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How does the predictive capacity of a virtual-reality CPT for children with ADHD differ by country? A transcultural study with Argentine and Spanish Children

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ABSTRACT

Background: Although many studies have analyzed the effectiveness of novel Continuous Performance Tests (CPTs) in diagnosing ADHD, very few studies have examined how cultural factors influence that effectiveness.
Aims: The present study aimed to analyze performance in a Virtual-Reality CPT in a sample of children resident in Spain and Argentina.
Methods and procedures: 138 students participated in this study. They were aged between 6 and 16 years old, with a mean age of 10.38 ($SD = 2.46$) and had been diagnosed with ADHD.
Outcomes and results: Commissions was the only significant variable in both discriminant models. In the Spanish population, the commissions variable was shown to correctly classify 49.4 % of the three types of ADHD presentation. However, in the Argentine population, the commissions variable correctly classified 68.3 %.
Conclusions and implications: These results may have been biased by the severity of the different types of presentation. In fact, it seems reasonable to think that the greater the severity, the better Aula Nesplora would predict the three types of presentation of ADHD. These results emphasize the need to consider other variables with a notable impact on daily life as children develop.

What this paper adds?

The present study addresses a notable research gap in protocols for evaluating and diagnosing ADHD by examining whether a Virtual Reality Test can predict the three types of ADHD presentation considering the country of origin (Argentina and Spain). More specifically, the findings show that although both populations had been diagnosed with the same disorder, the symptoms in the Argentine population were more severe. These results might be explained by the symptomatological complexity of ADHD and participants' subclinical problems. The results also show that, regardless of country and potential cultural influence on performance, the number of commission errors was the only variable that was able to significantly predict the type of ADHD presentation. Nonetheless, the predictive capacity of the commission variable was significantly greater in the Argentine population, where the amount of

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predictions was 18.9 percentage points greater than in the Spanish group. This result may have been biased by the severity of the different types of presentation. The study concludes the importance of thorough ADHD evaluation protocols that should be not solely based on performance in attentional tasks and/or observational scales but which also need to be tested and considered in relation to other variables with notable impact on daily life, such as the cultural or educational aspects that are so present in children's development.

1. Introduction

Attention Deficit Hyperactivity Disorder, or ADHD, is one of the most common disorders in childhood and adolescence, reaching a prevalence between 5 % and 7 % in this group (Song et al., 2021; Salari et al., 2023). The prevalence data exhibit notable variability depending the geographical location being examined. The prevalence rates of ADHD in Europe (around 5 %) are lower than in North America (around 9 %), which are in turn lower than in Latin America (where they are over 10 %) (Polanczyk et al., 2007). This variability in the prevalence data could be for various reasons: (1) methodological differences across studies; (2) the use of a different case definition; and (3) the fact that ADHD may be significantly influenced by sociocultural factors (Timimi & Taylor, 2004).

Most assessment protocols of ADHD around the world are based on the DSM-5-TR (American Psychology Association, [APA], 2022) and/or the ICD-11 (World Health Organization WHO, 2018) Criteria. The DSM-5-TR Diagnostic Manual (APA, 2022) and ICD-11 criteria are broadly similar but there are some differences that may significantly affect clinical and research practices.

In the DSM-5-TR (APA, 2022), both the inattention and hyperactivity-impulsivity lists contain a total of nine symptoms, and at least six out of the nine are required for diagnosis. The ICD-11 (WHO, 2018) contains a total of eleven symptoms, but it does not include a precise symptom count requirement. Moreover, although both the DSM-5-TR and ICD-11 require manifestations of ADHD by age 12, the ICD-11 requires evidence of significant inattention and/or hyperactivity-impulsivity symptoms before age 12, whereas the DSM-5-TR only requires that "several" symptoms be present before age 12. Thus, the fact that some countries use certain criteria as a reference can significantly alter the ADHD diagnostic process. Furthermore, although there are scales based on the DSM-5-TR criteria that have been shown to be valid and reliable, to date there are no scales based on the ICD-11 criteria, which complicates implementation.

Despite the existing data for adults showing similar rates of prevalence between the sexes (Faheem et al., 2022), data from diagnosis of children and adolescents shows that ADHD is diagnosed twice as often in boys than girls (Ayano et al., 2023). The disorder is characterized by difficulty in maintaining attention, inability to repress or curb behaviors (impulsivity), and by hyperactivity, in other words, ineffective regulation.

According to the criteria in the DSM-5-TR (APA, 2022) and the ICD-11 (WHO, 2018), ADHD has three types of presentation: (1) combined presentation, characterized by the presence of symptoms of hyperactivity and impulsivity, along with inattention; (2) predominantly inattentive presentation, characterized by the absence of symptoms related to hyperactivity and impulsivity, but by the presence of symptoms of inattention; and (3) predominantly hyperactive presentation, the main characteristic of which is the presence of 6 or more symptoms of hyperactivity and impulsivity, and the absence of symptoms of inattention.

In terms of how ADHD symptoms progress over time, it is worth noting that as people with ADHD age, inattention symptoms tend to remain stable, as the demands of attention increase with age, whereas symptoms related to hyperactivity and impulsivity tend to diminish (Stibbe et al., 2020; Mascaraque & Cohen, 2020). This means that late or ineffective interventions often lead to the presence of various problems associated with ADHD in adult life. Students with ADHD are more likely to have to repeat a school year, and are three times as likely to drop out or fail at school (Lawrence et al., 2020; Shroff et al., 2023). As adults, those who suffer from ADHD are more likely to not find work and to consume drugs (Harstad et al., 2020).

One of the possible causes of these problems associated with ADHD, both in childhood and adulthood, may lie in the impairment of executive functions in those suffering from the disorder (Hong et al., 2021; Miranda et al., 2020). Executive function is a construct that covers many cognitive processes, such as attention, emotion regulation, working memory, inhibition, planning and problem-solving, mental flexibility, etc. Executive functions play a fundamental role in everyday situations involving both (physical and mental) health and (psychological, cognitive and social) development (Barkley, 2022; Diamond, 2020). These functions being diminished may be related to low inhibitory control (impulsivity), as well as problems planning, or doing tasks in order and maintaining sufficient concentration to work on something continuously (Fan & Wang, 2022). It is important to note that deficits in executive functions are more strongly related to symptoms of inattention than to symptoms of hyperactivity/impulsivity (Sergeant et al., 2008). All of this, together with the complexity of symptoms and the impairment of executive functions—and the impact that has on the day to day lives of those who suffer from the disorder (Kim & Kim, 2021)—make it important to have early evaluations that consider the different ADHD profiles and aim to accurately detect the most significant difficulties in order to design interventions that are tailored as far as possible to each person's needs.

There are a variety of instruments for assessing ADHD that help professionals to make accurate diagnoses and distinguish ADHD from other pathologies or disorders that may have similar behavioral profiles (Conduct Disorder, Generalized Anxiety Disorders, Oppositional Defiant Disorder, among others). These tests consist of a set of questionnaires where observers respond to items to determine the presence or absence of behaviors that are characteristic of the disorder (Krieger et al., 2020). However, these instruments do have limitations, including observer subjectivity (Areces et al., 2019).

This situation led to the production of Continuous Performance Tests (CPT); neuropsychological performance tests for children who seem to present difficulties related to attention, inhibitory control, and processing speed, among others (Arrondo et al., 2024). Test subjects respond to a specific type of familiar stimuli (following the Go vs No-Go paradigm) presented through audio or visuals (Slobodin, 2020). The tests provide a range of variables, such as number of correct responses, omissions, commissions, time, and

variability of response. This makes them a good option for ADHD assessment as they are based only on the individual's own performance in the test. In fact, these tests are currently one of the most commonly included methods in ADHD symptom evaluation protocols (Areces et al., 2019; Slobodin et al., 2020; Zulueta et al., 2013), a category that includes the TOVA test (Test of Variables of Attention) (Greenberg, 1993) and the CSAT (Childhood Sustained Attention Test) (Servera & Llabrés, 2004).

Although CPTs are a useful tool that many clinicians include in their ADHD assessment protocols, they do have significant limitations. Firstly, they lack ecological validity. This validity is based on the extent to which the results would match what we find in real life (Areces et al., 2018; Seesjärvi et al., 2021). Secondly, CPTs as diagnostic tools have only a modest to moderate ability to differentiate ADHD from non-ADHD samples, so there is a need for a more comprehensive assessment that considers family, educational, contextual and cultural factors in constant interaction with the child's day-to-day life (Arrondo et al., 2024).

To overcome this limitation, performance tests began to be produced that use virtual reality to put the test-taker in a setting that is similar to their day-to-day reality. Examples of this new type of CPT include The Virtual Classroom (Rizzo et al., 2000) and Aula Nesplora (Climent et al., 2011). These tests immerse the children in a virtual world, simulating everyday situations, thus solving the problem of low ecological validity (Areces et al., 2020; Hilty et al., 2020). Many authors have noted that complementing CPTs with virtual reality solves the problems related to ecological validity, which is a notable advance in diagnosing people with ADHD (Areces et al., 2018; Cho et al., 2022).

1.1. The influence of culture on cognitive processes

Along similar lines, it is worth noting that although there have been studies comparing the performance of CPTs with VR and traditional CPTs (Rodríguez et al., 2018), hardly any studies have looked at the influence of the cultural factor on performance in a CPT. One study by Levav et al. (1998) compared performance in the AX-CPT (with audio and visual presentation) in children and adults from five countries. They found statistically significant differences in the number of errors by commission in visual tasks in the 8–12 year-old age group, as well as differences in auditory reaction in the 13–53 year-old group. More recently, Miranda et al. (2008) compared performance in the Conners CPT (Conners et al., 2003) between a sample from Brazil and one from the north of the United States. Their results showed that the Brazilian students generally scored significantly higher. This finding underscores the idea that sociocultural experiences have an influence on people's cognitive processing (Miranda et al., 2008). Culture has a general impact on the way humans process information and make executive decisions. For example, teachers' classroom management has been associated with children's cognitive and self-regulation skills (Barrett, 2020). In this regard, behavioral engagement has been shown to decline considerably faster in North American classrooms than in Chinese classrooms (Lan et al., 2011).

Similarly, a study by Kelkar et al. (2013) showed significant differences between Eastern and Western groups in executive functions. More specifically, Eastern subjects demonstrated higher performance in all tasks in the Trail Making Test (which involve visual scanning, number sequencing, letter sequencing, number-letter switching and motor speed). These findings could be explained by the fact that eye movements can differ as a function of culture. Eastern and Western subjects have been found to allocate attention resources differently when viewing a scene or a picture. While Westerners direct their attention primarily to the foreground and focus on details, Easterners focus their attention on the background and use more holistic pattern in their attention. Similarly, a study by Lucas et al. (2013) showed that Chinese preschoolers outperformed age-matched children from the United States in inhibition and attentional control tasks. From a cultural perspective, one possible explanation may involve cultural differences in parenting and teaching practices. This pattern of findings may arise because of the cultural emphasis on self-control during primary school years in Asian countries. In fact, observation studies in Chinese classrooms have noted that teachers demonstrate intensive training on skills such as following directions and concentrating on subject matter (Lan et al., 2011).

Along these lines, and using a cross-cultural perspective, Barrett (2020) highlighted the "reaction norm", which describes how a trait in a given organism develops differently depending on environmental circumstances. Consequently, there is a lack of evidence to date that CPT measures are not affected by cultural factors, hence the importance of studies such as ours, comparing different populations.

The objective of our study was to analyze performance in a virtual-reality CPT (specifically Aula Nesplora) (Climent et al., 2011) in a sample of children resident in Spain and Argentina. This means a transcultural analysis of the performance of the Aula Nesplora CPT. The specific objectives were: (1) to determine whether there are statistically significant differences in the three types of ADHD presentation in the two populations; and (2) to test the influence of each country's culture on how the Aula Nesplora test performs through two discriminant analyses in order to determine whether the significant variables are the same and the prediction scores are similar for both countries.

2. Method

2.1. Participants

The sample for this study consisted of 138 children. They were aged between 6 and 16 years old, with a mean age of 10.38 (SD = 2.46). The mean age of the boys was 10.59 (SD = 2.35), while the mean age of the girls was 9.77 (SD = 2.71). All of the children had been diagnosed with ADHD, and some presented a comorbidity with another disorder such as Learning Disabilities, ASD, or Conduct Disorder. The mean IQ score from the group was 98.31 (SD = 16.11).

The participants were not receiving any pharmacological treatment. They came from two very different clinical populations. In Spain (n = 77, 55.8 %) the sample was collected in a hospital, in Argentina (n = 61, 44.2 %) it came from a clinical center. The Spanish

sample was obtained from hospital outpatients), while the Argentine sample were receiving treatment at a clinic.

The Spanish group included 59 boys, 23 of whom exhibited predominantly hyperactive-impulsive presentation, 18 exhibited predominantly inattentive presentation, and 18 exhibited combined presentation. It also included 18 girls; 3 with predominantly hyperactive-impulsive presentation, 8 with inattentive presentation, and 7 with combined presentation. The mean age of this group was 10.58 (SD =2.45). The Argentine group included 44 boys; 4 with hyperactive-impulsive presentation, 21 with inattentive presentation, and 19 with combined presentation. It also included 17 girls; 1 with hyperactive-impulsive presentation, 13 with inattentive presentation, and 3 with combined presentation. The mean age of the Argentine group was 10.13 (SD =2.48).

Information about the distribution of the participants is shown in Table 1.

Subsequently, we confirmed that there were no statistically significant differences by sex (p = .562), age (p = .095), or IQ (p = .754). Given that these variables were not significant, we did not add any of them as covariates in the subsequent analysis to determine whether there were differences according to country of origin and ADHD presentation.

2.1.1. Inclusion criteria

Sample selection used a number of criteria for inclusion. First and foremost, the participants had to have a diagnosis of ADHD. They also had to be aged between 6 and 16 years old—the age range that the Aula Nesplora test was developed for, and they had to be resident at the time in Spain or Argentina. The inclusion criteria to participate in it were:

- Being diagnosed with ADHD (specifying its presentation).
- Being between 6 and 16 years of age.
- Presenting an IQ within the norm (M = 100; SD =15).

2.2. Procedure

Before applying the Aula Nesplora test, both centers received training in it from the test creators via monthly online meetings. Once the staff in both centers were trained, the project's lead researcher sent a form seeking informed consent from the parents of children who regularly attended the centers. This form summarised the Aula Nesplora test, described the objectives of the study and provided contact information for questions and comments. After a one-month wait, the test was applied to all children whose parents agreed to participate in the study.

The test takes a total of about 20–25 min to apply, but there is a short pause after the first part to let the examiner verify that the child is ready to continue with the rest of the test.

2.3. Instruments

Aula Nesplora (Climent et al., 2011): a virtual-reality based continuous performance test. It recreates the environment needed to

Table 1
Sociodemographic data for the ADHD sample.

Variables	*N*	%			
Gender					
Boys	103	74.6			
Girls	35	25.4			
Country of Residence					
Spain	77	55.8			
Argentina	61	44.2			
Bilingual					
No	135	97.8			
Yes	3	2.2			
Comorbidities					
ASD	5	3.6			
Conduct Disorders	6	4.3			
Learning Disorders	17	12.3			
Others	5	3.6			
ADHD presentation					
Inattentive	60	43.5			
Combined	48	34.8			
H/I	30	21.7			
	M	*SD*	Median	P25	P75
AGE	10.38	2.468	11	8	12
IQ	98.31	16.11	99	87.75	108

produce results while maintaining ecological validity.

Aula Nesplora immerses the participants in a test setting that resembles an ordinary classroom. It provides both visual and auditory stimuli, as well as distractors. The test is designed for children aged between 6 and 16 years old. It assesses variables such as impulsivity, attention, processing speed, and motor activity. The participant wears 3D glasses, earphones, and movement sensors in order to capture the best quality information possible without losing sight of the main objective, which is to simulate a classroom setting. Once the participant is set up, the test begins, where they find themselves sitting at a desk in the middle of a class with a blackboard in front of them.

From the beginning of the test, the subject is given instructions by a virtual teacher. In the first tasks the participant has to press a button any time they hear or see a stimulus that does not correspond to the stimulus "apple". In the second task the subject has to press a button only when they are presented with the stimulus "seven", aurally or visually.

These tasks provide a large amount of information in a set of variables: (1) Omissions (the number of times the subject should have pressed the button but did not); (2) Commissions (the number of times the subject should not have pressed the button but did so); (3) Response Time (how many milliseconds the participant took to react and respond); and (4) Motor Activity (this variable is recorded via sensors mounted on the 3D glasses the participant wears during the test). The variables are the same as those provided by other continuous performance tests, but the innovation of this tool is that provides the data according to channel used (auditory vs. visual) and environmental conditions (presence vs absence of visual and auditory distractors). Additionally, Aula Nesplora provides other objective parameters that may be important, such as head movements and attentional quality, which are not covered by traditional CPTs (Areces et al., 2018).

2.4. Data analysis

This empirical study examined the different study variables quantitatively. It used an ex post facto, descriptive design.

Preliminary analyses were performed on the variables to ensure sample homoscedasticity, and therefore suitability for parametric analysis. We calculated statistics for asymmetry and kurtosis for the variables being analyzed and confirmed that they followed a normal distribution based on the criteria from Kline (2013), according to which, values between 3 and 10 are the maximum accepted for asymmetry and kurtosis. Subsequently, two Multivariate Analyses of Variance (MANOVA) were calculated, with dependent variables being scores in errors of omission, errors of commission, response time, and motor activity. Fixed factors were the country of origin and ADHD presentation. Age, sex, and IQ were not controlled for, as they did not demonstrate statistically significant differences in the preliminary analysis. Finally, discriminant analysis was performed in order to compare the predictive capacity of VR-CPT in the Spanish and Argentine groups. All of the analyses were done using SPSS 24.0.v. (Arbuckle, 2016).

2.5. Ethical conditions

The study was conducted in accordance with the World Medical Association Code of Ethics (Declaration of Helsinki), which reflects the ethical principles for research involving humans (Williams, 2008). It was approved according to the relevant ethics committee guidelines (Reference: CPMP/ICH/135/95, Code: TDAH-Oviedo).

3. Results

3.1. Descriptive and preliminary analysis

Table 2 shows the descriptive statistics along with the values for asymmetry and kurtosis for the variables obtained from the Aula Nesplora tool. The results of the homoscedasticity tests show a normal distribution, which allows calculation of parametric analyses. In terms of descriptive statistics, it is worth noting that the typical scores in this test follow an inverse logic: a high value indicates poor performance in a given variable. In other words, the lower the score, the better the performance on that variable. In this regard, the general descriptive results indicate poorer performance in the omission (related to inattentive symptoms) and motor activity variables (related to hyperactive symptoms).

Table 2
Descriptive statistics for the study variables.

Variables	Min.	Max.	*M*	*SD*	Asym.	Kurt.
Omissions	37	80	58.80	10.28	.359	−.390
Commissions	20	80	53.52	11.44	−.439	.335
Response time	20	80	52.25	13.31	.128	−.260
Motor activity	22	80	54.80	15.26	−.079	−.664

Note. Min.= minimum value obtained in the variables (standardized scores); Max = maximum value obtained in the variables (standardized scores); *SD* = standard deviation; Asym.= asymmetry; Kurt.= kurtosis

3.2. Differences by country of origin

Table 3 shows the means and standard deviations for the variables by country of origin. Comparing the means for the two countries (typical scores) shows that the Argentine subjects performed worse in the omission variable (related to inattention) and motor activity variable (related to hyperactive symptoms). In contrast, the Spanish sample performed worse in the response time variable (related to a sluggish cognitive tempo).

The results of the MANOVA indicated that there were statistically significant differences in the Aula Nesplora variables by country of origin (λ =.406, $F(4132)$= 22.516, $p < .001$, $\eta_p 2$= .406). Inter-subject effects showed that there were statistically significant differences in the *omissions* and *motor activities* variables, with Spanish participants scoring higher (i.e., performing worse) than Argentine participants (see Table 4). It is worth reiterating that the Aula Nesplora test considers good performance when the variable scores are below 60 points.

3.3. Discriminant analysis by country of origin

Table 5 shows that only the commissions variable was significant in both discriminant models (the model with the Spanish group and the model with the Argentine group). Given that there were more than two classification groups, the canonical correlation of the commissions variable was used as a measure of the effect size (R^2 =.452), which was moderate in the Spanish group. More specifically, in the discriminant model for the Spanish group, the commissions variable was shown to correctly classify 49.4 % of the cases in the three types of ADHD presentation (λ =.796; $\chi^2_{(2)} = 16.929$; $p < .001$). More specifically, it correctly classified 84.6 % of those with inattentive presentation, 36 % of those with hyperactive-impulsive presentation, and 26.9 % of those with combined presentation.

In the discriminant model for the Argentine population, the commissions variables correctly classified 68.3 % of the ADHD presentation types (λ =.778; $\chi^2_{(2)} = 14.331$; $p < .001$). The canonical correlation also demonstrated moderate values (R^2 =.471). More specifically, commissions correctly classified 90.9 % of those with inattentive presentation, 20 % of those with hyperactive-impulsive presentation, and 45.5 % of those with combined presentation.

4. Discussion

This study had two objectives: (1) determine whether there were statistically significant differences in the three types of ADHD presentation in the two populations; and (2) assess the influence of each country's culture on the performance of the Aula Nesplora test via two discriminant analyses.

In terms of the first objective, we found that the Spanish and Argentine samples exhibited differences in performance in the Aula Nesplora Test. The Spanish sample demonstrated better performance in omissions and motor hyperactivity and worse performance in response time (slower reaction times than the Argentine sample). Although both populations had been diagnosed with the same disorder, the symptoms in the Argentine population were more severe. In this regard, considering that omission errors are related to the presence of inattention symptoms and motor hyperactivity (based on the child's head movements during the task and recorded by the 3D glasses) is related to impulsive and hyperactive behaviour (Areces et al., 2019), it could be said that this study showed significant differences in the types of ADHD presentation depending on the country of origin. More specifically, the results showed that the presentations or subtypes of ADHD in the Argentine population were more severe than in the Spanish population. These findings could be explained by two hypotheses: (1) the symptomatological complexity of ADHD and the absence of standardized evaluation protocols; and (2) the influence of cultural differences on cognitive processes.

According to first hypothesis, the differences could be due to the use of DSM-5-TR (APA, 2022) and/or ICD-11 (WHO, 2018) criteria, which are often influenced by the subjectivity of observers (when clear assessment protocols are not available) leading to a high rate of false positives and negatives (Areces et al., 2019). Furthermore, it should be noted that these types of manuals list many symptoms that may be common to other disorders (such as anxiety or conduct disorders) making it difficult to perform an accurate differential diagnosis (Cid-Duarte et al., 2023; Hours et al., 2022; Mansour et al., 2021). In fact, in many cases the level of severity recorded for a person with ADHD depends to a large extent on the evaluator's criteria. From this perspective, the results of this study could be partially explained by the subjective factor implicit in the diagnostic process of ADHD.

Table 3
Descriptive statistics by Country of Origin.

Country	Aula Nesplora variables			
	Omissions	Commissions	Response Time	Motor activity
Spain (n = 77)				
M	55.30	53,91	53.08	46.87
SD	8.46	9.5	11.90	12.38
Argentina (n = 61)				
M	63.21	53.03	51.21	64.80
SD	10.73	13.55	14.89	12.47

Note. *M* = Mean; *SD* = Standard Deviation.

Table 4
Inter-subject effects of the Aula Nesplora variables by country of origin.

Aula Nesplora variables	*F*(1,137)	$\eta_p 2$
Omissions	26.141 * **	.162
Commissions	0.195	.001
Response time	0.543	.004
Motor activity	70.301 * **	.342

Note. * ** $p < .001$

Table 5
Discriminant analysis by country: Spain vs. Argentina.

Significant Aula Nesplora Variables	*Standardized coefficients*	*Function coefficients*	*F* Spain $F_{(2, 74)}$ Argentina $F_{(2, 57)}$
Spain			
Commissions	1.00	0.126	9.511 * **
Constant		−2.058	
Argentina			
Commissions	1.00	0.040	8.147 * **
Constant		−0.915	

Note. *** $p < .001$

On the other hand, the second hypothesis suggests that these findings could be explained from a cultural perspective. Differences in parenting and teaching practices may affect the development of executive functions such as inhibitory control, mental flexibility, and planning (Hong et al., 2021; Miranda et al., 2020; Diamond, 2020). Argentine children with ADHD exhibiting more inattentive and impulsive behaviour than Spanish children could be due to differences in educational and parenting styles. These findings are in line with cross-cultural studies (Kelkar et al., 2013; Lan et al., 2011; Lucas et al., 2013) analysing executive functions in Asian and American children using CPTs. More specifically, the study by Lucas et al. (2013) showed that Asian children had better performance in inhibitory control and attentional tasks than American children due to the cultural emphasis on self-control in Asian schools. Similarly, Kelkar et al. (2013) noted that those from Eastern cultures had better performance in a Trial Making Test that those from Western cultures because the eye movements can differ as a function of the culture (Those from the West primarily direct their attention to the foreground, while those from the East focus their attention on the background).

According to previous scientific literature (Barrett, 2020; Kelkar et al., 2013; Lan et al., 2011), cross cultural approaches are essential for understanding how the executive functions can vary depending on the contextual and cultural conditions human beings develop in. In this regard, the educational environment, parenting styles, and the typical habits and routines in each culture can influence the development of executive functions, exacerbating or reducing the severity of ADHD symptoms.

In terms of the second objective, the number of commissions variable was the best predictor (in both populations) of subjects belonging to the ADHD presentation types. These results indicate that, regardless of country and potential cultural influence on performance, number of commissions was the only variable that could significantly predict the type of ADHD presentation. Nonetheless, the predictive capacity of the commissions variable was significantly greater in the Argentine population, where the percentage of correct prediction was 18.9 percentage points higher than in the Spanish group. It seems reasonable to think that the greater the severity, the better Aula Nesplora would predict whether a subject belongs to one type of presentation or another. The present study underscores the importance of taking a cross-cultural cognitive science perspective in order to understand how cognitive processes develop as a function of different contextual, cultural and social factors (Barrett, 2020). This perspective suggests that despite the objectivity of the CPTs, individual subjectivity prevails, and it is only from a social dimension that the development of cognitive processes in human beings (who are in constant interaction with the social environment) can be analyzed.

4.1. Strengths and limitations of the study

The main strength of this study is its innovation in measuring a virtual reality test's ability to predict the different presentations of ADHD considering the country of origin. In fact, the findings are a notable advance in clinical diagnosis since they demonstrate the importance of considering cultural aspects when evaluating ADHD symptoms. However, despite this innovation, this study also has limitations that should be mentioned. Firstly, it would be useful to increase the size of the sample and to examine more than two cultures to provide results that are more representative and generalizable. The second limitation concerns the use of a CPT as the only tool for predicting ADHD. As noted by Arrondo et al. (2024), at the clinical level and as stand-alone tools, CPTs have only a modest to moderate ability to differentiate ADHD from non-ADHD samples. Finally, another notable limitation is not having the severity levels for each type of presentation. Classifying the sample not only by ADHD presentation, but also by severity of symptoms (mild, moderate or severe) would ensure a comparison of clinical samples that are very similar in diagnostic terms. Only by ensuring the similarities between the two samples in terms of severity would we be able to conclude that any differences between them depend exclusively on the variables related to culture or the comorbidities present in the population being examined.

5. Conclusions and clinical implications

The findings from this study confirm how important it is to have thorough ADHD evaluation protocols that are not solely based on performance in just a few go-no go tasks or on scores in observational scales measuring ADHD symptomatology (Areces et al., 2019; Rodríguez et al., 2018). Instead, the results need to be tested and considered in relation to other variables with notable impact on day-to-day life, such as the cultural or educational aspects that are ever present as children develop (Slobodin & Masalha, 2020).

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Declaration of Competing Interest

The authors declare that they have no competing interests.

Data Availability

Data will be made available on request.

References

Arbuckle, J.L. (2016). Manual SPSS, version 24.0. SPSS Ed..

Areces, D., García, T., Cueli, M., & Rodríguez, C. (2019). Is a virtual reality test able to predict current and retrospective ADHD symptoms in adulthood and adolescence?. Article e274. *Brain Sciences, 9*(10). https://doi.org/10.1007/10.3390/brainsci9100274

Areces, D., Rodríguez, C., García, T., & Cueli, M. (2020). Is an ADHD observation-scale based on DSM criteria able to predict performance in a virtual reality continuous performance test?. Article e2409. *Applied Sciences, 10*(7). https://doi.org/10.3390/app10072409

Areces, D., Rodríguez, C., García, T., Cueli, M., & González-Castro, P. (2018). Efficacy of a continuous performance test based on virtual reality in the diagnosis of ADHD and its clinical presentations. *Journal of Attention Disorders, 22*(11), 1081–1091. https://doi.org/10.1177/1087054716629711

Arrondo, G., Mulraney, M., Iturmendi-Sabater, I., Musullulu, H., Gambra, L., Movila, T. M. N., Banaschewski, T., Simonoff, E., Döpfner, M., Hinshaw, S. P., Coghill, D., & Cortese, S. (2024). Systematic review and meta-analysis: Clinical utility of continuous performance tests for the identification of Attention-Deficit/Hyperactivity Disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*. https://doi.org/10.1016/j.jaac.2023.03.011

Ayano, G., Demelash, S., Gizachew, Y., Tsegay, L., & Alat, R. (2023). The global prevalence of attention deficit hyperactivity disorder in children and adolescents: An umbrella review of meta-analyses. *Journal of Affective Disorders, 339*, 860–866. https://doi.org/10.1016/j.jad.2023.07.071

Barkley, R. A. (2022). Improving clinical diagnosis using the Executive Functioning—Self-Regulation Theory of ADHD. *The ADHD Report, 30*(1), 1–9. https://doi.org/10.1521/adhd.2022.30.1.1

Barrett, H. C. (2020). Towards a cognitive science of the human: cross-cultural approaches and their urgency. *Trends in Cognitive Sciences, 24*(8), 620–638. https://doi.org/10.1016/j.tics.2020.05.007

Cho, Y. J., Yum, J. Y., Kim, K., Shin, B., Eom, H., Hong, Y., Heo, J., Kim, J., Lee, H. S., & Kim, E. (2022). Evaluating attention deficit hyperactivity disorder symptoms in children and adolescents through tracked head movements in a virtual reality classroom: the effect of social cues with different sensory modalities. Article e16. *Frontiers in Human Neuroscience*. https://doi.org/10.3389/fnhum.2022.943478

Cid-Duarte, S., Areces, D., & Núñez, J. C. (2023). Las Funciones Ejecutivas en Población Infanto-juvenil que presenta TEA y TDAH en comorbilidad: Una revisión sistemática. *Revista Dèlelőtt Psicología York EducaciónN, 18*(1), 30–39. https://doi.org/10.23923/rpye2023.01.232

Climent, G., Banterla, F., & Iriarte, Y. (2011). *AULA: Theoretical manual*. Nesplora Ed.

Conners, C. K., Epstein, J. N., Angold, A., & Klaric, J. (2003). Continuous performance test performance in a normative epidemiological sample. *Journal of Abnormal Child Psychology, 31*(5), 555–562. https://doi.org/10.1023/a:1025457300409

Diamond, A (2020). Executive functions. En Handbook of Clinical Neurology (pp. 225-240). https://doi.org/10.1016/b978-0-444-64150-2.00020-4.

American Psychiatric Association [APA]. (2022). *Diagnostic and Statistical Manual of Mental Disorders*. https://doi.org/10.1176/appi.books.9780890425787

Faheem, M., Akram, W., Akram, H., Khan, M. A., Siddiqui, F. A., & Majeed, I. (2022). Gender-based differences in prevalence and effects of ADHD in adults: A systematic review. Article e103205. *Asian Journal of Psychiatry, 75*. https://doi.org/10.1016/j.ajp.2022.103205

Fan, L., & Wang, Y. (2022). The relationship between executive functioning and attention deficit hyperactivity disorder in young children: A cross-lagged study. *Current Psychology, 42*(25), 21375–21383. https://doi.org/10.1007/s12144-022-03233-5

Greenberg, L. M. (1993). Developmental normative data on the Test of Variables of Attention (TOVA). *Journal of Child Psychology and Psychiatry, 34*, 1019–1030. https://doi.org/10.1111/j.1469-7610.1993.tb01105.x

Harstad, E., Katusic, S. K., Sideridis, G. D., Weaver, A. L., Voigt, R. G., & Barbaresi, W. J. (2020). Children with ADHD are at risk for a broad array of adverse adult outcomes that cross functional domains: Results from a Population-Based Birth Cohort study. *Journal of Attention Disorders, 26*(1), 3–14. https://doi.org/10.1177/1087054720964578

Hilty, D. M., Randhawa, K., Maheu, M. M., McKean, A. J., Pantera, R., Mishkind, M. C., & Rizzo, A. (2020). A review of telepresence, virtual reality, and augmented reality applied to clinical care. *Journal of Technology in Behavioral Science, 5*(2), 178–205. https://doi.org/10.1007/s41347-020-00126-x

Hong, J., Lee, Y. S., Hong, M., Kim, B., Joung, Y. S., Yoo, H. K., Kim, E. J., Lee, S. I., Bhang, S., Lee, S. Y., Bahn, G. H., & Han, D. H. (2021). Cognitive developmental trajectories in adult ADHD patients and controls: A comparative study. *Journal of Attention Disorders, 26*(3), 391–407. https://doi.org/10.1177/1087054720978548

Hours, C., Recasens, C., & Baleyte, J. M. (2022). ASD and ADHD comorbidity: What are we talking about?. Article e154. *Frontiers in Psychiatry, 13*. https://doi.org/10.3389/fpsyt.2022.837424

Kelkar, A. S., Hough, M. S., & Fang, X. (2013). Do we think alike? A cross-cultural study of executive functioning. *Culture and Brain, 1*, 118–137. https://doi.org/10.1007/s40167-013-0010-4

Kim, K., & Kim, H. J. (2021). Normal executive attention but abnormal orienting attention in individuals with sluggish cognitive tempo. Article e100199. *International Journal of Clinical and Health Psychology, 21*(1). https://doi.org/10.1016/j.ijchp.2020.08.003

Kline, R. B. (2013). Assessing statistical aspects of test fairness in structural equation modeling. *Educational Research and Evaluation, 19*, 204–222. https://doi.org/10.1080/13803611.2013.767624

Krieger, V., Amador-Campos, J. A., & Guàrdia-Olmos, J. (2020). Executive functions, personality traits and ADHD symptoms in adolescents: A mediation analysis. *PLoS One, 15*(5), Article e0232470. https://doi.org/10.1371/journal.pone.0232470

Lan, X., Legare, C., Ponitz, C., Li, S., & Morrison, F. (2011). Investigating the links between the subcomponents of executive function and academic achievement: A cross-cultural analysis of Chinese and American preschoolers. *Journal of Experimental Child Psychology, 108*, 677–692. https://doi.org/10.1016/j.jecp.2010.11.001

Lawrence, D., Houghton, S., Dawson, V., Sawyer, M., & Carroll, A. (2020). Trajectories of academic achievement for students with attention-deficit/hyperactivity Disorder. *British Journal of Educational Psychology, 91*(2), 755–774. https://doi.org/10.1111/bjep.12392

Levav, M., Mirsky, A. F., French, L. M., & Bartko, J. J. (1998). Multinational neuropsychological testing: Performance of children and adults. *Journal of Clinical and Experimental Neuropsychology, 20*, 658–672. https://doi.org/10.1076/jcen.20.5.658.1126

Lucas, A. J., Lewis, C., Pala, F. C., Wong, K., & Berridge, D. (2013). Social-cognitive processes in preschoolers' selective trust: Three cultures compared. *Developmental Psychology, 49*(3), 579–590. https://doi.org/10.1037/a0029864

Mansour, R., Ward, A. R., Lane, D. M., Loveland, K. A., Aman, M. G., Jerger, S., Schachar, R., & Pearson, D. A. (2021). ADHD severity as a predictor of cognitive task performance in children with Autism Spectrum Disorder (ASD). Article e103882. *Research in Developmental Disabilities, 111*. https://doi.org/10.1016/j.ridd.2021.103882

Mascaraque, P. S., & Cohen, D. S. (2020). Trastorno por déficit de atención con hiperactividad en la infancia y adolescencia. *Pedriatría Intengral, 24*(6), 316–324.

Miranda, B. R., Berenguer, C., Baixauli, I., Mira, Á., Martínez-Raga, J., & Miranda, A. (2020). Empirical examination of executive functioning, ADHD associated behaviors, and functional impairments in adults with persistent ADHD, remittent ADHD, and without ADHD. *BMC Psychiatry, 20*(1), 1–12. https://doi.org/10.1186/s12888-020-02542-y

Miranda, M. C., Sinnes, E. G., Pompéia, S., & Francisco Amodeo Bueno, O. (2008). A comparative study of performance in the Conners' Continuous Performance Test between Brazilian and North American children. *Journal of Attention Disorders, 11*(5), 588–598. https://doi.org/10.1590/S0004-282X2012000200004

Polanczyk, G., De Lima, M. S., Horta, B. L., Biederman, J., & Rohde, L. A. (2007). The worldwide prevalence of ADHD: A systematic review and metaregression analysis. *American Journal of Psychiatry, 164*(6), 942–948. https://doi.org/10.1176/ajp.2007.164.6.942

Rizzo, A. A., Buckwalter, J. G., Bowerly, T., Van Der Zaag, C., Humphrey, L., Neumann, U., & Sisemore, D. (2000). The virtual classroom: A virtual reality environment for the assessment and rehabilitation of attention deficits. *CyberPsychology Behavior, 3*(3), 483–499. https://doi.org/10.1089/10949310050078940

Rodríguez, C., Areces, D., García, T., Cueli, M., & González-Castro, P. (2018). Comparison between two continuous performance tests for identifying ADHD: Traditional vs. virtual reality. *International Journal of Clinical and Health Psychology, 18*(3), 254–263. https://doi.org/10.1016/j.ijchp.2018.06.003

Salari, N., Ghasemi, H., Abdoli, N., Rahmani, A., Shiri, M. H., Hashemian, A. H., Akbari, H., & Mohammadi, M. (2023). The Global prevalence of ADHD in children and adolescents: A systematic review and meta-analysis. Article e48. *Italian Journal of Pediatrics, 49*(1). https://doi.org/10.1186/s13052-023-01456-1

Seesjärvi, E., Puhakka, J., Aronen, E. T., Lipsanen, J., Mannerkoski, M., Hering, A., Zuber, S., Kliegel, M., Laine, M., & Salmi, J. (2021). Quantifying ADHD symptoms in Open-Ended Everyday Life Contexts with a new virtual reality task. *Journal of Attention Disorders, 26*(11), 1394–1411. https://doi.org/10.1177/10870547211044214

Sergeant, J.A., Willcutt, E., & Nigg, J. (2008). How Clinically Functional Are Executive Function Measures of ADHD? American Psychiatric Association.

Servera, J., & Llabrés, J. (2004). *Children sustained attention task (CSAT)*. TEA Ediciones.

Shroff, D. M., Dunn, N. C., Green, C. D., Breaux, R., Becker, S. P., & Langberg, J. M. (2023). Predictors of executive function trajectories in adolescents with and without ADHD: Links with academic outcomes. *Development and Psychopathology*, 1–14. https://doi.org/10.1017/s0954579423000743

Slobodin, O. (2020). The utility of the CPT in the diagnosis of ADHD in individuals with substance abuse: A systematic review. *European Addiction Research, 26*(4-5), 283–294. https://doi.org/10.1159/000508041

Slobodin, O., & Masalha, R. (2020). Challenges in ADHD care for ethnic minority children: A review of the Current literature. *Transcultural Psychiatry, 57*(3), 468–483. https://doi.org/10.1177/1363461520902885

Slobodin, O., Yahav, I., & Berger, I. (2020). A machine-based prediction model of ADHD using CPT data. *Frontiers in Human Neuroscience, 14*. Article e560021.

Song, P., Zha, M., Yang, Q., Zhang, Y., Li, X., & Rudan, I. (2021). The prevalence of adult attention-deficit hyperactivity disorder: A global systematic review and meta-analysis. Article e04009. *Journal of Global Health, 11*. https://doi.org/10.7189/jogh.11.04009

Stibbe, T., Huang, J., Paucke, M., Ulke, C., & Strauß, M. (2020). Gender differences in adult ADHD: Cognitive function assessed by the test of Attentional Performance. *PLOS ONE, 15*(10), Article e0240810. https://doi.org/10.1371/journal.pone.0240810

Timimi, S., & Taylor, E. (2004). ADHD is best understood as a cultural construct. *The British Journal of Psychiatry, 184*(1), 8–9. https://doi.org/10.1192/bjp.184.1.8

World Health Organization [WHO]. (2018). ICD-11: International classification if diseases 11th revisión: The Global Stardard for Diagnostic Health Information.

Williams, J. R. (2008). Revising the declaration of Helsinki. *World medical journal, 54*(4), 120–122.

Zulueta, A., Iriarte, Y., Díaz-Orueta, U., & Climent, G. (2013). AULA NESPLORA: Avance en la evaluación de los procesos atencionales. Estudio de la validez convergente con el test de percepción de diferencias "caras" (versión ampliada). *ISEP Science, 4*, 4–10.