EUROPEAN JOURNAL OF PAEDIATRIC NEUROLOGY XXX (2012) 1–8

Official Journal of the European Paediatric Neurology Society

Original article

Impact of time on task on ADHD patient's performances in a virtual classroom

Stéphanie Bioulac [a,b,*], Stéphanie Lallemand [b], Albert Rizzo [c], Pierre Philip [b], Colette Fabrigoule [b], Manuel Pierre Bouvard [a]

[a] Pôle Universitaire de Psychiatrie de l'Enfant et de l'Adolescent, Centre Hospitalier Charles Perrens, Bordeaux, France
[b] USR CNRS 3413, Centre Hospitalier Universitaire, Hôpital Pellegrin, Université Victor Segalen Bordeaux 2, Bordeaux, France
[c] University of California in Los Angeles, Los Angeles, CA, USA

ARTICLE INFO

Article history:
Received 16 December 2010
Received in revised form
29 July 2011
Accepted 6 January 2012

Keywords:
Attention deficit hyperactivity disorder (ADHD)
Virtual reality
Continuous performance test (CPT)
Impact of time

ABSTRACT

Background: Use of virtual reality tool is interesting for the evaluation of Attention Deficit/Hyperactivity Disorder (ADHD) patients. The virtual environment offers the opportunity to administer controlled task like the typical neuropsychological tools, but in an environment much more like standard classroom. Previous studies showed that a virtual classroom was able to distinguish performances of children with and without ADHD, but the evolution of performances over time has not been explored. The aim of this work was to study time on task effects on performances of ADHD children compared to controls in a virtual classroom (VC).

Methods: 36 boys aged from 7 to 10 years completed the virtual classroom task. We compared the performance of the children diagnosed with ADHD with those of the control children. We also compared attentional performances recorded in the virtual classroom with measures of the Continuous Performance Test (CPT II).

Results: Our results showed that patients differ from control subjects in term of time effect on performances. If controls sustained performances over time in the virtual reality task, ADHD patients showed a significant performance decrement over time. Performances at the VC correlated with CPT II measures.

Conclusion: ADHD children are vulnerable to a time on task effect on performances which could explain part of their difficulties. Virtual reality is a reliable method to test ADHD children ability to sustain performances over time.

1. Introduction

Attention Deficit/Hyperactivity Disorder (ADHD) is one of the most common childhood and adolescent psychiatric disorders, affecting over 5% of school age children.[1,2] ADHD is a developmental disorder characterized by difficulties with attention, hyperactivity and impulsivity which often lead to various behavioral problems and learning disabilities. Disturbances of attention are a core symptom of patients with ADHD, notably with distractibility and an

* Corresponding author. Pôle universitaire de psychiatrie de l'enfant et de l'adolescent, Centre hospitalier Charles Perrens, 121 Rue de la Béchade, F-33076 Bordeaux Cedex, France. Tel.: +33 556561719; fax: +33 556561715.
E-mail address: stephaniebioulac@hotmail.com (S. Bioulac).

1090-3798/$ – see front matter © 2012 Published by Elsevier Ltd on behalf of European Paediatric Neurology Society.
doi:10.1016/j.ejpn.2012.01.006

inability to stay on task which may strongly impact academic learning.

Virtual reality is a relatively new technology that enables individuals to immerse themselves in a virtual world. It offers several advantages compared to traditional neuropsychological assessment measures, including a more realistic, lifelike environment that may allow subjects to "forget" they are being assessed, a better participation and an increased generalization of learning.[3,4] This may be particularly beneficial to ADHD children who often show great interest and considerable success on computer, console or videogame tasks.[5–7] Clinicians, parents, teachers and authors like van der Meere[8] related that ADHD children could sustained their attention if they are really motivated.

At present, few studies have used virtual reality in child and adolescent psychiatry. Rizzo and his team developed a virtual classroom which was used to compare ADHD and control populations.[10–13] Most of the studies using this tool have found that children with ADHD make significantly less correct hits and more commission errors compared with controls, except in Adam's investigations where the difference between the ADHD group and the control group only approached significance.[3] ADHD children also had slower reaction times and higher reaction time variability compared with controls.[9,15] So, the virtual classroom developed by Rizzo was able to distinguish performances in children. Furthermore, virtual classroom (VC) measures were correlated with traditional assessment tools like various ADHD rating scales[3,14] or the Continuous Performance Test (CPT), a test widely used to assess the ability to sustain attention over time.

As underlined by Rapport,[16] few studies have explored time on task effect in ADHD. Some of them, for example Hooks,[17] using a CPT, and van der Merre,[18] using a change detection task, demonstrated a deterioration of performances over time for ADHD children. Others, for example Alberts[19] with a working memory task and Barkley[20] with a sequence detection task did not find this effect. Results are thus contradictory but hardly comparable because type of tests, duration of sessions (from 720 s to 2160 s), frequency of stimuli (from .625 stimuli per second to .03 per second) and frequency of targets presentation (from 1 target per 1.6 s to 1 target per 30 s) largely differed in various publications.

Time on task effects has never been studied using the virtual classroom. This tool is more comparable to the usual environment of children than any laboratory cognitive tools, and may be useful to study the ability to sustain attention over time in school situation.

The aim of this study was to test time on task effects in ADHD children and healthy controls using the virtual classroom developed by Rizzo. In order to better understand the relationship between a classical test and the virtual test, we added to our study a CPT test which is a classical tool used for ADHD patients.

2. Subjects and methods

2.1. Subjects

The sample consisted of boys aged between 7 and 10 years. The ADHD children were recruited among outpatients referred for a psychiatric examination to the Child and Adolescent Psychiatry Department, BordeauxUniversity Hospital. ADHD patients had been free of any psychostimulant medication for a minimum of 72 h. ADHD children were excluded if they presented with comorbid autism, mental retardation, or verbal scale IQ score <85.

The controls were recruited among the general population. They had no psychiatric diagnosis. Controls were excluded if they had a pathological T-score (>60) for attention problems on the Child Behavior Check List.[21,22] All the control children had received traditional schooling and none had repeated a year.

2.2. Methods

2.2.1. Assessment procedure

Clinical diagnosis of ADHD was made by a psychiatrist using DSM-IV criteria after several interviews with the child and his parents.[23] The parents of hyperactive children completed the Conners parents rating scale (CPRS).[24] The CPRS is a useful clinical tool for obtaining parental reports of childhood behavior problems. This questionnaire-based instrument presents a standardized measurement of children's behavior with a particular emphasis on hyperactivity.

For both groups of children, we collected the dimension "attention problems" on the Child Behavior Check List. Moreover, the State Trait Inventory Anxiety (STAI) (State form) was used to measure anxiety levels before and after completion of the VC.[25] Finally, a 22-item cybersickness scale was used to assess the level of discomfort after exposure to the VC. It comprised a list of symptoms and sensations associated with autonomic arousal (nausea, sweating, heart pounding, etc...), vestibular symptoms (dizziness, fainting, etc...), and respiratory symptoms (feeling short of breath). Items were rated on a scale from 0 to 4 (absent, weak, moderate, strong, very strong). This questionnaire was presented after completion of the experiment.[26,27]

2.2.2. Procedure

ADHD and controls children were tested at the beginning in the afternoon to try to minimize potential testing effects due to different time of the day. The same physician assessed the children with, first the CPT and, after 10 min, the test of the VC.

Written informed consent was obtained from the parents and children, respectively.

2.2.3. Virtual classroom

Virtual classroom developed by Rizzo et al. has been used.[9–12] This software was developed at the IntegratedMedia Systems Center at the University of Southern California in Los Angeles (Rizzo et al with Digital Media Works Inc (http://www.dmv.ca/). It was adapted for a French utilization by our team. The virtual classroom was a head-mounted display (HMD) virtual system for the assessment of attention processes. Each participant sat in front of a desk. Then, the physician fitted the HMD to the child's head and the system presenting the virtual classroom was

Please cite this article in press as: Bioulac S, et al., Impact of time on task on ADHD patient's performances in a virtual classroom, European Journal of Paediatric Neurology (2012), doi:10.1016/j.ejpn.2012.01.006

Table 1 – Patients and control subjects.

	ADHD group $n = 20$	Control group $n = 16$	p Mann–Whitney U test
Mean Age (years) (*SD*)	8.37 (± 0.89)	8.21 (± 1.00)	ns
Attention problems (CBCL) (*SD*)	71.40 (± 8.53)	53.78 (± 5.3)	<.001
STAI- state (before virtual classroom) (*SD*)	30.50 (± 3.65)	27.75 (± 2.98)	<.05
STAI-state (after virtual classroom) (*SD*)	28.70 (± 4.38)	27.18 (± 3.53)	ns
Cybersickness scale	0.55 (± 1.05)	0.56 (± 0.9)	ns

CBCL: Child Behaviour Check-List, STAI: State Trait Anxiety Inventory, SD: Standard Deviation.

activated. Subjects saw the interior of the classroom in the HMD. The scenario consisted of a standard rectangular classroom environment containing three rows of desks, a teacher's desk at the front, a blackboard across the front wall, a female virtual teacher between the desk and blackboard, on the left side wall a large window looking out on to a playground with buildings, vehicles, and people, and on each end of the wall opposite the window a pair of doorways, through which activity occurs.[14] The virtual teacher expressed the information to the subjects. They were instructed to view a series of letters on the blackboard and to press a mouse button as quickly as possible, only when they viewed the letter "K" preceded by the letter "A". Many distracters were presented in the classroom during the task including auditory distracters (pencils dropping, footsteps ...) visual distracters (paper airplane flying across the classroom...) and mixed distracters (auditory and visual distracters) such as a car rumbling by the outside window. The experiment comprised 5 blocks (for a period of 100 s each) with 20 targets (AK). Five hundred stimuli were presented during the whole task (500 s). During the VC task, we noted various indicators as follows: correct hits, commissions, hit reaction time, variability of hit reaction time and commission reaction time.

These indicators were also recorded for every block and group.

2.2.4. *CPT*

We used the CPT II, one of the most useful measures for ADHD assessment. Subjects had to react to target letters on the computer screen except on letter X.[28–30] The experiment comprised 6 blocks (for a period of 140 s). Each block contained 54 targets (except the block 1: 53 targets) and 6 non-targets. The task lasted for 14 min, and participants observed computer-generated letters presented at interstimulus intervals of 1, 2, and 4 s, with a display time of 250 ms. Results are described with four indicators as follows: correct hits (number of cases where a response occurs in presence of a target), commission errors (number of cases where a response occurs in presence of a non-target), mean reaction time (hit reaction time) and variability of hit reaction time (measured by standard deviation). These indicators were also recorded for every block and group.

2.3. *Statistical analysis*

Because most dependent variables were not normally distributed, non parametric tests were used.

The differences between ADHD children and controls were analyzed by using the Mann–Whitney test for demographic variables, CBCL attention problems score, STAI and cybersickness scale scores, and for global performance indicators of the VC and the CPT. The Mann–Whitney test was also used to compare performances between groups at every block. The Friedmann two ways analysis of variance by ranks test for repeated measures was used to analyze the evolution of performances over blocks. In the case of a significant time effect for a given group, the Wilcoxon rank sum test was used as post-hoc test, to compare performances between the first block and each further successive block. For the VC, dependent variables included the number of correct hits, the number of commissions and hit reaction time. For the CPT, dependent variables included the number of correct hits, hit reaction time and reaction time standard deviation. Bravais–Pearson correlations were used to assess the association in the whole group (ADHD and Controls) between VC measures and CPT measures.

Statistical significance was set at $p < .05$. Statistical analysis was performed with Statistica.

3. Results

3.1. *Patients and control subjects (Table 1)*

Our sample comprised 36 boys, 20 ADHD subjects and 16 controls. The mean age did not differ between the two groups. There were significant differences between the two groups regarding attention problems on the CBCL and on the state form of the STAI before the VC experiment. This later difference disappeared after the test. On cybersickness scale none of the child exhibited significant side effects (mean on the cybersickness scale: 0,55 (±.96)).

All ADHD children presented a verbal scale IQ score ≥85. Among the ADHD children, 2 had inattention sub-type and 18 had mixed sub-type. The mean hyperactivity index on the Conners parents rating scale was 70.45 (±8.45).

3.2. *Virtual classroom data*

Average performances on VC variables are shown in Table 2. Compared to ADHD children, controls had significantly more correct hits and less commission errors. Correct hits reaction time, correct hit reaction time variability and commission reaction time did not differ between the two groups.

Please cite this article in press as: Bioulac S, et al., Impact of time on task on ADHD patient's performances in a virtual classroom, European Journal of Paediatric Neurology (2012), doi:10.1016/j.ejpn.2012.01.006

Table 2 – Comparison of means for virtual classroom between ADHD and control groups.

	ADHD group $n = 20$	Control group $n = 16$	p Mann–Whitney U test
Total correct hits (SD)	67.95 (± 11.54)	85.81 (± 8.48)	<.001
Total commissions (SD)	21.05 (± 9.87)	14.87 (± 10.05)	<.05
Correct hits reaction time (sec) (SD)	.52 (± .10)	.54 (± .08)	ns
Reaction time variability (sec) (SD)	.21 (± .06)	.20 (± .05)	ns
Commissions reaction time (msec) (SD)	582 (± 139.88)	569 (± 203.24)	ns

SD: Standard Deviation.

Fig. 1 illustrates the evolution of the number of correct hits over the 5 blocks for the two groups. The number of correct hits in ADHD subjects was significantly lower, for each block, than in control subjects (Block 1: $u = 51$; $p < .001$; Block 2: $u = 80.5$; $p < .05$; Block 3: $u = 27$; $p < .001$; Block 4: $u = 55.5$; $p < .001$; Block 5: $u = 66.5$; $p < .01$). Friedman test showed a significant block effect with a tendency to decrease in ADHD patients (chi2 (4) = 25,229; $p < .001$) but not in controls. For ADHD children, the difference between the number of correct hits between blocks 1 and 2 was not significant ($z = -.104$, $p = .92$). Compared to block 1, patients performed significantly fewer correct hits for blocks 3 ($z = -2.985$, $p < .01$), 4 ($z = -3.350$, $p < .001$) and 5 ($z = -2.491$, $p < .05$).

Concerning the number of commission errors, ADHD children made significantly more commissions errors than controls only in the first block ($u = 95$; $p < .05$). Friedman test showed a significant block effect in ADHD patients only (chi2 (4) = 15,834; $p < .01$), with a tendency to decrease. Comparisons between the first and each successive blocks showed in ADHD a significant decrease uniquely between blocks 1 and 3 ($z = -3{,}443$, $p < .001$).

Concerning reaction time, there were no significant differences between ADHD and controls regardless of the block. Friedman test showed in ADHD patients only, a significant block effect with a tendency to increase (chi2 (4) = 10,115; $p < .05$). ADHD children showed a significant slowing of reaction time between the block 1 and blocks 3 ($z = -2{,}894$, $p < .01$) and 4 ($z = -2{,}651$, $p < .01$).

3.3. CPT data

Compared to controls, ADHD children showed significantly less correct hits, a slower reaction time and a larger reaction time standard deviation (Table 3). Commission errors did not differ between the two groups.

Fig. 2 shows the evolution of the number of correct hits over the 6 blocks for the two groups. ADHD children made significantly less correct hits than controls in blocks 3 ($u = 41$; $p < .001$), 4 ($u = 71$; $p < .01$), 5 ($u = 57$; $p < .001$) and 6 ($u = 83.5$; $p < .05$). Friedman test showed a significant block effect in control subjects with a tendency to increase (chi2 = 11,930,

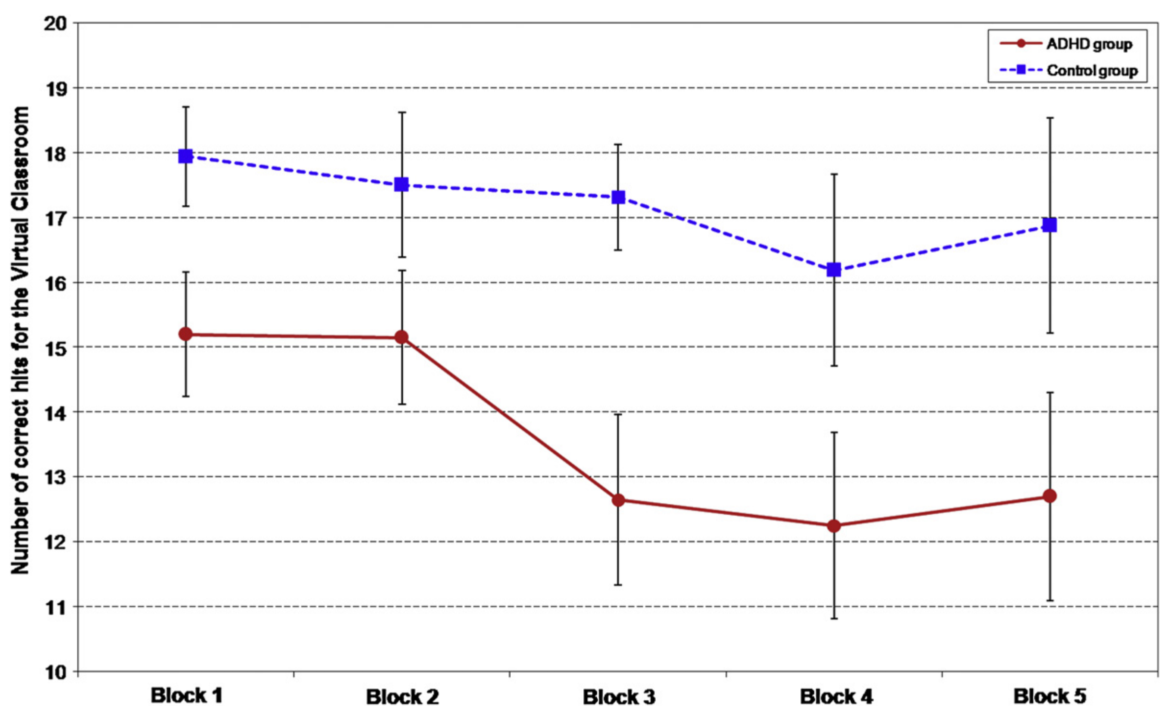

Fig. 1 – Evolution of number of correct hits for virtual classroom over 5 blocks of the two groups (with 95% confidence intervals).

Please cite this article in press as: Bioulac S, et al., Impact of time on task on ADHD patient's performances in a virtual classroom, European Journal of Paediatric Neurology (2012), doi:10.1016/j.ejpn.2012.01.006

Table 3 – Comparison of means for the CPT between ADHD and control group.

	ADHD group $n = 20$	Control group $n = 16$	p Mann-Whitney U test
Correct hits (SD)	297.20 (± 12.89)	312.16 (± 8.94)	<.001
Commissions (SD)	26.25 (± 5.06)	22.56 (± 6.35)	ns
Correct hits reaction time (msec) (SD)	460.15 (± 86.15)	412.31 (± 63.35)	<.05
Reaction time standard deviation (msec) (SD)	14.47 (± 5.13)	8.08 (± 2.15)	<.001

SD: Standard Deviation.

$p < .05$). In the ADHD subjects a tendency to decrease was observed which did not reach the level of significance (chi2[5] = 10,145; $p = .07$). For control children, comparisons of performances between the first and each successive blocks showed a significant increase in the number of correct hits between the block 1 and blocks 2($z = -1{,}921$, $p < .05$), 3 ($z = -2{,}732$, $p < .01$) and 5 ($z = -1{,}970$, $p < .05$).

ADHD children showed longer hit reaction time than controls in blocks 3 ($u = 88.0$; $p < .05$), 4 ($u = 82.5$; $p < .05$), and 6 ($u = 90.0$; $p < .05$). Friedman test showed no block effect in neither groups.

Reaction time standard deviation was significantly larger in ADHD children compared to controls for blocks 2 to 6 (block 2: ($u = 55$; $p < .001$)); block 3: ($u = 56$; $p < .001$); block 4: ($u = 71$; $p < .01$); block 5: ($u = 81$; $p < .05$); block 6: ($u = 45$; $p < .001$)). Friedman test showed a significant block effect for ADHD subjects only with a tendency to increase (chi2 = 16,914, $p < .01$). Reaction time standard deviation increased significantly in ADHD patients between the block 1 and blocks 4 ($z = -2{,}277$, $p < .05$) and 6 ($z = -2{,}128$, $p < .05$)..

3.4. *Correlations*

Correlational analysis revealed significant positive relationships between three performance indicators of the VC and the CPT: number of correct hits ($r = .623$, $p < .001$), hit reaction time ($r = .381$, $p < .05$) and standard deviation of hit reaction time ($r = .373$, $p < .05$).

4. Discussion

The goal of this work was to examine the evolution of performances over time in ADHD and control populations during the virtual classroom task. Our results showed that ADHD patients had a different evolution of performances on this task than control children. If control subjects sustained performances over time in the virtual reality task, ADHD patients showed a significant performance decrement with a decrease of correct hits and an increase of reaction time. As expected, the total number of correct hits and the total

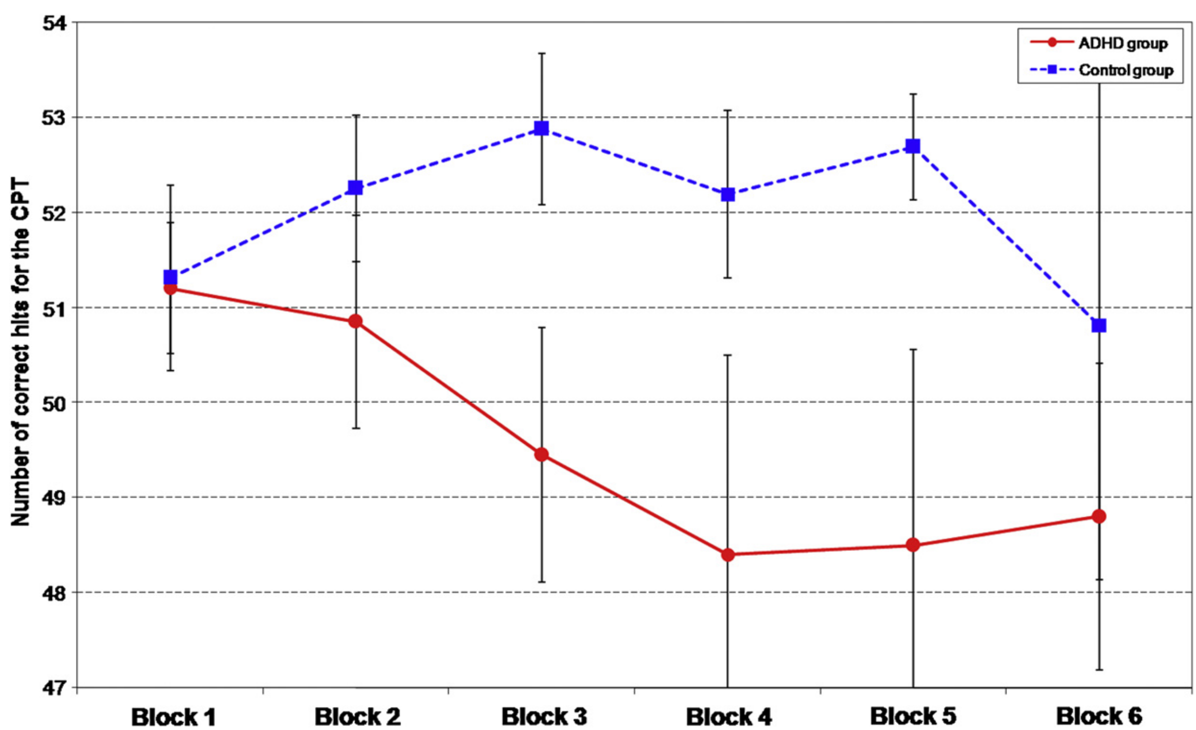

Fig. 2 – Evolution of the number of correct hits for the CPT over 6 blocks of the two groups (with 95% confidence intervals).

Please cite this article in press as: Bioulac S, et al., Impact of time on task on ADHD patient's performances in a virtual classroom, European Journal of Paediatric Neurology (2012), doi:10.1016/j.ejpn.2012.01.006

number of commissions were significantly different between the two groups in our study, using the French version of VC, as previously demonstrated with English and Hebrew versions.[9,14,15] To summarize, ADHD patients showed worse global performances than controls, and a decline of performances over time.

Concerning the pattern of results observed in the CPT, performances were impaired in ADHD children compared to control children for the number of correct hits, commissions and reaction time. No significant decrement of performances over blocks occurred in the ADHD group, but they did not show the improvement of performances observed in the control group.

Worse performances in ADHD children compared to controls were then observed both in the VC task and in the CPT. Moreover virtual classroom task measures (number of correct hits, hits reaction time and standard deviation of hit reaction time) correlated with CPT II measures. These results strongly suggest that the VC task and the CPT are indicators of the difficulty to recruit attentional control. The difficulty to regulate the attentional control in a demanding task has been studied using fRMI and has showed to be associated with an extensive neural dysfunction. "This dysfunctional regulation involves a large number of brain regions including regions related to overall arousal and attention, those involved in top-down biasing of attention and those involved in late stage selection and inhibition".[31]

In our study the deterioration of performances over time was evident in the VC task but not in the CPT. This difference may be explained by several reasons as there are several differences between the two tasks. This was however not due to the duration of the task because the VC task lasted for 500 s while the CPT lasted for 840 s. van der Meere[18] suggested that there is a beneficial effect of a fast stimuli presentation rate for ADHD children, but this hypothesis did not explain our results, the deterioration of time being more obvious in the VC, with a mean frequency of one stimulus per second, than in the CPT, with an interstimulus interval varying between one, 2 or 4 s. The VC task involved probably more complex cognitive mechanisms than the CPT. In the CPT inhibitory processes are implied, subjects having to respond to a frequent stimulus and to inhibit responding to an infrequent one, but minimal working memory load is imposed.[32] Contrarily, in the VC task, working memory is necessary for keeping in mind the last stimulus presented on the blackboard and to be able to identify the sequence AK. Having a working memory component however did not necessarily results in a detrimental effect over time since other tasks in the literature[19,20] having such a component did not showed this effect in ADHD patients. Another strong difference between the two tasks is the environmental context in the VC. To be able to attribute enough attention to the VC task, children have to inhibit the various potential distracters in the classroom (for example, teachers and other children movements, paper airplane...). This mechanism of resistance to distracter may increase the cognitive load of the task. In line with this idea, Rizzo,[9] using the VC version including distracter also used in our experiment, found that this version was more disruptive for ADHD performances than the version without distracter.

The structure of the VC is then more comparable, than the CPT, with classroom academic tasks. In the same lines, Rapport[16] noted that "classroom academic tasks involve controlled processing and place greater demand on cognitive resources, including the ability to store and manipulate information in working memory".

Concerning the number of commission errors, ADHD children made significantly more commissions errors than controls only in the first block. For ADHD group we can observe a decrease over time. This decrease of commission errors occurred at the same time than a slowing of reaction time and the decrease of correct hits. It may result from a speed-accuracy trade-off.

The evolution of reaction time variability over the successive blocks was not recorded on the VC task. So it was not possible to study in the VC task the difference in reaction time variability between the two groups which was observed across several cognitive tasks and the CPT.[33–36] Future investigations should examine if an increase in reaction time variability over blocks occurs with the decrease in performances.

All the subjects (patients and controls) perceived the VC task as being more enjoyable than the CPT, as in Pollack's study.[15] Subjective feelings of enjoyment were also more positive for virtual tools than classic tools on children with ADHD, autism and intellectual disability.[9,37,38] The current findings also demonstrate that use of a head device such as the HMD is comfortable and does not lead to cybersickness. This corroborates the data of Parsons and Pollack who used the same environment.[14,15] In addition, the VC session did not increase anxiety among the subjects as shown by the STAI. In fact, before the task ADHD patients were more anxious than controls but this difference disappear after the VC task.

The present study had some limitations. First our group was rather small so we have not taken comorbidity and DSM-IV sub-types into account. Our group was also exclusively composed of boys. The next step will be to test the reliability and validity of the VC task in a larger sample that includes girls and ADHD patients presenting limited comorbidities to allow regression analysis. Concerning the controls, we did not assess their IQ, but all of them had traditional schooling and none had repeated a year. For ADHD children, we used only the verbal IQ sub-scale, because performance subscales are closely linked with attentional competences.

5. Conclusion

Virtual reality is a relatively new technology and its application in child and adolescent psychiatry is recent. Using a virtual classroom task, we showed that ADHD patients exhibited a decline of performances over time in terms of speed and accuracy. ADHD children performed significantly worse on the task than control subjects, as indicated by the lower number of correct hits and a higher number of commissions. We then demonstrated a significant worsening of correct responses and reaction time over successive blocks which had previously never been analyzed. The time on task

Please cite this article in press as: Bioulac S, et al., Impact of time on task on ADHD patient's performances in a virtual classroom, European Journal of Paediatric Neurology (2012), doi:10.1016/j.ejpn.2012.01.006

effects in ADHD children illustrated the difficulty to stay on task for these subjects. This finding demonstrated that duration of the task is critical to handicap ADHD patients and could have implications in the way patients should be confronted to evaluations or even teaching.

The virtual reality classroom offers several advantages compared to classical tools such as more realistic and lifelike environment but also to record various measures in a standardized conditions. Again, the virtual classroom has proved to be a good clinical tool for evaluation of attention in ADHD but especially to explore time on task effects. The virtual classroom could be used in various future investigations: it may certainly be an effective tool to measure drug effects.[39] The virtual reality system can provide multimodal stimuli, such as visual and auditory stimuli. In the future, the virtual classroom can also be used to evaluate the patient's multimodal integration and to aid rehabilitation of cognitive abilities for example to entrain ADHD patients to resist to distracters.

Acknowledgments

We would like to thank Kattalin Etchegoyhen, Isabelle Viaud-Delmon and Etienne Guillaud for valuable contribution.

REFERENCES

1. Biederman J, Faraone SV. Attention-deficit hyperactivity disorder. *Lancet* 2005;**366**(9481):237–48.
2. Zuddas A, Ancilletta B, Muglia P, Cianchetti C. attention deficit hyperactivity disorder: a neuropsychiatric disorder with childhood onset. *European Journal Paediatric Neurology* 2000;**4**(2):53–62.
3. Adams R, Finn P, Moes E, Flannery K, Rizzo AS. Distractibility in Attention Deficit/ Hyperactivity Disorder (ADHD): the virtual reality classroom. *Child Neuropsychology* 2009;**15**(2):120–35.
4. Schultheis MT, Rizzo AA. The application of virtual reality technology for rehabilitation. *Rehabilitation Psychology* 2001;**46**:296–311.
5. Bioulac S, Arfi L, Bouvard MP. Attention deficit/hyperactivity disorder and video games: a comparative study of hyperactive and control children. *European Psychiatry* 2008;**23**(2):134–41.
6. Nash H. Kids, family and chaos. Torrensville, South Australia: Ed Med, 1994.
7. Serfontein G. *The hidden hadicap: how to help children who suffer from dyslexia, hyperactivity and learning difficulties*. East Roseville, Australia: Simon and Scherster Australia; 1990.
8. van der Meere JJ. The role of attention. In: Sandberg S, editor. *Hyperactivity and attention disorders of childhood*. Cambridge, UK: Cambridge University Press; 2002.
9. Rizzo AA, Bowerly T, Buckwalter JG, Klimchuk D, Mitura R, Parsons TD. A virtual reality scenario for all seasons: the virtual classroom. *CNS Spectrum* 2006;**11**(1):35–44.
10. Rizzo AA, Buckwalter JG, Van der Zaag C. Virtual environment applications in clinical neuropsychology. In: Stanney KM, editor. *The handbook of virtual environments*. New-York: Erlbaum Publishing; 2002. p. 1027–64.
11. Rizzo AA, Buckwalter JG, Neumann U, Chua C, Van Rooyen A, Larson P, et al. Virtual environments for targeting cognitive processes: an overview of projects at the University of Southern California. *CyberPsychology and Behavior* 1999;**2**(2):89–100.
12. Rizzo AA, Buckwalter JG. The status of virtual reality for the cognitive rehabilitation of persons with neurological disorders and acquired brain injury. *Studies in Health Technology and Informatics* 1997;**39**:22–33.
13. Rizzo AA, Buckwalter JG. Virtual reality and cognitive assessment and rehabilitation: the state of the art. *Studies in Health Technology and Informatics* 1997;**44**:123–45.
14. Parsons TD, Bowerly T, Buckwalter JG, Rizzo AA. A controlled clinical comparison of attention performance in children with ADHD in a virtual reality classroom compared to standard neuropsychological methods. *Child Neuropsychology* 2007;**13**(4):363–81.
15. Pollack Y, Weiss PL, Rizzo AA, Weizer M, Shriki L, Shalev RS, et al. The utility of a continuous performance test embedded in virtual reality in measuring ADHD-related deficits. *Journal of Developmental & Behavioral Pediatrics* 2009;**30**(1):2–6.
16. Rapport MD, Kofler MJ, Alderson RM, Timko Jr TM, DuPaul GJ. Variability of attention process in ADHD. *Journal of Attention Disorders* 2009;**12**(6):563–73.
17. Hooks K, Milich R, Lorch EP. Sustained and selective attention in boys with attention deficit hyperactivity disorder. *Journal of Abnormal Child Psychology* 1994;**23**:69–77.
18. van der Meere J, Shalev R, Börger N, Gross-Tsur V. Sustained attention, activation and MPH in ADHD: a research note. *Journal of Child Psychology and Psychiatry* 1995;**36**:697–703.
19. Alberts E, van der Meere JJ. Observations oh hyperactive behaviour during vigilance. *Journal of Child Psychology and Psychiatry* 1992;**33**:1355–64.
20. Barkley RA, Anastopoulos AD, Guevermont DC, Fletcher KE. Adolescents with ADHD: patterns of behavioral adjusment, academic functionning, and treatment utilization. *Journal of the AmericanAcademy of Child and Adolescent Psychiatry* 1991;**30**:752–61.
21. Achenbach T. *Manual for the child behavior checklist*. Burlington University of Vermont, Department of Psychiatry; 1992.
22. Fombonne E, Chehdan F, Carradec AM, Achard S, Navarro N, Reis S. Le Child Behavior Checklist: un instrument pour la recherche en psychiatrie de l'enfant. *Psychiatry and Psychobiologie* 1988;**3**:409–18.
23. APA. *Diagnostic and statistical manual of mental disorders (DSM-IV)*. 4th ed. Washington DC: APA Press; 1994.
24. Conners CK. Rating scales in ADHD: use in assessment and treatment monitoring. *Journal of Clinical Psychiatry* 1988;**59**:24–30.
25. Spielberger CD, Vagg PR. Psychometric properties of the STAI: a reply to Ramamaiah, Franzen, and Schill. *Journal of Personality Assessment* 1984;**48**(1):95–7.
26. Schubert T, Friedman F, Regenbrecht. The experience of presence: factor analytic insights. *Presence: Teleoperators and Virtual Environments* 2001;**10**:266–81.
27. Viaud-Delmon I, Warusfel O, Seguelas A, Rio E, Jouvent R. High sensitivity to multisensory conflicts in agoraphobia exhibited by virtual reality. *European Psychiatry* 2006;**21**(7):501–8.
28. Rosvold HE, Delgado JM. The effect on delayed-alternation test performance of stimulating or destroying electrically structures within the frontal lobes of the monkey's brain. *Journal of Comparative & Physiological Psychology* 1956;**49**(4):365–72.
29. Conners CK, Staff M. *Conners' continuous performance test II: computer program for windows technical guide and sofware manual*. North Tonwanda, NY: Multi-Health Systems; 2000.
30. Epstein JN, Erkanli A, Conners CK, Klaric J, Costello J, Angold A. Relations between continuous performance test

Please cite this article in press as: Bioulac S, et al., Impact of time on task on ADHD patient's performances in a virtual classroom, European Journal of Paediatric Neurology (2012), doi:10.1016/j.ejpn.2012.01.006

performance measures and ADHD behaviors. *Journal of Abnormal Child Psychology* 2003;**31**(5):543–54.
31. Banich MT, Burgess GC, Depue BE, Ruzic L, Bidwell C, Hitt-Lausten S, et al. The neural basis of sustained attention and transient attentional control in young adults with ADHD. *Neuropsychologia* 2009;**47**:3095–104.
32. Denney CB, Rapport MD, Chung KM. Interactions of task and subject variables among continuous performances tests. *Journal of Child Psychology Psychiatry* 2005;**46**(4):420–35.
33. Andreou P, Neale BM, Chen W, Christiansen H, Gabriels I, Heise A, et al. Reaction time performance in ADHD: improvement under fast-incentive condition and familial effects. *Psychological Medicine* 2007;**37**(12):1703–15.
34. Castellanos FX, Tannock R. Neuroscience of attention-deficit/hyperactivity disorder: the search for endophenotypes. *Nature Review Neurosciences* 2002;**3**(8):617–28.
35. Klein C, Wendling K, Huettner P, Ruder H, Peper M. Intra-subject variability in attention-deficit hyperactivity disorder. *Biological Psychiatry* 2006;**60**(10):1088–97.
36. Nigg JT. Neuropsychologic theory and findings in attention-deficit/hyperactivity disorder: the state of the field and salient challenges for the coming decade. *Biological Psychiatry* 2005;**57**(11):1424–35.
37. Yalon-Chamovitz S, Weiss PL. Virtual reality as a leisure activity for young adults with physical and intellectual disabilities. *Research in Developmental Disabilities* 2008;**29**(3):273–87.
38. Parsons TD, Rizzo AA, Rogers S, York P. Virtual reality in paediatric rehabilitation: a review. *Developmental Neurorehabilitation* 2009;**12**(4):224–38.
39. Pollack Y, Shomaly HB, Weiss PL, Rizzo AA, Gross-Tsur V. Methylphenidate effect in children with ADHD can be measured by an ecologicaly valid continous performance test embedded in virtual reality. *CNS Spectrums* 2010;**12**(2):125–30.