Anuario de Psicología
2009, vol. 40, nº 2, 211-222

The assessment of Attention Deficit Hyperactivity Disorder in children using continous performance tasks in virtual environments*

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The assessment of Attention-Deficit/Hyperactivity Disorder (ADHD) involves the use of different instruments, and one of the most frequently used is the Continuous Performance Test (CPT). Virtual reality allows for the achieving of the presentation of stimuli with high levels of control. In addition, it facilitates the presentation of distracters with a high level of resemblance to elements which in fact can be found in the real world by placing them in a similar context. Thus, it is possible to assume that a higher ecological validity can be found in CPT tests performed in this manner as compared to the traditional CPT test.

During the last years Rizzo developed a virtual reality based CPT called "the Virtual Classroom". Several studies show that "Virtual Classroom" is an effective measure to identify attention difficulties in children with ADHD. Our research team developed a virtual CPT, similar to the "Virtual Classroom", that allows to execute four different tasks: an auditory task with non-distractive stimuli, an auditory task with distractive stimuli, a visual task with non-distractive stimuli and a visual task with distractive stimuli. In this study, we offer additional data supporting the validity of using this type of technology for the assessment of ADHD.

Keywords: *ADHD, CPT, virtual reality.*

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* *Acknowledgments:* The current study has been partially financed by the Ministry of Education and Science, Consolider-C Project (SEJ2006-14301/PSIC).
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Original recibido: octubre 2008. *Aceptación final:* mayo 2009.

Evaluación del Trastorno por Déficit de Atención con Hiperactividad en niños mediante tareas de ejecución contínua en entornos virtuales

Uno de los instrumentos más empleados para la evaluación del Trastorno por Déficit de Atención con Hiperactividad (TDAH) es el Test de Ejecución Continua (CPT). Utilizando realidad virtual es posible presentar estímulos con un elevado grado de control, y algunos de ellos pueden ejercer la función de distractores muy similares a los que se encuentran en la realidad. Por ello cabe pensar que las pruebas CPT realizadas mediante realidad virtual pueden tener un mayor grado de validez ecológica que las que se realizan de modo tradicional.

Durante los últimos años Rizzo ha desarrollado una prueba CPT denominada "Virtual Classroom" que puede ser presentada mediante realidad virtual, y diferentes estudios han encontrado que es un procedimiento eficaz y válido para evaluar el déficit de atención en niños con TDAH. Nuestro equipo de investigación ha desarrollado una prueba CPT virtual similar, mediante la que es posible aplicar cuatro tipos de tareas de ejecución continua: visuales y auditivas con y sin distractores. En este estudio se ofrecen datos adicionales que confirmar la validez de este tipo de pruebas para la evaluación de las dificultades atencionales.

Palabras clave: *TDAH, CPT, realidad virtual.*

Attention-Deficit/Hyperactivity Disorder (ADHD) is characterized by attention difficulties, impulsiveness and hyperactivity. Some epidemiological studies on ADHD suggest an incidence estimated at 5% in school-age children (Biederman & Faraone, 2005). Often, the main features of ADHD are associated to learning disabilities and behaviour disorders. An important issue related to ADHD is proper diagnosis. The assessment of ADHD involves the use of protocols and other procedures including questionnaires, reports by parents and teachers, direct observation, interviews, intelligence tests, attention tests, etc. One of the most frequently used instruments is the Continuous Performance Test (CPT).

Continuous performance tests have demonstrated their potential to identify children who can be diagnosed with ADHD (Gordon, Fisher & Newby, 1995; Harper, Aylward & Brager, 2002; Cantwell, Satterfield, & Lesser, 1972). Although some authors point out that the accuracy of CPT in the diagnosis of ADHD is limited (Nigg, Hinshaw & Halperin, 1996), experimental studies demonstrate that differences between ADHD and non ADHD individuals are commonly detected with this test (Riccio, Reynolds & Lowe, 2001).

There are different types of CPT. CPT tests may vary in terms of the stimulus modality presented (i.e., visual and auditory CPT). They can also be classified according to the instructions given. A CPT with simple instructions requires the individual to respond to the presence of a "target" stimulus, whereas a CPT with more difficult instructions requests the individual to respond to the presence of a stimulus when it is preceded by another specific stimulus.

Recently, there is a growing interest in auditory CPTs given that performance differences registered between the auditory and visual CPT can be a great aid to distinguish ADHD from learning disabilities. It is also possible to find an attentional deficit in only one of the two modalities, an important aspect that will guide the diagnosis and intervention purposes (Harper *et al*., 2002).

During the last years Rizzo and his research team developed a virtual reality based CPT called "the Virtual Classroom" (Rizzo *et al.,* 2000, 2004, 2006; Adams, Finn, Moes, Flannery & Rizzo, 2009). The "Virtual Classroom" offers the opportunity to evaluate an individual's performance in a CPT task in a classroom simulated with the application of the virtual reality technology, hence, increasing the ecological validity of assessment. The individual is situated in a Virtual Classroom where a blackboard, some classmates, school desks, etc. are shown. The individual is then requested to perform a visual CPT responding to the stimuli shown on the blackboard. The stimulus is presented on the screen for 150 milliseconds with an interval of 1350 milliseconds between stimuli. Some of the stimuli (20%) are "target stimuli" and two types of task, with and without distracting stimuli, are presented. Three different types of distracting stimuli can be included: auditory, visual and a combination of both.

A combination of visual and auditory tasks provides more information than CPTs presented in only one modality (Doyle, Biederman, Seidman, Weber & Faraone, 2000). Therefore, with the purpose of adding the possibility of performing auditory tasks our research team developed a virtual CPT, similar to the "Virtual Classroom", that allows to execute four different tasks: an auditory task with non-distractive stimuli, an auditory task with distractive stimuli, a visual task with non-distractive stimuli and a visual task with distractive stimuli. The study aimed at measuring the performance of ADHD and non-ADHD children in the developed CPT. Results are presented below.

Method

Sample

The sample was composed of 20 participants aged between 6 and 11 years old. The total sample was divided in two groups. A subset of 10 participants diagnosed with ADHD by the "Centro de Salud Mental Infantil y Juvenil del Hospital Sant Joan de Déu de Barcelona" conformed the experimental group. Nine of the participants received a diagnosis of ADHD combined type whereas only one subject had a diagnosis of ADHD predominantly inattentive type. All of them were medicated with methylphenidate and were not requested to drop the treatment to perform the test. The non-ADHD group was composed of ten participants from a suburban municipality of Barcelona.

All participants in the control group performed the EDAH test (Farré & Narbona, 1998) to confirm that none would reach scores indicating a possible ADHD diagnosis. Participants in this group were also required not to have a prior history of psychological or neurological disorders. The group of children with ADHD had three female and seven male participants whereas the group of non-ADHD children had four female and six male participants. To be included in the study, all participants were also required to have an Intelligence Quotient (IQ) superior to 80.

Measures

Virtual environments were designed with 3D Studio, Virtools 3 Dev and Poser. The resulting environment consisted of a virtual simulation of a classroom that allowed for the presentation of CPT tests and the registration of performance in four conditions: auditory CPT without distracters, auditory CPT with distracters, visual CPT without distracters, and visual CPT with distracters. Visual Basic and Microsoft Access were used to develop a module to register performance data and an interface to aid the administration of each assessment task. The test was presented on a 19-inch screen. The position of participants in the virtual environment was stable and head turning could be controlled through mouse movements.

Figure 1. Screen captures of the virtual simulation.

Procedure

Every virtual environment presented a 3D avatar simulating a teacher who explained the task that needed to be performed from the beginning to the end of the test. The presentation of stimuli had a duration of 300 milliseconds in both visual and auditory virtual environments. A one-second interval was considered between the presentation of stimuli. The CPT was composed of six blocks containing 100 stimuli each, 20 were designed as target stimuli. Target stimuli were distributed randomly. The test had a total duration of 10 minutes. The word "casa" was the target stimulus in the auditory virtual environment while the rest of the stimuli were 80 words of direct syllabic structure (disyllabic words with the structure consonant-vowel + consonant-vowel) and the same phonological structure as the target stimulus (i.e., “paso”, “poso”, “perro”, “cara”, etc.). The visual virtual environment considered a pencil drawing projected on the blackboard as the target stimulus. The rest of the stimuli were diverse drawings presented in the same sequence used for the auditory virtual environment. Both the visual and the auditory virtual environments could be presented with or without distracting stimuli. Distracters were identical in shape, duration (4 seconds) and presentation for both environments. Distracters could be auditory, visual and combined (auditory and visual) stimuli and were randomly distributed along the test administration in their respective conditions. The four conditions (visual-auditory/with distracters-without distracters) had a random sequence of administration for each participant.

TABLE 1. DISTRACTERS

Auditory distracters	*Visual distracters*	*Combined distracters*
Radio turns on.	A banner falls from a wall.	A classmate sharpens a pencil.
Classmates speak.	A classmate teases the classmate in the next seat.	A boy plays and shoots a ball in the courtyard.
A noise of a can breaking.	A light goes dim.	Teacher’s mobile phone rings and she turn it off.

Results

Statistical analysis was performed using repeated measures ANOVAs, with one inter-variable: group of participants, with two levels (target group and control group) and three intra-variables: block (with six values), sensorial modality (visual and auditory) and distracters (with or without distracters). Omission errors, commission errors, reaction time for correct responses, reaction time for commission errors, reaction time variability in correct answers and reaction time variability in commission errors were analyzed as dependent variables. Only omission errors, reaction time for correct responses and reaction time variability for correct responses are revised in the present study.

We first examined if both groups (target group and control group) were homogenous in personal variables such as gender, age and intelligence quotient (IQ). Results demonstrated there were no significant differences between the age mean values in the two groups ($t= 0.64$; $p= 0.43$). There were no significant differences for the IQ mean values in both groups ($t= -0.67$; $p= 0.51$). No differences were found in the gender distribution (chi-squared= 0.22; $p= 0.63$).

Omission errors

The mean value for omission errors found for the ADHD group (6.02; SD= 0.69) was much higher than the registered for the non-ADHD group (1.89; SD= 0.7) and this difference was statistically significant ($F= 17.78$; $p< 0.001$).

This general difference remains the same when comparing the omission errors of each group separately in each condition. The omission error mean for children with ADHD in the visual task was 6.49 (SD= 0.73), whereas the mean for non-ADHD children was 1.75 (SD= 0.74). The omission error means in the auditory task were 5.5 (SD= 0.79) and 2.02 (SD= 0.77) for each group respectively. The interaction between group (target group and control group) and sensory modality (visual and auditory) was not significant (F= 1.84; p= 0.19), suggesting that the difference of omission errors between the two groups occurs in the same pattern for both the visual and the auditory modality of CPT. When comparing the omission errors of each group in tasks that considered the absence or presence of distracters we found that children with ADHD had a mean value of 4.62 for this type of errors when performing tasks without distracters (SD= 0.68). This mean reached a 7.4 (SD= 0.78) in the presence of distracters. The influence of distracters on the number of omission errors was not as considerably high in non-ADHD children, since their registered mean value for omissions in tasks without distracters went from 1.46 (SD= 0.67) to a mean of 2.31 (SD= 0.76) when performing tasks with distracters. This larger effect of distracters on children with ADHD was perceivable in the significant interaction between the variables group (target group participants and control group participants) and distracters (with and without distracters): F= 8.10 (p= 0.011).

In order to analyze the evolution of performance along time, the interaction between the variables "group" and "block" was examined and significant values were found to indicate the evolution of omission errors was different for each group (F= 3.14; p= 0.012). Children with ADHD showed an already worse performance at the beginning of the test and their performance progressive decay was much larger as they advanced through the task.

TABLE 2. EVOLUTION OF OMISSION ERRORS IN THE TWO GROUPS AS THEY PERFORM THE TEST

Group	*Block*	*Mean*
ADHD	1	4,35
	2	5,72
	3	6,47
	4	6,42
	5	5,65
	6	7,52
Non-ADHD	1	1,72
	2	1,77
	3	2,15
	4	1,67
	5	1,95
	6	2,05

Next, the difference observed in the evolution of performance between the two groups (in all the six blocks presented in each virtual environment) was examined to know if they occurred similarly in the performance of visual and auditory tasks. The nonsignificant three-way interaction between the variables "group", "block" and "sensorial modality" confirmed that the difference previously observed in the evolution of performance was similar in both visual and auditory tasks (F= 0.89; p= 0.489). The three-way interaction was also not significant between the variables "group", "block" and "distracters" (F= 0.89; p= 0.489) suggesting that the difference in the evolution of performance between groups was equal in the presence and absence of distracters. Figures 2, 3, 4 and 5 offer a summarized report of the results obtained in each of the four conditions (visual-auditory/without-with distracters) and in consideration of its duration (blocks).

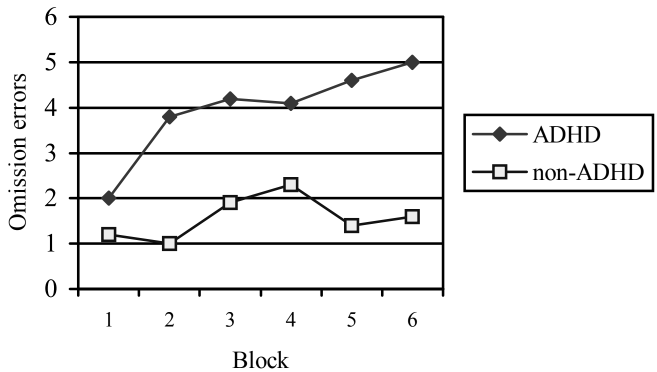

Figure 2. Omission errors of the ADHD and non-ADHD groups in the auditory virtual environment without distracters.

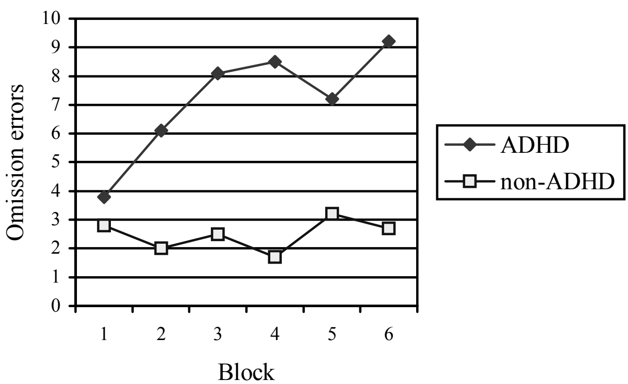

Figure 3. Omission errors of the ADHD and non-ADHD groups in the auditory virtual environment with distracters.

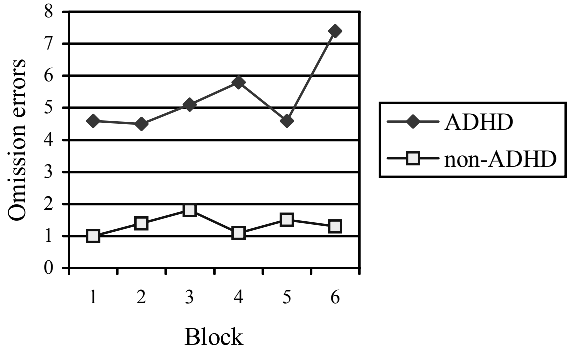

Figure 4. Omission errors of the ADHD and non-ADHD groups in the visual virtual environment without distracters.

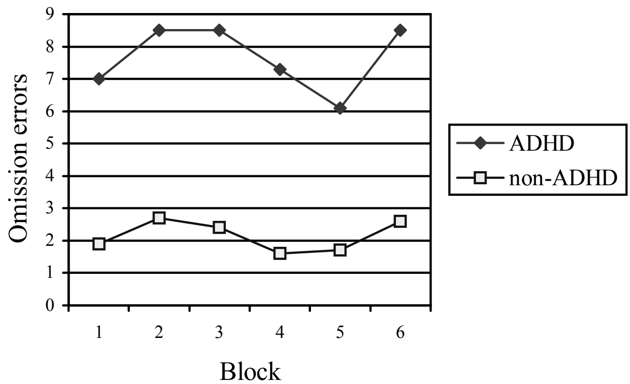

Figure 5. Omission errors of the ADHD and non-ADHD groups in the visual virtual environment with distracters.

Reaction time

No significant differences were found among the reaction time measures for correct responses between children with ADHD and non-ADHD children. ($F= 0.001$; $p= 0.970$). The reaction time mean value (in milliseconds) was 687.36 (SD= 21.94) for children with ADHD and 688.53 (SD= 20.81) for non-ADHD children. No significant differences were found between the reaction time measures of both groups for correct responses considering the sensorial modality of the task (visual or auditory) (F= 2.38; p= 0.141), the presence or absence of distracters (F= 0.001; p= 0.974) and the duration of the task (F= 1.18; p= 0.324). A significant main effect associated to the sensory modality was found given that the reaction time for correct responses in the visual task (717.26; SD= 19.08) was slower than the registered in the auditory task (658.63; SD= 13.8) (F= 17.68; p= 0.001). Another significant main effect was observed in the duration of the task, since as the task was performed the reaction time for correct responses was increased (F= 5.662; p< 0.001).

Reaction time variability

Variability in reaction time for correct responses was next analyzed. In the first place, standard deviation mean values for each group were compared, and significant differences between the target participants and control participants were found. This value was higher for children with ADHD (154.89; SD= 6.09) than it was for non-ADHD children (124.44; SD= 6) (F=12.46; p= 0.002). The difference of time reaction variability between groups remained the same for both the visual and the auditory tasks as the interaction between "group" and "sensory modality" was not significant (F= 0.34; p= 0.565). The interaction between "group" and "distracters" was also nonsignificant (F= 1.83, p= 0.193), indicating that the general differences of reaction time variability for correct responses found in target participants and control participants remained the same when tasks were performed with distracters as when performed without distracters. Similarly, the interaction between "group" and "block" was also nonsignificant (F= 1.299; p= 0.271), suggesting that differences between the two groups on this dependent variable remained the same all along the task.

Discussion and conclusions

The current results show that the presentation of a CPT using virtual reality technology is an effective procedure to identify attentional difficulties in children with ADHD, since their performance in the test was significantly lower and registered a more substantial progressive decline compared to the children in the control group. Differences between groups were expressed in both auditory and visual tasks and became more evident with the presence of distracters. These findings are in line with prior studies in which similar attentional difficulties were found by using the traditional design of CPT (Riccio *et al.,* 1996; López-Campo *et al*., 2005; Katsuo *et al*, 1998; Baker *et al*., 1995; Nigg *et al*., 1996; Harper *et al*., 2002).

Children with ADHD showed a larger reaction time variability associated to correct responses compared to non-ADHD children while performing the test. Similar results were found in many other studies. In example, Rovet & Hepworth (2001) also found a high reaction time variability in their ADHD group. Othmer, Kaiser & Othmer (1992) reported on similar variability differences among groups. Johnson *et al*. (2007), Klein, Wendling, Huettner, Ruder & Peper (2006), Williams, Strauss, Hultsch, Hunter & Tannock (2007), Wodka *et al*. (2007) and Suskauer *et al*. (2008) suggested similar findings. The differences reported above are stable during the test and occur in both visual and auditory tasks and when distracters are included as when they are not. A possible explanation of the appearance of this feature in ADHD is offered by Castellanos *et al*. (2005) who suggest the existence of a possible catecholaminergic deficit. As stated by some authors (Vaurio, Simmonds & Mostofsky, 2009), the variability of reaction time could be an intermediate endophenotype in ADHD, given that it was found to be highly correlated with impulsivity and inattention self-reports (Simmonds, Pekar & Mostofsky, 2008), suggesting that response variability contributes to the expression of the diagnostic features of the disorder. Moreover, some studies found close relatives of ADHD individuals to show a high variability in reaction time measures (Bidwell, Willcutt, DeFries & Pennington, 2007).

Similar to Adams *et al*. (2009), who report findings compatible with the current results when using the Virtual Classroom test, we can state that CPT tests performed in the context of virtual environments are sensitive to discriminate attentional deficits in children with ADHD. Parsons, Bowerly, Buckwalter & Rizzo (2007) demonstrated data supporting the validity of the virtual design of CPT by finding positive correlations between the results obtained with the Virtual Classroom test and the traditional CPT designed by Connors. The current results offer additional data supporting the validity of using this type of technology for the assessment of ADHD. Virtual reality allows for the achieving of the presentation of stimuli with high levels of control and consistency. In addition, it facilitates the presentation of distracters with a high level of resemblance to elements which in fact can be found in the real world by placing them in a similar context. Thus, it is possible to assume that a higher ecological validity can be found in CPT tests performed in this manner as compared to the traditional CPT test. Virtual classrooms in which tests are administered offer the opportunity of evaluating performance under conditions that resemble a natural situation, presenting at once distracters with a high level of control.

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