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Implication of Visuospatial and Phonological Working Memory in the Clinical Heterogeneity of Attention-Deficit/Hyperactivity Disorder (ADHD)

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Título: Implicación de la memoria visoespacial y fonológica en la heterogeneidad clínica del Trastorno por Déficit de Atención con Hiperactividad (TDAH).

Resumen: *Introducción:* Recientemente se ha incrementado el interés en el estudio de los déficits neuropsicológicos que subyacen al TDAH. Entre ellos, destaca la Memoria de Trabajo (MT) en sus dimensiones visoespacial y fonológica. El objetivo del presente estudio fue explorar las diferencias de rendimiento en memoria a corto plazo y memoria de trabajo visoespacial y fonológica entre un grupo control y un grupo clínico, teniendo en cuenta la heterogeneidad clínica del trastorno.

Método: Se formó un grupo clínico de 76 niños con un diagnóstico previo de TDAH, divididos según su subtipo clínico: TDAH predominantemente inatento (n = 26, edad M = 10,9, SD = 1,8; 66% varones), y TDAH combinado (n = 50, edad M = 10.8, DT = 1.9; 61.5% varones). Además, se formó un grupo control conformado por niños sin diagnóstico TDAH (n = 40, edad M = 10.2, SD = 1.9; 57.5% varones). A todo ellos se les administró un batería de pruebas para medir la memoria a corto plazo y la memoria de trabajo, tanto visoespacial como fonológica.

Resultados: El grupo TDAH obtuvo un peor rendimiento en las tareas de Memoria de Trabajo visoespacial (Tarea Corsi) y fonológica ("Letras y Números" de WISC). Este peor rendimiento se mantuvo también para los subtipos clínicos. No se halló relación entre las dimensiones del TDAH y el rendimiento en las tareas neuropsicológicas empleadas.

Discusión: Este estudio aporta evidencia empírica a la hipótesis que sugiere que los niños con TDAH presentan un menor rendimiento en tareas que implican la memoria de Trabajo, tanto respecto a la memoria de trabajo fonológica como visoespacial. Además, los resultados de este estudio sugieren que no existiría una relación entre las dimensiones principales del TDAH y el rendimiento en las tareas de memoria de trabajo.

Palabras clave: TDAH; Rendimiento Neuropsicológico; Memoria a Corto Plazo; Memoria de Trabajo Visoespacial; Memoria de Trabajo Fonológica.

Abstract: *Introduction:* The interest in studying the neuropsychological deficits that lie behind ADHD, among which the Working Memory (WM) stands out in its visuospatial and phonological dimensions, has been on increase. The aim of the current study was to explore the performance differences concerning the short-term memory and the visuospatial and phonological working memory among control and clinical groups acknowledging the clinical heterogeneity of the disorder.

Method: A group of 76 children with a prior diagnosis of ADHD was divided by the clinical subtype of the disorder: ADHD predominantly inattentive (n = 26, age M = 10,9, SD = 1,8; 66% male), and combined ADHD (n = 50, age M = 10.8, DT = 1.9; 61.5% male). Additionally, a control group of *typically developing* children was formed (n = 40, age M = 10.2, SD = 1.9; 57.5% male). Both groups completed a task battery to aimed to measure the short-term memory, as well as the visuospatial and phonological working memory.

Results: The ADHD group showed a decreased performance at visuospatial (Corsi Block Task), as well as phonological (WISC Letter-Number Sequencing) working memory tasks. The decreased performance was consistent among the clinical subtypes. The dimensions of ADHD and the performance output in the neuropsychological tasks used in the study were not related.

Discussion: This study offers empirical evidence to the hypothesis that suggests that children with ADHD show a poor performance than controls at Working Memory tasks, including both visuospatial and phonological WM. In addition, the results of the study suggested that there is no correlation between the dimensions of the ADHD and the performance output in the Working Memory tasks.

Key Words: ADHD; Neuropsychological Performance; Short-Term Memory; Visuospatial Working Memory; Phonological Working Memory.

Introduction

The validity of the bidimensional structure of the Attention-Deficit and Hyperactivity Disorder (ADHD) –defined by the "inattention" and "hyperactivity/impulsivity" dimensions – holds a broad empirical support (Willcutt et al., 2012). Nevertheless, the clinical heterogeneity of ADHD is patent in many different levels (Wåhlstedt, Thorell, & Bohlin, 2009), most notably at neuropsychological level (Coghill, Seth, & Matthews, 2014; Sjöwall, Backman, & Thorell, 2015; van Hulst, de Zeeuw, & Durston, 2015). Some authors have suggested that it is the deficits in executive function that underlays ADHD-specific difficulties (Barkley, 1997; Castellanos & Tannock, 2002; Gau & Shang, 2010; Sergeant, Geurts, & Oosterlaan, 2002), rendering the executive function deficit as a cognitive endophenotype of ADHD (Castellanos & Tannock, 2002), often associated with the prefrontal cortex, particularly in its dorsolateral area (Smith & Jonides, 1999). Regardless, the impairment executive functions in ADHD don't seem to be a necessary, or enough of a condition to cause the disorder (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005).

The executive functions include a variety of cognitive superior-order abilities, where the response inhibition, the working memory (WM), and cognitive flexibility are considered as core functions (Miyake et al., 2000). Numerous studies suggest that the executive function deficits in ADHD are related with the WM (Diamond, 2005; Kasper, Alderson, & Hudec, 2012; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005). The WM provides short-term storage and information manipulation needed for complex cognitive tasks such as language comprehension, learning, and reasoning (Baddeley, 1992), as well as planning, problem-solving and goal-directed behavior (Martinussen et al., 2005). The WM is composed of two subsystems of the specific domain involved in arbitrating the short-term information storage: the articulatory loop and the visuospatial sketchpad (Baddeley & Hitch, 1974). The *articulatory loop* is responsible for short-term memory storage and verbal information rehears-

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al, whereas the *visuospatial sketchpad* is in charge of visuospatial information rehearsal as well as short-term memory storage. The two storage subsystems assist the *central executive*, described as a general domain component of limited capacity that is responsible for attentional control. The central executive steps in when higher processing levels are needed within the WM, supervising and coordinating the two memory subsystems of a specific domain.

Given the importance of the role that WM could be playing in ADHD, during the past years there has been an increasing interest in identifying whether the deficiencies seen in cognitive task performance that measure the WM are due to a deficiency in one of the specific domain system, or both, or whether this deficiency is the result of a more generalised deficit related to the deterioration of the central executive, i.e. the retention and manipulation of information (Alderson, Hudec, Patros, & Kasper, 2013; Guérard & Tremblay, 2008; Kofler, Rapport, Bolden, Sarver, & Raiker, 2010; Martinussen & Tannock, 2006; Willcutt et al., 2005). In this regard, Brocki, Rendall, Bohlin, and Kerns (2008) imply a higher deficit in phonological WM in ADHD, as previous studies suggest (Alderson et al., 2013). However, other studies hint that the deficiencies lie in the visuospatial WM (Martinussen et al., 2005; McInnes, Humphries, Hogg-Johnson, & Tannock, 2003; Rapport et al., 2008; Rommelse et al., 2008; Westerberg, Hirvikoski, Forssberg, & Klingberg, 2004; Willcutt et al., 2005). A third group of investigations point at a more generalised WM decay, a central executive deficit (Alderson, Kasper, Hudec, & Patros, 2013; Dovis, Van der Oord, Wiers, & Prins, 2013; Nyman et al., 2010; Raiker, Rapport, Kofler, & Sarver, 2012; van Ewijk et al., 2014).

On the other hand, many empirical investigations found a relationship that bonds the performance of WM-related tasks with the severity of ADHD symptoms. Thus, Tillman, Eninger, Forssman, and Bohlin (2011), found a proportionally inverse relationship between the performance in phonological and visuospatial WM tasks and the levels of inattention, as well as a significant relationship between hyperactivity/impulsivity symptoms and the phonological WM performance, not in the visuospatial component. These results suggest the implication of different processes of the components that form the WM given the dimensions of ADHD (Tillman et al., 2011), for example, the symptoms of hyperactivity (Rapport et al., 2008), impulsivity (Raiker et al., 2012) or inattention (Burgess et al., 2010; Holmes et al., 2010; Kane et al., 2007), as well as a greater connection between the central executive dysfunction and inattention (Willcutt et al., 2005b).

The WM is considered key for understanding the events taking place in time, establishing cause-effect relationships and connect them with previous information, which allows for the deduction of a general principle or creating new associations and information (Diamond, 2012). Accordingly, it is suggested that there's a strong relationship between the WM and the academic performance i.e. learning (Gathercole & Alloway, 2007), particularly between the different components of the WM and the academic performance (St Clair-Thompson & Gathercole, 2006; Swanson & Kim, 2007; Wilson & Swanson, 2001). The population with ADHD have been found as worse performing in WM-related tasks than the general population (Kasper et al., 2012), also suggesting that the WM deficit could justify the comorbidity associated with the disorder (Diamond, 2005). Perhaps the previous literature of experimental and meta-analytic studies present contradictory conclusions about the WM deficit in ADHD, maybe as a consequence of methodological variables such as the constitution of heterogeneous groups that make no differences between the subtypes of the disorder (Kasper et al., 2012), the broad age spectrum within the study, dismissing the possible age-related effects (Martinussen et al., 2005) or not acknowledging the comorbidity associated to ADHD at the time of studying the relationship between the WM and the disorder (Martinussen & Tannock, 2006). Consequently, given the impact that the WM seems to have in academic performance, which is observable deteriorated in ADHD (Rogers, Hwang, Toplak, Weiss, & Tannock, 2011), we find a deeper exploration of the relationship existing between the WM and the normal properties of ADHD relevant, the goal being a better understanding that would allow for specific interventions on the cognitive performance of this population group.

The main objective of the current study was to explore the role the WM plays in the clinical heterogeneity of ADHD. The first objective was to explore the relationships among the performances in neuropsychological tasks of verbal and visuospatial memory, and the clinical heterogeneity of ADHD. The second objective was to analyze the role of the WM in its verbal and visuospatial dimensions in the different ADHD subtypes.

Method

Participants

The study was formed by 116 children of both sexes with ages ranging between 8 and 14 (Table 1). During the study, there was assembled a clinical group of children with a previous diagnosis of ADHD and with a clinically significative symptomology (n = 76, age M = 10.8, SD = 1.9), divided by the clinical subtypes, i.e. ADHD predominantly inattentive (ADHD-I; n = 26, age M = 10,9, SD = 1,8; 66% male), and combined ADHD (ADHD-C; n = 50, age M = 10.8, SD = 1.9; 61.5% male). A control group was formed by children without ADHD diagnosis nor associated symptomology during the time the study took place (n = 40, age M = 10.2, SD = 1.9; 57.5% male). Neither of the participants presented a severe clinical comorbidity. Even though the 53.8% of the ADHD-I group and the 52% of the ADHD-C group underwent a pharmacological treatment for ADHD, neither of them were under the effects of medication during the study.

Table 1. Demographic and Clinical Information of the Sample.

Variables *M*(*DT*)	Control Group (1)	Clinic Groups ADHD-I (2)	ADHD-C (3)	*F*/χ^2	Post-Hoc[a]
N	40	26	50		
Age	10.2(1.9)	10.8(1.9)	10.9(1.8)	n.s	
Men (%)	57.5	66	61.5	n.s	
Medicated (%)		53.8	52.0	n.s	
ADHD-RS-IV Parents					
Inattention	4.0(2.4)	17.6(4.1)	20.7(4.2)	187.0*	1<2.3
Hyp/Imp	3.4(2.8)	7.8(4.6)	18.5(3.9)	113.1*	1<2<3
ADHD-RS-IV Teachers					
Inattention	5.2(4.8)	18.8(3.9)	19.6(3.9)	107.2*	1<2.3
Hyp/Imp	3.2(3.8)	5.8(6.6)	18.6(5.9)	74.3*	1<2<3
ADHD-CDS	5.8(4.6)	19.5(5.6)	24.6(7.9)	87.5*	1<2<3

Note. ADHD-I = ADHD predominantly Inattentive type group; ADHD-C = ADHD Combined type; Hyp/Imp. = Hyperactivity/Impulsivity; ADHD-RS-IV = ADHDA-Rating Scale IV; ADHD-CDS = ADHD Concomitant Difficulties Scale.
[a] < > indicates that the group(s) on the left of the symbol had worse performance.
*p < .05

Measures

The following clinical and neuropsychological performance measures were used in the study:

Clinical measures

-ADHD Rating Scale-IV (ADHD-RS) (DuPaul, Power, Anastopoulos, & Reid, 1998). It's a Likert-type scale that consists of nine items for measuring the symptoms of lack of attention and nine items for measuring the symptoms of hyperactivity/impulsivity, punctuating every item by the frequency scale of four points starting at 0 ("Rarely or never") to 3 ("Very frequently"). The scale showed an adequate internal consistency so much on the family's side (Cronbach's α = .93 and .88, inattention and hyperactivity/impulsivity, respectively) as on teacher's (Cronbach's α = .94, so much for inattention as for hyperactivity/impulsivity).

-ADHD Concomitant Difficulties Scale (ADHD-CDS) (Fenollar-Cortés & Fuentes, 2016). It is a brief scale of 13 items with 4 answer options of veracity, ranging from 0 ("Not true") to 3 ("Completely true"), which measures the difficulties concomitant to ADHD, and includes areas such as emotional management, fine psychomotricity, executive functions, reading and math performance, quality of life and sleeping habits. Cronbach's α for the scale was .90.

Neuropsychological Tasks

- *Sub-test "Digits", The Weschler Intelligence Scale for Children* (WISC-IV) (Wechsler, 2005). Within this verbal memory task (Passolunghi & Mammarella, 2010) the evaluated subject is asked to repeat a set of numbers of growing order, first in direct order (used for measuring the phonological short-term memory), then in inverse order (measuring the phonological WM). The dependent variable is the number of series remembered correctly.
- *Sub-test "Letters and Numbers", de* WISC-IV (Wechsler, 2005). In this task, the subject must remember verbally a series of numbers and letters presented together. The dependent variable is the number of series remembered correctly. It is a phonological/verbal WM measure (Alderson et al., 2013).
- *Working Memory Visuospatial (WMVS)* Task (adapted from Rapport et al., 2008). It this task, which is considered as a WM visuospatial measure, the subject has to reproduce a sequential series of black and red points in a matrix of 9 fixed locations (800 ms. y 200 ms. intertapping). The red points have to be omitted. Every successful trial adds one more point in the subsequent series. The dependent variable is the number of series reproduced in the correct order by the subject.
- *Corsi Block-tapping Task* (adapted from Corsi, 1973). The subject is presented with a matrix of 4 fixed locations which flash successively (800 ms. y 200 ms. intertapping), and the subject must repeat the sequence in the same order. The slots flash for 800 ms. followed by intertapping intervals of 200 ms. The dependent variable is the number of series reproduced in the correct order by the subject. This task is considered a measure of short-term visuospatial WM (Pickering & Gathercole, 2004; Richardson, 2007). In the present study, the task is by condition presented mute and monochromatic.
- *"The children´s size-ordering task" (CSOT)* (McInerney, Hrabok, & Kerns, 2005). It's a short task intended to measure the verbal WM. In this task the subject is presented with a list of words related to common use objects, red loudly by the evaluator at a pace of one word per second, and the subject must remember and verbalize the list of words, but in reversed order of size/extension. At first, the test starts with two to seven words for rehearsal purposes. The test has no time limit. The dependent variable is the total of elements remembered correctly.
- *Memory match task*. This lab-based task consists of a set of cards displayed in a 7x8 matrix, containing an image in the hidden face. The subject's task is to select pairs of cards, which after being selected, displayed the hidden image for two seconds, then remember the location of

each card in order to find a match of identical images which after being selected, were removed from the set. It is a measure of visuospatial WM. The dependent variable is the time spent to match all the cards.

Procedure

The authors contacted 23 education centers from the metropolitan area of the city of Murcia (Spain), of which 19 showed interest in participating in the study. The criteria for clinical group inclusion was to have a previous diagnosis of ADHD made by a mental health specialist separate from the study, show ADHD symptomology during the moment of the study, not being diagnosed with a severe mental disorder, not having physical problems that could affect the performance in execution tasks, and in case of being pharmacologically treated, to be in medication withdrawal for at least 24 hours before the tests take place. The criteria for the control group was: not to have a previous diagnosis or show symptoms of ADHD at the time of the study, be free of physical problems or mental disorders that could affect the execution tasks, and have an average scholar performance in regard to the rest of the class.

The algorithm of decision for the classification of experimental subjects in clinical subgroups was carried out through the ADHD-RS-IV scale, keeping in consideration the total punctuation as well as the number of symptoms present at the moment of the study. The children that surpassed the 90th percentile, as well as showed 6 or more symptoms in both dimensions – "inattention" and "hyperactivity/impulsivity"-, agreed upon by parents and teachers, were assigned to the ADHD-C group. The subjects included in the ADHD-I group followed the same conditions in the "inattention" dimension only.

The tests were executed in random order, in hypostimulant environments and under the supervision of the investigators. All the families were properly informed about the purpose of the study and signed in agreement for their children to participate in the study.

The investigation protocol was approved by the Ethical Committee of Clinical Research of the University of Murcia.

Data Analysis

The data analysis of this study consists of three phases:

In the first place, Kolmogórov-Smirnov (K-S) tests were conducted in order to contrast with the normality in data distribution differentiating the control and clinical groups, as well as the Levene's tests for equality of variance.

The possible differences between the clinical and control groups were explored for every single of the neuropsychological measures. Given the nonparametric distribution of data, the Mann Whitney U and Kruskal-Wallis H tests were used, as well as the *r* test, in order to calculate the scale of the effect. For the sake of interpretation of the scale of the effect, we'll establish .1 as small, .3 as medium and .5 as large (Coolican, 2009, p. 395).

(iii) The study of the relationship between the clinical variables measured with the scales and the performance in the neuropsychological tasks, was conducted in two parts: The first phase consisted in the exploration of the relationship between said clinical variables and the performance in the neuropsychological tasks through the Spearman correlation analysis, given the nonparametric distribution of data. During the second phase, the tasks that showed a significant correlation with the clinical scores were standardized as Z punctuations and included in multiple regulation models with the clinical punctuations as dependent values.

Results

A non-normal data distribution among the tasks has been observed (K-S $< .05$), with the prevalence of homogeneity of variances (Levene's tests $> .05$). A decision to use non-parametric tests was taken based on these results. There haven't been found significant differences based on age ($t(114) = -1.67$, $p = .098$), nor sex ($\chi^2(1) = 0.54$, $p = .547$).

Differences between groups based on the performance in neuropsychological tasks

The performance differences in neuropsychological tasks have been explored between clinical and control groups, as well as among clinical subgroups and control group. The clinical group performed worse compared to the control group in the WMVS task (clinical group $Mdn = 27$, control group = 33), $U = 1080.5$, $p = .011$, $r = -.24$, and the Numbers and Letters task (clinical group $Mdn = 5$, control group = 7), $U = 879$, $p < .001$, $r = -.35$. The scale of the effect oscillated between small and medium. In the rest of the tasks, no significant differences were found.

With the purpose of comparing the performance between the clinical subgroups and the control group, the Kruskal-Wallis tests were conducted (Table 2). The same significant differences have been found in the same tasks as in the previous section (i.e., WMVS & Numbers and Letters). In said tasks, the control group performed significantly better (*U* entre 227 y 722; *p*s $< .05$) than the subgroups ADHD-C and ADHD-I. The task that showing the largest difference between control group and clinical subgroups was "Numbers and Letters" ($r = -.38$ for the ADHD-C group, $r = -.40$ for the ADHD-I group), followed by the WMVS test ($r = -.24$ to $-.26$, ADHD-C and ADHD-I, respectively). Although the scale of the effect was larger for the differences between the control group against the ADHD-I group than against ADHD-C group, no differences had been found between the clinical subgroups.

The relationship between the dimensions of ADHD and the performance in neuropsychological tasks.

Partial correlation analysis (adjusted age) between the dimensions of ADHD and the performance in neuropsychological tasks had been conducted, differentiating between the clinical group and the control group. None of the neuropsychological measures correlated significantly ($p > .05$) with the dimensions of ADHD nor with the concomitant difficulties, for any of the groups. As expected, the regression analysis haven't produced statistically significant results.

Table 2. Comparison of the performance on WM tasks between the ADHD subclinical and control groups.

Variables *M*(*DT*)	Control group (1)	ADHD-I (2)	ADHD-C (3)	H^a	Dif.[b]	*U*	*n*	*p*	*r*
WMVS	39.9(21.7)	31.2(18.3)	31.5(17.5)	6.56*	1>2	359	66	.034	-.26
					1>3	721.5	90	.023	-.24
Corsi Block-Tapping Task	5.7(2.7)	5.7(2.2)	5.0(1.8)	1.83	1,2,3	n.s.			
Memory Match task	199.9(62.7)	207.5(71.4)	207.7(66.2)	0.65	1,2,3	n.s.			
Direct Digits	10.4(3.0)	10.0(3.2)	9.58(2.8)	1.74	1,2,3	n.s.			
Inverse Digits	10.6(3.4)	9.4(3.8)	9.3(3.0)	2.33	1,2,3	n.s.			
Letters and Numbers	6.5(2.1)	4.8(1.9)	5(1.9)	14.34*	1>2	277	66	.001	-.40
					1>3	602	90	.001	-.38
WM WISC-IV	88.2(14.3)	80.2(13.7)	80.4(12.4)	8.63*	1>2	341.5	66	.019	-.29
					1>3	674.5	90	.008	-.28
CSOT	13.0(6.5)	16.4(6.5)	16.9(6.7)	0.25	1,2,3	n.s.			

Note. ADHD-I = ADHD predominantly Inattentive type group; ADHD-C = ADHD Combined type; ADHD-RS-IV = ADHD-Rating Scale IV; ADHD-CDS = ADHD Concomitant Difficulties Scale.
[a] Significant differences between groups.
[b]Kruskal Wallis *H* Test
*$p < .05$

Discussion

The aim of this investigation was to explore the differences in performance between the groups corresponding to the subtypes of ADHD and the control group, to explore the relationship between the clinical heterogeneity of ADHD and the neuropsychological task performance which measure the components of the WM and the short-term memory in it's phonological and visuospatial dimensions, as well as to explore the role that WM plays as a predictive variable of clinical heterogeneity of ADHD.

The control group showed a better performance both in phonological (Bolden, Rapport, Raiker, Sarver, & Kofler, 2012) and visuospatial (Kofler et al., 2010; Martinussen et al., 2005; Rapport et al., 2008; Willcutt et al., 2005) working memory than ADHD subgroups (Alderson et al., 2013; Kasper et al., 2012; Schoechlin & Engel, 2005; Schweitzer, Hanford, & Medoff, 2006). However, the difference in phonological WM was limited to Letters and Numbers task, while the performance in Inverse Digits task was similar between ADHD and control groups (Holmes et al., 2014; Rosenthal, Riccio, Gsanger, & Jarratt, 2006).

Similarly, Mayer and Calhoun (2006) found that 88% of ADHD subjects had a poor performance in WM, which suggested that Working Memory Index from WISC could be useful as ADHD marker. However, it has been suggested that WISC-Inverse Digits task could really not need central executive component of working memory (Moleiro et al., 2013). That is, the WISC-Inverse Digits task would be qualitatively different from the Letters and Numbers task, in which the subject has to manipulate various kinds of stimuli at the same time.

Our findings are in line with previous studies which suggest a similar performance both in phonological and visuospatial short-term memory between ADHD and TD children (Alloway, 2011; Gibson, Gondoli, Flies, Dobrzenski, & Unsworth, 2009). In contrast, our results differ from previous studies which suggest neurobiological mechanisms and cognitive profiles differentiated by ADHD subtypes (Castellanos & Tannock, 2002).

Previous studies suggested a relationship between deficits in WM -for both phonological (Tillman et al., 2011) and visuospatial (Chhabildas, Pennington, & Willcutt, 2001) dimensions- and ADHD hyperactivity/impulsivity symptoms (Rapport et al., 2008) as well as in the attention processes (Burgess et al., 2010; Kane et al., 2007; Kofler et al., 2010; Martinussen & Tannock, 2006; Thorell, 2007). However, we did not find significant relationships between WM performance and ADHD dimensions. Contrary to Thaler, Bello, & Etcoff, (2013), the differences in WM performance we found between groups were limited to a categorical approach, not dimensional. That is, there were no relationships between ADHD symptoms severity and WM performance. However, the inconsistency of the results regarding the relationship existing between WM and ADHD could be a consequence of the different methodologies used in other studies (Kasper et al., 2012).

The current study has some limitations which should be taken into account. In our opinion, the most relevant limitation is related to the tasks used to assess the WM performance. Laboratory tasks have shown a low ecological value. Accordingly, recent studies have noted the need to assess the Executive Functions in children with ADHD by including rating scales for teachers and parents (Barkley & Murphy, 2010; Shimoni, Engel-Yeger, & Tirosh, 2012). We included the ADHD-CDS, which includes items related to daily activities that require the executive functions implication (e.g., planning, time management, limits, among others). Unfortunately, the scale was used for the clinical assessment of the ADHD cases.

Future studies should include different assessment tools such as performance tasks and behavior ratings in order to explore the relationships between WM and ADHD clinical heterogeneity. Another limitation of the study was that the comorbid disorders that often occur with ADHD were not taken into consideration. Despite the doubts related to the validity of the ADHD predominantly hyperactive-impulsive presentation (Willcutt et al., 2012). It could be of interest to include this ADHD subclinical presentation in future research. Finally, even though the ADHD cases were in medication withdrawal for at least 24h. before data collection, it could be interesting to explore the long-term effects of ADHD medication on the WM task performance.

Conclusion

This study provides empirical evidence to the hypothesis stating that children with an ADHD diagnosis would significantly underperform their peers that have no ADHD diagnosis. This underperformance affects both visuospatial and phonological WM. However, no relationship had been found between the punctuation and the man dimensions of the disorder (i.e., inattention and hyperactivity/impulsivity) and the performance of tasks that measure the WM in its visuospatial and phonological dimensions. Thus, the severity of the behavioral clinical picture of ADHD is not necessarily corresponding to the worse performance at the tasks.

Besides, these results suggest that the incorporation of measures of WM within the ADHD evaluation protocols could result in potential clinical use in the process of diagnosing the disorder.

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