	CR[2]	P<[3]
Structural Model[4]				
Activation left cortex → TOVA variability	.783	.114	8.308	.001
Activation left cortex → TOVA D prime	.537	.012	6.601	.001
Activation central cortex → TOVA response time	.753	.102	8.041	.001
Activation left cortex → TOVA Commissions	.678	.125	7.687	.001
Activation central cortex → TOVA Omissions	.870	.088	8.337	.001
TOVA D prime → TOVA ADHD Index	.712	.083	18.539	.001
TOVA variability → TOVA ADHD Index	.108	.011	2.689	.007

TOVA response time → TOVA ADHD Index	.193	.008	5.104	.001
Measurement Model[5]				
Activation left cortex → nirHEG-Fp1	.589	—	—	—
Activation left cortex → Q-EEG-Fp1	.399	.001	6.785	.000
Activation central cortex → nirHEG-FpZ	.552	—	—	—
Activation central cortex → Q-EEG-Cz	.511	.000	10.371	.000

Note. [1]Standardized errors, [2] Critical ratio, [3] Probability, [4] structural model (relation between the independent and the dependent variables in the model), [5] measurement model (relation between the latent variables in the model and the observed variables).

With regard to the assessment of the predictions implicit in the re-specified model without ADHD, the results indicated that almost all hypotheses were confirmed in measurement part. Latent variable named Activation left cortex was significantly and positively explained by Q-EEG-Fp1 (β = .40), however, in contrast to our prediction, its relation with nirHEG-Fp1 (β = .59) was not statistically significant. Activation central cortex was significantly and positively explained by Q-EEG-Cz (β = .51) and not by nirHEG-FpZ (β = .55).

In the structural part of the model, Activation left cortex significantly and positively explained TOVA variability (γ = .78), TOVA Commissions (γ = .67) and TOVA D prime (γ = .53). Also, as predicted, Activation central cortex positively and significantly influenced both TOVA Omissions (γ = .87) and TOVA response time (γ = .75). Moreover, like hypothesized TOVA IGCE was significantly and positively explained by TOVA variability (β = .11), TOVA response time (β = .19) and TOVA D prime (β = .71). Lastly, as a consequence of the res-pecification of the initial model, a direct negative relation between TOVA Commissions and TOVA response time was found (β = -.39).

Due to the goodness-of-fit and the confirmation of our predictions, this model is considered adequate to explain the relations of the data matrix. Nevertheless, as the initial model had been modified (freeing a parameter), and some of the initial hypotheses had not been confirmed, we decided to specifically test this model with the sample of subjects with ADHD to verify the results obtained.

Multi-group Analysis

Multi-group analysis was carried out as a cross-validation strategy to verify whether a model that has been re-specified in one sample (without ADHD) can be replicated in a second independent sample (with ADHD), which was the key aim of this study. Specifically, we used an invariance-testing strategy to test the replicability of structural paths across groups.

In the above analysis, assuming that the unconstrained model is similar in both groups, the results showed statistically significant differences concerning the five criteria examined (table 4). However, no statistically significant differences were found to structural weights, [$\chi^2(3) = 6.411$, $p = .093$, NFI = .002, IFI = .002, RFI = -.001, TLI = -.001]. Moreover, assuming the absence of differences in structural weights, no statistically significant differences were found in structural co-variances, structural residuals, and in measurement residuals.

Table 4. Nested model comparison (assuming model unconstrained correct)

	^{1}*MW*	^{2}*SW*	^{3}*SC*	^{4}*SR*	^{5}*MR*
χ^2	45.104	51.515	93.428	133.575	510.189
Df	7	10	13	14	28
P	.000	.000	.000	.000	.000
NFI	.012	.013	.024	.034	.131
IFI	.012	.013	.024	.035	.133
RFI	.009	.008	.019	.032	.121
TLI	.010	.008	.020	.032	.124

Note. ^{1}Measurement Weights, ^{2}Structural Weights, ^{3}Structural Covariance, ^{4}Structural Residuals, ^{5}Measurement Residuals).

However, as these data revealed the equality of the models between samples taken as a whole, we determined the extent to which the model is invariant in all its parameters. Summing up, the results obtained were cross-validated and thus indicated that the re-specified model of the sample without ADHD was replicated in an independent sample (with ADHD)

Testing the previous goodness-of-fit model in ADHD Group

In the ADHD Group, the goodness-of-fit of the hypothesized model was not adequate [$\chi 2$ (27) = 98.684; χ^2/df = 3.655; p = .000; GFI = .931; AGFI = .860; CFI = .973; TLI = .954; RMSEA = .102(.081-.124), $p \leq .001$]. Considering the criteria used to judge the goodness-of-fit indices, the RMSEA index revealed that the previous model did not optimally represent the relationships observed in the empirical data matrix. After examining the co-variance matrix and the modification indices, we considered including (in our model) the direct effect of the latent variable *Activation central cortex* on TOVA and D Prime. From a theoretical perspective, the inclusion of this effect seemed to be logical, because D prime is a measure of the quality of concentration obtained from the total number of omission and commission errors. Also, the central cortex area allows which is affected in students with ADHD reflected in a lower quality of the concentration given the higher number of errors. As well as eliminate indirect effect between TOVA commissions and TOVA response time (with a not significant effect p = .251). This relationship can be found in students without ADHD, but not in students with ADHD. It is because commissions are related to impulsivity, and RT is related to inattention. Thus, when both variables (impulsivity and RT) are affected, these variables can be clearly distinguished.

Re-specification of the model

Like in Control Group, statistically and theoretically it seemed appropriate to slightly modify the initial model in the ADHD sample by including the direct effect *Activation central cortex* on TOVA and D-Prime, and thus eliminate one indirect effect. With this minimal change, the results indicated that the fit of the re-specified model was good, [$\chi2(27) = 98.684$; $\chi^2/df = 2.476$; $p \leq .001$; GFI = .952; AGFI = .902; CFI = .985; TLI = .975; RMSEA = .076 (.053-.099), $p = .031$], and also that the improvement over the initial model was statistically significant ($\Delta\chi^2(1) = 31.820$). As expected, this newly estimated parameter was found to be statistically significant and positive ($r = .27$). Neither the residuals, nor the modification indices, indicated that any further changes to the model were necessary (see Figure 3).

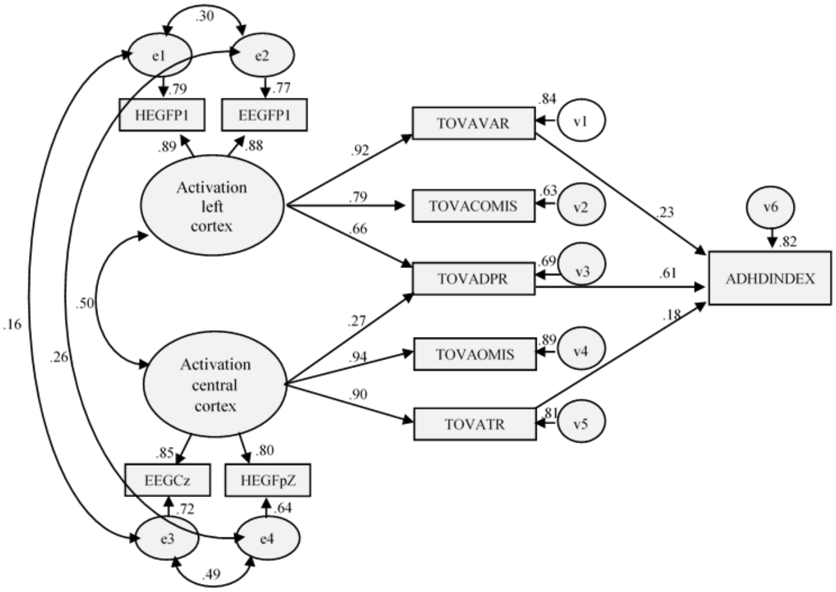

Figure 3. Final model (ADHD Group): structural and measurement coefficients

The results are presented in Table 3. In both samples, the estimated parameters approximated the expected magnitudes and sign, and the standard errors were neither excessively large nor small. In the control Group, with the exception χ^2 and its associated probability, the fit-indices indicated that the hypothesized model optimally represented the relationships of in the empirical data matrix. However, the data concerning fit were somewhat lower than in the first analysis. For example, χ^2 was higher than the value of the calibration sample [e.g. $\Delta\chi^2(1) = 40.76$, and the χ^2/df ratio rose from 2.145 to 2.476]. Table 5 shows the coefficients of the relationships in the measurement and structural models, as well as their corresponding estimation errors, critical ratio, and associated probability.

Table 5. Results of testing the re-specified model in the ADHD sample).

	Standardized Coefficients	SE[1]	CR[2]	P<[3]
Structural Model[4]				
Activation left cortex → TOVA variability	.918	.045	21.557	.001
Activation left cortex → TOVA D prime	.662	.005	13.364	.001
Activation central cortex → TOVA response time	.900	.055	17.427	.001
Activation central cortex → TOVA D prime	.272	.004	5.780	.001
Activation left cortex → TOVA Commissions	.794	.055	16.459	.001
Activation central cortex → TOVA Omissions	.944	.058	18.387	.001
TOVA D prime → TOVA ADHD Index	.608	.091	14.251	.001
TOVA variability → TOVA ADHD Index	.233	.007	5.929	.001
TOVA response time → TOVA ADHD Index	.179	.006	5.601	.001
Measurement Model[5]				
Activation left cortex → nirHEG-Fp1	.889	—	—	—
Activation left cortex → Q-EEG-Fp1	.877	.000	25.201	.000
Activation central cortex → nirHEG-FpZ	.803	—	—	—
Activation central cortex → Q-EEG-Cz	.847	.000	23.173	.000

Note. [1]Standardized errors, [2] Critical ratio, [3] Probability, [4] structural model (relation between the independent and the dependent variables in the model), [5] measurement model (relation between the latent variables in the model and the observed variables).

With regard to the predictions of the model, the results obtained in ADHD model are higher than without ADHD sample, except that the relationship between TOVA and IGCE was significantly and positively explained by TOVA variability (β = .23), TOVA response time (β = .18) and TOVA D prime (β = .61). Globally there were small variations that were higher in than the magnitude of the statistics obtained. *Activation left cortex* significantly and positively explained TOVA variability (γ = .92), TOVA Commissions (γ = .79), and TOVA D prime (γ = .66). *Activation central cortex* also positively and significantly explained both TOVA Omissions (γ = .94) and TOVA response time (γ = .90), both of which are related to attention and concentration. Lastly, as a likely consequence of the re-specification of the *with ADHD* model, a relationship between TOVA Commissions and TOVA RT was not found.

Discussion and Conclusions

The current research attempted to deepen our knowledge of the relationship between activation and executive function measures, by examining the relationship between brain activation in selected areas and differences in executive measures. To achieve this aim we employed SEM measures, which also included latent variables such as left and central cortex activation. Although previous studies have analyzed the relationship between activation and execution, SEM has seldom been used in the past. In general, the results showed a different model for ADHD group and control group. So, one conclusion of the study is the presence of a model in which is related in a particular way, the activation in specific areas and the profile of execution of students with ADHD.

Relationship of the variables in the model

In general, the data provided by the fit of the model (both in the ADHD and Control groups) provided evidence supporting some of the hypotheses proposed in the model. Therefore, the findings of this study appear to agree with those obtained in previous studies based on more conventional strategies of data analysis, such as hierarchical regression analysis and analysis of variance. The major findings discussed below concern the relationship between activation and execution, and the difference between the ADHD model and the Control model (Arns et al., 2009; Cubillo et al., 2012).

In this study, it was especially noteworthy that the relationship between activation (central and left prefrontal) and execution was stronger in ADHD subjects than in the control group. The explanation could be that subjects with ADHD show lower cortical activation (Gonzalez-Castro et al., 2013; Lansbergen et al., 2011) and blood oxygenation with scores ranging between .38 and .41 for electrical activation, and between 65 and 80 for blood oxygenation, the latter of which directly affects performance patterns (in small ranges between 40 and 80). The activation levels of the control group were found to be within normal limits, however, they showed greater variations (e.g. scores ranged from .51 to .99 for electrical activation, and from 86 to 120 for blood oxygenation). All of that can be reflected in different executive patterns (large ranges of scores ranging between 85 and 120). This finding highlights the importance of analyzing electrical activation and/or blood oxygenation in the cortex. Since it is an issue that is directly related to the executive function of the subject.

Moreover, the relationship between cortical activation and executive function shows differential results depending on the brain area assessed (i.e. a low activation in a specific area can be related to a particular pattern of execution). Regarding left cortical activation, is highlighted the results indicated that differing beta-theta ratios and low blood oxygenation in area Fp1 can be related to hyperactivity and impulsivity symptomatology.

Furthermore, when the electric activation shows low levels in Fp1, these data are also supported by nirHEG results and a low performance in TOVA tests. Similarly, when the electrical activation is within normal ranges blood oxygenation and TOVA test results are also normal. While these results have been observed in previous studies analyzing the relationship between Q-EEG and TOVA, and between nirHEG and TOVA (González-Castro et al., 2013), the present research was focused on the relationships of all electrical-activation variables through a latent variable.

On the other hand, in the case of central activation, this relationship shows lower rates, and although it is observed that those who present low activation levels measured by the beta-theta ratio in Cz, also present a low oxygenation measured by nirHEG in FpZ, as well as a greater number of omission errors and worst response time; the findings do not reach so high interaction as the previous case. In any case, it has to be emphasized that being different points (Cz / FpZ), is logical that correlations decrease slightly in spite of still showing a significant relationship. Furthermore, it is possible that FpZ is also influenced by other variables besides inattention, such as emotion or anxiety control, that many studies have located in Fp2.

Firstly, given these results, the relationship between activation and execution seems to be a reliable measure for ADHD symptoms. Secondly, with regard to the differences between models from ADHD group and the control group, could be necessary its incorporation into assessment protocols in order to achieve more reliable and accurate diagnosis. Control group model shows a relationship between commissions and RT. In this sense, it is expected that an increasing of the number of commissions leads, in turn, to a low response time. By contrast, in the case of ADHD, the presence of a high commissions do not lead to a lower RT levels, since this student group also present a deficit in this variable (Leth-Steensen, Elbaz, & Douglas, 2000).

In the ADHD Group model, it can be observed a relationship between central activation of the cortex and D prime variable offered by TOVA. This fact makes sense, because D prime variable is obtained from the number of omissions and commission errors. Both are produced by a low level of activation in central cortical and left prefrontal brain areas. In this way, ADHD Group showed a greater number of errors both by omission and commission. Nevertheless, subjects from control group do not make omission errors, at least not significantly (González-Castro et al., 2013). Finally, comparation of both models showed differences between central and prefrontal activation relationship. While in the Control Group this relationship is .67, in the ADHD group decreases to .50. In this sense, in children without ADHD there is a relationship between different brain areas. But in the case of ADHD, the alteration in the cortical activation might present only in a specific area (Hart, Radua, Nakao, Mataix-Cols, & Rubia, 2013). This aspect has relevance for ADHD assessment, supported the idea about the alteration in the cortical activation and its measured through both electrical activity and blood oxygenation (Toomin & Jeffrey, 2009). Likewise, it is also relevant for intervention, since an improvement in the symptomatology would pass by an increase in the activation levels in the area which specifically is found more altered (Duric et al., 2014; González-Castro et al., 2016; Holtmann et al., 2014). This would imply a significant improvement because as has been reflected in this study, low activation levels in a specific area (central or left prefrontal) is particularly related to an executive profile (inattentive or impulsive/hyperactive).

Implications for Practice

Our results have important implications in ADHD diagnosis. An Activation-Executive diagnosis model was tested to improve the assessment process in ADHD, also explained variables interactions. Moreover, this study lends support to prior studies stating that the prefrontal area is essential in ADHD assessment (Rubia et al., 2011). This leads to a model of activation in which the central prefrontal and left prefrontal areas present lower activation in children with ADHD compared to controls (Gonzalez et al., 2013). These results suggest the importance of including different measures for the symptoms analysis with the aim to stablish a specific intervention and differentiate those cases that may need pharmacological support, or other interventions such as behavior therapy, neurofeedback or combine treatment. In this sense, the analysis of the activation allows professionals to determine the severity of the disorder and the intervention required.

Limitations of the study

Although the present study has produced interesting results, the implications derived from them should be taken cautiously as some theoretical and methodological limitations can be pointed out.

Firstly, it would have been convenient to compare the results obtained by these tests with those provided by other empirically-validated tests as SPECT or fMRI, in order to compare the levels of cortical activation through blood flow and their correlations with the values provided by the HEG. Secondly, in future research, it would be appropriate to consider not only the differences between controls and ADHD subjects, but also between the subtypes of the disorder (which could reveal that different activation and execution models are needed). It would be desirable control variables and problems related to ADHD (such as anxiety or depression) which could affect the obtained results (Rodríguez, González-Castro, García, Núñez, & Álvarez, 2014) and specially, taking into account that the presence of a pure ADHD group is an infrequent situation. Finally, we have to note the broad age range of the sample as another limitation and highlight the interest of analyzing these measures as function of age.

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Estudio 2

Second study published in *Journal of Attention Disorders* [Segundo estudio publicado en la revista *Journal of Attention Disorders*]:

Efficacy of a Continuous Performance Test Based on Virtual Reality in the Diagnosis of ADHD and Its Clinical Presentations

Débora Areces[1], Celestino Rodríguez[1], Trinidad García[1], Marisol Cueli[1],
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Article

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Efficacy of a Continuous Performance Test Based on Virtual Reality in the Diagnosis of ADHD and Its Clinical Presentations

Débora Areces[1], Celestino Rodríguez[1], Trinidad García[1], Marisol Cueli[1], and Paloma González-Castro[1]

Abstract

Objective: To analyze the diagnostic effectiveness of the AULA Nesplora test to discriminate the different ADHD presentations: impulsive/hyperactive (I/H), inattentive, and combined.**Method:** A total of 117 students (76.9% male and 23.1% female) between 5 and 16 years of age (*M* = 11.18 years, *SD* = 3.10 years) participated, and were divided into three groups with ADHD according to their presentation, and a control group. **Results:** Each of the test conditions allowed the discrimination between the I/H and combined presentations with respect to the control group, and between the I/H and inattentive presentations. However, differences among ADHD presentations were only evident when the results were separately analyzed for the visual and auditory modalities. **Conclusion:** This study showed that the indicators offered by the AULA Nesplora test (omissions, commissions, response times, and motor activity) make it possible to establish a differential diagnosis of ADHD presentations when analyzed under different contextual conditions. *(J. of Att. Dis. XXXX; XX(X) XX-XX)*

Keywords
ADHD, ADHD presentations, AULA Nesplora test, virtual reality, diagnosis

Introduction

ADHD is a common disorder in childhood and one of the most frequent conditions affecting school performance. Studies analyzed at the international level cite prevalence rates ranging from 5% to 7% in the school-age population (Polanczyk, Willcutt, Salum, Kieling, & Rohde, 2014; Steinau, 2013). This disorder is characterized by a persistent behavioral pattern associated with inattention, overactivity (or hyperactivity), and difficulty in controlling impulses, leading to four subcategories or presentations: the combined presentation, the predominantly inattentive presentation, the inattentive/restrictive presentation, and the predominantly impulsive/hyperactive presentation (hereafter I/H; American Psychiatric Association [APA], 2013).

Recent research on ADHD highlights the existence of an executive function (EF) impairment in this population, which would explain its difficulty in controlling impulsive responses, resisting interference, organizing activities in a sequential manner, and sustaining cognitive effort while performing an activity (Barkley & Murphy, 2010; García, González-Pienda, Rodríguez, Álvarez, & Álvarez, 2014).

Given the symptomatic complexity of ADHD (Biederman, Petty, Evans, Small, & Faraone, 2010; Ramos-Quiroga et al., 2012) and its high prevalence rates (Polanczyk et al., 2014), professionals must have reliable and valid instruments to diagnose this disorder. In this context, questionnaires based on behavioral observations, including the Evaluation of Attention Deficit and Hyperactivity (EDAH; Farré & Narbona, 2001), the Behavior Assessment System for Children (BASC; Reynolds & Kamphaus, 2004), the Child Behavior Checklist (CBCL; Achenbach, 1991), and the Conners' scales (Conners, 1995), are widely used to detect the key symptoms of ADHD (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2014). However, the use of these instruments as the sole assessment measure has certain limitations, including potential subjectivity on the part of the observer (García, González-Castro, Areces, Cueli, & Rodríguez, 2014).

Other widely used tests in ADHD diagnosis are those based on a participant's performance, with the most

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Objective: To analyze the diagnostic effectiveness of the AULA Nesplora test to discriminate the different ADHD presentations: impulsive/hyperactive (I/H), inattentive, and combined. **Method**: A total of 117 students (76.9% male and 23.1% female) between 5 and 16 years of age (M = 11.18 years, SD = 3.10 years) participated, and were divided into three groups with ADHD according to their presentation, and a control group. **Results**: Each of the test conditions allowed the discrimination between the I/H and combined presentations with respect to the control group, and between the I/H and inattentive presentations. However, differences among ADHD presentations were only evident when the results were separately analyzed for the visual and auditory modalities. **Conclusion**: This study showed that the indicators offered by the AULA Nesplora test (omissions, commissions, response times, and motor activity) make it possible to establish a differential diagnosis of ADHD presentations when analyzed under different contextual conditions.

Keywords: ADHD, ADHD presentations, AULA Nesplora test, virtual reality, diagnosis.

Introduction

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Other widely used tests in ADHD diagnosis are those based on a participant's performance, with the most important being the so-called Continuous Performance Test (CPT). Within this group, Conners' CPT (Conners, 1995), the Children Sustained Attention Task (CSAT; Servera & Llabrés, 2004), the Integrated Visual and Auditory Test (IVA; Tinius, 2003), and the Test of Variables of Attention (TOVA; Greenberg, 1993) are noteworthy. These tests provide quantitative data on different variables of interest (e.g., omissions, commissions, response time, variability, and post-commission response time) and have been shown to be useful in examining the relationships between various performance variables and the phenotypic behavior of ADHD students (Epstein et al., 2003) and in the differential diagnosis of ADHD and its different presentations (Bart, Raz, & Dan, 2014; González-Castro, Rodríguez, López, Cueli, & Álvarez, 2013; Miranda et al., 2012). In particular, the research conducted by González-Castro and collaborators analyzes performance in CPTs (specifically, the TOVA) in a wide sample of students between 8 and 13 years of age with the three different presentations of ADHD (i.e., combined, predominantly inattentive, and I/H presentations) and controls.

However, this type of test is commonly criticized for its low ecological validity (García, González-Castro et al., 2014; Gioia, Kenworthy, & Isquith, 2010). According to these authors, attention deficit, motor hyperactivity, and cognitive impulsivity do not always occur when a child is in a small room, with a single adult, and under controlled contextual conditions, as is often the case in testing situations. These conditions differ considerably from those present in real life.

Various studies indicate that the use of tools based on virtual reality represents a breakthrough in the diagnosis of ADHD, precisely because it allows comparing control and ADHD groups in a realistic environment (Adams, Finn, Moes, Flannery, & Rizzo, 2009; Bioulac et al., 2012; Iriarte et al., 2012). In this sense, it is necessary to highlight that the closest precedent of the AULA Nesplora would be the so-called "Virtual Reality Classroom" (Adams et al., 2009; Rizzo et al., 2001). Although the AULA Nesplora follows the same logic as its predecessor, that is, presenting a task of sustained attention and inhibition of responses in the context of a virtual classroom, it represents a step forward in the sense that it provides information differentiated by the sensory channel (visual and auditory), type of task (x-go and x-no go), and presence or absence of distractors, in addition to providing a reliable indicator of motor activity during performance (Díaz-Orueta et al., 2014). Therefore, this test would provide more detailed and accurate information than the CPTs traditionally employed. The research conducted by previous authors have found that AULA Nesplora was even able to discriminate between children with ADHD under medication and those with no medication via the indicators offered by the test.

Along the same lines, previous studies using virtual reality tools have limitations that must be taken into account. One limitation relates to the sample size, as is the case for the research conducted by Adams et al. (2009), which consists of a sample of 19 participants with ADHD and 16 controls, 8 to 16 years of age. Although the results indicate lower performance levels and a greater tendency to distraction in the former group, the reduced sample size represents an issue when generalizing results. Perhaps in this case, referring to trends would be more appropriate. Another limitation relates to the fact that, to date, no study has considered the type of presentation of ADHD. Thus, the potential discriminative utility of the test has not yet been studied in this regard. Therefore, the present study aims to analyze the effectiveness of AULA Nesplora in discriminating among the three groups of students with ADHD (inattentive, I/H, and combined presentations) and a control group. To analyze its effectiveness, the variables studied by the test (omissions, commissions, response time, and motor activity) are taken into account to address the following: a general measure of the indicators provided, the task type (go vs. no-go), the influence of contextual features (presence vs. absence of distractors), and the sensory modality in which stimuli are presented (visual vs. auditory channels).

Given that the different presentations of the disorder are characterized by differential symptoms, there should exist different behaviors in the diagnostic groups studied in addition to differences between ADHD and controls, with the contextual characteristics of the task acting as an important constraint in students' performance.

In this regard, at a general level (without taking into account the contextual characteristics of the task) and bearing in mind the results of previous studies (Díaz-Orueta et al., 2014), the symptoms associated with impulsivity and hyperactivity are expected to present through an increasing number of commissions and greater motor activity. Conversely, the characteristic symptoms of inattention should be expressed as an increasing number of omissions and greater response times.

More specifically, the group with a predominantly I/H presentation, characterized by low inhibition and little resistance to distraction, is expected to perform worse than the remaining groups in the presence of distractors (i.e., more commissions and increased motor activity) because distractors generate increased levels of impulsivity in participants. By contrast, in the absence of distractors, it is likely that combined and inattentive presentations show lower performances (especially regarding omissions and response time), given that in the absence of distractors, sustaining attention plays a large role, whereas impulsivity control comes in second.

Third, regarding the type of channel presenting the stimuli (auditory vs. visual) and taking into account the influence of prior training derived from the everyday use of new technologies (the use of computers, game consoles, etc.), poorer discrimination in the visual channel in comparison with the auditory channel is expected between the different presentations in the response time variable, as previous training tends to decrease response times considerably, which in turn diminishes the differences between students with ADHD and controls.

Finally, with respect to the type of task (i.e., go/no-go protocols), considering that the first task correlates with impulsivity symptoms, worse results will be obtained by predominantly I/H and combined presentations, with a large number of commissions and increased motor activity. By contrast, for the second task, aimed at measuring attention, worse results are expected at the level of omissions and response time mainly in the group with inattentive and combined presentations.

Method

Participants

This study made use of a non-probabilistic clinical sample composed of 90 males (76.9%) and 27 females (23.1%) between 5 and 16 years of age (M = 11.18 years, SD =

3.10 years) and with an average IQ of 105.17 (SD = 13.52). The participants in the ADHD groups were identified according to the Diagnostic and Statistical Manual of Mental Disorders (5th ed.; DSM-5; APA, 2013), resulting in a control group (n = 28, 23.93%), an inattentive ADHD group (n = 28, 23.93%), an I/H ADHD group (n = 29, 24.78%), and an ADHD combined group (n = 32; 27.35%; Table 1). No statistically significant differences were found between the groups with respect to IQ (p = .539), but minor differences in age appeared, F(3, 109) = 4.964, p = .003, η2 = .120. However, both variables are included as covariates in subsequent statistical analyses.

Table 1. Descriptive Statistics for IQ, Ages, and EDAH Scale.

Variables	Control *n* = 27 *M* (*SD*)	AD *n* = 27 *M* (*SD*)	I/H *n* = 28 *M* (*SD*)	ADHD *n* = 31 *M* (*SD*)
IQ	105.26 (12.58)	105.89 (12.59)	110.00 (14.42)	107.06 (12.28)
Age	12.67 (0.70)	10.96 (2.90)	9.64 (3.08)	11.45 (3.06)
EDAH.I/H	83.25 (10.90)	68.56 (20.34)	93.46 (9.15)	91.38 (6.96)
EDAH.AD	78.50 (18.50)	90.78 (7.37)	82.92 (10.73)	93.50 (3.11)
EDAH.ADHD	83.75 (14.36)	81.00 (11.46)	92.08 (6.52)	96.25 (2.96)

Note. EDAH = Evaluation of Attention Deficit and Hyperactivity; AD = attention deficit; I/H = impulsive/hyperactive; EDAH.I/H = the score in the impulsivity/hyperactivity items; EDAH.AD = the score in the items that measure attention deficit; EDAH.ADHD = the score in the items that measure ADHD.

Inclusion criteria

First, the Wechsler Intelligence Scale for Children–IV scale (WISC-IV; Wechsler, 2005) was used to eliminate participants with an IQ lower than 80 and greater than 130. None of the participants with ADHD was receiving medication at the time of assessment.

A MANOVA lead to statistically significant differences between the three comparison groups, λ = .484, F(9, 224) = 2.919, p = .005; η2= .215. Table 1 shows that the measures of attention deficit (EDAH.AD), F(3, 114) = 3.478; p = .027; η2= .240, and hyperactivity/impulsivity (EDAH.I/H), F(3, 114) = 4.908; p = .006; $\eta 2$= .309, were used separately and jointly (EDAH.ADHD), F(3, 114) = 5.222; p = .005; $\eta 2$ = .322.

Instruments

The following instruments were used to perform the present study:

The *WISC-IV* by Wechsler (2005) is a tool that assesses individual intelligence in children and adolescents between the ages of 6 years and 16 years 11 months. In this study, it was used to obtain a measure of total IQ (TIQ).

The Scale for the Assessment of ADHD (EDAH; Farré & Narbona, 2001) was administered to families. It comprises 20 items that provide information on the presence of symptoms relating to attention deficit and hyperactivity/ impulsivity and helps differentiate between predominantly I/H, inattentive, and combined ADHD. A score above 90% in its subscales indicates attention deficit, hyperactivity/ impulsivity, or both. In this case, the following variables were taken into account: EDAH.I/H (the score in the impulsivity/ hyperactivity items), EDAH.AD (the score in the items that measure attention deficit), and EDAH.ADHD (the score in the items that measure ADHD).

AULA Nesplora (Climent, Banterla, & Iriarte, 2011) is the main object of study. This continued assessment task evaluates attention, impulsivity, processing speed, and motor activity in participants between 6 and 16 years of age. The task is performed in a virtual reality environment, which is shown through three-dimensional (3D) glasses (Head Mounted Display, HMD) equipped with motion sensors and headphones. The virtual stage presented through the HMD is similar to a classroom. The participant takes the perspective of a student sitting in one of the desks and facing the chalkboard. Head movements are detected by sensors located in the glasses; thus, the software updates the angle of vision, giving the participant the feeling of actually being in a virtual classroom.

The test consists of three phases that are gradually explained by a virtual teacher. The objective of the first phase is to immerse the participant in the context of virtual reality, and it consists of visually locating balloons and popping them. Below is a task based on the "x-no" paradigm (traditionally known as "no-go") in which the participant must press a button provided that he or she does not see or hear the stimulus "apple." Finally, an "x" paradigm (or "go") is incorporated, with participants being asked to press a button whenever they see or hear the number "seven." Thus, not only the delivery response but also its inhibition is assessed. The variables provided by the instrument do not differ from those of other CPTs regarding attention deficit and hyperactivity/impulsivity measures; however, they complement this information, differentiating these measures by the sensory modality (visual vs. auditory), presence/ absence of distractors, and task type (go vs. no-go). These measures are the following:

> Omissions: These are errors that occur when the participant must respond to the target stimulus but does not do so. It is a measure related to selective and focused attention. AULA Nesplora offers a general index called total omissions, in addition to more specific indicators, where omissions are differentiated by the sensory modality (auditory vs. visual omissions), presence of distractors (omissions with vs. without distractors), and type of task (omissions in x-no vs. X).
>
> Commissions: These occur when the participant clicks on the button, even if the target stimulus has not been presented. This measure correlates with a lack of motor control or inhibition of response. AULA Nesplora also offers the previous measures

for this variable: total commissions by the sensory modality, presence of distractors, and task.

Average response time: Average response time is the reaction time in milliseconds, and it is used as a measure for processing speed. AULA Nesplora collects the values for this variable under the same conditions noted for the two previous variables.

Response times are measured not only when correct answers are provided but also when errors by commission occur.

Motor activity: The 3D glasses used in this test have a motion sensor that records the entire motor activity of the participant during the test. In this manner, head movements are captured to register their frequency and relevance (i.e., required vs. unnecessary movements).

Procedure

Considering the objective of this research, we studied participants with ADHD who came to the clinical service for a diagnosis. To that end, once parental consent to evaluate the children was provided, the corresponding tests were conducted to verify the diagnosis and to participate in this research.

Data Design and Analysis

This study used as ex post facto descriptive-comparative design for four groups, three corresponding to the three types of ADHD presentations and a control group.

First, the descriptive statistics for the variables under study were analyzed, with special attention to asymmetry and kurtosis values. Kline's (2011) criterion, according to which the maximum scores accepted for asymmetry and kurtosis range between 3 and 10, was employed. The results indicated that the variables met this criterion, which allowed parametric analysis. Subsequently, to analyze the differences between the groups, a MANCOVA was performed, using age and IQ as covariates. The dependent variables were the attention measures derived from the gross AULA Nesplora scores (omissions, commissions, response time, and motor activity). These measures were taken globally (total scores in the test) and separately for the different conditions offered by the test (presence vs. absence of distractors, auditory vs. visual channel, and X vs. no-X task) to determine whether these conditions differently affect the presentations of ADHD. The group was the independent variable. Once the existence of statistically significant differences was verified, to determine in which diagnostic groups these differences lie, a post hoc analysis was conducted using Scheffé's test for multiple statistical comparisons. Cohen's (1988) delta was used as a measure of effect size. Cohen's classic work defines a small effect size as $\eta 2 = .010$ (Cohen's $d = 0.20$), a medium effect size as $\eta 2 = .059$ (Cohen's $d = 0.50$), and a large effect size as $\eta 2 = .138$ (Cohen's $d = 0.80$).

SPSS 19 (Arbuckle, 2010) was used in the analysis of data, establishing $p < .05$ as the criterion for statistical significance.

Results

As shown in Table 2 and according to the Kline (2011) criteria, it was found that the variables had a normal distribution.

Table 2. Descriptive Statistics for AULA Nesplora Variables.

	Diagnostic groups					
	AD	I/H	ADHD	Cont.		
Variables	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	Asymmetry	Kurtosis
General						
O	27.15 (28.40)	24.79 (20.50)	33.77 (28.95)	7.44 (7.35)	1.558	1.891
C	10.70 (5.24)	20.50 (10.09)	15.65 (7.34)	9.00 (4.55)	1.080	0.931
RT	921.45 (149.66)	835.82 (159.47)	901.59 (157.36)	808.05 (99.96)	0.694	0.012
MA	0.38 (0.26)	0.74 (0.70)	0.57 (0.49)	0.23 (0.13)	2.062	4.191
Channel						
Visual						
O	17.37 (17.48)	16.71 (15.08)	25.74 (25.27)	5.67 (6.30)	1.729	2.755
C	6.37 (3.38)	11.68 (5.09)	8.55 (4.99)	5.44 (2.37)	0.837	0.601
RT	775.82 (190.28)	722.40 (136.14)	757.68 (182.47)	660.44 (110.14)	0.899	0.315
Auditory						
O	9.78 (14.76)	8.07 (7.12)	8.03 (7.33)	1.78 (1.71)	3.087	11.060
C	4.33 (3.02)	8.82 (5.47)	7.26 (4.09)	3.56 (2.86)	1.089	0.832
RT	1074.45 (131.12)	942.05 (189.56)	1022.04 (135.95)	960.92 (116.40)	0.448	0.171
Distractors						
Presence						
O	10.67 (12.25)	9.18 (6.96)	11.74 (9.45)	3.22 (3.30)	1.595	2.753
C	4.33 (3.11)	8.18 (3.76)	5.81 (3.15)	3.70 (2.01)	0.870	0.598
RT	931.62 (155.26)	830.38 (179.04)	909.06 (166.63)	762.01 (196.84)	–□.360	2.865
MA	0.37 (0.28)	0.69 (0.67)	0.58 (0.52)	0.24 (0.14)	2.173	5.203
Absence						
O	16.96 (16.37)	15.61 (14.20)	22.03 (20.01)	4.22 (4.30)	1.682	2.367
C	6.37 (3.39)	12.32 (7.29)	9.84 (5.27)	5.30 (3.22)	1.286	1.477
RT	915.59 (155.71)	841.13 (148.13)	897.84 (159.19)	798.47 (96.71)	0.726	0.007
MA	0.42 (0.29)	0.83 (0.79)	0.62 (0.53)	0.25 (0.14)	2.213	5.439
Task						
x-no go						
O	22.63 (25.38)	17.79 (15.24)	26.19 (24.06)	5.85 (5.51)	1.754	2.641
C	10.11 (6.81)	15.32 (6.00)	11.97 (4.88)	7.93 (3.61)	1.032	1.969
RT	904.45 (152.37)	798.86 (170.75)	883.82 (158.12)	794.07 (105.03)	0.668	0.071
MA	0.30 (0.23)	0.59 (0.65)	0.47 (0.43)	0.18 (0.08)	2.503	6.918
x-go						
O	4.52 (4.24)	7.00 (6.18)	7.58 (6.73)	1.59 (2.56)	1.502	2.051
C	1.81 (2.11)	5.21 (5.49)	3.68 (3.61)	1.07 (1.92)	1.936	3.581
RT	984.44 (157.65)	982.24 (218.44)	986.48 (183.91)	863.18 (115.42)	0.019	0.459
MA	0.44 (0.31)	0.86 (0.81)	0.64 (0.58)	0.27 (0.17)	2.215	5.881

Note. AD = attention deficit; I/H = predominantly hyperactive/impulsive presentation; ADHD = combined presentation; Cont. = control group; *M* = mean; *SD* = standard deviation; O = omissions; C = commissions; RT = response time associated with a correct answer; MA = motor activity during the activities; x-no go = the individual should not hit the button before the target stimulus; x-go = the individual should hit the button before the target stimulus.

Table 3 shows the results of the MANCOVA, taking into account age and IQ as covariates. These results show the general measures of AULA Nesplora first and then for each of the conditions of the test separately. As shown, statistically significant differences were found between the groups. In this regard, it is worth noting that high scores in the different test indicators are related to poor performance.

Table 3. Differences Among the Groups for Each AULA Nesplora Variable.

	Differences			
Variables	*F*(3, 107)	η^2	Post hoc	*d* Cohen
General				
O	6.713***	.158	AD > Cont*	0.97
			ADHD > Cont*	1.23
C	10.298***	.224	I/H > ADHD***	1.24
			ADHD > Cont**	1.09
			I/H > Cont***	1.49
RT	6.072***	.145	AD > Cont*	0.91
MA	3.324*	.085	I/H > Cont***	1.02
			AD < I/H*	0.75
			ADHD > Cont*	0.94
Channel				
Visual				
O	6.894***	.162	ADHD > Cont***	1.08
C	9.097***	.203	AD < I/H***	0.40
			I/H > ADHD*	0.63
			I/H > Cont***	1.59
			ADHD > Cont*	0.79
RT	4.358**	.109	—	
Auditory				
O	2.745*	.071	AD < I/H*	0.78
C	7.635***	.176	AD < I/H**	1.03
			DA < ADHD*	0.82
			I/H > Cont***	1.22
			ADHD > Cont**	1.05
RT	6.103***	.146	AD < I/H*	0.82

Distractors				
Presence				
O	5.160***	.126	AD > Cont*	0.85
			ADHD > Cont**	1.23
C	9.316***	.207	I/H > Cont***	1.13
			I/H > AD***	1.51
RT	5.914***	.142	AD > Cont*	0.87
			ADHD > Cont**	0.83
MA	3.083*	.080	I/H > Cont**	0.94
			ADHD > Cont*	0.88
Absence				
O	7.062***	.165	AD > Cont*	1.34
			ADHD > Cont**	1.21
C	7.640***	.176	I/H > AD***	1.06
			I/H > Cont***	1.26
			ADHD > Cont**	1.04
RT	6.012***	.144	AD > Cont*	0.76
MA	3.339*	.086	I/H > AD*	0.70
			I/H > Cont***	1.03
Task				
x-no go				
O	6.121***	.146	AD > Cont*	0.93
			ADHD > Cont***	1.15
C	6.288***	.150	AD < I/H**	0.83
			I/H > Cont***	1.51
			ADHD > Cont*	0.95
RT	6.369***	.152		
MA	2.666	.070	I/H > Cont**	0.89
			ADHD > Cont*	0.92
x-go				
O	6.182***	.148	I/H > Cont**	1.14
			ADHD > Cont***	1.17
C	4.370**	.109	I/H > AD*	0.83
			AD > Cont***	1.02
			ADHD > Cont*	1.59
RT	2.289	.060		
MA	3.114*	.080	I/H > AD*	0.69
			I/H > Cont***	1.02

Note. O = omissions; AD = attention deficit; ADHD = combined presentation; C = commissions; I/H = predominantly hyperactive/impulsive presentation; Cont. = control group; RT = response time associated with a correct answer; MA = motor activity during the activities; DA = predominantly inattentive presentation; x-no go = the individual should not hit the button before the target stimulus; x-go = the individual should hit the button before the target stimulus.

*$p < .05$. **$p < .005$. ***$p < .001$.

General Measures

In terms of the general measures, the MANCOVA indicated the existence of statistically significant differences between groups, $\lambda = .449$, $F(13, 105) = 44.240$, $p < .001, \eta2 = .145$. IQ yielded no differences ($p = .270$), but age did, $F(4, 104) = 29.075$, $p < .001, \eta2 = .558$. These differences were found in the different variables studied, effect sizes being considerably higher in the case of commissions and omissions (Table 2). As might be expected, differences were found not only between the control group and the different groups with ADHD but also among the three presentations. In this sense, the omissions variable detected differences among the groups that share an inattention component (AD and ADHD) and controls, with a larger deficit in the former two groups. The commission variable differed between those groups with an impulsivity/hyperactivity component (I/H and ADHD) and controls and between the two presentations. The presence of impulsivity/hyperactivity symptoms was related to a greater number of commissions. Differences in motor activity were very similar to those found in commissions (here, with differences between the AD and I/H groups), indicating greater activity in the groups with impulsivity/hyperactivity components. Finally, response time showed differences between the predominantly inattentive group and the control group, with the former group having slower performances.

Sensory Channel

The results of the test were analyzed based on the sensory channel. A MANCOVA was conducted separately for each sensory modality. In the visual channel, after controlling for IQ ($p = .244$) and age effects, $F(3, 105) = 44.240$, $p < .001, \eta2 = .558$, statistically significant differences were found between the groups, $\lambda = .624$, $F(9, 255) = 6.070$, p

$<.001$, $\eta 2 = .145$. It should be noted that, specifically in the omissions variable, differentiating between the control and the combined group was possible; the combined group had poorer scores. The commissions variable, however, distinguished between the presentations that share impulsive and hyperactive symptoms (I/H and combined presentation) and between these and the inattentive presentation or the control group. The reason is the I/H and the combined presentations have the worst scores in that variable. The response time in the visual channel revealed no differences across presentations because the four groups obtained similar response times.

When performing the same analysis for the auditory channel, after controlling for the IQ ($p = .885$) and age covariates, $F(3, 105) = 24.021$, $p < .001$,$\eta 2 = .407$, there were also statistically significant differences, $\lambda = .697$, $F(9, 255) = 4.552$, $p < .001$, $\eta 2 = .114$. The results showed the effectiveness of each variable in differentiating between diagnostic groups. When analyzing the omissions variable, it was possible to differentiate between predominantly inattentive and I/H presentations; the former group had worse scores. Regarding commissions, it was possible to distinguish between the predominantly I/H and the combined presentations and also between each one of these presentations and the control group. Regarding response time, although there were no differences between groups concerning the visual channel, when examining variables related to the auditory channel, it was possible to distinguish between the inattentive and I/H presentations.

Presence/Absence of Distractors

A differential analysis relating the conditions offered by AULA Nesplora and the presence or absence of distractors was conducted. For the analysis of the results in the absence of distractors, IQ ($p = .239$) and age were taken as covariates $F(4, 104) = 32.471$, p

$< .001$,$\eta 2 = .555$, and the existence of statistically significant differences between the groups was detected, $\lambda = .627$, $F(12, 275) = 4.432$, $p < .001$,$\eta 2 = .144$. Given the significance of the results, the post hoc analysis demonstrated the discriminatory power of the different variables analyzed. Specifically, the omissions variable allows differentiating between the control group and those presentations that share the inattention component (predominantly inattentive and combined presentations). By contrast, the commissions variable allows differentiating between predominantly I/H and inattentive presentations and the control group. Response time distinguished the control group from the inattentive and combined presentations. Similarly, the analysis of the motor activity variable made it possible to differentiate the I/H presentation from the inattentive presentation and the control group.

When analyzing the results in the presence of distractors, the same covariates were considered: IQ ($p = .814$) and age $\lambda = .603$, $F(4, 104) = 17.141$, $p < .001$,$\eta 2 = .397$, and significant differences were found between the groups: $\lambda = .606$, $F(12, 275) = 4.777$, $p < .001$,$\eta 2 = .154$. As in the presence of distractors, the omissions variable distinguished between the control and the inattentive and combined presentation groups. In terms of the commission variable, in addition to differentiating between the same groups that showed differences in the presence of distractors (predominantly inattentive presentation from I/H presentation and the control group), it allows discriminating between the combined presentation and the control group. However, unlike the previous situation (in the presence of distractors), response time only distinguishes between the control group and the predominantly inattentive presentation. With regard to motor activity, it was possible to distinguish between the I/H presentation and the inattentive presentation as well as the control group.

X/No-X Paradigm

We conducted a MANCOVA for each task type used by the AULA Nesplora test. Similar to the previous analysis, in Task 1 (no-X), the effect of the variables was controlled: IQ ($p = .177$) and age, $F(4, 104) = 22.124$, $p < .001, \eta2 = .460$, pointing to statistically significant differences between the groups, $\lambda = .631$, $F(12, 275) = 22.124$, $p < .001, \eta2 = .142$. Thus, it was observed that omissions discriminate between the control group and inattentive and combined presentations. Commissions allowed distinguishing between the I/H and inattentive presentations and the control group, in addition to differentiating between the combined presentation and the control group. With regard to response time, there were no differences between the groups. Motor activity distinguished between the control group and the I/H and combined presentations.

The same analysis was performed for Task 2, taking IQ ($p = .176$) and age as covariates, $F(4, 104) = 24.438$, $p < .001$, $\eta2 = .485$, and statistically significant differences were also found $\lambda = .746$, $F(12, 275) = 2.692$, $p < .001, \eta2 = .093$. In this case, the omissions variable has a discriminatory power different from that presented in other situations, showing differences between the control group and the presentations with impulsive and hyperactive symptoms (I/H and combined). The commission variable follows the same line as in previous cases, showing differences between the control group and the combined and inattentive presentations and between the combined and inattentive presentations. As in Task 1, the response time variable does not present differences among groups. However, motor activity has established differences between the I/H and inattentive presentations and between the control group and the I/H presentation.

Discussion and Conclusion

The objective of this study was to verify the effectiveness of the AULA Nesplora test in discriminating between the different presentations of ADHD and between these presentations and the control group, and the results showed the effectiveness of the diagnostic test for differentiating between presentations. In addition, considering that ADHD in its inattentive presentation that often goes unnoticed (Rodriguez et al., 2009) because it does not present disruptive behavior in the classroom, it is relevant to use evidence such as that provided by the AULA Nesplora test that allows its discrimination from a control group or the different presentations of ADHD (I/H or combined presentation).

Thus, after analyzing the variables in each of the conditions referred to by the test, it was found that all of them made it possible to distinguish between predominantly I/H and combined presentations with respect to the control group and between I/H and inattentive presentations. By contrast, differentiation between certain presentations has only been demonstrated under one of the conditions analyzed.

First, analyzing the general indicators provided by the test showed results similar to those obtained in previous studies (Egeland, 2007; González-Castro et al., 2013). ADHD presentations sharing inattention as a symptomatic component (inattentive and combined presentations) showed a greater number of omissions and response time. However, the presentations characterized by impulsivity and/or hyperactivity (presentation I/H and combined) showed a greater number of commissions and a high level of motor activity.

Subsequently, after analyzing the performance of the presentations of ADHD both in the presence and absence of distractors, the presence of a stable performance profile for each was detected. In both cases, I/H presentation has been characterized by a large number of commissions and a high level of motor activity, whereas the predominantly inattentive presentation obtained lower performance levels for omissions and response time (Iriarte et al., 2012). However, contrary to expectations, both the control group and the different presentations of ADHD showed lower performance levels in the absence of distractors. This finding may be because distractors in the AULA Nesplora test provide motivation for the task, which positively affects participants’performance.

In terms of the sensory channel, it was found that the analysis of visual and auditory channels separately hints at differences between presentations that were undetected in other conditions established by the test. Thus, differences between the I/H and combined presentations are only evidenced in the omissions registered by the visual channel, with the I/H presentation having lower performance levels. However, the distinction between the inattentive and combined presentations has only been manifested in the commission variable through the auditory channel, with the result that the inattentive presentation has increased response times. These results suggest that analysis of the indicators by sensory modality is relevant for providing a differential diagnosis of ADHD and its presentations (Sancho, Pardo, González, & García, 2015). In addition, the data obtained are consistent with previous studies (Grizenko, Paci, & Joober, 2009) that indicated inattentive presentation as having behavior substantially different from the other presentations. Furthermore, it was observed that the response time collected by the visual channel presents no differences between groups. As described in one of the baseline hypotheses, this absence of differences may be due to the training effect in the visual channel, which causes a significant decrease in response times.

Regarding the type of task, Climent et al. (2011) argue that the x-go task is effective in the identification of inattention symptoms whereas the x-no go task is more effective in the detection of inhibitory deficits; the results in the present study show a different pattern. Specifically, the x-go task has not shown inattention symptoms because it has not allowed for a clear distinction between the predominantly inattentive presentation and the control group. This finding may be because it is a simple task, and the number of errors due to omission, although higher than in the control group, had no significant differences. No-go tasks established differences among the I/H and inattentive participants and controls. In this sense, x-nogo inhibition tasks not only show symptoms of impulsivity and hyperactivity in the predominantly I/H presentation (Diaz-Orueta, et al., 2014; Iriarte et al., 2012) but also negatively affect the inattentive presentation.

Therefore, these results confirm that AULA Nesplora shows a tendency to effectively detect the different presentations of ADHD, with certain differences when analyzing the same variables under different conditions. The results obtained in the present study may be useful in guiding practitioners toward a better interpretation and diagnosis on the basis of the information provided by this test.

However, some limitations of the study should be considered in future research. First, the sample size must be expanded to check whether the discriminative capacity shown by the evidence in the present study is maintained. In addition, it would be desirable to expand this evaluation through the use of tests that evaluate performance functions such as planning, working memory, and cognitive flexibility, which have been shown to play an important role in the diagnosis of ADHD (García et al., 2014) and would, therefore, produce a more complete diagnostic profile.

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Estudio 3

Third study published in the Journal *Anales de Psicología* [Tercer estudio publicado en la revista *Anales de Psicología*]:

Naming Speed and its effect on attentional variables and reading errors depending on the diagnosis

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Naming Speed and its effect on attentional variables and reading errors depending on the diagnosis

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Título: La velocidad de denominación y su efecto en variables atencionales y errores de lectoescritura en función del diagnóstico.
Resumen: Si bien la velocidad de denominación, generalmente evaluada con pruebas como el RAN/RAS ha demostrado su utilidad en la predicción de ciertos errores lectores y dificultades atencionales, hasta el momento no se ha analizado que variables predicen el rendimiento en la prueba. El objetivo del presente estudio es comprobar el poder explicativo de determinadas variables lectoras y atencionales sobre la velocidad de denominación en función del diagnóstico. Se utilizó una muestra de 132 estudiantes divididos en cuatro grupos (Control, n=34; Dificultades Lectoras, n=22; TDAH, n=41; y TDAH y Dificultades Lectoras, n=35). Los resultados mostraron: 1) en ausencia de dificultades, la velocidad de denominación es explicada por el CI, la edad y el género; 2) ante dificultades lectoras, las variables con mayor poder predictivo son los errores de lectura; 3) ante dificultades atencionales, son ciertas variables atencionales como los índices proporcionados por el TOVA, las que muestran una mayor significatividad.
Palabras Clave: Velocidad denominación; ran/ras; dificultades lectoras; TDAH; problemas atencionales.

Abstract: While naming speed, which is usually assessed with tests such as RAN / RAS, has proven to be useful in predicting certain reading errors and attentional difficulties, the variables that predict performance in the test have not been examined before now. The objective of this study is to test the explanatory power of certain reading and attentional variables over naming speed performance depending on diagnosis. A sample of 132 students, divided into four groups (Control, n=34; Reading difficulties, n= 22; ADHD, n=41; and ADHD+Reading Difficulties, n=35) was used. The results show: 1) without any difficulties, naming speed is explained by IQ, age and gender; 2) in the presence of reading difficulties, reading errors are the variables with more explanatory power; 3) in the presence of attentional difficulties, certain attentional variables such as those provided by the TOVA test were shown to be more significant.
Key words: Naming speed; ran/ras; reading difficulties; ADHD; attentional problems.

Introduction

Much research has looked at a variety of early indicators of Reading Learning Difficulties (RLD) with the aim of timely intervention and long term improvement. It is widely accepted that phonological awareness is able to predict future reading achievement (Aguilar, Navarro, Mechano, Alcale, Marchena, & Ramiro, 2010), and it has been shown that training in phonological skills improves reading and writing acquisition (Defior, 2008).

The ability of phonological awareness to predict RDL, in this case- achievement in naming tasks, has become the object of a variety of studies, as it is an independent factor which contributes to early reading and which is acquired before beginning infant education (Norton & Wolf, 2012). Various research points towards the fact that time taken naming stimuli is closely related to accuracy and fluency in reading words and pseudo-words (Aguilar et al., 2010;), as well as comprehension (Arnell, Joanisse, Klein, Busseri, & Tannock, 2009; Georgiou, Parrila & Kirby, 2009), and reading speed (Norton & Wolf, 2012). For some researchers (Georgiou, Parrila, Cui, & Papadopoulos, 2013), these results are due to both tasks demanding serial processing and oral production of visual stimuli. On the other hand, Loveall, Channell, Phillips and Conners (2013), among others, explain this association by referring to the fact that both reading and visual stimulus naming need access to orthographic representations in long term memory. Other studies suggest that visual stimulus naming activates brain areas related to reading (Liao et al., 2015). In short, they all posit that reading and naming are complex tasks that require processes in common.

The relationship between naming ability and attention has also been the subject of recent research (Pham, Fine, & Semrud-Clikeman, 2011). This relationship has been confirmed, especially in cases of subjects presenting Attention Deficit and Hyperactivity Disorder (ADHD) with a predominantly inattentive profile. That research supposed that difficulties of reading and attention shared certain symptoms such as slow processing speed (Shanahan et al., 2006), or problems of semantic processing (Tannock, Banaschewski, & Gold, 2006), which may influence the results of naming tasks. Most of this research has used the *Rapid Automatized Naming and Rapid Automatized Stimulus* test -RAN/RAS- (Wolf & Denckla, 2005), which is made up of six visual stimulus naming tasks, and scored based on time taken (in seconds) for each task. Some studies indicate that depending on the nature of the stimuli used in the naming tasks, subjects demonstrate reading or attentional difficulties. It has been observed that the alphanumeric RAN (that is, tasks composed of letters or numbers) is more closely associated with reading (Pham et al., 2011), while the non-alphanumeric RAN (tasks composed of colours or objects) is associated with attentional processes (Kieling et al., 2010; Roessner et al., 2008).

In this respect, various researchers state that low scores in the non-alphanumeric RAN in subjects with attentional difficulties are due to the existence of more than one plausible name for a given object or colour, producing a greater demand on attention and the need for more careful, detailed processing than that required for recognising letters or digits (Tannock et al., 2006). Furthermore, letters and numbers

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Abstract

While naming speed, which is usually assessed with tests such as RAN / RAS, has proven to be useful in predicting certain reading errors and attentional difficulties, the variables that predict performance in the test have not been examined before now. The objective of this study is to test the explanatory power of certain reading and attentional variables over naming speed performance depending on diagnosis. A sample of 132 students, divided into four groups (Control, n=34; Reading difficulties, n= 22; ADHD, n=41; and ADHD+Reading Difficulties, n=35) was used. The results show: 1) without any difficulties, naming speed is explained by IQ, age and gender; 2) in the presence of reading difficulties, reading errors are the variables with more explanatory power; 3) in the presence of attentional difficulties, certain attentional variables such as those provided by the TOVA test were shown to be more significant.

Key words: Naming speed, ran/ras, reading difficulties, ADHD, attentional problems.

Introduction

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The ability of phonological awareness to predict RDL, in this case- achievement in naming tasks, has become the object of a variety of studies, as it is an independent factor which contributes to early reading and which is acquired before beginning infant education (Norton & Wolf, 2012). Various research points towards the fact that time taken naming stimuli is closely related to accuracy and fluency in reading words and pseudo-words (Aguilar et al., 2010;), as well as comprehension (Arnell, Joanisse, Klein, Busseri, & Tannock, 2009; Georgiou, Parrila & Kirby, 2009), and reading speed (Norton & Wolf, 2012). For some researchers (Georgiou, Parrila, Cui, & Papadopoulos, 2013), these results are due to both tasks demanding serial processing and oral production of visual stimuli. On the other hand, Loveall, Channell, Phillips and Conners (2013), among others, explain this association by referring to the fact that both reading and visual stimulus naming need access to orthographic representations in long term memory. Other studies suggest that visual stimulus naming activates brain areas related to reading (Liao et al., 2015). In short, they all posit that reading and naming are complex tasks that require processes in common.

The relationship between naming ability and attention has also been the subject of recent research (Pham, Fine, & Semrud-Clikeman, 2011). This relationship has been con-firmed, especially in cases of subjects presenting Attention Deficit and Hyperactivity Disorder (ADHD) with a predominantly inattentive profile. That research supposed that difficulties of reading and attention shared certain symptoms such as slow processing speed (Shanahan et al., 2006), or problems of semantic processing (Tannock, Banaschewski, & Gold, 2006), which may influence the results of naming tasks. Most of this research has used the Rapid Automatized Naming and Rapid Automatized Stimulus test -RAN/RAS-(Wolf & Denckla, 2005), which is made up of six visual stimulus naming tasks, and scored based on time taken (in seconds) for each task. Some studies indicate that depending on the nature of the stimuli used in the naming tasks, subjects demonstrate reading or attentional difficulties. It has been observed that the alphanumeric RAN (that is, tasks composed of letters or numbers) is more closely associated with reading (Pham et al., 2011), while the non-alphanumeric RAN (tasks composed of colours or objects) is associated with attentional processes (Kieling et al., 2010; Roessner et al., 2008).

In this respect, various researchers state that low scores in the non-alphanumeric RAN in subjects with attentional difficulties are due to the existence of more than one plausible name for a given object or colour, producing a greater demand on attention and the need for more careful, detailed processing than that required for recognising letters or digits (Tannock et al., 2006). Furthermore, letters and numbers represent an automised code whereas objects and colours do not, and as such, the latter consumes resources of attention.

In light of previous research and the need to understand how the variables of reading and attentional difficulties influence naming speed, the aim of this current study is to analyse the explanatory power of certain variables related to reading (type of reading error), and attention (commission, omission, and D´ as given by TOVA) when it comes to naming speed, and how this varies in terms of diagnosis (ADHD, RLD, ADHD+RLD, control group).

Bearing in mind the processes involved in naming visual stimuli, it is expected that naming speeds in the different tasks making up the RAN/RAS (objects, colours, numbers, letters, letters-numbers, letters-numbers-colours) will be differentially related to the various variables involved in reading and writing, and attentional processes, especially in those groups who have some kind of difficulty. More specifically, following on from researchers such as Kieling et al. (2010) and Pham et al. (2011), it is expected that the alphanumeric RAN (tasks made up of numbers or letters) will be more closely related to reading while non-alphanumeric RAN (tasks made up of colours or objects) will be associated with attentional processes.

Method

Participants

This study used a non-probabilistic clinical sample comprising 78 boys (59.4%) and 54 girls (40.6%) aged between 5 and 16 (*M* = 9.88; *SD* = 2.87) with a mean IQ of 99.03 (*SD* = 11.85), who had been referred to a clinic for evaluation.

This sample was divided into four clinical groups (Table 1) according to previous diagnosis: The control group (*n* = 34; 25.6 %), RLD group (*n* = 22; 16.5%), ADHD (*n* = 41; 30.8%), and the group with both ADHD and RLD (*n* = 35; 26.3 %). IQ was measured using the WISC-IV scale (Weschler, 2005), subjects scoring below 80 or above 130 were removed from the sample. In addition, in order to confirm the diagnosis of ADHD, the Evaluation of Attention Deficit with Hyperactivity (EDAH) scale was applied (Farre & Narbona, 2001). Following that, a Multivariate Analysis of Covariance was performed to check for statistically significant differences between the four groups, $\lambda = .738$, $F(9,277) = 3.751$, $p < .001$, controlled for the effect of age, $p = .068$ and IQ, $p = .358$. Similarly, given that the scale provides differential scores for each subtype of ADHD, statistically significant differences were looked for in the following variables: Hyperactivity (EDAH-H), $F(1, 122) = 5.446$, $p < .001$, $\omega^2 = .091$, Attention-(EDAH-DA), $F(1, 122) = 8.790$, $p < .001$, $\omega^2 = .136$, and Hyperactivity+Attention (EDAH-ADHD), $F(1, 122) = 12.096$, $p < .001$, $\omega^2 = .191$.

Table 1. Means and Standard Deviations for Intelligence Quotient (IQ), age, and EDAH score for the four groups.

Goups	IQ			Age		EDAH.H		EDAH.DA		EDAH.TDAH	
	n	*M*	*DT*	*M*	*DT*	*M*	*DT*	*M*	*DT*	*M*	*DT*
Control	34	101.85	13.13	10.64	3.23	72.59	23.31	80.53	21.73	81.81	21.00
RLD	22	96.82	8.12	9.36	2.98	62.81	33.13	71.43	22.69	70.95	24.95
ADHD	41	100.66	12.22	10.60	2.67	84.51	17.69	89.46	14.31	92.95	9.25
ADHD+RLD	35	95.77	11.48	8.61	2.16	84.77	20.94	93.23	10.03	95.03	8.70
Total Sample	132	99.03	11.85	9.88	2.87	77.71	24.43	84.94	18.84	86.75	18.44

Note. *M* = Mean; *SD* = Standard Deviation; RLD = Reading Learning Difficulties; ADHD = Attention Deficit and Hyperactivity Disorder; ADHD+RLD = Attention Deficit Hyperactivity Disorder and Reading Learning Difficulties. EDAH.H = mean score in hyperactivity scale; EDAH.DA = mean score in attentional deficit scale; EDAH.TDAH = mean score in ADHD scale.

Lastly, with the aim of detecting whether there were significant differences between the four groups in the IQ and age variables, an analysis of variance (ANOVA) was performed. The results showed that, while there was no significant difference between the groups in terms of IQ, $p = .130$, there were differences in terms of age $F(3,129) = 4.483$, $p = .01$, $\omega^2 = .085$.

Instruments

The *Wechsler Intelligence Scale for Children-IV* (WISC-IV) (Wechsler, 2005) was used to evaluate IQ in the sample and to remove those individuals with IQs below 80 or over 130. This is an individually administered test composed of 15 subtests which provide information on cognitively specific areas. It is applicable to children and adolescents aged between 6 and 16. In this study only the Total Intelligence Quotient (TIQ) was considered.

In order to verify previous diagnoses of ADHD, the *Evaluation of Attention Deficit with Hyperactivity scale -EDAH-* was used (Farré & Narbona, 2001) in the version for families. This is made up of 20 items that evaluate attention deficit, hyperactivity, and impulsivity, which allows the distinction to be made between ADHD that is predominantly hyperactive-impulsive, inattentive, or combined. In this case the following variables were considered: *EDAH.H* (score in hyperactivity items), *EDAH.DA* (score in items which measure attention deficit) and *EDAH.ADHD* (score in items measuring ADHD).

To evaluate reading errors, the *TALE Reading and Writing Analysis Test* (Toro & Cervera, 1995) was used. This test determines a subject's general reading level and specific reading characteristics at a given moment during their schooling. In this study the following types of reading and writing errors were considered: omission, addition, substitution, inversion, and rotation.

The *Rapid Automatized Naming and Rapid Alternating Stimulus Tests* -RAN/RAS- (Wolf & Denckla, 2005) were used to evaluate naming speed. This is a test of naming speed that reflects the relationship between processing speed and reading speed. The test consists of four naming tests with different single stimulus type (letters, numbers, colours, objects) and two naming tests with alternating stimuli (letters-numbers, letters-numbers-colours). The scores in each task are based solely on the time taken (in seconds) to name each one of the six stimulus matrices.

Finally, the *Test of Variables of Attention*-TOVA- (Greenberg, Kindschi, & Corman, 1996) was used. This is a Continuous Performance Test -CPT- which consists of the presentation of two stimuli on a computer screen over 22.5 minutes. When the first of the stimuli appears on the screen (a square in the upper border), the student must press a button (attention task), and when the second image appears (a square in the bottom part of the screen) the student should not do anything (inhibition task). The TOVA provides information on the following variables: omission, commission, response time, variability, D´(Quality of achievement during the test), and IGCE (Executive Control Index).

Procedure

The sample came from a psycho-educational clinic attended by children diagnosed with RLD and/or ADHD by members of the School Guidance and Educational Psychology Team (*Equipo de Orientación Escolar y Psicopedagógica*: EOEP) in the Principality of Asturias, Spain. Team members use the following protocol. Firstly, once teachers have identified a low achieving student without apparent cause (motivation problems, discipline problems etc.) they request a specialist evaluation from a member of the EOEP team (psychologist, educational specialist, educational psychologist) who visits the school and looks at the case. In order to carry out the evaluation, the specialist administers various psychological tests which provide information about intellectual capability, attentional indices, reading abilities and so on. In that way learning problems due to some kind of disability (visual, hearing, etc) can be discounted. Then, once the evaluation is complete, and when the case requires it, the professional may make appropriate modifications to the child's schooling according to whatever is impeding academic achievement.

For the current study, students who had been diagnosed by members of the EOEP team as having learning difficulties and/or ADHD were invited to the clinic to confirm their diagnosis. To that end, once parental consent had been signed for the child's evaluation, a series of tests was administered to verify the diagnosis of RLD and ADHD. Those with a previous diagnosis of ADHD were given the Diagnostic Interview for Children (DISC-IV: Shaffer, Fisher, Lucas, Dulcanquellin, & Schwab, 2000), along with their parents. To be more specific, this study used the part of the interview which includes the history of progression, observation during play, and the criteria of the DSM-IV-TR (APA, 2000). In addition, the EDAH scale (Farré & de Narbona, 1998) in its aforementioned family version was administered to ensure the correct assignation of subjects to their respective groups.

Similarly, in order to confirm the diagnosis of individuals with learning difficulties the following criteria were used (Jiménez, Rodríguez, & Ramírez, 2009): (a) poor achievement in a reading test, (b) low grades in other academic areas (for example, arithmetic), and (c) a score of more than 80 in an intelligence test, specifically in the WISC-IV (Wechser, 2005). Subjects scoring less than 80 or more than 130 were eliminated. The inconsistency between reading achievement has been questioned (Jiménez et al., 2011) and has not been included in the definition of learning difficulties in this study.

Statistical design and analysis

Once the diagnoses had been verified, a ex post facto design was used to look at the predictive value of the variables. A hierarchical regression analysis was done which included three models, developed in each of the study groups (ADHD; RLD; ADHD+RLD; and the control): model 1 looked at general variables such as IQ, age, and gender; model 2 used the variables from model 1 and added the different types of reading errors identified by the TALE test (inversion, rotation, addition, substitution) from Toro & Cervera (1995); and finally, model 3 used the variables from the previous two models plus the three indicators from the TOVA test (Greenberg, Kindschi, & Corman, 1996): omission, commission, and D´. Only those variables demonstrating a significant correlation with naming speed variables (Table 3) were included in the model. Data analysis was done using SPSS v.19.0 (Arbuckle, 2010). Differences were considered significant a level of $p < .05$.

Results

One important assumption when carrying out this study was that the variables follow a normal distribution according to Kline's (2011) criteria, in which, scores between 3 and 10 are the maximum accepted for asymmetry and kurtosis, in addition to the Kolmogorov-Smirnov test for the various tasks in the RAN/RAS, in each of the four groups. As can be seen in Table 2, all of the variables analysed met these criteria.

Table 2. Means, standard deviations, asymmetry, kurtosis, and Kolmogorov-Smirnov Z for diagnostic groups for each task in the RAN/RAS test.

Diagnosis	RAN Tasks	*M*	*SD*	Asymmetry	Kurtosis	*Z* Kolmogorov-Smirnov	Asymptotic. Sig *(billateral)*
CG (n=34)	Objects	42.44	12.47	.506	-.290	.522	.552
	Colours	42.56	12.38	.844	.322	.540	.540
	Numbers	24.41	5.54	.242	-.722	.810	.810
	Letters	25.50	6.81	.545	-.153	.455	.455
	LN	28.62	7.29	-.234	-.933	.687	.687
	LNC	31.59	9.71	.109	-.698	.824	.824
RLD (n=22)	Objects	56.95	19.17	.958	.004	.930	.353
	Colours	64.14	37.52	1.960	3.196	1.222	.101
	Numbers	38.09	18.98	1.426	1.685	.862	.448
	Letters	38.86	16.82	.753	-.401	.844	.475
	LN	45.91	21.39	.636	-.881	.777	.582
	LNC	51.18	27.55	1.417	1.510	.889	.408
ADHD (n=41)	Objects	44.20	13.84	1.055	.401	1.033	.237
	Colours	44.22	16.35	1.237	1.358	.858	.454
	Numbers	26.02	9.18	2.171	5.846	1.418	.036
	Letters	28.78	13.10	2.509	8.659	1.096	.181
	LN	31.61	14.68	2.384	7.866	1.335	.057
	LNC	34.93	18.68	2.492	7.730	1.193	.116
ADHD+RLD (n=35)	Objects	57.40	18.71	2.068	5.861	1.180	.123
	Colours	63.60	20.54	1.606	4.065	.824	.506
	Numbers	40.91	22.55	1.699	1.872	1.597	.012
	Letters	43.49	23.98	2.062	5.339	1.005	.265
	LN	49.89	28.14	1.821	4.230	1.171	.129
	LNC	56.06	29.69	1.565	2.341	.968	.306

Note. *M* = Mean; *SD* = Standard Deviation; RLD = Reading Learning Difficulties; ADHD = Attention Deficit and Hyperactivity Disorder; ADHD+RLD= Attention Deficit Hyperactivity

Disorder and Reading Learning Difficulties; LN = naming task with letters and numbers; LNC = naming task with letters, numbers, and colours.

Following that, a MANCOVA test was performed, with covariables IQ (p = .290) and age, F(6,124) = 16.099, p < .001 checking for statistically significant differences in the four groups in terms of the results of the RAN/RAS tests, λ = .738, F(18,357) = 4.108, p = .028. Given the significance of these results, inter-subject effects were examined which demonstrated significant differences for each of the naming tasks: Objects, F(3,129) = 4.829, p = .003, ω^2= .043; Colours, F(3,129) = 3.884, p = .011, ω^2= .039; Numbers, F(3,129) = 7.120, p < .001, ω^2= .085; Letters, F(3,129) = 5.666, p = .001, ω^2 = .062; Letters and Numbers, F(3,129) = 6.529, p < .001, ω^2 = .013; Letters, Numbers and Colours F(3,129) = 4.372, p = .006, ω^2 = .045.

Similarly, as shown in Table 3, on analysing the correlations between variables related to reading and attentional processes and achievement in RAN/RAS tasks, it can be seen that time taken to name visual stimuli correlates significantly with most of the errors in reading and writing (errors of inversion, errors of addition, errors of rotation, and errors of substitution) as well as with certain variables from the TOVA test, namely: omission, commission, and D´.

Table 3. Bivariate correlations (Pearson) between naming tasks and variables from the TALE and TOVA tests.

		Naming Tasks					
		Objects	Colours	Letters	Numbers	LN	LNC
TALE	omission	.166	.167	.132	.137	.149	.166
	inversion	.334***	.282***	.418***	.430***	.424***	.367***
	addition	.212*	.138	.242*	.187	.246**	.225*
	rotation	.371***	.450***	.470***	.355***	.482***	.512***

	substitution	.389***	.397***	.319***	.321***	.363***	.390***
TOVA	omission	-.357***	-.272**	-.286**	-.245**	-.275**	-.245*
	commission	-.215*	-.182	-.246**	-.173	-.261**	-.198*
	RT	.049	.041	.069	-.009	.073	.051
	Variability	-.017	-.067	-.029	-.091	.005	-.040
	D prime	-.403***	-.318**	-.336**	-.290**	-.320***	-.286***
	GECI	-.100	-.085	-.095	-.098	-.072	-.080

Note. RT = Response time; GECI = General index of executive control; LN = Letters and numbers; LNC = Letters, numbers and colours.
**p* < .05; ***p* < .01; ****p* < .001.

The variables from the TALE and TOVA tests which demonstrated significant correlation with naming tasks in the RAN were taken as independent variables in a hierarchical regression analysis for each of the four diagnostic groups. The hierarchical regression analysis for the control group (Table 4) demonstrated that model 1 (with IQ, gender, and age variables) explains the majority of the variance explained as the introduction of other variable types related to reading and attention (models 2 and 3) leads to increases in variance explained which are not significant.

Table 4. Hierarchical regression analysis models with dependent variables for the Control Group.

		Raw.Obj	Raw.Col	Raw.N	Raw.L	Raw.LN	Raw.LNC
MODEL 1	Gender	-.404	-.377	-.397	-.603	-.130	-.398
		(-3.252**)	(-2.260*)	(-1.862)	(-3.191**)	(-.689)	(-2.146*)
	IQ	-.441	-.029	.046	-.196	-.231	-.101
		(-3.480**)	(-.167)	(.210)	(-1.015)	(-1.196)	(-.535)
	Age	-.839	-.701	-.511	-.515	-.793	-.667
		(7.170***)	(-4.456***)	(-2.545)	(-2.891*)	(-4.447***)	(-3.812**)
	R^2	.834	.700	.511	.527	.614	.629
	F(3,31)	10.096***	4.534*	6.951**	6.905**	7.360**	5.789**

MODEL 2	Gender	-.469	-.297*	-.438	-.591	-.345	-.361
		(-3.643**)	(-1.363)	(-1.862)	(-2.889*)	(-1.505)	(-1.388)
	IQ	-.478	.123	.310	-.059	-.214	-.095
		(-3.697**)	(.563)	(1.312)	(-.288)	(-.933)	(-.364)
	AGE	-.963	-.662	-.584	-.713	-.869	-.598
		(-7.524***)	(-3.056*)	(-2.496)	(-3.506**)	(-3.816**)	(-2.314*)
	TALE. inversion	-.068	.157	-.043	.084	-.345	.039
		(-.457)	(.626)	(-.158)	(.358)	(-1.309)	(.130)
	TALE. addition	-.286	.070	-.043	-.376	-.112	.150
		(-2.521*)	(.365)	(-.208)	(-2.087)	(-.556)	(.654)
	TALE. rotation	.164	-.334	-.523	-.165	.010	-.060
		(1.155)	(-1.391)	(-2.016)	(-.734)	(.040)	(-.209)
	TALE. substitution	-.183	.117	.183	-.231	.137	.086
		(-1.535)	(.583)	(.843)	(-1.224)	(.647)	(.357)
	R^2	.914	.755	.714	.784	.729	.651
	ΔR^2	.080	.055	.203	.168	.115	.021
	F(7,27)	3.963*	3.212*	4.674*	3.461*	2.396	3.485*
MODELO 3	Gender	-.522	-.219	-.436	-.667	-.517	-.506
		(-1.535*)	(-.761)	(-1.222)	(-2.328)	(-1.774)	(-1.314)
	IQ	-.558	-.028	.249	-.129	-.355	-.085
		(-3.727*)	(-.110)	(.804)	(-.518)	(-1.403)	(-.255)
	Age	-.860	-.518	-.470	-.523	-.731	-.687
		(-5.036**)	(-1.820)	(-1.333)	(-1.845)	(-2.536*)	(-1.805)
	TALE. inversion	-.156	.231	-.059	-.047	-.599	-.138
		(-.743)	(.659)	(-.136)	(-.135)	(-1.684)	(-.294)
	TALE. addition	-.240	.097	-.010	-.302	-.023	.162
		(-1.898)	(.461)	(-.037)	(-1.436)	(-.109)	(.576)
	TALE. rotation	.261	-.236	-.462	-.052	.204	-.021
		(1.571)	(-.854)	(-1.348)	(-.191)	(.729)	(-.058)

TALE. substitution	-.128	-.044	.210	-.045	.288	.186
	(-.634)	(-.130)	(.504)	(-.135)	(.848)	(.413)
TOVA. omission	-.292	-.517	-.209	-.248	-.528	-.001
	(-1.350)	(-1.433)	(-.467)	(-.689)	(-1.442)	(-.002)
TOVA commission	-.120	-.130	.011	.034	-.355	-.260
	(-.699)	(-1.433)	(.030)	(.119)	(-1.229)	(-.680)
TOVA. D prime	.178	.598	.100	-.083	.317	-.008
	(638)	(1.289)	(.175)	(-.179)	(.676)	(-.013)
R^2	.936	.823	.728	.825	.818	.683
ΔR^2	.022	.068	.015	.040	.089	.033
F(10,24)	2.792	1.607	2.819	2.701	1.295	2.367*

Note. Values in the table are the β regression coefficient, those in brackets are the *Student t*. R^2 = variance explained; ΔR2=change in variance explained. Raw.Obj = score obtained for naming Objects; Raw.Col = score obtained for naming Colours; Raw.N = score obtained for naming Numbers; Raw.L= score obtained for naming Letters; Raw.LN = score obtained for naming Letters and Numbers; Raw.LNC = score obtained for naming Letters, Numbers and Colours.

$^*p < .05$; $^{**}p < .01$; $^{***}p < .001$.

It is clear from the regression analysis for the RLD group (Table 5), that model 2 has statistically significant predictors. Within model 2 it can be seen that for colour naming tasks the statistically significant predictor is the number of substitution errors in the TALE test. For naming tasks with numbers, or letters and numbers, the statistically significant predictor is the number of errors of inversion in the TALE test. When the naming task is only letters, there were two significant predictors: the number of inversion and rotation errors. Lastly, in naming tasks with alternating letters, numbers and colours, the significant predictor is the number of errors of rotation.

Table 5. Hierarchical regression analysis models with dependent variables for the RLD Group.

		Raw.Obj	Raw.Col	Raw.N	Raw.L	Raw.LN	Raw.LNC
MODEL 1	Gender	.163	.384	.106	.144	.227	.354

		(.906)	(2.005)	(.523)	(.808)	(1.481)	(2.057)
	IQ	-.166	.214	.350	.170	.174	.149
		(-.920)	(1.115)	(1.727)	(.955)	(1.131)	(.864)
	Age	-.708	-.474	-.493	-.677	-.719	-.604**
		(-3.899**)	(-2.450*)	(-2.413*)	(-3.774**)	(-4.640***)	(-3.476)
	R^2	.554	.494	.437	.565	.675	.592
	F(3,19)	5.789**	4.560*	3.618*	6.055**	9.714***	6.780**
MODEL 2	Gender	.085	.180	.137	.044	.167	.180
		(.440)	(1.452)	(1.089)	(.320)	(1.430)	(1.302)
	IQ	-.435	-.051	.025	-.197	-.085	-.142
		(-2.032)	(-.371)	(.177)	(-1.298)	(-.658)	(-.933)
	Age	-.695	.002	-.028	-.369	-.312	-.232
		(-2.688*)	(.010)	(-.167)	(-2.021)	(-2.014)	(-1.259)
	TALE. Inversion	.511	.121	.663	.643	.389	.287
		(1.947)	(.720)	(3.900**)	(3.468**)	(2.474*)	(1.540)
	TALE. addition	-.360	-.037	.144	-.018	.136	-.068
		(-1.513)	(-.242)	(.931)	(-.106)	(.954)	(-.401)
	TALE. rotation	.194	.336	.130	.480	.280	.390
		(.735)	(1.998)	(.760)	(2.578*)	(1.776)	(2.085*)
	TALE. substitution	-.067	.594	.218	-.102	.197	.313
		(-.234)	(3.252**)	(1.180)	(-.507)	(1.153)	(1.542)
	R^2	.709	.798	.878	.855	.895	.853
	ΔR^2	.156	.387**	.441**	.290*	.220*	.260*
	F(7,15)	3.485*	10.581***	10.225***	8.394**	12.238***	8.274**
MODEL 3	Gender	-.028	.252	.176	-.011	.101	.254
		(-.120)	(1.938)	(1.383)	(-.063)	(.966)	(1.747)
	IQ	-.349	-.002	.126	-.122	.018	-.070
		(-1.406)	(-.015)	(.926)	(-.673)	(.159)	(-.447)

Age	-.602	.017	.139	-.274	-.208	-.163
	(-1.820)	(.093)	(.766)	(-1.142)	(-1.394)	(-.785)
TALE. inversion	.437	.161	.677**	.605	.342	.326
	(1.526)	(1.004)	(4.323)	(2.911)	(2.652*)	(1.820)
TALE. addition	-.478	.111	.210	-.067	.098	.077
	(-1.585)	(.655)	(1.272)	(-.306)	(.721)	(.407)
TALE. rotation	.360	.353	.093	.566*	.422	.386
	(1.168)	(2.043)	(.550)	(2.527)	(3.034*)	(1.997)
TALE. substitution	-.249	.678	.310	-.183	.084	.418
	(-.731)	(3.547**)	(1.659)	(-.739)	(.548)	(1.954)
TOVA. omission	-.482	.081	.163	-.234	-.358	.136
	(-1.274)	(.381)	(.786)	(-.851)	(-2.096)	(.571)
TOVA commission	.154	.308	.321	.171	.278	.356
	(.536)	(1.915)	(2.046)	(.823)	(2.149*)	(1.982)
TOVA. Dprime	.007	-.064	-.420	-.102	-.068	-.200
	(.018)	(-.274)	(-1.841)	(-.338)	(-.361)	(-.766)
R^2	.772	.826	.932	.880	.954	.910
ΔR^2	.062	.047	.054	.025	.058	.058
F(10, 12)	2.367	9.073**	9.543**	5.117*	14.365***	7.103**

Note. Values in the table are the β regression coefficient, those in brackets are the *Student t*. R^2 = variance explained; ΔR2 = change in variance explained. Raw.Obj = score obtained for naming Objects; Raw.Col = score obtained for naming Colours; Raw.N = score obtained for naming Numbers; Raw.L = score obtained for naming Letters; Raw.LN= score obtained for naming Letters and Numbers; Raw.LNC= score obtained for naming Letters, Numbers and Colours.
**p* < .05; ***p* < .01; ****p* < .001.

With the ADHD group, it was found that although model 2 is significant when subjects are naming matrixes made up of objects, letters and numbers, or letters, numbers and colours; model 3 has greater explanatory power when naming matrixes made up of letters or colours (Table 6).

Table 6. Hierarchical regression analysis models with dependent variables for the ADHD group

		Raw.Obj	Raw.Col	Raw.N	Raw.L	Raw.LN	Raw.LNC
MODEL 1	Gender	.066	-.126	-.031	.050	.083	-.163
		(.358)	(-.603)	(-.155)	(.295)	(.384)	(-.836)
	IQ	.151	.276	-.023	-.077	.023	-.274
		(.881)	(1.438)	(-.126)	(-.489)	(.117)	(-1.527)
	Age	-.659	-.569*	-.673	-.742	-.538	-.675
		(-3.552**)	(-2.725)	(-3.398**)	(-4.361***)	(-2.494*)	(-3.465**)
	R^2	.505	.373	.437	.584	.332	.455
	F(3,38)	5.777**	3.373*	4.392*	7.940**	2.820	4.738*
MODEL 2	Gender	.153	.106	.106	.047	.099	-.111
		(.921)	(.555)	(.575)	(.281)	(.469)	(-.537)
	IQ	.110	.157	-.141	-.112	-.025	-.298
		(.647)	(.804)	(-.739)	(-.650)	(-.117)	(-1.393)
	Age	-.640	-.682	-.747	-.712	-.506	-.653
		(-3.499**)	(-3.250**)	(-3.663**)	(-3.877**)	(-2.167*)	(-2.852*)
	TALE. inversion	1.285	2.105	1.453	.334	.656	.748
		(2.013)	(2.873*)	(2.041)	(.521)	(.805)	(.936)
	TALE. addition	-.222	-.295	-.364	-.125	-.217	-.046
		(-1.322)	(-1.528)	(-1.944)	(-.741)	(-1.010)	(-.221)
	TALE. rotation	-.770	-1.774	-1.013	.131	-.082	-.312
		(-1.234)	(-2.478*)	(-1.456)	(.208)	(-.102)	(-.400)
	TALE. substitution	-.226	-.474	-.313	-.137	-.162	-.251
		(-1.138)	(-2.081*)	(-1.411)	(-.685)	(-.639)	(-1.010)
	R2	.751	.672	.691	.749	.549	.610
	ΔR2	.246	.299*	.254	.165	.262*	.155
	F(7,34)	5.610**	3.810*	4.174*	5.538**	2.719*	2.908*

MODEL 3	Gender	.433	.374	.220	.268	.118	.083
		(1.833)	(1.417)	(.726)	(1.253)	(.388)	(.273)
	IQ	.299	.320	-.054	.030	-.034	-.216
		(1.421)	(1.358)	(-.199)	(.158)	(-.126)	(-.794)
	Age	-.503	-.570	-.707	-.644	-.585	-.572
		(-2.375*)	(-2.412*)	(-2.602*)	(-3.353**)	(-2.153)	(-2.097)
	TALE. inversion	1.370	2.070	1.607	.424	.677	.423
		(1.903)	(2.572*)	(1.739)	(.649)	(.733)	(.456)
	TALE. addition	-.242	-.306	-.371	-.130	-.195	-.049
		(-1.487)	(-1.686)	(-1.777)	(-.885)	(-.936)	(-.232)
	TALE. rotation	-1.207	-2.159	-1.340	-.361	-.402	-.344
		(-1.640)	(-2.624*)	(-1.418)	(-.541)	(-.425)	(-.362)
	TALE. substitution	-.447	-.743	-.391	-.359	-.290	-.526
		(-1.923)	(-2.863)	(-1.311)	(-1.703)	(-.974)	(-1.759)
	TOVA. omission	.031	-.114	-.054	-.212	-.526	-.151
		(.111)	(-.361)	(-.150)	(-.828)	(-1.452)	(-.416)
	TOVA commission	-.851	-.969	-.430	-.942	-.651	-.757
		(-2.016)	(-2.053*)	(-.794)	(-2.457*)	(-1.200)	(-1.390)
	TOVA. Dprime	.329	.438	.290	.584	.724	.238
		(.896)	(1.069)	(.615)	(1.755)	(1.538)	(.503)
	R^2	.825	.781	.711	.856	.711	.417
	ΔR^2	.073	.109	.021	.107	.117	.098
	F(10,31)	4.698**	3.563*	2.459	5.922**	2.457	2.430

Note. Values in the table are the β regression coefficient, those in brackets are the *Student t*. R^2 = variance explained; ΔR2 = change in variance explained. Raw.Obj = score obtained for naming Objects; Raw.Col = score obtained for naming Colours; Raw.N = score obtained for naming Numbers; Raw.L = score obtained for naming Letters; Raw.LN = score obtained for naming Letters and Numbers; Raw.LNC = score obtained for naming Letters, Numbers and Colours.
*p < .05; **p < .01; ***p < .001.

In the co-morbid group (Table 7), model 2 is significant for all of the RAN tasks, with significantly increased explained variance when the tasks are made up of only letters or letters and numbers alternately.

Table 7. Hierarchical regression analysis models with dependent variables for the ADHD+RLD group.

		Raw.Fig	Raw.Col	Raw.N	Raw.L	Raw.LN	Raw.LNC
MODEL 1	Gender	-.262	-.309	-.189	-.296	-.382*	-.180
		(-1.726)	(-2.068)	(-1.189)	(-1.979)	(-2.400)	(-1.242)
	IQ	.311	.270	.288	.201	-.012	.374
		(-1.726*)	(1.912)	(1.918)	(1.423)	(-.079)	(2.732*)
	Age	-.515	-.554	-.474	-.596***	-.544**	-.536
		(-3.394**)	(-3.706***)	(-2.977**)	(-3.984)	(-3.418)	(-3.703**)
	R^2	.367	.386	.304	.385	.304	.424
	F(3,32)	5.984**	6.508**	4.517**	6.479**	4.511**	7.606***
MODEL 2	Gender	-.311	-.385	-.198	-.358	-.442	-.210
		(-1.983)	(-2.578*)	(-1.190)	(-2.480*)	(-2.887**)	(-1.461)
	IQ	.279	.183	.230	.115	-.110	.317
		(1.865)	(1.289)	(1.447)	(.833)	(-.754)	(2.319*)
	Age	-.500	-.595	-.446*	-.596	-.544	-.503
		(-3.133**)	(-3.916***)	(-2.630)	(-4.054***)	(-3.490**)	(-3.446**)
	TALE. inversion	-.304	-.417	-.012	-.244	-.239	-.203
		(-1.076)	(-1.550)	(-.041)	(-.935)	(-.866)	(-.785)
	TALE. addition	.181	.188	-.128	.096	.052	-.007
		(.802)	(.876)	(-.533)	(.462)	(.234)	(-.034)
	TALE. rotation	.426	.506	.327	.534	.569	.492
		(1.893)	(2.365*)	(1.365)	(2.575*)	(2.590**)	(2.389*)
	TALE. substitution	-.042	-.200	-.086	-.217	-.227	-.045
		(-.206)	(-1.039)	(-.398)	(-1.162)	(-1.146)	(-.241)
	R^2	.458	.509	.387	.540	.483	.547

	ΔR^2	.091	.123	.083	.155*	.179*	.123
	F(7,28)	3.256**	4.000**	2.437*	4.532*	3.608**	4.652**
MODEL 3	Gender	-.370	-.393	-.213	-.361	-.426	-.221
		(-2.366*)	(-2.535*)	(-1.173)	(-2.292*)	(-2.560*)	(-1.444)
	IQ	.376	.303	.243	.118	-.131	.355
		(2.283*)	(1.860)	(1.270)	(.710)	(-.752)	(2.199*)
	Age	-.410	-.510	-.432	-.593	-.565	-.473
		(-2.494*)	(-3.133**)	(-2.266)	(-3.588***)	(-3.241**)	(-2.939**)
	TALE. inversion	-.222	-.441	-.002	-.257	-.257	-.257
		(-.773)	(-1.548)	(-.006)	(-.888)	(-.843)	(-.912)
	TALE. addition	.170	.238	-.126	.107	.052	.044
		(.748)	(1.055)	(-.478)	(.467)	(.217)	(.198)
	TALE. rotation	.445	.516	.330	.534	.564	.494
		(2.038*)	(2.383*)	(1.303)	(2.429*)	(2.433*)	(2.308*)
	TALE. substitution	-.001	-.163	-.071	-.204	-.241	.009
		(-.005)	(-.808)	(-.298)	(-.994)	(-1.112)	(.047)
	TOVA. Omisiones	.002	-.198	-.009	-.036	.004	-.174
		(.007)	(-.909)	(-.035)	(-.161)	(.017)	(-.804)
	TOVA commission	.338	.049	.076	.008	-.092	.040
		(1.688)	(.248)	(.329)	(.039)	(-.433)	(.203)
	TOVA. Dprime	-.389	-.096	-.048	.038	.085	.115
		(-1.572)	(-.390)	(-.169)	(.151)	(.325)	(.472)
	R^2	.547	.556	.391	.541	.489	.565
	ΔR^2	.090	.046	.046	.001	.006	.019
	F(10,25)	2.902*	3.000*	1.539	2.833*	2.296*	3.120**

Note. Values in the table are the β regression coefficient, those in brackets are the *Student t*. R^2 = variance explained; ΔR2=change in variance explained. Raw.Obj = score obtained for naming Objects; Raw.Col = score obtained for naming Colours; Raw.N = score obtained for naming Numbers; Raw.L = score obtained for naming Letters; Raw.LN = score obtained for naming Letters and Numbers; Raw.LNC = score obtained for naming Letters, Numbers and Colours.
**p* < .05; ***p* < .01; ****p* < .001.

Discussion and Conclusions

This comparative study aimed to analyse the explanatory power of certain variables related to reading and attention over naming speed and to examine variation in explanatory power in terms of diagnosis (ADHD, RLD, ADHD+RLD, control group). The results confirm that although the RAN/RAS test is influenced by variables of distinct natures (chronological age, reading and writing errors, attentional variables…), said variables have varying weight, and differential effect, depend-ing on the diagnostic group being analysed.

As previous research, has stated, RAN/RAS naming tasks are closely related to variables involved in reading and writing processes (Arnell et al., 2009; Georgiu et al., 2009; Gasperini, Brizzolara, Cristofani, Casalini, & Chilosi, 2014) and attentional processes (Roessner et al., 2008; Stringer, Toplak, & Sta-novich, 2004). This may be because naming tasks activate a series of interrelated processes which need a specified time be-tween them. Because of that, when one of these processes is affected as a consequence of some kind of difficulty (reading or attentional), the naming speeds slow significantly compared to the control group (Norton & Wolf, 2012).

Although most research cited has examined variables which influence execution of the RAN/RAS tests generally (without looking at the type of difficulty that the subjects present) (Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002), this study has found differential functioning of the models depending on which diagnostic group is being analysed. In other words, the percentage of variance explained by each of the variables in the three models changes depending on the subjects' diagnoses.

Naming speed in the control group is fundamentally ex-plained by model 1 which includes variables such as age, IQ and gender. This may be due to the fact that naming speed de-pends on the level of automatisation of various processes, and this automatisation is positively related to IQ and age (Norton & Wolf, 2012). The explanatory power of the gender variable is underpinned by the neurological differences be-tween men and women in early years (Tian, Wang, Yan & He, 2011).

Unlike the control group, the naming speeds from the RLD group cannot be explained solely by model 1, as mem-bers of this group have problems with the lexical and/or phonological route, in addition to alterations in saccadic movement (Rodríguez, González-Castro, Álvarez, Álvarez & Cueli, 2012). This symptomatology means that model 2 best explains achievement of students with RLD, considering the frequency of the various types of reading errors.

In the ADHD group, it could be seen how the attentional variable “commission” had a close relationship with naming colours and letters. While the existing relationship between naming colours and ADHD is in line with previous research (Roessner et al., 2008), the same cannot be said of the rela-tionship between the alphanumeric RAN and ADHD, as the majority of studies state that deficits in the alphanumeric RAN are related specifically to the presence of reading difficulties (Pham, Fine, & Semrud-Clikeman, 2011). This may be because those studies have been carried out in opaque languages like English, rather than transparent languages such as Spanish. The relationship may indicate the underlying importance of at-tention in reading processes (Lora & Díaz, 2011).

Finally, the comorbid group (ADHD+RLD) produced similar results to the RLD group, as model 2 contained significant predictors of RAN/RAS test results and the highest percentage of variance explained. This would indicate that the comorbidity of these two difficulties presents a complex symptomatology which cannot be reduced to a simple sum of the characteristic symptoms of ADHD and RLD (García et al., 2013).

This study has demonstrated how a range of different variables have greater or lesser influence depending on the presence or absence of reading and/or attentional difficulties. In other words, the weight of each of the variables changes de-pending on the diagnosis being examined.

The principal practical implication of these results will be found when it comes to interpreting scores in naming speed tests. As seen in this study, a low score in naming certain visual stimuli may be due to the presence of reading or attentional difficulties. This means that, when faced with a low RAN/RAS score, an educational professional should try to as-certain the cause through tests related to reading and attention.

There are limitations to this research which should be borne in mind in future work, such as increasing the sample size of each of the diagnostic groups with the aim of looking more deeply into the influence of these variables on the speed of naming visual stimuli.

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Estudio 4

Fourth study accepted in the *Journal of Child Neuropsychology* [Cuarto estudio aceptado en la revista *Child Neuropsychology*]:

Naming Speed as a Predictive Diagnostic Measure in Reading and Attentional Problems

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ABSTRACT
This study aimed to describe and compare naming speed abilities in children diagnosed with either Reading Learning Difficulties (RLD) or Attention Deficit/Hyperactivity Disorder (ADHD), or comorbidity for both (ADHD+RLD). To examine the explanatory power of naming speed and ADHD symptomatology in predicting group associations (while controlling for gender and age), the "Rapid Automatized Naming and Rapid Alternating Stimulus Tests" (RAN/RAS) were utilized. A sample of 101 children (age range = 5–16 years) was divided into four groups: RLD (*n* = 14), ADHD (*n* = 28), comorbid (*n* = 19), and control (*n* = 40). There were statistically significant differences in RAN/RAS results among the diagnostic groups. Moreover, discriminant analysis revealed that naming speed tasks significantly predicted reading and attentional problems, especially at earlier ages. These results demonstrate the potential usefulness of RAN/RAS in the diagnosis of reading and attentional problems, particularly if the children are aged from 5 to 9.

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RAN/RAS; naming speed; reading difficulties; ADHD; early childhood

Naming speed tasks are defined as the ability to name, as quickly as possible, different familiar stimuli such us numbers, letters, colors, and figures (Georgiu, Aro, Liao, & Parrila, 2016). As in cases of phonological deficits in children with Reading Learning Difficulties (RLD), a naming speed deficit frequently persists from early school age to adulthood (van den Bos, 1998).

Current research has highlighted that naming speed can predict reading accuracy and fluency, and several authors have thereby shown the relationship between naming speed and word and/or pseudoword reading or math/spelling difficulties (Donker, Kroesbergen, Slot, van Viersen, & de Bree, 2016; Georgiou, Parrila, Cui, & Papadopoulos, 2013; Mazzocco & Grimm, 2013). Likewise, other studies have demonstrated the existence of a strong relationship between naming speed and reading comprehension, as well as its relationship with reading speed (Wolff, 2014). In this sense, it has been argued that children with RLD show significantly slower naming speed rates than children without RLD. More specifically, children with RLD have been found to display greater difficulties when the naming speed tasks are exclusively based on letters and numbers (Chang et al., 2014; Clikeman, Guy, & Griffin, 2000; Mazzocco & Grimm, 2013). These studies were designed to investigate the hypothesis of a

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Abstract

This study aimed to describe and compare naming speed abilities in children diagnosed with either Reading Learning Difficulties (RLD) or Attention Deficit/Hyperactivity Disorder (ADHD), or comorbidity for both (ADHD+RLD). To examine the explanatory power of naming speed and ADHD symptomatology in predicting group-associations (while controlling for gender and age) the 'Rapid Automatized Naming and Rapid Alternating Stimulus Tests' (RAN/RAS) were utilized. A sample of 101 children (age range = 5-16 years) was divided into four groups: RLD (n = 14), ADHD (n = 28) Comorbid (n = 19), and Control (n = 40). There were statistically significant differences in RAN/RAS results among the diagnostic groups. Moreover, discriminant analysis revealed that naming speed tasks significantly predicted reading and attentional problems, especially at earlier ages. These results demonstrate the potential usefulness of RAN/RAS in the diagnosis of reading and attentional problems, particularly if the children are aged from 5 to 9.

Key words: RAN/RAS, naming speed, reading difficulties, ADHD, early childhood.

Introduction

Naming speed tasks are defined as the ability to name -as quickly as possible- different familiar stimuli such us: numbers, letters, colors and figures (Georgiu, Aro, Liao, & Parrila, 2016). As in cases of phonological deficits in children with Reading Learning Difficulties (RLD), a naming speed deficit frequently persists from early school age to adulthood (Van den Bos, 1998).

Current research has highlighted that naming speed can predict reading accuracy and fluency, and several authors have thereby shown the relationship between naming speed and word and/or pseudoword reading or math/spelling difficulties (Donker, Kroesbergen, Slot, Van Viersen, & De Bree, 2016; Georgiou, Parrila, Cui, & Papadopoulos, 2013; Mazzocco & Grimm, 2013). Likewise, other studies have demonstrated the existence of a strong relationship between naming speed and reading comprehension, as well as its relationship with reading speed (Wolf, 2014). In this sense, it has been argued that children with RLD show significantly slower naming speed rates than children without RLD. More specifically, children with RLD have been found to display greater difficulties when the naming speed tasks are exclusively based on letters and numbers (Clikeman, Guy, & Griffin, 2000; Chang et al., 2014; Mazzocco & Grimm, 2013). These studies were designed to investigate the hypothesis of a *processing speed deficit*, which states that children with RLD are unable to reach the necessary speed to capture letter patterns that are present in written language (Bowers & Newby-Clark, 2002).

In the same way, word naming has also been investigated extensively in ADHD, and most results have indicated impairments in both children and adults with the disorder

(Laasonen, Lehtinen, Leppämäki, Tani, & Hokkanen, 2010), however, children appear to have more difficulties than adults do (Frazier, Youngstrom, Glutting, & Watkins, 2007). Using the RAN/RAS test, many authors have shown how children with ADHD present lower performances in naming speed tasks, specifically in those composed of figures and colors (Clikeman et al., 2000; Hinshaw, Carte, Fan, Jassy, & Owens, 2007; Roessner, et al., 2008). These naming speed impairments in subjects with ADHD are perhaps expectable, as successful performance in these sorts of tasks requires processes involving attention to the stimuli, as well as switching and disengaging attention under certain circumstances (e.g. alternating stimuli tasks); and would thus be most affected by inattention rather than impulsivity/hyperactivity symptoms (Norton & Wolf, 2012). Despite all of these findings, the predictive value of naming speed tasks in the diagnosis of ADHD has not been examined to date.

In general terms, the research described above has shown that naming speed is an efficient predictor of reading problems, and could thus also be predictive of attentional impairment, depending on the type of stimuli considered (Chang et al., 2014; Clikeman et al., 2000; Mazzocco & Grimm, 2013).

This is important, given the practical relevance of analyzing and delimiting execution-performance profiles in children with ADHD and RLD, especially considering the high comorbidity of both disorders (García et al., 2013; González-Castro, Rodríguez, Cueli, García, & Álvarez, 2015). According to Zamora, López & Gómez (2009), the percentage of comorbidity of ADHD and RLD ranges from 8 to 39%. Rodríguez et al. (2009), as well as García et al (2013), have also argued that the comorbidity of ADHD and RLD is related to the presence of a common deficit in the executive functions system, such as impairments in working memory, inhibitory control and processing speed.

The majority of these studies have followed the technique of de Denckla and Rudel (1976), using the *Rapid Automatized Naming and Rapid Alternating Stimulus Tests* (RAN/RAS) (Norton et al., 2014; Norton & Wolf, 2012; Wolf & Denckla, 2005). This test comprises four primary naming speed tasks, in which all visual stimuli displayed are exclusively letters, numbers, colors and figures; and two additional naming tasks composed of visual stimuli presented randomly and alternately (2-SET: letters and numbers; and 3-SET: letters, numbers and colors). For each naming task, the child is asked to name (as quickly as possible) the different stimuli that compose the naming matrix. The administration of the whole test takes from 5 to 10 minutes, depending on the child´s age, reading skills and language fluency (i.e. first or second language).

Performance of RAN/RAS tests requires several processes that are interconnected (Wolf & Denckla, 2005), such as attentional and visual processes, the integration of visual patterns and orthographic information, and the recovery of phonological labels. Frequently, these processes are impaired in ADHD and/or RLD children (González-Castro, Rodríguez, López, Cueli, & Álvarez, 2013) and this impairment is manifested through a greater decrease in naming speed ability. There is an extensive body of research (Georgiou, Papadopoulos, & Kaizer, 2014; Norton & wolf, 2012; Tan, Spinks, Eden, Perfetti, & Siok, 2005) that has led us and other researchers to consider RAN tasks as being one of the best and most internationally-valid predictors of reading fluency, perhaps universally across all known orthographies. Several authors have previously highlighted the usefulness of RAN/RAS tests concerning the early detection of attentional and reading problems, because (in contrast with other tests), these tests provide an early indicator of vital reading and attention skills well before children are able to read and write efficiently (Areces, Rodríguez, González-Castro, García, & Cueli, 2017). In particular, the alphanumeric nature of the RAN test (tasks composed of letters or numbers) has been more closely associated with reading abilities (Pham, Fine, & Clikeman, 2011), while the non-alphanumeric RAN test (tasks composed of colors or objects) has been more associated with attentional processes (Kieling et al., 2010; Roessner et al., 2008). Thus, lower naming speed scores in the non-alphanumeric component of the RAN (common in subjects with attentional difficulties) are most likely due to the existence of more than one plausible name for a given object or color, thereby producing a greater demand on attention and the need for more careful and detailed processing than that required for recognizing letters or digits (Tannock, Banaschewski, & Gold, 2006). In other words, letters and numbers engage largely automated decoding processes, whereas objects and colors do not, and as such, the latter consume more resources relating to attention.

However, despite the large amount of evidence suggesting the diagnostic usefulness of this measure in identifying reading and attentional problems, very few studies have been carried out with Spanish speakers. This highlights the need for additional studies in the Spanish population, because it is important to answer the following questions: 1) Do children perform differently in RAN/RAS as a function of their attentional and reading problems? 2) Are naming tasks effective for detecting reading and attentional problems? 3) Is the discriminant capacity of RAN/RAS test the same in different age groups?

These critical questions gave rise to the impetus to carry out the present study, which was designed in the context of the following objectives and hypotheses.

This study has two main objectives: 1) to describe and compare the naming speed in a sample composed of children and adolescents RLD, with and without ADHD, using the variables provided by RAN/RAS test; and 2) to examine the explanatory power of naming speed and ADHD symptomatology (provided by EDAH scale, completed by the families, Farré & Narbona, 2001) to predict group association, controlling for the potential effect of gender and age.

Based on previous research (Clikeman Guy, & Griffin, 2000; Roessner et al., 2008) it was expected that children with ADHD and RLD will obtain lower scores in naming speed than the control group. According to the second objective, as different studies confirm, the amount of time invested by participants on naming different types of stimuli have a strong correlation with reading skills and attentional processes. In this sense, several authors argued that, although the RAN/RAS test represents a high-quality measure for detecting children with Reading Difficulties and attentional problems, its diagnostic capacity decreases with age, due to the automation of attentional and reading processes (Elosúa et al., 2012). Accordingly, as age increases, the difficulty levels of the naming tasks are likely to become lower. Therefore, the effectiveness of RAN/RAS might decrease with age, and professionals may need to use other specific diagnostic tools, such as those based exclusively on DSM criteria (APA, 2013).

Concerning the predictive value of RAN/RAS, cross-cultural research has shown that this test is predictive of reading outcomes across a variety of languages including Dutch (Van den Bos, 1998), German (Wimmer, 1993), Hebrew (e.g., Bental & Tirosh, 2007), French (e.g., Plaza & Cohen, 2004), or Greek (Georgiou, Papadopoulos, & Kaizer, 2014; Papadopoulos, Spanoudis, & Georgiou, 2016). Thus, a statistically significant predictive value of the test detecting reading difficulties is expected to be found in the present study. In the same way, given that RAN/RAS tasks rely on continuous responding, and children must pay attention in order to perform well and quickly execute the tasks, it is therefore reasonable to question whether RAN/RAS is also predictive of attentional problems. This is particularly relevant considering the high comorbidity between LRD and ADHD (García et al., 2013; González-Castro et al., 2015).

Method

Participants

This study used a non-probabilistic clinical sample of 101 participants, 64 males (63.4%) and 37 females (36.6%), between 5 to 16 years of age (*M* = 10.10; *DT* = 3.15). Average IQ of the sample was 97.40 (*SD* = 11.58). The Wechsler Intelligence Scale for Children–IV s (WISC-IV; Wechsler, 2005) was used to measure intellectual ability. Participants showing extreme IQ values (lower than 80 and greater than 130) were excluded from the sample. Only one student was excluded from the study on this basis, because of having an IQ below 80.

The participants in the ADHD and RLD groups were identified according to the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM-5*; APA, 2013), resulting in four groups: Control group (*n* = 40, 39.6%), RLD group (*n* = 14, 13.9%), ADHD group (*n* = 28, 27.7%), and Comorbid group of ADHD and RLD (*n* = 19; 18.8%). None of the participants with ADHD were receiving medication at the time of assessment (Table 1).

Table 1. Descriptive statistics of IQ and Age for the four diagnostic groups

Groups		IQ		Age	
	n	*M*	*SD*	*M*	*SD*
CG	40	99.03	10.25	10.88	3.11
RLD	14	99.50	6.83	9.79	3.22
ADHD	28	100.43	14.26	10.54	3.14
ADHD+RLD	19	95.11	12.63	8.05	2.39
Total Sample	101	98.74	11.58	10.10	3.15

Note. *M* = Mean; *SD*= Standard Deviation. CG = Control group; RLD = Reading Learning Difficulties; ADHD = Attention Deficit and Hyperactivity Disorder; ADHD+RLD = Attention Deficit and Hyperactivity Disorde with Reading Learning Difficulties.

No statistically significant differences were found among the groups with respect to IQ (p = .472), although some differences in age were highlighted, F(3, 100)= 3,287*;* p = .024*;* η^2 = .092.

Instruments

The Wechsler Intelligence Scale for Children-IV (WISC-IV) (Wechsler, 2005) was used to evaluate IQ. Those individuals with IQs below 80 or over 130 were excluded from the sample. WISC-IV is an individually administered test composed of 15 subtests which provide information on specific cognitive areas. It can be administered to children and adolescents between 6 and 16 years. In this study, only the Total Intelligence Quotient (TIQ) was considered.

As mentioned earlier, *Rapid Automatized Naming and Rapid Alternating Stimulus Tests* -RAN/RAS- (Wolf & Denckla, 2005) were used to evaluate naming speed. This is a test of naming speed that reflects the relationship between processing speed and reading speed. The test consists of four naming tests with different single stimulus type (letters, numbers, colors, objects) and two naming tests with alternating stimuli (letters-numbers, letters-numbers-colors). The scores in each task are based solely on the time taken (in seconds) to name each one of the six stimuli matrices.

In order to determine the relevance of ADHD symptoms in the diagnosis of ADHD (with or without RLD), *The Scale for the assessment of Attention Deficit Hyperactivity Disorder* (EDAH) (Farré & Narbona, 2001) was utilized (as per: *EDAH - version for families*). It consists of 20 items that provide information on the presence of symptoms related to attention deficit and hyperactivity/impulsivity. It differentiates between ADHD and control groups, as well as between the primary ADHD subtypes. The following variables were included in the present study: EDAH-AD (score in the items that measure Attention Deficit), EDAH-I/H (score in Impulsivity/Hyperactivity items), and EDAH-ADHD (score in the combined subtype; Attention Deficit plus Impulsivity/Hyperactivity symptoms).

Procedure

The sample was recruited from a psychotherapeutic center attended by children diagnosed with RLD and/or ADHD. They were identified by government-registered mental-health professionals (typically psychologists) as per guidelines in the DSM-5 criteria for ADHD and Reading Learning Difficulties (DSM-5: American Psychiatric Association, 2013). The schools attended by the participants were in urban and semi-urban zones from a region in the north-west of Spain.

The control sample was recruited from the same schools to serve as a control healthy comparison group. Participants were included in the control group if they had no reported history of serious behavioral or emotional problems in school or at home and also no reported history of reading and attentional problems.

The study was conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki), which reflects the ethical principles for research involving humans (Williams, 2008) and was approval by the Ethics Committee. All subjects and their parents gave written informed consent after receiving a comprehensive description of the study protocol. Participants had voluntarily agreed to be involved in this study and they were not given any monetary or school-based incentives to take part in it. To that end, once parental consent to evaluate the children was provided, the study's corresponding tests were administered in order to verify the objectives of this research.

Data analysis

This study analyzed the differences in naming speed between four diagnostic groups (Control;,ADHD; RLD; ADHD+RLD), and examined the discriminant value of naming speed and attentional symptoms provided by the EDAH scale in predicting group-association. To accomplish this, all data analyses were conducted in three steps:

First, the descriptive statistics for the variables under study were analyzed, paying special attention to skewness and kurtosis. Following the criterion of Kline (2011), the maximum scores accepted for skewness and kurtosis were limited to a range of 3 to 10. The majority of the variables measured in the present study met this criterion, with some exceptions regarding time invested (in seconds) for naming numbers within the ADHD groups. The results thus allowed us to perform parametric analyses.

Second, multivariate analysis of covariance (MANCOVA) were performed to analyze differences in naming speed between the four diagnostic groups, taking into account the type of stimuli (figures, colors, letters and numbers) as dependent variables, and using age as a covariate. Cohen´s (1988) delta was used as a measure of effect size. The author defines a small effect size as $\eta2 = .010$ (Cohen's $d = .20$), a medium effect size as $\eta2 = .059$ (Cohen's $d = .50$), and a large effect size as $\eta2 = .138$ (Cohen's $d = .80$). Scheffé multiple comparisons were used to determine statistically significant differences between pairs of groups. These analyses assumed the previous step of the discriminant analysis.

Third, once the existence of statistically significant differences between the groups was verified, different discriminant analyses were conducted to determine the relevance of each dependent variable (naming speed variables by RAN/RAS and attentional symptoms by EDAH) to predict group association, taking age-group into account (group 1: age range 5-9, and group 2: age range 10-16). Four discriminant analyses were performed: two of the procedures were to test the relevance of the studied variables predicting RLD group membership (a discriminant analysis was conducted for each age group), and the other two were to examine the reliability of the aforementioned variables in predicting ADHD group membership (two different analyses for each age group).

SPSS 19 (Arbuckle, 2010) was used in the analysis of data, utilizing $p < .05$ as the criterion for reaching statistical significance. Bonferroni protection was used for the interpretation of *p* values in multiple comparisons ($p < .05/6 = .008$).

Results

Differences between groups in naming speed

Table 2 shows the descriptive statistics for each RAN measure. Results from the MANCOVA, taking into account age, $\lambda = 0.430$, $F(3, 100) = 1.948$, $p \leq .001$, $\eta^2 = .470$ and IQ *(p = .378)* as covariates, showed that there were statistically significant differences between the groups, $\lambda = 0.705$, $F(18, 249) = 1.826$, $p = .023$, $\eta^2 =.110$ in the studied variables. At this point, it is worth noting that high scores in the RAN/RAS test are indicative of high response times, which are related to poor performance in the naming tasks.

Table 2. Descriptive statistics of the RAN/RAS tasks for the diagnostic groups.

Groups	RAN tasks	*M*	*SD*	Skewness	Kurtosis
CG	Objects	41.13	10.788	.459	-0.520
(*n* = 40)	Colors	40.46	9.660	.313	-0.674
	Numbers	25.79	11.200	4.031	20.974
	Letters	26.62	7.859	.446	-0.791
	LN	28.90	8.042	.082	-1.021
	LNC	31.54	11.206	1.548	4.767
RLD	Objects	54.93	20.938	1.296	0.853
(*n* = 14)	Colors	70.36	44.597	1.560	1.186
	Numbers	42.00	34.122	2.819	9.013
	Letters	46.00	42.486	2.855	9.107
	LN	53.21	49.465	2.776	8.619
	LNC	55.36	44.370	2.130	4.469

ADHD	Objects	50.86	23.095	1.173	0.358
(*n* = 28)	Colors	52.89	26.880	1.565	2.008
	Numbers	31.04	21.781	3.508	13.905
	Letters	30.43	18.420	2.486	7.377
	LN	37.93	26.084	2.577	7.512
	LNC	40.85	28.090	2.527	7.708
ADHD+RLD	Objects	58.79	20.203	2.404	8.138
(*n* = 19)	Colors	67.11	24.177	1.575	3.261
	Numbers	44.42	23.784	1.576	1.812
	Letters	48.84	28.683	1.749	3.492
	LN	58.47	32.509	1.491	2.581
	LNC	61.00	30.894	1.177	1.969

Note. *M* = Mean; *SD* = Standard Deviation; CG = Control group; RLD = Reading Learning Difficulties; ADHD = Attention Deficit and Hyperactivity Disorder; ADHD+RLD = Attention Deficit and Hyperactivity Disorder with Reading Learning Difficulties.

On the other hand, inter-subject effects demonstrated the presence of statistically significant differences between groups in each of the naming tasks, with the exception of the number naming task: objects, $F(1, 98) = 3.174$, $p = .028$; $\eta^2 = .093$; colors, $F(1, 98) = 5.664$, $p = .001$; $\eta^2 = .154$; numbers, $F(1, 98) = 1.777$. $p = .157$, $\eta^2 = .054$; letters, $F(1, 98) = 2.696$, $p = .05$, $\eta^2 = .080$; letter and numbers $F(1, 98) = 3.176$, $p = .028$, $\eta^2 = .093$;and letters, numbers and colors, $F(1, 98) = 3.297$, $p = .024$, $\eta^2 = .096$.

Post hoc analyses (Table 3) revealed significant group differences with Bonferroni protection ($p<05/6=.008$) that the total score in some of the naming tasks generated differences between the Control group and the Comorbid group (ADHD+RLD). By contrast, the color naming task generated differences between the Control group and the

RLD group.

Table 3. Scheffé Multiple Comparison for the four groups

RAN/RAS Tasks	RLD vs. CG		ADHD vs. CG		ADHD+RLD vs. CG		RLD vs. ADHD		ADHD+RLD vs. RLD		ADHD+RLD vs. ADHD	
	MD	*d*	*MD*	*d*	*MD*	*d*	*MD*	*d*	*MD*	*d*	*MD*	*d*
Objects	13.80	1	10.32	0.61	17.66	1.24	3.48	0.11	3.86	0.19	7.35	0.34
Colors	29.90***	1.28	12.38	0.69	26.64***	1.72	17.06	0.52	-3.25	0.1	13.81	0.54
Numbers	16.21	0.84	5.65	0.35	18.36	1.17	10.56	0.41	2.42	0.09	12.98	0.58
Letters	19.38	0.89	4.24	0.32	22.23**	1.3	15.15	0.54	2.84	0.08	17.99	0.79
LN	24.32	0.96	9.73	0.55	29.58***	1.55	14.58	0.42	5.26	0.13	19.84	0.70
LNC	23.82	1	9.31	0.47	29.46***	1.52	14.51	0.43	5.64	0.16	20.15	0.70

Note. *MD*= Mean Differences; *d*= cohen's d effect size; LN= Letters and Numbers; LNC= Letters, Numbers and Colors; CG = Control group; RLD = Reading Learning Difficulties; ADHD = Attention Deficit and Hyperactivity Disorder; ADHD+RLD = Attention Deficit and Hyperactivity Disorder with Reading Learning Difficulties.
*** significant with Bonferroni protection (*p*< .05/6= .008).

Discriminant value of RAN/RAS and attentional variables in the diagnosis of RLD and ADHD

Given that one of the objectives of the present study was to analyze the diagnostic relevance of RAN/RAS and attentional variables to predict group membership (presence or absence of ADHD and RLD), and considering the importance of age in the RLD and ADHD diagnosis, the total sample was divided into two age-groups (Table 4).

The first group was made up 52 participants, 27 males (51.9%) and 25 females (48.1%), from 5 to 9 years of age (*M* = 7.42; *SD* = 1.29) divided into the four diagnostic groups. Average IQ for this group was 98.21 (*SD* = 11.96). No statistically significant differences were found between groups in IQ (*p* = .583) and age (*p* = .429).

The second group was composed of 59 participants, 37 males (75.5%) and 12 females (24.5%), from 10 to 16 years of age (*M* = 12.94; *SD* = 1.70), with an average IQ of 99.31 (*SD* = 11.25). As with the first group (described above), no statistically significant differences were found between groups in IQ (*p* = .581) and age (*p* = .451)

Table 4. Descriptive statistics for IQ and age in function of the aged group.

	Group aged 5-9 years					Group aged 10-16 years				
Groups		IQ		age			IQ		age	
	n	*M*	*SD*	*M*	*SD*	n	*M*	*SD*	*M*	*SD*
CG	18	99.33	10.79	7.84	.942	22	98.77	10.03	13.36	1.67
RLD	7	102.43	4.12	7.14	1.46	7	96.57	7.99	12.43	1.98
ADHD	11	98.00	14.84	7.18	1.54	17	102.00	14.11	12.71	1.57
ADHD+RLD	16	95.25	13.49	7.25	1.39	3	94.33	8.38	12.33	2.08
Total sample	52	98.21	11.96	7.42	1.29	49	99.31	11.25	12.94	1.70

Note. M = Mean; SD = Standard Deviation; CG = Control group; RLD = Reading Learning Difficulties; ADHD = Attention Deficit and Hyperactivity Disorder; ADHD+RLD = Attention Deficit and Hyperactivity Disorder with Reading Learning Difficulties.

Table 5 shows the results of discriminant analyses for the diagnostic groups with and without RLD. The resultant data showed that only the score obtained in naming colors (RAN7RAS) was a statistically significant predictor of group membership, both for the group aged from 5 to 9 years, and for the group aged from 10 to 16 years. In the younger group (5 to 9 years of age), this model classified 78% of the sample correctly (83.3% from the Control group, and 73.9% from the RLD group). On the other hand, for the older group, this model classified 77.4% of the sample correctly (90.50% from the Control group, and 50% from the RLD group).

Table 5. Results of discriminant analyses for predicting RLD group membership, using stepwise method. Analyses with RAN/RAS variables and ADHD symptoms for age conditions.

	Standardized Coefficients	Function Coefficients	*F*
RAN/RAS test from 5 to 9 years of age			
Raw.Col	1.000	.036	12.830
Constant		-2.341	
RAN/RAS test from 10 to 16 year of age			
Raw.Col	1.000	.124	10.171
Constant		-4.784	

Note. Raw.Col= score obtained in naming colors.
All models are significant at a p < .001 level. Only the variables that resulted statistically significant are shown.

Table 6 shows the results of discriminant analyses for the diagnostic groups with and without ADHD. Conversely to the previous case, some differences between the age-groups were found. In relation to the younger group (5 to 9 years of age), only the score obtained in naming colors through RAN/RAS test and the inattention symptoms from EDAH were statistically significant predictors of group membership. This model classified 84.1% of the sample correctly (64.7% from the control group, and 96.3% from the ADHD group). On the other hand, for the older group, the results from discriminant analyses indicated that the RAN/RAS variables did not show explanatory power for predicting group membership, and only inattention, impulsive and hyperactivity symptoms were statistically significant predictors. Specifically, this model classified 76.9% of the sample correctly (83.3% from the control group, and 71.4% from the ADHD group).

Table 6. Results of discriminant analyses for predicting ADHD group membership, using stepwise method. Analyses with RAN/RAS variables and ADHD symptoms for age conditions.

	Standardized Coefficients	Function Coefficients	*F*
	RAN/RAS test from 5 to 9 years of age		
Raw.Col	.609	.040	16.350
EDAH.AD	.769	.037	12.685
Constant		-5.810	
	RAN/RAS test from 10 to 16 year of age		
EDAH.AD	.606	.045	13.548
EDAH.I/H	.922	.049	10.187
Constant		-7.677	

Note. Raw.Col= score obtained in naming colors; EDAH.AD = attention deficit symptoms in EDAH test; EDAH.I/H = impulsivity/ hyperactivity symptoms in EDAH test.

All models are significant at a p < .001 level. Only the variables that resulted statistically significant are shown.

Discussion and conclusions

This study aimed to (1) analyze performance differences in RAN/RAS tasks in four diagnostic groups (Control group, RLD group, ADHD group, and RLD+ADHD group), and (2) verify the explanatory power of RAN/RAS variables and ADHD symptoms by EDAH scale to predict the diagnosis of ADHD and/or RLD in two different age groups.

Regarding the first objective, results showed that children and adolescents with Reading Difficulties (with or without ADHD association) obtained lower performance in RAN/RAS tasks than the Control group (Chang et al., 2014; Clikeman, Guy, & Griffin, 2000; Donker, Kroesbergen, Slot, Van Viersen, & De Bree, 2016). In addition, the present research has shown that the naming tasks consisting of colors and alternating stimuli (letter-numbers and letters-numbers-colors) were effective in identifying Reading Difficulties. These findings showed some differences with previous studies which had highlighted that alphanumeric RAN (tasks composed of letters or numbers) has been associated with reading (Pham, Fine, & Clikeman, 2011), while the non-alphanumeric RAN (tasks composed of colors or objects) has been related to attentional processes (Kieling et al., 2010; Roessner et al., 2008). These differences can be explained by two key factors. The first of these may well be related to differences in the transparency of the languages, since the majority of previous studies have been carried out in opaque languages like English (Areces et al., 2017). With respect to the second factor, these results could be also explained by the fact that, although the majority of children are used to naming letters and numbers (due to school training), they are not so familiar with naming tasks consisting of colors or randomly alternating stimuli. In this sense, and because these tasks are not automated processes, the children who belonged to the control group manifested a slight decrease in naming speed, while the children with reading and attentional problems experienced a larger and more significant impairment in these sorts of tasks (Tannock, Banaschewski, & Gold, 2006).

Concerning ADHD performance in RAN/RAS tasks, similar results to previous English-based studies (Clikeman Guy, & Griffin, 2000; Roessner et al., 2008) were observed, in that children with ADHD obtained worse scores in naming tasks that were based on figures and colors exclusively. In this sense, and as previous studies have noted, rapid naming speed tasks have been shown to be an important component of discriminant function analysis batteries for distinguishing ADHD and non-ADHD groups (Carte, Nigg, & Hinshaw, 1996; Tannock, Martinussen, & Frijters, 2000).

On the other hand, it is worth noting that when the total sample was considered, the results indicated that the symptomatology of ADHD and RLD appear to interact with each other, as the comorbid group (ADHD+RLD) showed a distinct profile regarding the performance of naming tasks. These results are also coherent with the findings of previous studies that have found greater consequences and difficulties in the comorbid group (Rodríguez et al., 2009; García et al., 2013). However, these additional difficulties cannot be simply explained by the additive effects of ADHD and RLD symptomatology.

Likewise, in relation to the second objective, analysis of how naming speed and ADHD symptoms (based on DSM criteria) might predict group classification (e.g. ADHD, RLD, or Control), the results showed that the RAN/RAS test is more effective in the detection of RLD (with or without ADHD) at early ages (specifically, from 5 to 9 years) (Clikeman, Guy, & Griffin, 2000; Mazzocco & Grimm, 2013). This could be explained by the fact that above 10 years of age, the difficulty level of naming tasks is lower, thus all diagnostics groups will show better performance. Conversely, under 10 years of age, when children still do not have fully-automated reading skills, they will have more difficulty with naming tasks by RAN/RAS test (particularly, the children with attentional and reading problems) (Elosúa et al., 2012). In the same line, there are several studies which have found significant differences in the performance of RAN/RAS tasks composed of colors and letters between samples of children with and without learning difficulties, when they are under 10 years of age (Dos Santos, De Lima, & Ciasca, 2016).

Similarly, the present study also verifies that RAN/RAS tasks can be effective measures in the diagnosis of ADHD, but only when children are under 10 years of age.

In this sense, as children get older, the clinical effectiveness of DSM criteria (APA, 2013) which are contained in several observation scales (including the EDAH scale), become better predictors of diagnosis than performance in naming tasks. Accordingly, once the possible presence of ADHD is detected by means of the RAN/RAS test, the clinician would need to carry out an exhaustive and comprehensive assessment based on the performance and diagnostic criteria in established clinical guides and manuals.

In general terms, taking into account the results obtained in this study, it is possible to affirm that RAN/RAS test is more effective in the detection of reading and attentional problems at early ages. From the age of 10 onwards, there are hardly any differences between groups.

Limitations of the present study

Finally, is important to highlight some limitations of the present study that should be considered in future research. The main limitation is related to the composition of the groups. Specifically, it would be interesting to divide the RLD group according to the affected reading route (lexical, phonological or both routes). This differentiation would allow researchers to know whether RAN/RAS test is equally effective depending on the affected reading route. Likewise, it would be also interesting to differentiate the ADHD group with regard to the type of presentation (predominantly inattentive, predominantly impulsive and hyperactive and combined presentation) in order to verify the diagnostic specificity of the RAN/RAS test to a greater extent. In addition, sample size must be expanded in order to better determine whether the discriminative capacities of the measures used in the present study are similar to those of the measures used in previous studies. Lastly, it would be interesting to combine RAN/RAS measures with other diagnostic systems that are now providing important insights into the processes involved in reading and attentional control tasks, such as eye-tracking techniques (e.g. Al Dahhan et al., 2014; Kuperman, Van Dyke, & Henry, 2016).

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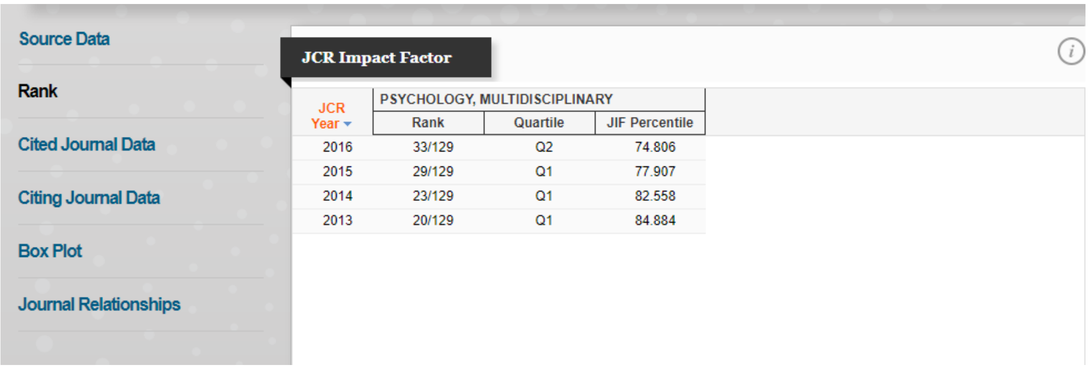
Informe del factor de impacto de las publicaciones

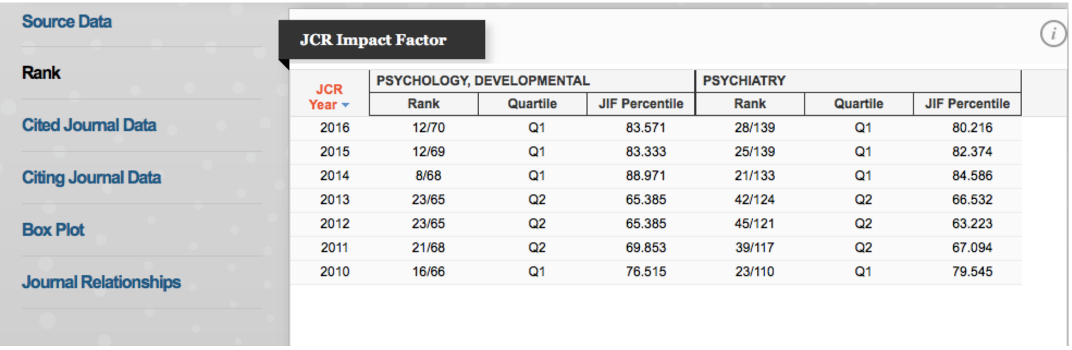
A continuación, se presenta la información referente al Factor de Impacto de las revistas en las que se han publicado los trabajos mencionados. Todas ellas se encuentran incluidas en *JCR Social Science Edition*. De este modo, para obtener el Factor de Impacto de cada una de las mismas, se consideró la información aportada por la *Web of Sciences*. Concretamente, se empleó el año 2016 como referencia, al ser la última anualidad recogida hasta el momento.

1. Revista *Frontiers in Psychology*: esta revista cuenta con Factor de Impacto = 2.321, y se encuentra en el segundo cuartil. Esta revista se sitúa en el puesto 33 de 129 de las revistas en marcadas en Psicología Multidisciplinar.



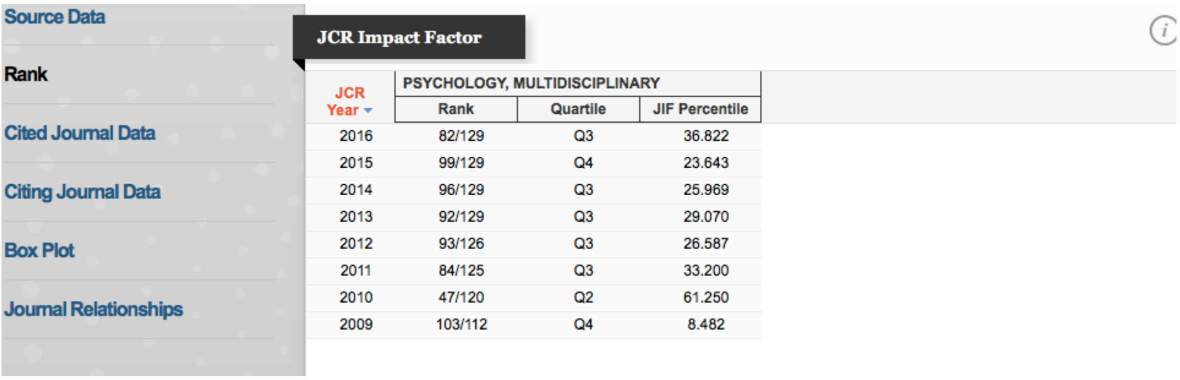
JCR Year	PSYCHOLOGY, MULTIDISCIPLINARY		
	Rank	Quartile	JIF Percentile
2016	33/129	Q2	74.806
2015	29/129	Q1	77.907
2014	23/129	Q1	82.558
2013	20/129	Q1	84.884

2. Revista *Journal of Attention Disorders*: cuenta con una Factor de Impacto = 3.378, y se encuentra en el primer cuartil. Más específicamente se encuentra en el puerto número de 12 de un total de 70 revistas bajo la categoría de Psicología del Desarrollo.



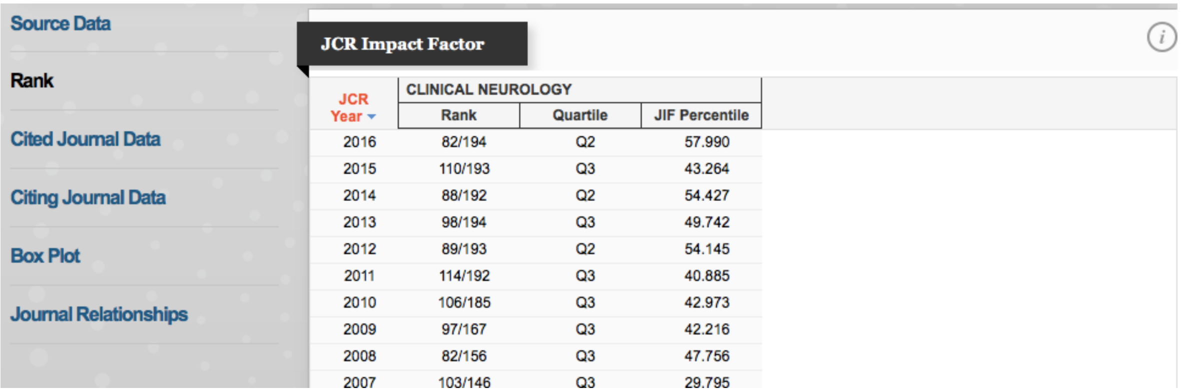
JCR Year	PSYCHOLOGY, DEVELOPMENTAL			PSYCHIATRY		
	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile
2016	12/70	Q1	83.571	28/139	Q1	80.216
2015	12/69	Q1	83.333	25/139	Q1	82.374
2014	8/68	Q1	88.971	21/133	Q1	84.586
2013	23/65	Q2	65.385	42/124	Q2	66.532
2012	23/65	Q2	65.385	45/121	Q2	63.223
2011	21/68	Q2	69.853	39/117	Q2	67.094
2010	16/66	Q1	76.515	23/110	Q1	79.545

3. Revista de *Anales de Psicología*: posee un Factor de Impacto = 0.871, y se encuentra en el tercer cuartil. Se encuentra en el puesto número 82 de un total de 129 revistas enmarcadas en la categoría de Psicología Multidisciplinar.



JCR Year	PSYCHOLOGY, MULTIDISCIPLINARY		
	Rank	Quartile	JIF Percentile
2016	82/129	Q3	36.822
2015	99/129	Q4	23.643
2014	96/129	Q3	25.969
2013	92/129	Q3	29.070
2012	93/126	Q3	26.587
2011	84/125	Q3	33.200
2010	47/120	Q2	61.250
2009	103/112	Q4	8.482

4. Revista *Child Neuropsychology*: presenta un Factor de Impacto = 2.660, y se encuentra en el Segundo cuartil. Ocupa el puesto 82 de un total de 194 revistas que pertenecen a la categoría de Neuropsicología Clínica.



JCR Year	CLINICAL NEUROLOGY		
	Rank	Quartile	JIF Percentile
2016	82/194	Q2	57.990
2015	110/193	Q3	43.264
2014	88/192	Q2	54.427
2013	98/194	Q3	49.742
2012	89/193	Q2	54.145
2011	114/192	Q3	40.885
2010	106/185	Q3	42.973
2009	97/167	Q3	42.216
2008	82/156	Q3	47.756
2007	103/146	Q3	29.795

Trabajos Complementarios

Trabajo complementario 1

First complementary study that now is under review in *JOVE Journal* [Primer trabajo complementario actualmente en proceso de revisión en la *revista JOVE*):

Using brain activation (nir-HEG/Q-EEG) and execution measures (CPTs) in a ADHD assessment protocol

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Abstract

Attention Deficit with Hyperactivity Disorder (ADHD) is a problem that impacts academic performance and has serious consequences which result in difficulties in scholastic, social and familial contexts. One of the most common problems in the identification of this disorder relates to the apparent over diagnosis of the disorder due to the absence of global protocols for assessment. The research group of School Learning, Difficulties and Academic Performance (ADIR) from the University of Oviedo, has developed a complete protocol which suggests the existence of certain patterns of cortical activation and executive control for identifying ADHD more objectively. This protocol takes into consideration some of the hypothetical determinants of ADHD, including the relationship between activation of selected areas of the brain, and differences in performance on various aspects of executive functioning such as omissions, commissions or response times, using innovative tools of Continuous Performance Testing (Aula Nesplora and TOVA test) and using brain activation (nir-HEG/Q-EEG) and execution measures (CPTs). This model of assessment aims to provide an effective assessment of ADHD symptomatology in order to design an accurate intervention and make appropriate recommendations for parents and teachers.

***Keywords*:** ADHD; Assessment; Continuous Performance Test; Virtual Reality; Executive Functions; Cortical Activation Measures; QEEG; nir-HEG.

Introduction

The overall goal of the present protocol is to develop a complete procedure or model of assessment for the diagnosis of Attention Deficit with Hyperactivity Disorder, otherwise known as ADHD.

ADHD is one of the problems that impacts academic performance. It is understood to be a persistent pattern of inattentive, restless and impulsive behavior which is more frequent and severe than that typically observed in subjects at a similar stage of development[1,2].

The latest edition of the Diagnostic and Statistical Manual[1] presents the following modifications regarding this disorder: 1) ADHD has been included as a neurodevelopmental disorder, 2) the age of onset has been modified – symptoms should appear before age 12, 3) subtypes have been replaced by three types of presentations – predominantly hyperactive/impulsive; predominantly inattentive; and combined presentation, and 4) comorbidity with autism spectrum disorders is allowed.

There are different estimations of prevalence rates depending on the country or region analyzed[3-5]. An international global systematic[3] review observed an average of 5.29%. However, applying DSM-IV criteria[4], the percentage ranges from 5.9 to 7.1%. Similarly, a meta-analysis of ADHD in a Spanish population provided an average of 6.8%[5]. The variations in prevalence rates could be due to the different assessment protocols used.

Although there is a considerable body of research suggesting a neurological basis for ADHD, the origins of this disorder remain unclear. Several studies have highlighted that ADHD is associated with a dysfunction in the central nervous system, characterized by a developmental delay and cortical hypoactivation related to a deficit in the dopaminergic and noradrenergic systems[6]. The noradrenergic system is responsible for the modulation of selective attention and the levels of general activation necessary to perform a task, while the dopaminergic system is associated with the ability to control one´s behavior, both at an executive and motivational level. In this sense, the low cortical activation associated with the dopaminergic and noradrenergic systems is presumed to be the basis for the inhibitory and attentional deficits that characterize ADHD. Other studies have focused on the existence of an executive function (EF) impairment in the ADHD population[7], which would explain the difficulty children with ADHD have controlling impulsive responses, resisting interference or distraction, organizing activities in a sequential manner, and sustaining cognitive effort while performing an activity.

Generally, these characteristic symptoms of ADHD have serious consequences which result in difficulties in scholastic, social and familial contexts. Children with ADHD have a higher probability of repeating a grade and/or completing fewer grades at school than children without ADHD. Moreover, dropping out of high school is three times more likely among youth with ADHD[8].

One of the most common problems in the identification of ADHD is the over diagnosis of the disorder due to the absence of global protocols for assessment. The fact that professionals do not have a general protocol based on objective variables is causing a large percentage of false positive and false negative cases of ADHD. For this reason, the research group of School Learning, Difficulties and Academic Performance (ADIR) from the University of Oviedo has been working on developing a complete protocol to identify patterns of cortical activation and executive control to provide a more objective diagnosis of ADHD than what is currently in use.

This protocol is especially relevant because it takes into consideration that the cortical activation collected in the frontal and prefrontal cortex impacts the executive function. The purpose of this protocol is to provide a more objective diagnostic procedure for this developmental disorder than is currently available, and to deepen our knowledge of the relationship between activation measures and executive function measures. The procedure will also take into consideration some of the hypothetical determinants of ADHD, both in the relationship between activation of selected areas of the brain and differences in performance on various aspects of executive functioning such as omissions, commissions or response times.

Protocol

1. Parents reports

1.1. Conduct an interview with families of the patients.

1.2. Have families and/or teachers of the patient complete the **Scale for the Assessment of Attention Deficit Hyperactivity Disorder**[10]. This scale comprises 20 items that provide information on the presence of symptoms related to attention deficit and hyperactivity/impulsivity which are referred in DSM IV TR.

2. Cognitive measures

2.1. To measure the attentional variables, administer a cognitive scale.

2.1.1. Administer the **WISC-IV**[11], which is a widely-used cognitive scale for assessing individual intelligence in children and adolescents between the ages of 6 years and 16 years 11 months.

2.1.2. Analyze in depth the cognitive profile obtained by the scale. The results from the Wechsler scale could be influenced by ADHD, leading to lower scores in processing speed and working memory in comparison with perceptual reasoning and verbal comprehension.

3. Executive measures using Continuous Performance Tests

3.1. Analyze the performance of the children using two Continuous Performance Tests (CPT): AULA Nesplora and TOVA.

3.1.1. Administer the **Aula Nesplora**[12]. This is a CPT based on a virtual reality environment that reproduces the conditions of a regular classroom. It evaluates attention, impulsivity, processing speed, and motor activity in children and adolescents between 6 and 16 years of age.

3.1.1.1 Ask the participant to wear the 3D glasses (Head Mounted Display, HMD) and headphones. These glasses are connected to the PC (figure 1).

Figure 1. 3D virtual glasses used during AULA Nesplora test

3.1.1.2 Ask the patient to hold the button with the dominant hand before starting the virtual attentional tasks.

3.1.1.3 Have the patient explore the virtual environment (a typical classroom) and take the perspective of a student sitting at one of the desks looking at the blackboard (figure 2).

Figure 2. Virtual classroom provided by AULA Nesplora Test

3.1.1.4 Have the patient follow the virtual teacher, who guides him/her through the tasks. The first part the patient performs is the training part, which consists of visually locating balloons and popping them pressing the button.

3.1.1.5 Have the patient continue to the next step which is the first exercise. This is based on the “x-no” paradigm (traditionally known as “no-go”), where the patient must press the button when he or she does not see or hear the stimulus “apple”.

3.1.1.6 Have the patient complete the last exercise by following the instructions to press the button whenever he/she sees or hears the number “seven”.

3.1.1.7 After completion of the Aula Nesplora test (the duration is about 20 minutes), produce a report compiling results for the following variables: omissions, commissions, response time, and variability. Complement this information by differentiating these measures of sensory modality (visual vs. auditory), presence/ absence of distractors, and task type (go vs. no-go), thereby leading to different execution profiles.

3.1.2. Administer the **Test of Variables of Attention** (TOVA[13]). This is a CPT that can be used in a visual or auditory version, but in this protocol only the visual version is used. The visual norms for the TOVA go from 4 years to more than 80, by age and gender.

3.1.2.1. Make sure that the patient is relaxed and ready to start.

3.1.2.2. Ensure the patient is holding the button (which is connected to a PC) with his/her dominant hand.

3.1.2.3. Inform the patient of the following instructions for the test: “you have to press the button when you see a black square in the upper part. However, do not press the button when the black square is in the bottom part” (figure 3).

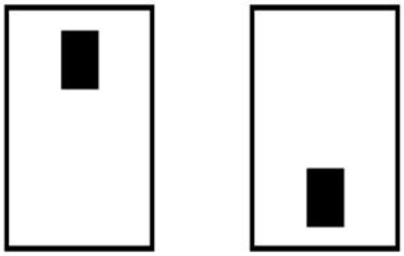


Figure 3. Images present in TOVA Test

3.1.2.4. Have the patient perform the training part (which lasts for approximately 3 minutes) until it is clear the patient understands the task.

3.1.2.5. Tell the patient that the task is very long and that she/he must keep still and concentrate on doing the tasks.

3.1.2.6. Have the patient complete the TOVA task. It is divided into two sections. The first section is boring and fatiguing as the target is only presented (randomly) once every 3.5 non-target presentations. During the second half targets are presented once for every non-target and the patients must suppress the tendency to respond more regularly.

3.1.2.7. After completion of the test, generate the TOVA report which compiles the following variables: omissions, RT, commissions, variability, D prime (performance quality or quality of concentration during the test based on the number of errors in the test) and ADHD Index, attributable to a profile of attention deficit with hyperactivity, according to the test manual. This ADHD Index is obtained from the sum of: TR of first half + D prime second half + total variability and is interpreted as attributable to ADHD when the score is lower than -1.80.

4. Cortical Activation Measures (QEEG and nir-HEG)

4.1. Measure the cortical activation levels of the patient by using the **nir-HEG tool** to measure blood oxygenation in specific areas. Because children with ADHD show low cortical activation in the dopaminergic and noradrenergic systems a differential pattern of electro cortical activity is observed in a state of rest which is characterized by increased theta -and decreased beta- activity. The nir-HEG uses functional near-infrared spectroscopy to measure color changes of the blood in the brain to indicate areas saturated with blood; oxygenated blood is bright red whereas de-oxygenated blood is a deep, almost purplish crimson. Figure 4 shows the nir-HEG equipment which includes the Peanut HEG (hardware device), Headband (nIR light emitting sensor device) and HEG-Studio (software).

Figure 4. nir HEG hardware

4.1.1. Inform the patient that he/she cannot move and must be still.

4.1.2. Put the band on the patient forehead in a specific area: Fp1 (for assessment of inhibition capacity) and Fpz (for the assessment of attention capacity).

4.1.3. Make sure that no external light enters the band.

4.1.4. Put the peanut HEG (which is connected to the headband) on the neck of the patient.

4.1.5. Turn on the peanut hardware to connect the band to the PC.

4.1.6. Measure the blood oxygenation of a specific area through the nir-HEG program for approximately 35 seconds.

4.1.7. Analyze the nir-HEG Ratio of the patient provided by the program. The standardized reference value is established at 100 (SD = 20) and is used to calibrate all new spectrophotometers. In addition to this measure, nir-HEG provides an Attention Index (AI), indicating malfunctioning of the intention to increase the HEG ratio; that is, the participant is incapable of increasing the ratio and, thereby, brain activation. This apparently indicates a lapse in attentional process and is equivalent to a measure of sustained attention or capacity of concentration.

4.2. Measure the **cortical activity levels** of the patient using **The Quantified Electroencephalogram** (QEEG), (The Biofeedback Institute of Los Angeles; **¡Error! Referencia de hipervínculo no válida.** is a computerized EEG system which records electrical activity in the brain to provide levels of cortical activation through the beta/theta ratio. It measures attention in general, independently of the task to be performed.

4.2.1. Inform the patient of the correct abdominal breathing required during the test.

4.2.2. Put an electrode on the corresponding cortical area (Cz, Fp1) to record the beta/theta ratio of the patient.

4.2.3. Put two more control electrodes on the patient´s left and right earlobe.

4.2.4. Ensure the patient has her or his eyes open during the assessment.

4.2.5. Place an EMG system on the right forearm to identify the degree of movement.

4.2.6. Inform the patient that he/she must remain relaxed, without moving, breathing slowly and evenly, and concentrating exclusively on the computer screen on which the theta and beta waves emitted by them are displayed successively.

4.2.7. Measure the cortical activation for a maximum duration of 10 minutes.

4.2.8. Analyze the results. When the beta/theta ratio is lower than 50% at Cz, it is related to associated deficit of sustained attention and if the ratio is also lower at Fp1, then the attentional deficit is associated with a lack of executive control, attributable to hyperactivity[15].

Representative results

Using the assessment procedure presented here, it is possible to carry out an effective assessment about ADHD symptomatology in order to design an accurate intervention and make recommendations for parents and teachers.

Once clinicians had the informed consent from the families, a cognitive scale (WISC IV) was administered to the children in order to exclude those patients who present low or high capacities. The following steps then compiled an attentional profile of the children using the Continuous Performance Test and Activation Cortical Techniques (QEEG and HEG). Figure 5 shows the results of children with and without ADHD in the Aula Nesplora test. These results show the children with ADHD have more omissions and commissions errors, as well as higher motor activity and larger response times

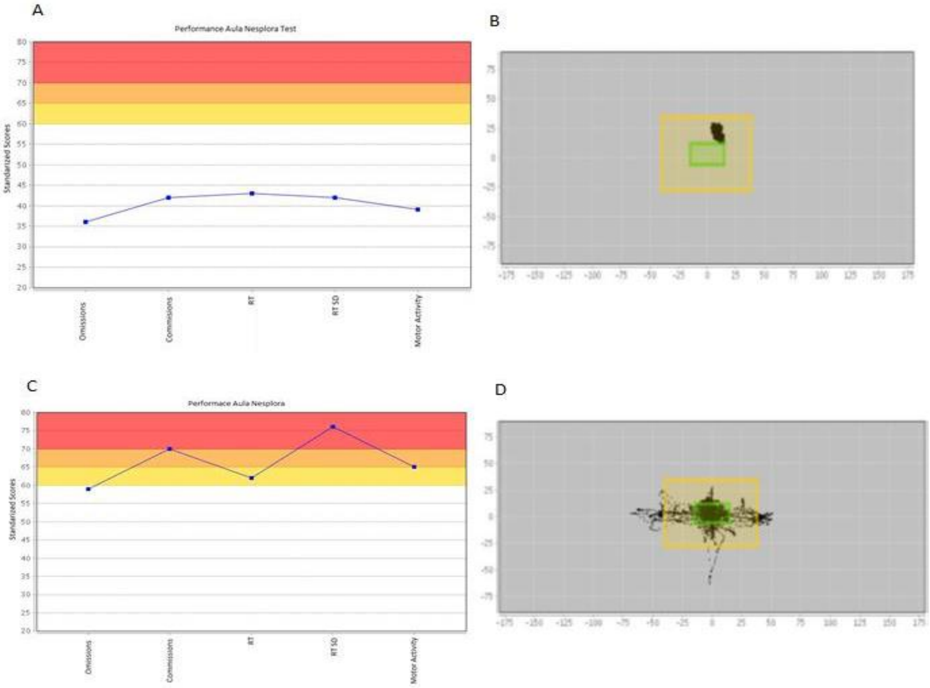
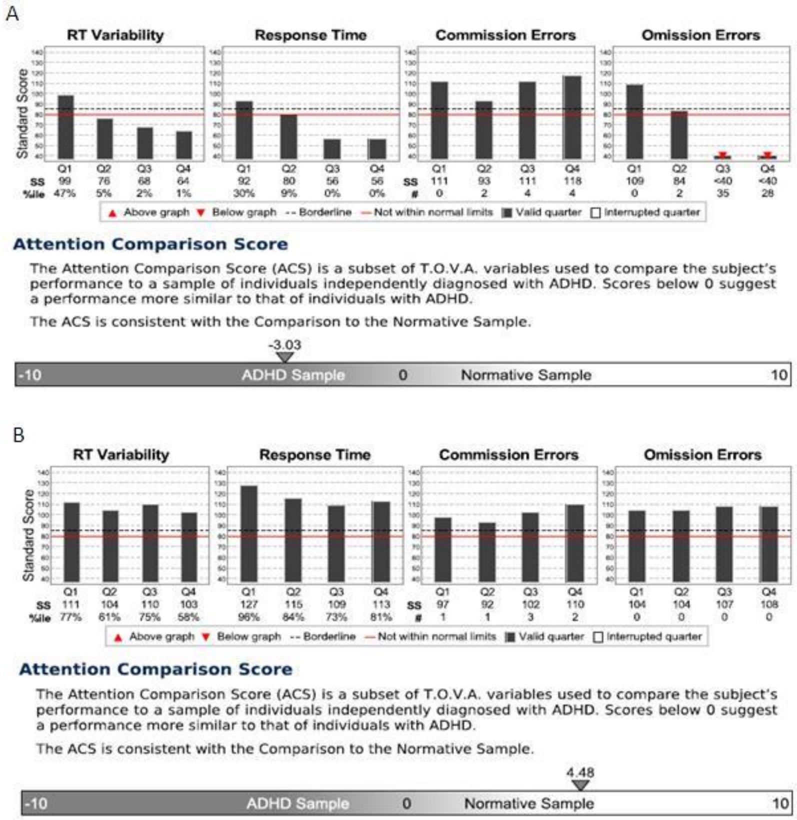


Figure 5. Performance and motor activity during Aula Nesplora Tasks
AULA Nesplora tasks provide performance results for different variables related to ADHD symptoms (e.g., Omissions, Commissions, Response Times, Variability in Response Times) (**A, C**), as well as a graphical representation of the motor activity during the task collected by a motor sensor placed in the 3D glasses (**B, D**). Figures **A** and **B** represent the performance in Aula Nesplora tasks of a child without ADHD, while figures **C** and **D** represent the performance of a child with ADHD.

Similarly, figure 6 shows the results obtained by TOVA Test showing how the child with ADHD presented larger percentages in omissions, commissions, response times and in the variability of the respond. While the child without ADHD showed the best scores at the end of the tasks, the child with ADHD did not showed improvement in any of the four blocks.



Attention Comparison Score

The Attention Comparison Score (ACS) is a subset of T.O.V.A. variables used to compare the subject's performance to a sample of individuals independently diagnosed with ADHD. Scores below 0 suggest a performance more similar to that of individuals with ADHD.

The ACS is consistent with the Comparison to the Normative Sample.

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The ACS is consistent with the Comparison to the Normative Sample.

Figure 6. Profile provided by TOVA in the main variables.
Figure A represents the profile of a student with ADHD while figure B shows the execution of a child with a performance similar to the normative group.

Figure 7 shows an example of the Cortical Activation collected by nir-HEG in a child affected by ADHD who obtained 24.5 percentage points below the average in Fp1 region.

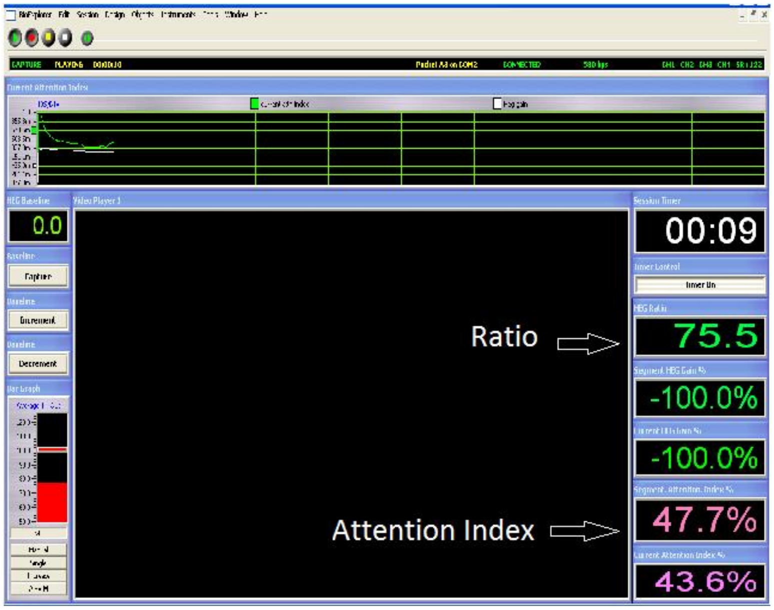

Figure 7. Cortical Activation data collected by the nir-HEG

Similarly, an example of the measures collected by QEEG in a child with ADHD (FP1 region) are shown in figure 8 that evidences how the symptoms of ADHD cause a decreased in cortical activation (ratio beta/theta under 0.5).

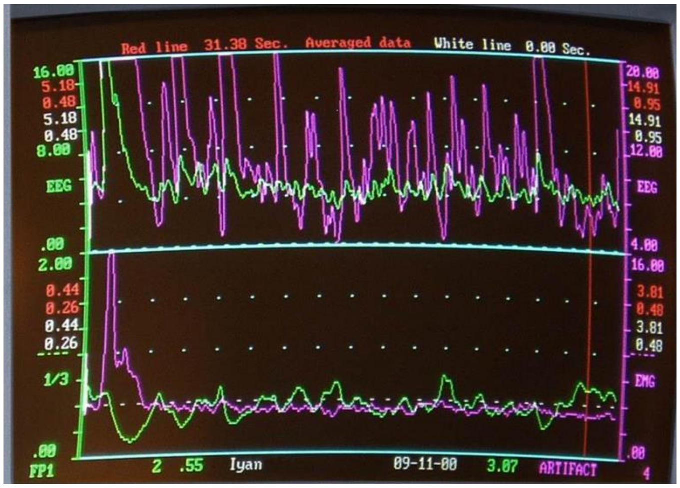

Figure 8. Cortical activation measures in FP1 region through QEEG

Discussion

Here we present an effective protocol for assessing ADHD from 6-16 years of ages. Given the symptomatic complexity of ADHD and its high prevalence rates, professionals must have reliable and valid instruments to diagnose this disorder. Generally, questionnaires based on behavioral observations are widely used. However, the use of these instruments as the sole assessment measure has certain limitations, including potential subjectivity on the part of the observer[16].

For this reason, it is very relevant to contrast the information obtained by observation scales with the cognitive profile of the children and the performance in CPTs. Professionals can then perform a more realistic and reliable assessment and, thus provide recommendations for parents and teachers that are more specifically adapted to the individual needs of each child.

However, a critical step of this protocol is the management of exclusion criteria; professionals must ensure the ADHD symptoms are not due to another cause such as perceptive, emotional or social problems.

A minor limitation of this protocol is the time required to complete each assessment. Generally, this protocol is best divided into several sessions to ensure patient well-being.

The applicability of this method has been presented in previous studies[9] which showed the effectiveness of the assessment model (figure 9) for getting an accurate diagnosis of ADHD according with DSM criteria.

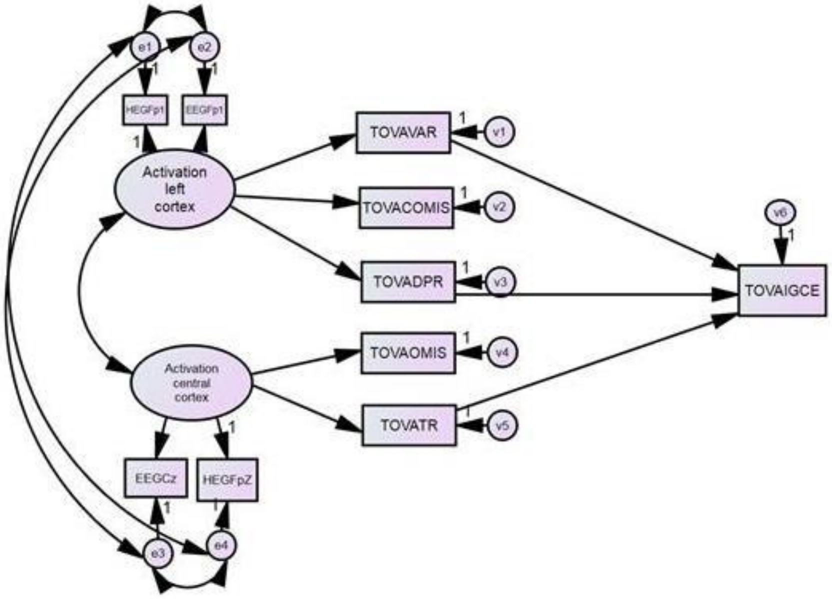

Figure 9. Model of ADHD assessment provided by Rodríguez et al., 2016.
Variables in the model: HEG-Fp1(nir-HEG ratio: left pre-frontal cortex); HEG-FpZ (nir-HEG ratio: central zone pre-frontal cortex); QEEG-Fp1(beta-theta ratio: left pre-frontal cortex); QEEG-CZ (beta-theta ratio: central cortex); TOVA-OMIS (CPT: omissions); TOVA-COMIS (CPT commissions); TOVA-VAR (CPT: variability); TOVA-TR (CPT: response time); TOVA-DPR (CPT: D prime); ADHD-INDEX (CPT: ADHD index). This model shows a stronger relationship between activation (central and left prefrontal) and execution in ADHD subjects than in the control group. When the electric activation shows low levels in Fp1, these data are also supported by nir-HEG results and a low performance in TOVA tests. Similarly, when the electrical activation is within normal ranges blood oxygenation and TOVA test results are also normal.

Acknowledgments

This work has been supported by a project of the Principality of Asturias (FC-15-GRUPIN14-053) and a predoctoral grant from the Severo Ochoa Program (BP14-030). We would like to thank Anna Bujnowska for her contribution and Heather Marsh and Nigel Marsh for their help.

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Trabajo Complementario 2

Second complementary study under review in *PlosOne* [Segundo trabajo complementario bajo revisión en la revista *PlosOne*]:

Analysis of cognitive and attentional profiles in children with and without ADHD using an innovative virtual reality tool

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2 Psychology and Human Development. University College London (United Kingdom)

Abstract

In previous studies, children with Attention-Deficit Hyperactivity Disorder (ADHD) have been found to have more difficulties with processing speed, working memory, and attentional tasks. The present study aimed to compare the cognitive variables (working memory and processing speed) and the attentional profiles of a sample of students with and without ADHD, using scales from the WISC-IV, and the virtual reality-based attentional test known as *'Aula Nesplora'*; and determine the extent to which the aforementioned variables may predict student group membership. A total of 88 students took part in this study (66 males and 22 females), aged from 6 to 16 years (M = 10.20; SD = 2.79). The sample was divided into two groups: an ADHD group (n = 50) and a Control group (n = 38). Students in the ADHD group obtained lower scores in working memory and in processing speed, as well as demonstrating poorer performance in Aula Nesplora than did their peers. Working memory, and the number of omissions, were both shown to be reliable predictors of group membership. This study revealed the importance of obtaining data from attentional variables differentiated by modality when considering cognitive variables, in order to gain a more accurate diagnosis of ADHD.

Keywords: virtual reality, working memory, processing speed, attentional test.

Introduction

ADHD (Attentional Deficit and Hyperactivity Disorder) is a common neuropsychiatric disorder in childhood with prevalence rates ranging from 5 to 7% in the school-age population [1]. According to the American Psychiatric Association [2] children with ADHD experience high levels of overactivity, impulsivity, and inattention. Three subcategories or presentations of the disorder can be distinguished according to these symptoms: the combined presentation, the predominantly inattentive presentation, and the predominantly impulsive/hyperactive presentation.

Generally, the characteristic symptoms of ADHD have serious consequences which result in difficulties in scholastic, social and familial contexts [3,4]. Specifically, children with ADHD have a higher probability of repeating a grade and completing fewer grades at school than children without ADHD. Moreover, dropping out of high school is three times more likely among youth with ADHD [5].

With the aim of preventing these consequences, the attentional profile of children with ADHD has been widely studied by means of Continuous Performance Tests (CPTs), which provide quantitative data on different attentional variables of interest and have been shown to be useful in the diagnosis of ADHD [6]. Nonetheless, these types of tests are commonly criticized for their low ecological validity [7]. The symptoms of ADHD not always are revealed when a child is performing a neutral task in a small room, with a single adult, and under controlled contextual conditions, as often happens in testing situations. Moreover, many authors [8,9] sustained that these assessment tools presented sufficient sensitivity to ADHD, but specificity was not adequate. Sensitivity consists on the ability of a test to identify the presence of a disorder, while specificity refers to the ability of a test to detect the absence of a disorder, in this case the absence of ADHD. In this sense, although ideally the CPTs should have high in both attributes, frequently the clinician must sacrifice the degree of one or the other such attribute, thus adding emphasis to false positive diagnostic errors (higher sensitivity) or to false negative errors (higher specificity) [8].

Efforts to find improved assessment methods that offer-higher ecological validity, as well as better sensitivity and specificity levels, have led to ~~a~~ new technique for evaluating ADHD that are based on the use of Virtual Reality (VR). Nowadays, new technological developments in the field of VR have generated an innovative and interesting option for carrying out neuropsychological evaluations of many cognitive processes [10]. These advances present a huge number of advantages over more traditional techniques [11]. For example, the therapist has more control over the content and assessment process and the patient is assessed in a more realistic environment [12]. Accordingly, Aula Nesplora represents an important innovation in the diagnosis of ADHD [13]. This novel test involves tasks of sustained attention and response inhibition, which take place in the context of a virtual classroom. Moreover, Aula Nesplora offers additional information which is very useful for ~~the~~ intervention guidelines, as it provides attentional data which is differentiated by the sensory channels (visual and auditory), the type of task (x-go and x-no go tasks), and the presence or absence of distracters. In addition, the test provides a reliable indicator of motor activity during performance [14]. This information is important in determining the severity of ADHD, a key aspect of an ADHD diagnosis referred to in the DSM-5 [2], and also in providing insights into the modalities of presentation or type of tasks that the child can benefit from in further interventions. For example, by use of an Aula Nesplora report, clinicians are now able to identify whether a participant can concentrate better when the information is presented by the visual or the auditory channel. With regard to the effectiveness of Aula Nesplora, different studies have demonstrated that the Aula Nesplora test is not only useful for differentiating between ADHD and non-ADHD symptomatology [12], but it also useful for discriminating across the different types of ADHD presentations [12, 15]. A recent study [15] found that the many additional variables provided by Aula Nesplora made it possible to distinguish predominantly Impulsive/Hyperactivity (I/H) and Combined presentations of ADHD from control group data, while also detecting the differences between the I/H and Inattentive presentations. However, differences between the Inattentive and Combined presentations were only identified when the Aula Nesplora test results relating to the auditory channel were considered.

In addition to obtaining an attentional profile in children with ADHD, several studies have also identified cognitive variables which are impaired in ADHD [16,17]. In particular, the comparisons of the cognitive profiles of children with ADHD and average intelligence, using the WISC-IV [18], have shown that children with ADHD perform more poorly on working memory and processing speed than on perceptual organization and verbal comprehension [18 - 21]. These results are similar to other studies which found that children with ADHD, Learning Disabilities and Autism typically present with impairments in working memory, processing speed and graphomotor skills [22].

Regarding processing speed, a large amount of research~~es~~ supports the view that a low score in processing speed is one of the best predictors of ADHD, especially for those with inattentive symptoms [21, 23]. Moreover, there is a great deal of evidence suggesting that deficits in processing speed affect more complex reading skills (e.g. reading fluency), which might explain the high co-occurrence of ADHD and Reading Disabilities [24, 25].

On the other hand, with respect to the Executive Functions, many authors have observed an impairment in working memory in children with ADHD [26 - 28]. Working memory is a limited-capacity system for temporarily storing and processing internally held information for use in guiding behavior [29]. Gallagher and Blader [30] highlighted that while children with ADHD share some neuropsychological features with children suffering from other mental disorders (e.g. schizophrenia, anxiety, depression), ADHD is associated with a particular neuropsychological profile, characterized (along with other problems) by specific impairments in working memory processes. Similarly, other authors [31] confirmed that impairments of various working memory components are present in children with ADHD.

Other researchers have focused on working memory as a key component, analyzing whether academic problems in ADHD are due to ADHD symptoms, working memory deficits, or both [32]. The results are mixed, with some authors affirming that working memory has a direct effect on academic performance [33,34], while others suggest that an impairment in working memory increases rates of internalizing/externalizing problems, which in turn, affect academic performance [35]. Internalizing problems are behaviors that usually cause internal distress such us anxiety and depression. In contrast, externalizing problems are behaviors that generate conflict with others, such us aggressive, rule-breaking and impulsive behavior [36].

These findings suggest that both processing speed and working memory are relevant neurocognitive markers of ADHD and other disorders which share common symptoms [20].

Given the high prevalence rates of ADHD and the low ecological validity of the majority of CPTs, virtual reality tasks provide a means of examining the relationship between performance and cognitive profiles in a more realistic environment. Moreover, is also important to verify the explanatory power of the attentional and cognitive variables to predict the group membership (ADHD and No ADHD) in order to know which variables better predict group membership and verify their specificity and sensitivity levels of the tests.

Overview of the present study

Considering that the field of assessment tools for detecting the ADHD is still in development, there is a need to continue research aimed at better understanding the effectiveness of attentional and cognitive variables in the diagnosis of this disorder. This study thus has two main objectives: 1) to describe and compare the cognitive and attentional profile of a sample of students with and without ADHD, using the working memory and processing speed scales from WISC-IV, and Aula Nesplora variables (general measures and by modality); and 2) to determine the extent to which the aforementioned variables predict student group membership, controlling for the potential explanatory effect of gender and age.

Taking into account that children with ADHD usually show lower scores in working memory and processing speed than their peers [21, 23, 26, 27], and given that analyzing these differences in one of the goals of the present study, only the scales of perceptual reasoning and verbal comprehension from WISC-IV will be used as inclusion criteria. Thus, students with an IQ between 85 and 130 in perceptual reasoning and verbal comprehension were included in the present sample.

Method

Participants

A non-probabilistic sample of 88 students took part in this study, 66 males (75%) and 22 females (25%) between 6 and 16 years of age (*M* = 10.20; *SD* = 2.79). Of the total sample, 50 (56.8%) had a diagnosis of ADHD and 38 (43.2%) were controls. The average IQ (using standard scores) of the total sample was 110.05 (*SD* = 13.93). Only the following two scales from the WISC-IV were considered for inclusion criteria: Verbal Comprehension (*M* = 114.17; *SD* = 13.77), and Perceptual Reasoning (*M* = 108.37; *SD* = 15.48); as the remaining scales (Processing Speed, and Working Memory) were the dependent variables in the present study. There were large and significant differences between the groups [processing Speed: $F(1,87)$ =4.607, p = .033, $\eta p2$ = .102 ; working memory: $F(1,87)$ = 9.633, p = .003, $\eta p2$ = .051]. No statistically significant differences were found between ADHD groups in perceptual reasoning ($F(1,87)$ = 2.868, p = .081, $\eta p2$ = .032), or verbal comprehension ($F(1,87)$ = 3.799, p = .159, $\eta p2$ = .042) and age ($F(1,87)$ = 3.061, p = .806, $\eta p2$ = .001). However, although there were no differences in age considering the age range of the sample, age was included as a covariate in subsequent statistical analyses, in order to avoid the explanatory effect of this variable within each diagnostic group. None of the participants with ADHD was receiving pharmacological treatment at the time of evaluation.

Instruments

The following instruments and measures were used in the present study:

The Wechsler Intelligence Scale for Children-IV (WISC-IV) by Wechsler [18] was used as a measure of intelligence, expressed in terms of Intelligence Quotient (IQ). This scale can be administered to children and adolescents between the ages of 6 years and 16 years 11 months, and provides a general estimation of subject IQ as well as four different measures related to different abilities. In the present study, the four components of working memory, processing speed, verbal comprehension and perceptual reasoning were used, whereas a measure of total IQ was not included. The focus of the study was on specific abilities rather than general intellectual capacity. The standard scores of working memory and processing speed were included as dependent variables in the present study, while IQ in verbal comprehension and perceptual reasoning were used for sample inclusion purposes. Cronbach´s Alpha of the WISC-IV was .677 in the current sample.

Aula Nesplora [13] was administered in order to determine participants' attentional profile. This is a Continuous Performance Test (CPT) based on a virtual reality environment that reproduces the conditions of a regular classroom. Aula Nesplora evaluates attention, impulsivity, processing speed, and motor activity in children and adolescents between 6 and 16 years of age. The virtual reality environment is shown through 3D glasses (Head Mounted Display, HMD). Motion sensors and headphones are also included in order to make the task as realistic as possible. The participant takes the perspective of a student sitting in one of the desks looking at the blackboard. Head movements are registered by sensors located in the glasses; thus, the software updates the angle of vision, giving the subject the feeling of actually being in a virtual classroom.

The duration of Aula Nesplora test lasts for 20 minutes. The test consists of three phases that are gradually explained by a virtual teacher. The objective of the first phase is to immerse the participant in the context of virtual reality, and it consists of visually locating balloons and popping them. Below this scene is a task based on the "x-no" paradigm (traditionally known as "no-go") in which the participant must press a button provided that he or she does not see or hear the stimulus "apple." Finally, an "x" paradigm (or "go") is also incorporated, with participants being asked to press a button whenever they see or hear the number "seven". Thus, not only the delivery response but also its inhibition is assessed.

As described in the studies of Díaz-Orueta et al. [14], the features of Aula Nesplora parameters present some differences to other CPTs due to the more complex nature of stimuli present in this test. Therefore, while the time of exposure for visual stimuli is 250 ms, for auditory stimuli the mean time is 650 ms, as the exposure is a function of the length of each word being presented (e.g. ranging from 470 ms for the shortest word, to a maximum of 891 ms). In addition, once the auditory or visual item is presented, the child has a maximum of 2500 ms to press the button and thus register his or her answer into the frame of the presented stimulus. The total number of the Aula Nesplora items presented is 360 (of which 180 are 'targeted stimuli', and 180 are 'non-targeted' stimuli).

Regarding the distribution of the distractors, it is different depending on the type of task ("x-no", or "x"). During the first task ("x-no" items) there are 9 distractors (two visual, three auditory and four combined). However, in the second task ("x" items) there are 7 distractors (two visual, three auditory and one combined).

The variables provided by the instrument do not differ from those of other CPTs regarding attention deficit and hyperactivity/impulsivity measures (omissions, commissions, response time, and motor activity); however, they complement this information, by differentiating the measures of sensory modality (visual vs. auditory), presence/ absence of distractors, and task type (go vs. no-go), thereby leading to different execution profiles. High scores in these measures are related to attentional deficits. Both the general and specific measures (variables analyzed by different conditions) have been shown to provide different contributions to the explanation of inattention and hyperactivity/impulsivity symptoms in ADHD [15], thus analyzing each of the conditions separately is pertinent. Raw scores in omissions, commissions, response times and motor activity for the entire task (general measures), as well as per each of the six conditions individually, were included as dependent measures in the present study. The only exception to this related to visual and auditory stimulation conditions, as a measure of motor activity is not be provided. Cronbach´s Alpha in this sample was .621.

The Scale for the assessment of Attention Deficit Hyperactivity Disorder (EDAH) [37] was completed by families (children´s parents). It consists of 20 items that provide information on the presence of symptoms related to attention deficit and hyperactivity/impulsivity. It differentiates between ADHD and control groups, as well as between ADHD presentations. The following variables were included in the present study: EDAH-AD (score in the items that measure Attention Deficit), EDAH-I/H (score in Impulsivity/Hyperactivity items), and EDAH-ADHD (the sum of attention deficit plus Impulsivity/Hyperactivity symptoms). The reliability of the instrument, using Cronbach´s

Alpha, is high for the whole scale (.929) and its components: DA (.898), H (.849), and CD (.899). Cronbach´s Alpha was .855 in the current sample.

Procedure

The ADHD sample was recruited from a hospital clinical service who came for a diagnosis. They were identified by mental-health professionals (typically one or more psychiatrist-neurologist) as fulfilling the DSM-5 criteria for ADHD [2]. Subjects who presented with a cognitive deficit, Asperger’s syndrome, Guilles de la Tourette syndrome, anxious depressive disorders or comorbid behavioral/learning disorders were excluded from the study. The schools attended by the participants were in urban and semi-urban zones from a region in the north-west of Spain.

A further control sample was recruited from the same schools to serve as a non-ADHD control group. Students were included in the control group if they had no reported history of behavioral or emotional problems in school or at home. Participants with a IQ below 85 and over 130 in these scales were excluded from the study. The participants came from families of medium socio-economic status.

Although students´ assignation to groups was made based on DSM-5 Criteria (APA, 2013), the EDAH scale [37] was completed by families (parents) in order to verify that students in the different groups differed on the scales of attention deficit and impulsivity/hyperactivity symptoms. Table 1 shows results from this analysis.

Table 1. ADHD symptoms in the diagnostic groups and differences (EDAH)

	Diagnostic groups		Total sample	Differences		
	ADHD	Control				
	M(SD)	*M(SD)*	*M(SD)*	*F*	*p*	ηp^2
EDAH-AD Raw score	9.96 (2.473)	6.88 (3.193)	8.78 (3.214)	7.379	.009	.129
EDAH-I/H Raw score	8.78 (3.994)	6.00 (3.317)	7.44 (3.908)	15.281	<.001	.234

EDAH-ADHD Raw score	18.63 (5.108)	12.50 (5.605)	15.83 (6.061)	15.400	<.001	.235

Note**.** EDAH-AD = attention deficit symptoms; EDAH-I/H = impulsivity/hyperactivity symptoms; EDAH-ADHD = attention deficit + impulsivity/hyperactivity symptoms.
ADHD (n = 50), Control (n =38).

As Table 1 shows there were statistically significant differences between the groups in both attention deficit and impulsivity/hyperactivity symptoms. Students in the ADHD group showed more symptoms in both scales, as expected. When both symptoms were taken together, groups differences remain constant. Moreover, in the ADHD group, although there were no statistically significant differences (p= .065), means indicated a higher presence of attention deficit symptoms in this group, in comparison to impulsivity/hyperactivity symptoms.

The study was conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki), which reflects the ethical principles for research involving humans [38]. All subjects and their parents gave written informed consent after receiving a comprehensive description of the study protocol. Participants had volunteered to be involved in this study and they were not given any incentive to take part in it. To that end, once parental consent to evaluate the children was provided, the corresponding tests were conducted to verify the diagnosis and to participate in this research.

Data analysis

This study analyzed the differences in cognitive and attentional variables between two groups of students with and without ADHD, and examined the discriminant value of these variables in predicting group membership. In order to accomplish that, data analyses were conducted in three steps:

First, the descriptive statistics for the variables under study were analyzed, paying special attention to skewness and kurtosis. Kline's criterion [39], according to which the maximum scores accepted for skewness and kurtosis range between 3 and 10, was used. The majority of these variables met this criterion, with some exceptions regarding commissions in the ADHD group, and omissions in the control group. Results allowed us to perform parametric analyses (Table 2).

Second, multivariate analyses of covariance (MANCOVA) were performed to analyze the differences between the groups, using age as a covariate. A MANCOVA was conducted to analyze differences in working memory and processing Speed. Regarding attentional variables, different MANCOVAs were carried out, one using the total scores in the test (omissions, commissions, response time and motor activity) and six separate MANCOVAs for the different conditions offered by the test (visual vs. auditory channel; and X vs. no-X task; presence vs. absence of distractors) in order to determine which of these conditions generated the greatest differences between the groups. The group was the independent variable.

Finally, once the existence of statistically significant differences between the groups was verified (Table 2), different discriminant analyses were conducted to determine the specificity and sensitivity levels of each dependent variable (cognitive and attentional variables) in identifying subjects in each group. Four discriminant analyses were performed: the first analysis with the general scores of Aula Nesplora, and other three for each pair of test conditions. Thus, visual vs. auditory channel, X vs. X-no task, and presence vs. absence of distractors were grouped in pairs, as MANCOVAs revealed a quite similar pattern of differences regarding each component of the dyad (Table 2). Age and gender were also included in the analyses to determine their potential discriminant value. Age was recoded as a dummy variable for these analyses. Since significant but not too high correlations between variables is an important criterion to conduct discriminant analysis, Pearson´s correlations between attentional and cognitive measures were calculated, using Aula Nesplora general measures. SPSS 19 [40] was used in the analysis of data, establishing $p < .05$ as the criterion for statistical significance.

Results

Differences in cognitive and attention variables between students with and without ADHD

Table 2 shows descriptive statistics of the dependent variables and results from MANCOVA, taking into account age as covariate. As shown, statistically significant differences were found between the groups with and without ADHD in most of the studied variables, with large effect sizes in some cases. In this regard, it is worth remembering that high scores in Aula Nesplora variables are related to poor performance.

Table 2. Differences between groups and descriptive statistics for the dependent variables

	Diagnostic groups						Differences	
	ADHD			Control				
	M(SD) *Raw score*	*K*	*S*	*M(SD)* *Raw score*	*K*	*S*	*F*	ηp^2
Cognitive variables								
WM	103.16 (12.321)	.845	.164	111.447 (12.564)	.640	.272	9.633**	.102
PS	98.10 (13.158)	-.173	.276	103.89 (13.210)	-.398	.088	4.607*	.051
Attentional variables								

Aula Nesplora General

O	41.06 (29.391)	-1.121	.514	14.68 (1.960)	12.472	2.937	34.802***	.290
C	19.20 (18.325)	14.496	3.363	12.63 (7.521)	.266	.865	4.231*	.047
TR	954.197 (145.446)	.375	.002	854.333 (111.187)	1.012	.785	15.787***	.157
MA	.799 (.617)	2.665	1.337	.441 (.287)	.740	1.084	11.209***	.117

Aula Nesplora Visual Channel

O	27.42 (21.017)	-.900	.625	10.71 (10.076)	12.466	3.045	24.516***	.224
C	10.20 (9.491)	11.309	2.873	7.26 (4.209)	.854	1.009	3.071	-
TR	808.342 (146.187)	.298	.297	711.969 (129.560)	.810	1.049	14.808***	.148

Aula Nesplora Auditory Channel

O	13.64 (16.278)	4.820	2.190	3.97 (3.605)	1.039	1.195	13.474***	.137
C	9.00 (9.647)	13.243	3.298	5.37 (4.253)	-.364	.815	4.715*	.053
TR	1091.088 (152.135)	.643	-.176	1000.307 (046)	.288	.323	9.864**	.104

Aula Nesplora X-Tasks

O	70.58 (23.896)	.326	1.020	52.774 (19.925)	1.303	1.256	14.341***	.144
C	8.24 (5.384)	15.617	4.168	2.29 (3.179)	3.483	2.002	5.376*	.059
TR	1040.879 (186.796)	-.479	.250	943.652 (138.989)	-.253	.331	10.088**	.106
MA	.957 (.771)	4.514	1.600	.506 (.335)	.302	.928	11.287***	.117

Aula nesplora X-no Tasks

O	34.02 (25.989)	-.898	.632	12.00 (12.460)	14.171	3.133	29.248***	.256
C	10.96 (5.897)	.270	.453	10.34 (5.181)	-.101	.200	.222	-
TR	932.789 (149.410)	.710	.033	831.425 (111.296)	1.073	.779	14.360***	.145
MA	.606 (.509)	2.842	1.553	.348 (.268)	2.261	1.642	8.779**	.094

Aula Nesplora Distractors

O	15.38 (11.597)	-.204	.836	5.89 (5.321)	6.987	2.159	27.793***	.264
C	6.50 (5.358)	5.238	1.915	5.50 (3.311)	.141	.642	.955	-
TR	967.650 (154.926)	.960	-.142	852.341 (117.145)	1.108	.818	17.218***	.168
MA	.767 (.600)	2.100	1.254	.455 (.294)	.071	.989	8.822**	.094

Aula Nesplora No distractors

O	25.68 (18.870)	-1.092	.527	8.79 (9.257)	12.306	2.972	33.676***	.284
C	12.70 (13.606)	16.646	3.623	7.13 (4.839)	.206	1.015	5.746*	.063
TR	945.213 (148.947)	-.187	.238	856.168 (114.666)	1.014	.738	12.577***	.129
MA	.885 (.682)	2.955	1.401	.478 (.311)	1.360	1.187	11.825***	.122

Note. M = mean; SD = standard deviation; K = Kurtosis; S = Skewness; WM = Working memory; PS = Processing Speed; O = omissions; C = commissions; RT = response time associated with a correct answer; MA = motor activity during the task (this measure is not provided for visual and auditory channels).
ADHD (n = 50), Control (n =38).
$^{*}p< .05$. $^{**}p< .005$. $^{***}p< .001$.

Cognitive measures

MANCOVA indicated that both working memory and processing speed standard scores differed statistically significantly between the diagnostic groups, $\lambda = .884$; $F(3,84) = 5.438$; $p = .006$; $\eta 2 = .115$. Although there were no statistically significant differences in age, the analysis revealed a trend of age effects on AULA Nesplora performance (p = .059). As shown in Table 2, students without ADHD systematically showed higher IQ scores in working memory and processing speed, although effect size was considerably lower in the case of the first variable (Table 2).

These scales correlated significantly with each other, $R^2 = .384$, $p < .001$ and with the scales of verbal comprehension and perceptual reasoning. Specifically, working memory correlated positively and significantly with both the additional scales [$R^2 = .223$, $p < .05$, and $R^2 = .271$, $p < .05$ for verbal comprehension and perceptual reasoning, respectively] while processing speed only correlated significantly (also positively) to perceptual reasoning, $R^2 = .333$, $p < .01$. The correlation between verbal comprehension and perceptual reasoning was .609 ($p < .01$).

Attentional Measures

Results from Aula Nesplora general measures (raw scores), as well as for each of the six conditions of the test are presented in Table 2. As can be observed, there was significant variability among students in the studied variables, with large standard deviations. It is worth noting in this sense that both ADHD and control groups show a considerably higher number of omissions than commissions in general and across the different conditions. Means indicate that the group with ADHD shows a greater amount of omissions and commissions, as well as longer response times and higher motor activity, than the group without ADHD. These differences are statistically significant in most of the cases, with large effect sizes.

Aula Nesplora General

In terms of the raw scores of general measures, the MANCOVA indicated the existence of statistically significant differences between groups, $\lambda = .646$; $F(4,82) = 11.221$; $p < .001$; $\eta 2 = .354$. Age was also a statistically significant variable, $\lambda = .594$; $F(4,82) = 13.994$; $p < .001$; $\eta 2 = .406$, showing an even greater effect size than attentional variables. Statistically significant differences between groups were observed for all the variables with omissions and response time having the largest effect sizes (Table 2).

Aula Nesplora by condition

Concerning stimulation channel, MANCOVA indicated the existence of significant differences between groups in both visual, $\lambda = .727$; $F(3,83) = 10.382$; $p < .001$; $\eta 2 = .273$ and auditory, $\lambda = .734$; $F(3,83) = 10.038$; $p < .001$; $\eta 2 = .266$ channels. The visual channel showed a slightly larger effect size than the auditory channel. The covariate age was also statistically significant [visual channel, $\lambda = .595$; $F(3,83) = 18.834$; $p < .001$; $\eta 2 = .405$; auditory channel, $\lambda = .724$; $F(3,83) = 10.571$; $p < .001$; $\eta 2 = .276$]. Taking into consideration each variable separately, omissions and response time generated the largest differences for both conditions (Table 2).

With regard to the X vs. X-No condition, statistically significant and large differences between the groups were obtained [X task, $\lambda = .770$; $F(4.82) = 6.110$; $p < .001$; $\eta 2 = .230$; X-No task, $\lambda = .660$; $F(4,82) = 10.554$; $p < .001$; $\eta 2 = .340$]. The X-No task showed a considerably larger effect size than the other condition. Again, the covariate age was statistically significant [X task, $\lambda = .564$; $F(4,82) = 15.821$; $p < .001$; $\eta 2 = .436$; X-No task, $\lambda = .570$; $F(4,82) = 15.461$; $p < .001$; $\eta 2 = .430$]. Considering each variable separately, omissions and response time were the variables that showed the largest differences. In this case, the variable commissions did not reach statistical significance.

Finally, considering the presence or absence of distractors, MANCOVA showed the existence of statistically significant differences between students with and without ADHD in both conditions [distractors, $\lambda = .645$; $F(4,82) = 11.30$; $p < .001$; $\eta 2 = .355$; without distractors, $\lambda = .666$; $F(4,82) = 10.270$; $p < .001$; $\eta 2 = .334$]. The X-No task showed a higher effect size than the other condition. Age was statistically significant [distractors, $\lambda = .630$; $F(4,82) = 12.057$; $p < .001$; $\eta 2 = .370$; no distractors, $\lambda = .593$; $F(4,82) = 14.086$; $p < .001$; $\eta 2 = .407$]. Consistent with the previous condition analyzed, omissions and response time were the most significant variables. While commissions were less frequent in the group without ADHD in both conditions, significant differences between the groups were only found in absence of distractors.

Discriminatory value of cognitive and attentional variables identifying students with and without ADHD

First of all, correlation analyses revealed the existence of statistically significant associations between cognitive and attentional measures, but only in the case of working memory. This variable correlated negatively with all the Aula Nesplora general measures, being significant in the case of omissions, $R^2 = -.224$, $p < .05$, and response time, $R^2 = -.217$, $p < .05$.

Table 3 shows results from the different discriminant analyses, whose objective was to examine the explanatory power of the attentional and cognitive variables to predict student group membership (ADHD or Control group). To this end, attentional variables provided by Aula Nesplora were used (Aula Nesplora general measures, and separated analyses for pairs of conditions). Additionally, WISC-IV working memory and processing speed were also included as potential predictors of group membership, along with age and gender. Standardized coefficients represent the correlations between the discriminant function and the variables, revealing the most influential variable in each case. Function coefficients provide the resulting discriminant function.

Table 3. Results of discriminant analyses, using stepwise method. Analyses with Aula Nesplorageneral variables, and for pairs of conditions.

	Standardized Coefficients	Function Coefficients	*F*
	Aula Nesplora General		
O	1.193	.050	26.077
Age	.610	.217	17.444
Constant		-3.690	

Aula Nesplora Visual vs. Auditory Channel			
O (Visual)	.798	.045	19.173
O (Auditory)	.525	.042	13.021
Age	.515	.183	10.807
WM	-.359	-.029	9.758
Constant		-.092	
Aula Nesplora X vs. X-no			
O (X-no)	.832	.039	23.181
WM	-.498	-.040	15.199
Constant		3.315	
Aula Nesplora Distractors vs. No distractors			
O (No distractors)	.838	.054	25.694
Age	.696	.248	16.882
RT (Distractors)	.462	.003	13.044
C (No distractors)	.429	.040	11.419
Constant		-6.966	

Note. WM = Working memory; O = omissions; C = commissions; RT = response time associated with a correct answer).
All models are significant at a p < .001 level. Only the variables that resulted statistically significant are shown.

Considering the first model (with Aula Nesplora general measures), only omissions and age were statistically significant predictors of group membership. Omissions showed the highest standardized coefficient, being the most relevant variable identifying subjects with and without ADHD. The statistics indicated that the older the student and the higher the score in omissions, the higher the probability to present ADHD. This model classified 76.1% of the sample correctly (66% from the control group, and 89.5% from the ADHD group).

Taking into consideration the different conditions of the task, omission was present in all the models tested, being the strongest predictor of student group membership. This variable was significant in both visual and auditory conditions, as well as in X-no task and under the no distractors paradigm, showing the same relationship to ADHD symptoms as in the previous model. Age was also a significant predictor in most of the models, showing in all of them a positive relationship with the presence of ADHD. working memory turned was a significant predictor of group membership only in some test conditions (i.e., Visual vs. Auditory channel, and X vs. X-no task), but was not for the general measures, or when the condition Presence vs. Absence of distractors was taken into account. Finally, when the last pair of conditions were analyzed, two new variables were significant (i.e. response time under the distractors condition, and commissions under the no distractors condition). These three models classified correctly a similar amount of students as the model with general measures: the models with both Visual vs. Auditory channel and X vs. X-no task classified correctly 75% of the sample (66% and 64% of the controls, and 86.8% and 89.5% of the students with ADHD, respectively), while in the case of the Distractors vs. No distractors condition, 76.1% of the students were correctly classified (70% from the control group, and 84.2% from the ADHD group).

On the whole the results indicated that the models that best classified students with ADHD were the model which consisted of the general measures of attention, and the one that related to X vs. X-no conditions. On the other hand, the model that best identified students without ADHD is the last model, which included the Distractors vs. No Distractors condition. The current results demonstrate an important role of omissions, age, and working memory deficits in predicting the probability of a child receiving a diagnosis of ADHD.

Discussion and Conclusions

The objectives of this study were (1) to describe and compare the cognitive and attentional profile of a sample of students with and without ADHD working memory and processing speed scales from WISC-IV, and attentional variables provided by virtual assessment tool Aula Nesplora; and (2) to determine the extent to which the aforementioned variables predicted student group membership, including the potential explanatory effect of gender and age., In line with previous studies the two groups of children differed significantly on the basis of their cognitive and attentional profile (Bart et al., 2014; García et al., 2014; Thaler et al., 2013).

At the cognitive level, children with ADHD showed lower scores in working memory and processing speed than the group without ADHD, although larger effect sizes between the groups were found in working memory rather than in processing speed. These results are consistent with previous studies which have demonstrated how children with ADHD perform worse in processing speed and working memory tasks than their peers without ADHD (Fried et al., 2016; Mayes & Calhoun, 2006).

At the attentional level, students with ADHD showed poorer performance in Aula Nesplora (more frequent omissions and commissions, higher response time and motor activity) than the control group. In addition, the characteristics of the Aula Nesplora test (different modalities or conditions) made it possible to describe some executive profiles under specific conditions. For example, when the results were analyzed as a function of the sensory modality, students make more commissions and omissions when the visual channel was used, in comparison to when the auditory channel was examined for both the ADHD and Control groups. On the other hand, when the results were analyzed according to the type of task, both groups (ADHD and Control group) produced more omissions as well as higher motor activity in Go-tasks. Given its design, Aula Nesplora provides the possibility of obtaining different executive profiles, that are displayed under different contextual and stimulatory conditions, which may have important implications for the design and implementation of more adjusted interventions based on these profiles.

These results are similar to those obtained by Iriarte et al. (2012). For the general measures (average score for each variable, regardless of the condition), results showed that omissions and response time were the variables which generated the largest differences between the groups. Moreover, this pattern remained when each specific condition was analyzed (e.g., presence and absence of distractors, visual and auditory channel, go/no go tasks). The relevance of these variables, related to inattentive symptoms in previous studies (Areces et al., in press), and can be explained by the high prevalence of attention deficit symptoms reported in the current sample of students with ADHD. Nonetheless, separate analysis by modality showed that the statistical power of the test in discriminating students with and without ADHD was higher for the visual channel, for x-no tasks and in presence of distractors. These results demonstrate the importance of collecting the same variables under different conditions in order to obtain an accurate diagnosis while increasing ecological validity by means of new assessment tools (García et al., 2014). The Aula Nesplora, unlike other traditional CPTs, provides the possibility of discriminating between tasks in both presence and absence of distractors, an aspect that is relevant to the diagnosis of ADHD (Díaz-Orueta et al., 2014; Iriarte et al., 2012) and important for the modification of classroom learning environments.

Similarly, although both cognitive and attentional components were important in order to establish a profile in ADHD, the amount of variance explained by attentional variables was larger than the explained by cognitive variables in the present study, as indicated by the effect sizes. This means that although cognitive profiles in ADHD can be used to provide a diagnosis of ADHD they may be insufficient to establish a diagnosis by themselves (Mayes & Calhoun, 2006).

Concerning the second objective whose purpose was to determine the extent of attentional and cognitive variables for predicting student group membership, results showed that specific attentional and cognitive variables analyzed allowed the classification of a significant proportion of the students into diagnostic group. Particularly, omissions, working memory, and age, were revealed as the most significant predictors within the different models analyzed. In this sense, working memory impairments, an increase in age, and the presence of a large amount of omissions in Aula Nesplora were significantly related to a high likelihood to have a diagnosis of ADHD. The models were more useful discriminating subjects with ADHD than controls, as expected given the nature of the task, aimed to identify students with the disorder. In this sense, it is observed that similar to other CPTs this virtual tool has demonstrated to have better levels of sensitivity than specificity (Riccio & Reynolds, 2001; Sollman et al., 2010). These results are consistent with previous studies that have identified the existence of a strong relationship between ADHD and working memory impairment. These studies highlighted how working memory affects students' performance on attentional tasks. These results suggest that poor performance in attentional tasks and CPTs may not only be due to attentional problems, but also may be explained by working memory impairment (Fried et al., 2016; Mayes & Calhoun, 2006;

Nyden et al., 2001). Findings from the present study also demonstrate the importance of age in the diagnosis of ADHD. This relationship between age and performance on attentional tasks is predicted since previous research suggests that the persistence of ADHD symptoms over time, might be an important indicator about the severity of ADHD and its presentations (Barkley & Murphy, 2010).

Finally, these findings suggest that, focusing only on one of the test conditions (e.g. Visual vs. Auditory channels) may have some advantages over the whole test, such as a reduction in data interpretation. However, this study also highlights the necessity of taking into account additional measures (working memory, for instance) in order to reach a similar discriminant value than that provided by the whole test itself and age, a model that, in turn, results more parsimonious. This would ultimately depend upon professionals´ choice and assessment purposes. Although this study suggests preliminary evidence supporting this hypothesis, additional studies are necessary.

Limitations and future directions

Some limitations of the present study should be considered in future investigations. Firstly, additional studies with a wider sample size are needed in order to examine whether the statistical power of the variables analyzed are similar to that obtained in the present study. In addition, in order to identify the evolution process of ADHD symptoms, it is important to analyze the statistical power of the variables in the different age groups. Finally, a direct comparison between the Aula Nesplora with other traditional CPTs would test the benefits of the use of ecologically valid tools in the ADHD diagnosis.

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Discusión de resultados

Esta tesis doctoral se ha desarrollado como compendio de cuatro estudios aceptados y dos trabajos complementarios, los cuales se han llevado a cabo siguiendo tres objetivos generales. El primero de los objetivos trata de elaborar un modelo de evaluación del TDAH que considera las relaciones existentes entre variables de diferente tipología (en concreto, entre el rendimiento en tareas de ejecución y la activación cortical en áreas prefrontales). Por su parte, el segundo de los objetivos, pretende analizar si la incorporación de la realidad virtual a los test de ejecución continua (CPT) supone o no un avance en la evaluación de la sintomatología TDAH. Por último, el tercer objetivo trata de comprobar cómo se relaciona el rendimiento en las tareas de denominación con los problemas de atención y/o de lectura.

De este modo, cada uno de los objetivos mencionados permitió extraer diferentes resultados significativos, los cuales serán mencionados a continuación.

En relación al primero de los objetivos se llevaron a cabo dos estudios. En el primero de ellos, se propuso un modelo diagnóstico que tuviera en cuenta la relación entre variables de ejecución y variables de activación cortical en individuos con y sin TDAH. Concretamente, se observó que la relación entre las medidas de activación cortical y las medidas de ejecución es significativamente mayor en individuos con TDAH que en individuos sin dicho trastorno. Una posible explicación, consistiría en que el grupo con TDAH ha mostrado una activación cortical y oxigenación sanguínea (en las regiones Cz/Fpz y Fp1) significativamente por debajo de la media, lo que afecta notoriamente al rendimiento en tareas de ejecución continua (Lansbergen, Arns, Van Dongen-Boomsma, Spronk, & Buitelaar, 2011; Cubillo et al., 2012).

Además, al analizar la relación entre la activación cortical y la función ejecutiva, también se observaron resultados diferenciales dependiendo del área cerebral evaluada (Willcutt et al., 2012) (es decir, la activación en un área específica puede estar relacionada con un patrón particular de ejecución). Respecto a la activación cortical izquierda (Fp1), los resultados indicaron diferentes proporciones en la ratio beta-theta y una baja oxigenación de la sangre ante individuos que presentan una sintomatología de hiperactividad e impulsividad, que afecta al rendimiento de las tareas de ejecución continua cometiendo un mayor número de errores por comisión. Por otro lado, en el caso de la activación central (Cz/Fpz), se observa que aquellos que presentan bajos niveles de activación medidos a través de la relación beta-theta con el QEEG, también presentan una baja oxigenación medida por el nir-HEG, así como un mayor número de errores de omisión y mayores tiempos de respuesta en las tareas de ejecución continua (González-Castro et al., 2013).

Tales resultados son relevantes para la intervención, ya que una mejora en la sintomatología TDAH pasaría por un aumento en los niveles de activación en el área que se encuentra específicamente más alterada (Duric, Abmus, & Elgen, 2014; González-Castro, Cueli, Rodríguez, García, & Álvarez, 2016).

De esta forma, el modelo de evaluación propuesto en este estudio fue incorporado en el segundo de los trabajos de tipo descriptivo, cuyo objetivo consistió en elaborar un protocolo de evaluación del TDAH en el que se consideren variables de distinta tipología, las cuáles se encuentran relacionadas entre sí: variables cognitivas, variables de ejecución, variables de activación cortical… De este modo, para cada área o capacidad evaluar se han descrito una serie de pasos que permitirán detectar con mayor precisión y objetividad en qué nivel se encuentra el problema de TDAH.

En cuanto al segundo de los objetivos, el cuál trataba de comprobar en qué medida la realidad virtual en los CPTs es eficaz en el diagnóstico del TDAH, se llevaron a cabo otros dos estudios. El primero de ellos, trató de analizar la capacidad discriminativa de un CPT de realidad virtual (Aula Nesplora) entre los distintos tipos de presentaciones del TDAH, así como entre tales presentaciones y el grupo control. A nivel general, los resultados fueron similares a los de estudios precedentes (Egeland, 2007), los cuáles señalaron que la presentación combinada e inatenta del TDAH obtienen un mayor número de omisiones y tiempo de respuesta; mientras que la presentación de tipo impulsiva/hiperactiva se relaciona con un mayor número de comisiones (Rodríguez, et al., 2011).

Además, cuando se analizó el rendimiento en las tareas de ejecución continua en función del canal sensorial (auditivo o visual) se encontró que dicha diferenciación permite discriminar entre presentaciones de TDAH que no se detectan en un análisis general (es decir, cuando se analiza el rendimiento medio en las variables sin tener en cuenta otro tipo de características contextuales). Así, las diferencias entre la presentación impulsiva e hiperactiva y la presentación de tipo combinada sólo se evidencian en las omisiones registradas por el canal visual, obteniendo la presentación impulsiva e hiperactiva niveles de rendimiento más bajos. Del mismo modo, la distinción entre la presentación inatenta y la de tipo combinada sólo se ha manifestado en número de comisiones recogidas en el canal auditivo.

En este sentido, estos resultados sugieren que AULA Nesplora (CPT con realidad virtual) muestra una tendencia a detectar eficazmente las diferentes presentaciones de

TDAH, con ciertas diferencias al analizar las mismas variables bajo diferentes condiciones proporcionadas por la prueba (Sancho, Pardo, González, & García, 2015).

Considerando estos resultados, la siguiente cuestión planteada consistía en comprobar la capacidad discriminativa de Aula Nesplora para detectar casos con y sin TDAH. Más concretamente, en el segundo trabajo enmarcado en el segundo de los objetivos generales, se pretendía verificar el poder explicativo de variables cognitivas (proporcionadas por las Escala Wechsler, 2005) y de ejecución (recogidas con la prueba Aula Nesplora) para predecir la pertenencia a los grupos (con TDAH y sin TDAH) con el fin de conocer qué variables predicen mejor la pertenencia a un grupo determinado, así como de verificar los niveles de especificidad y sensibilidad de las pruebas. Los resultados revelaron que las variables que tienen un mayor poder explicativo son el número de omisiones, el rendimiento en memoria de trabajo y la edad. Estos resultados sugieren que el mal desempeño en las tareas de atención no sólo puede ser debido a problemas de atención, sino que también puede ser explicado por deterioro de la memoria de trabajo (Fried et al, 2016). Asimismo, el hecho de que la variable edad tenga un valor explicativo significativo en la predicción del TDAH, puede deberse a que la persistencia de los síntomas del TDAH en el tiempo ha mostrado ser un indicador importante acerca de la gravedad del TDAH y sus presentaciones (Barkley & Murphy, 2010).En cuanto a los niveles de especificidad y sensibilidad de la prueba Aula Nesplora, al igual que otros CPTs, los resultados mostraron mayores niveles de sensibilidad que de especificidad (Riccio & Reynolds, 2001).

Finalmente, el tercero de los objetivos consistía en analizar la relación entre velocidad denominación con variables relacionadas con la atención y la lectura. Para ello, el primero de los estudios trato de comprobar cómo los errores de lectura y las variables de ejecución predicen el rendimiento en tareas de denominación de estímulos visuales. Los resultados han comprobado que si bien las tareas de denominación (a través de la prueba RAN/RAS) se ven influidas por variables de distinta naturaleza (edad cronológica, errores de lectoescritura, variables de ejecución…), tales variables tienen un efecto diferencial en función del grupo diagnóstico analizado. Concretamente, los tiempos de denominación analizados en el grupo control quedan explicados fundamentalmente por las variables género, CI y edad. Por su parte, cuando se analiza el grupo con dificultades lectoras, no es posible predecir los tiempos de denominación en base a las variables contempladas en el modelo anterior (CI, edad y género), ya que en este caso se requiere de la inclusión de variables adicionales relacionadas con los errores de lectura. Mientras que, por su parte, cuando se analiza el grupo con TDAH, éste requiere de la inclusión del número de comisiones. Tales resultados muestran la relación existente entre las tareas de denominación y los procesos lectores y atencionales implicados en ellas (Roessner et al., 2008; Stringer, Toplak, & Stanovich, 2004).

En este sentido, comprobada la relación entre las tareas de denominación y las variables implicadas en la lectura y los procesos atencionales, el siguiente objetivo consistió en analizar el poder explicativo de las tareas de denominación para predecir la presencia o ausencia de dificultades lectoras y/o atencionales. Los resultados de este estudio mostraron que las tareas de denominación eran más eficaces en la detección de dificultades lectoras a edades tempranas (por debajo de los 10 años). Esto puede ser debido a que, por encima de los 10 años, el grado de dificultad de las tareas de denominación decrece de forma considerable y todos los grupos (tanto lo que tienen dificultades lectoras como lo que no) obtienen un rendimiento medio, medio-alto (Elosúa et al., 2012). De igual modo, los resultados encontraron que las tareas de denominación solo son capaces de detectar los problemas atencionales a edades tempranas. A partir de los 10 años, los síntomas recogidos en el DSM (APA, 2013) contenidos en diferentes escalas de observación, son mejores predictores de los problemas atencionales que el rendimiento obtenido en las tareas de denominación.

Implicaciones prácticas

Considerando los resultados obtenidos, una de las implicaciones más significativas que se puede extraer de la presente tesis doctoral es la necesidad de llevar a cabo una evaluación precisa y exhaustiva que no debe de limitarse a la evaluación de la atención, sino que deben ser medidas otras variables como las variables cognitivas o variables relacionas con la activación cortical, además de las variables autobiográficas aportadas por la entrevista. Asimismo, también se ha podido comprobar la eficacia de evaluar la atención con pruebas dotadas de validez ecológica (que utilicen la realidad virtual para sumergir al evaluado en una clase similar a la que se encuentra diariamente). Este tipo de pruebas permiten detectar los problemas atencionales o de tipo conductual de una forma más realista que las pruebas basada de papel y lápiz. De este modo, se ha comprobado la eficacia de las mismas para diferenciar entre los tres tipos de presentación del TDAH. Además, es posible detectar la influencia de los elementos distractores en la sintomatología TDAH, lo que supone un dato muy relevante para planificar la intervención.

Finalmente, otra implicación práctica relevante derivada de esta tesis doctoral, sería el uso de las tareas de denominación para detectar de forma temprana niños en riesgo de padecer problemas lectores y/o atencionales. El hecho de poseer indicadores tempranos, facilita a los profesionales poder trabajar con los niños/as de forma previa a que se manifiesten de forma clara los síntomas, de tal forma que disminuye la probabilidad de complicaciones futuras.

Limitaciones y líneas futuras

Es conveniente señalar las limitaciones presentes en los estudios que componen esta tesis doctoral. En primer lugar, sería conveniente aumentar la muestra, con el fin de detectar si los resultados se mantienen en muestras más representativas. Por otro lado, otra limitación que debe ser tenida en cuenta en futuros trabajos de investigación consistiría en comprobar si la capacidad predictiva de las tareas de denominación se ve influida por los distintos tipos de presentación de TDAH.

En sentido, como línea futura, se plantea continuar con el análisis de la eficacia en herramientas de evaluación del TDAH. Para ello, se trabajará para disponer de mayor tamaño de muestra de sujetos con y sin TDAH, lo que permitirá diferenciarlos por edades (en el grupo con TDAH también se diferenciará, a su vez, por el tipo de presentaciones) con el objetivo de detectar el tipo de herramienta más eficaz dada una edad y unas características atencionales y comportamentales observables.

Conclusiones

- Un bajo rendimiento en variables de ejecución (especialmente el número de omisiones, comisiones, tiempo de respuesta…) recogidas por un CPT se relaciona con una baja activación cortical y unos bajos niveles de oxigenación sanguínea en las áreas prefrontales Fp1 y Cz/Fpz (medidas obtenidas a través del QEEG y el nir-HEG).
- La relación entre variables de ejecución y de activación cortical han mostrado diferencias en función del tipo de presentación de TDAH. Más específicamente, los síntomas asociados a impulsividad e hiperactividad se evidencian en forma de un mayor número de comisiones y un baja activación cortical y oxigenación sanguínea en las regiones Fpz/Cz. Mientras que, por otro lado, los síntomas de inatención se manifiestan en forma de un incremento significativo en el número de omisiones y descenso en la activación cortical y oxigenación sanguínea en la región Fp1.
- En los protocolos diagnósticos del TDAH se debe evaluar más allá de la atención. Es importante que los profesionales tengan en cuenta y analicen diferentes tipos de variables: variables autobiográficas (obtenidas a través de entrevista), variables cognitivas (obtenidas a través del perfil cognitivo, en especial es necesario prestar atención a la memoria de trabajo y la velocidad de procesamiento), variables de ejecución (atención, control inhibitorio…) así como los niveles de activación cortical en las áreas prefrontales.
- La realidad virtual en los CPTs ha mostrado ser eficaz en la población analizada para detectar los diferentes tipos de presentación de TDAH, que en ocasiones resulta complejo llevar a cabo su discriminación.

- El número de errores por omisión recogidos a través de un CPT que utiliza realidad virtual (Aula nesplora), el rendimiento en la memoria de trabajo (obtenido a través de la escala Weschler), y la edad de los estudiantes, han mostrado ser tres variables relevantes a la hora de detectar un caso/no caso de TDAH.
- Las variables relacionadas con la lectura (los errores presentes en la lectura) y las variables de ejecución relacionadas con la atención (índices ofrecidos por el CPT: omisiones, comisiones, tiempo de respuesta …) han mostrado tener un valor explicativo diferencial sobre los tiempos de denominación en función del diagnóstico analizado.
- El tiempo invertido en las tareas de denominación (en concreto, la tarea de denominación compuesta por colores) predice el 73% de los casos con Dificultades Lectoras con edades comprendidas entre los 5 y los 9 años. A partir de los 10 años, no ha mostrado ser eficaz en la detección de las mismas.
- Para predecir adecuadamente la pertenencia al grupo con TDAH, el rendimiento obtenido en las tareas de denominación no es suficiente por sí solo, ya que es necesario que éste se acompañe de información relativa a la sintomatología TDAH (contenida en el DSM-5) presente en cada caso.

Conclusions

- Low performance in execution variables (especially the number of omisions, commissions, response time…) as obtained through a CPT relates to low cortical activation and low blood oxygenation levels in pre-frontal areas (as measured by the QEEG and nir-HEG).
- The relationship between execution and cortical activation variables has shown differences depending on the types of occurrence of ADHD. More specifically, symptoms associated to impulsiveness and hyperactivity appear in the form of a higher number of commissions and low cortical activation and blood oxygenation in the Fpz/Cz regions, whereas symptoms of inattention appear in the form of a significant increase in the number of omissions and a decrease in cortical activation and blood oxygenation in the Fp1 region.
- Diagnostic tests for ADHD must evaluate further from attention. It tis important for professionals to consider and analyse different types of variables: autobiographical variables (obtained through an interview), cognitive variables (obtained through the cognitive profile, particularly working memory and processing speed), execution variables (attention, inhibitory control…), together with prefrontal cortical activation levels.
- Virtual reality in CPTs has proved efficient in the detection of the different type of presentation of ADHD in the sample analysed.
- The number of omission errors registered with a CPT using virtual reality (using Aula Nesplora test), working memory performance (as obtained with the Weschler

schale) and the age of the students have proved relevant variables in predicting group membership: a case/non-case of ADHD

- Variables relating to reading (errors in reading) and execution variables relating to attention (as indexed by the CPT: omissions, commissions, response time…) have differential explanatory value, depending on the diagnostic group analysed.
- The amount of time used up in naming tasks (particularly the naming task with colours) predicts a 73% of cases with reading difficulties in ages 5 to 9. After the age of 10 it has not proved efficient in detecting such difficulties.
- In order to adequately predict group membership for ADHD, performance in naming tasks alone is not sufficient, as it must be complemented with information about the ADHD symptoms (as contained in the DSM-5) present in each case.

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