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Temporal Perception and Delay Aversion: A videogame screening tool for the early detection of ADHD

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Artículo Original

Abstract

Attention-deficit/hyperactivity disorder (ADHD) is a behavioral syndrome where inattention and/or hyperactivity impair social, academic or occupational function. Cognitive impairments in temporal abilities and delay aversion have been related to ADHD. The aim of this study is to design a game-like software that assesses temporal perception for the early detection of ADHD. Method: Two groups of 7 to 10 children (17 with ADHD and 17 control children) were compared on their performance on four game-like software based on Delay Aversion, Anticipation, Synchronization Tapping and Time reproduction experimental tasks. Results: All games detected significant differences between groups in accuracy or variability. The Discriminant function correctly classified 82.4% of the cases. Conclusions: Although the conversion of experimental tasks into game-like software implies a compromise between experimental rigour and screening efficiency, the use of videogames to measure cognitive processes is a potential tool for preventive healthcare.

Key Words:
ADHD; Temporal processing; Screening; Computer games

Resumen

Procesamiento temporal y aversión a la espera: el uso de videojuegos como herramienta de tamizaje para la detección temprana de TDAH. El trastorno por déficit atencional e hiperactividad (TDAH) está caracterizado por un patrón comportamental de inatención y/o hiperactividad que afecta el desempeño social, académico y laboral de las personas. Varios estudios han reportado alteraciones cognitivas en el TDAH, vinculadas al procesamiento temporal y a la aversión a la postergación. El objetivo de este trabajo fue diseñar una herramienta de tamizaje computarizada basada en tareas experimentales de procesamiento temporal y aversión a la espera para la detección temprana del TDAH. Método: Dos grupos de niños con edades entre 7 y 10 años (17 con TDAH y 17 controles), fueron evaluados en su desempeño en cuatro juegos computarizados basados en cuatro diferentes paradigmas experimentales: Aversión a la Postergación, Anticipación, Sincronización y Reproducción Temporal. Resultados: Todos los juegos mostraron diferencias significativas en cuanto a precisión o variabilidad para alguna de las condiciones. El análisis discriminante clasificó correctamente 82,4% de los casos. Conclusión: A pesar del compromiso que existe entre la rigurosidad de una tarea experimental y su conversión a un formato lúdico computarizado, el uso de videojuegos para medir procesos cognitivos es una potencial herramienta en el campo de la salud preventiva.

Palabras claves:
TDAH; Procesamiento temporal; Tamizaje; Juegos de video

Tabla de Contenido

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1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by a pattern of symptoms of inattention, overactivity and/or impulsiveness, that are age inappropriate, persistent, pervasive, and present in multiple settings (e.g., school and home) (APA, 2000; DSM-IV-TR). Although it is typically first diagnosed in childhood, ADHD can substantially affect individuals across their lifespan. In Uruguay, close estimates on a 6-11-years-old sample describe a prevalence of 7.6% (Viola &

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Garrido, 2009).

Despite all this, there is not a fully acquainted explanation of the nature of these impairments and no single test to make a diagnosis. Several studies on cognition have tried to explain the underlying cognitive impairments of ADHD. Although there is not a consent on what best explains ADHD behavior, previous studies have found that ADHD is significantly related to delay aversion (Dalen, Sonuga-Barke, Hall & Remington, 2004; Solanto, Abikoff, Sonuga-Barke & Schachar, 2001), deficits in inhibitory control (Barkley, 1997), reaction time variability (Castellanos et al., 2005), basic information processing (Salum et al., 2014), and emotional deficits (Martel, 2009). There is also a large amount of evidence from different experimental paradigms of an impairment in temporal processing in the domains of temporal reproduction (Smith, Taylor, Rogers, Newman & Rubia, 2002), time discrimination (Toplak, Rucklidge, Hetherington, John & Tannock, 2003; Toplak & Tannock, 2005b), anticipation (Rubia, Halari, Christakou & Taylor, 2009) and synchronization tapping (Toplak & Tannock, 2005a).

The dual pathway model explains this heterogeneity as two more or less independent patterns of deficit, each affecting some ADHD patients: one mediated by inhibitory based executive dysfunction and the other linked to altered signalling of delayed rewards (Sonuga-Barke, 2002). In a recent contribution, Sonuga-Barke, Bitsakou and Thompson (2010) proposed that timing, inhibition and delay deficits in ADHD are dissociable from each other and that substantial sub-groups of patients might be affected in only one domain. This runs counter with proposals of timing deficits being the underlying core of the diverse range of problems seen in ADHD supported by other authors, and proposes multidimensional models of ADHD to better explain the disorder.

Traditionally, ADHD is diagnosed through a clinical interview where experts mostly evaluate behavioral symptoms related to the disorder like inattention, hyperactivity and impulsivity. To assist the diagnostic process, professionals use standardized questionnaires to request information from parents and teachers, like the Conners 10 - Symptom Abbreviated Questionnaire (Conners, 1973) or *Child Behavior Ckeck-List* CBCL (Achenbach & Edelbrock, 1983). However, many studies have shown that therapists do not weigh all diagnostic criteria equally, even though this is a requirement in both the DSM–IV and the ICD–10, but they are influenced by their subjective assumptions about the disorder (Brüchmuller, Margraf & Schneider, 2012). Thus, becoming an identified ADHD patient is influenced by the gap between children behavior and the expectations of the adults about how children ought to behave (Moffitt & Melchior, 2007). This has led to several attempts of developing objective questionnaires and tests on the core domains (mainly attentional) in which children with ADHD are impaired, such as the Continuous Performance Test (Barkley, 1991), the Test of Variables of Attention T.O.V.A. (Forbes, 1998) and the Letter Cancellation Test (Lezak, 1983) which would assist professional diagnosis. Put together with the growing ability to recreate complex scenarios and control experimental variables, videogames have been used to analyse complex quantitative data on subjects' actual behavior in the executive functions domain (Heller et al., 2013). The results for sensitivity and also specificity reported in this study (-about 75 % for different clinical groups) make game-like software a potential effective tool to assist diagnosis.

A promising approach to contribute to this scenario is identifying problems that might affect development in children as early as possible in order to better understand the nature of the impairments which could provide more effective interventions. The first critical step to diagnosing and providing help for children is for healthcare providers and early education providers to perform high-quality first-level developmental screenings on all children, not just those with suspected problems. Screening tests must take a short time of application, be inexpensive to administer and score, be acceptable to patients, produce reliable results and have adequate validity.

As with diagnosis, recent research on cognitive impairments associated with ADHD provides evidence that can be used to develop accurate performance-based screening tools. Together with the advantages related to game-like software stated above and the extent of today's connectivity, videogames could provide a powerful ground for massive screening, allowing the possibility of assessing behavior and cognitive processes and being attractive to children (Riveros, Sepúlveda, Figueroa & Rosas, 2015). Videogames are intrinsically motivating which may enable the assessment of several cognitive processes without hampering performance. Enhancing motivation, however, must be done cautiously (Ryan, Rigby & Przybylski, 2006).

Research on temporal processing has used game-like software as an experimental paradigm with significant differences between control and ADHD groups (Toplak & Tannock, 2005a; Rubia, Taylor, Taylor

& Sergeant, 1999). These differences decrease with reward delivery but persist in a temporal reproduction task (Mcinerney & Kerns, 2003). Although this shows that performance impairment is not explained by motivation only, there is a decrease in the performance difference between groups that might come from transforming these tasks into game-like structures.

Taking these matters into consideration, we designed a game-like software that assesses temporal processing and delay aversion. This software was applied to a sample of children with ADHD and a control group of children with typical development (aged 7 to 10). Turning experimental tasks into videogames for a potential screening tool required a compromise between experimental rigour and screening tool efficiency (easy to apply, short and attractive for children). By combining paradigms from temporal processing and delay-related deficits we expected to identify different performance-based measures that would discriminate both groups. We then analysed the strength of these games as a potential screening tool. As a result, the games correctly identified 82.4% of both ADHD and control participants.

2. Method

2.1. *Participants*

Two groups of children participated in this study: 17 children (*M* = 9.17 yo; *SD* = 1.17; 76.5% male) with a confirmed clinical diagnosis of ADHD based on DSM-IV criteria and 17 control children (*M* = 9.25 yo; *SD* = 1.09; 64.7% male). All participants had self-reported good vision and hearing. They were recruited through advertisement at the pediatric office as well as from the referents and staff of the pediatric neuropsychiatry office from Montevideo's Police Hospital. According to the protocol approved by the local Research Ethical Committee of the Faculty of Psychology and in accordance with the 2008 Declaration of Helsinki, all children had the informed consent form signed by their parents or legal guardians in order to participate.

Participants had a clinical diagnosis based on the following: (I) semi-structured interviews conducted separately with parents and children by healthcare professionals from the Hospital's Neuropsychiatry Department; (II) Conners' Rating Scales-Revised (Conners, 1997) reported by parents and teachers to obtain standardized measures of behavior; and (III) Wechsler Intelligence Scale (WISC IV) to provide an estimation of intellectual ability and discard other difficulties not associated with ADHD. We had previously excluded three participants from the analysis because of low IQ (IQ=62), psychomotor impairments and failure to complete the whole experimental phase.

2.2. *Apparatus*

Presentation and data collection were done using a Toshiba Satellite L645-SP4025L (14 in., 60 Hz). Keyboard was used for response input. All tasks were programmed in C++ language.

2.3. *Experimental tasks*

Experimental tasks consisted of four game-like software based on modified psychophysics tasks that measure temporal processing.

2.3.1. *Delay Aversion game*

Based on Sonuga-Barke (2002) we designed a game that involved a trade-off between immediate but small rewards or delayed and larger rewards. The game consisted of a space scenario with two spacecrafts that appeared on the left side of the screen moving synchronously towards the right side, each on a different side of a horizontal barrier that divided the screen. Ships moved automatically and children only controlled when to shoot. The barrier had three windows and children had to choose only one of them to shoot per trial (Figure 1, A). Children were told that an alien ship was invading the Earth and they had to defend it by shooting the enemy ship using the spacebar. The bottom spacecraft was controlled by the participants and the upper spacecraft was driven by Martians. Reward depended on the shooting window: one, two and three points were added to a total score placed in the upper left corner if they shoot in the first, second or third window, respectively. Therefore, the more they waited, the more reward they got. Distances between first-second and second-third window varied across trials to avoid habituation and boredom. Each trial ended whenever they fired a shot. The game finished after three practice trials and 12 experimental trials were completed.

2.3.2. *Anticipation game*

Based on Toplak and Tannock (2005b) we designed a game to measure the internal representation of time. Participants were asked to execute a motor response by pressing the spacebar in the precise moment that a spacecraft appeared (Figure 1, B). The goal of the game was to destroy the spacecraft. Stimuli were presented in three blocks of short and long durations: 1000, 500 and 2000 ms (in this order). For each timing interval eleven practice trials (visible ships) were displayed in which children had to internalize the onset timing of the spacecraft. Children were told that this phase was important because the enemy ship would gain the ability to turn invisible after a while, and to shoot it they had to learn the ship delay. Then, an invisible phase that consisted of ten trials was displayed (invisible ships). Performance on this latter phase was considered for analyses. In all trials, visual and audio helpers were displayed as feedback in cases where responses were too late or too early. A trial was considered successful if they shot within a certain temporal window of the ship delay. This temporal window was proportional to ship delay. The game ended when participants had completed ten trials per stimulus delay.

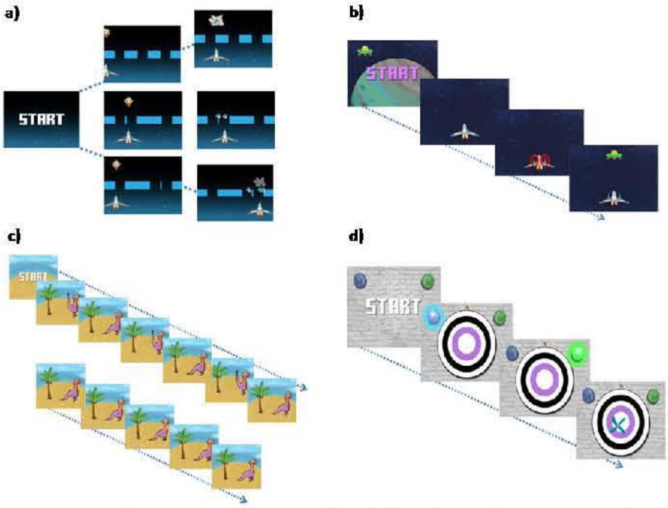
2.3.3. *Synchronization Tapping*

We developed a tapping task based on Toplak and Tannock (2005b) to measure the ability to synchronize a motor response with a given rhythmic stimulus. To this end, we designed a game in which a dinosaur hits the ground with its tail at a constant rhythm (Figure 1, C). Children were instructed to press the spacebar to synchronize with the dinosaur and join in as quickly as possible because the dinosaur would stop and they should continue by themselves until the end of the trial. The game measured children intertap duration on the testing phase (ten taps without dinosaur) which were considered for analyses. Two different intertap durations were used (400 ms and 1200 ms) on each modality (bimodal, visual and auditory).

2.3.4. *Time reproduction*

Based on McInerney and Kerns (2003) we designed a game that assesses children's ability to reproduce the duration of a given stimuli. This game was developed simulating a dart game with two button targets at the top of the screen with blue and green colors respectively (Figure 1, D). Trial began with a stimulus presented in one of three modalities: bimodal (blue light and continuous tone), visual (blue light) or auditory (continuous tone). Participants had to shoot a dart by reproducing the stimulus duration pressing the spacebar to turn on a green light or to produce a tone, depending on trial modality. The second light (green light) and sound provided feedback on how long they were pressing the spacebar. Accuracy correlated to closeness of dart to bullseye. Two practice and eight experimental trials with times ranging from 1000 to 22000 milliseconds were presented per modality (8 x 3).

Figure 1.
Games of Temporal Processing and Delay Aversion.



Note: (a) Delay Aversion: example of the three shooting window configurations used in this game. (b) Anticipation game: during the learning phase where the spacecraft is visible. (c) Synchronization Tapping screenshots illustrate the dinosaur hitting the ground with its tail during the learning phase (above) and the testing phase where the dinosaur remains stationary (below). (d) Duration Reproduction game during visual modality, participants had to reproduce stimuli´s duration to hit the bullseye.

2.4. *Procedure.*

Children attended twice to complete all the tasks. Fifteen of our participants used medication for ADHD symptoms and were asked to withdraw the medication 24 hr prior to both sessions. In the first visit they were interviewed and clinically evaluated to confirm or reject the ADHD diagnosis. Their parents or legal guardians answered the Conners Rating Scale and a semi structured interview to explore aspects of child development and sociodemographic factors. This session lasted about 70 minutes. In the second session children played the four games individually in a counterbalanced order with resting intervals under the supervision of one experimenter. Children sat in front of the computer with their eyes about 35 cm away from the screen. During the game, participants used headphones to avoid distractions. Score reward was given in each trial based on participants' performance and at the end of each game they always obtained a medal according to their score: gold, silver and bronze. All sessions lasted over 40 minutes. Each child received a juice and a certificate of participation as a gift. This was not anticipated until the experimental phase ended. Families received reimbursement for travel expenses.

2.5. *Data Analysis.*

For Delay Aversion game mean window shooting rate was used as the dependent variable. For Anticipation, Synchronization and Reproduction games two main composite variables were used to analyze children's responses: (a) mean accuracy performance, calculated as the absolute mean difference (AMD) between children's response and stimulus duration; and (b) intraindividual variability (IV) as the mean of the standard deviation. The AMD and IV variables were calculated for Time Reproduction game with slight differences. Given that differences between groups have been reported across different time durations (McInerney & Kerns, 2003) performance was assessed by modality, calculating accuracy as a coefficient (|stimulus duration - response| / stimulus duration). In addition, anticipatory behavior was analysed to examine differences due to impulsive behavior not detected by AMD or IV. Overall, no effect was found that could not be explained by the effect of the other variables (AMD and IV) for all temporal processing games. For this reason this analysis was not reported.

2.7. *Outliers.*

Each deviant score (> 3 SD from the group mean) was excluded from the analyses in cases where this extreme deviation was not a part of the subject's overall performance in that game.

2.8. *Gender and age.*

In order to examine the effect of gender and age we conducted separate t-tests on all standardized and experimental measures for the control and experimental groups. We found a gender effect for short durations in the control group for the Anticipation game in AMD (500 ms: $p = .04$) and for the Synchronization game in visual modality for the AMD (400 ms: $p = .020$) and IV (400 ms: $p = .04$). In the experimental group, we found an effect for short durations in the Anticipation Game in IV (500 ms: $p = .02$) (see supplementary material, Table s1). There was also an effect of Age in both groups. In the control group, the Age effect was observed in longer durations for the Synchronization game in IV for the visual modality (1200ms: $p = .04$) and in AMD in the Reproduction game under bimodal ($p = .01$; variability: $p = .001$) and visual ($p = .01$) modalities (see supplementary material, Table s2). There was also an Age effect for longer durations in the Experimental group during the Anticipation game for AMD (1000 ms: $p = .02$; 2000 ms: $p = .003$) and for the visual modality of the Synchronization game (400 ms: $p = .03$; 1200 ms: $p = .001$). Given these results, Gender and Age variables were included as covariate for the Analysis of Variances in the games where an effect was found.

To explore all variables of interest on temporal perception we conducted repeated measures Analysis of Variance (ANOVA) with *group* as a between-subjects factor. Within factors and covariates are later described for each game. Effect sizes were also calculated. Finally, we conducted a Discriminant Analysis with *group* as the dependent variable to assess the power of these games as a potential screening tool.

3. Results

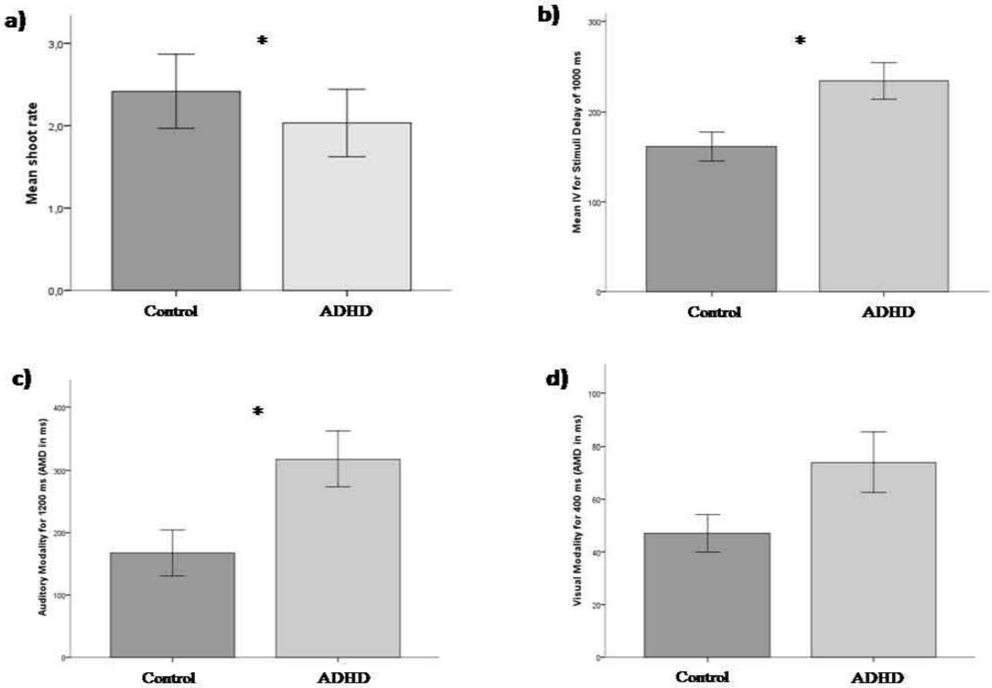
3.1. *Delay aversion.*

An independent-samples t-test was conducted with window shooting rate as the dependent variable. Window shooting rate was significant between groups ($t(32) = 2.602$; $p = .014$) showing a lower mean for the ADHD group ($M = 2.03$; $SD = .4$) compared to the control group ($M = 2.42$; $SD = 0.45$), which means that they consistently shot before than the control group (see Figure 2, A).

3.2. *Anticipation.*

Absolute Mean Difference (AMD) and Intra-individual Variability (IV) were separately analyzed by a 3 (Stimulus delay: 500, 1000 and 2000 ms) repeated measures ANOVA. Group was considered as a between-subjects factor and Age and Gender as covariables. Stimuli delay ($F(1.3, 39.5) = 21.4$, $p < .0001$, $\eta 2 = .42$) and Age ($F(1, 30) = 58.45$, $p = .008$, $\eta 2 = .22$) showed a significant effect over AMD in both groups. Group presented a certain trend toward significance ($F(2, 60) = 2.69$, $p = .076$), showing that ADHD participants had a higher mean for stimuli duration of 1000 ms ($M = 321.98$; $SD = 114.41$) compared to control participants ($M = 232.25$ms; $SD = 102.03$ms) (post hoc t-test, $p = .023$). No other significant main effects or interactions were found. IV analysis also showed a significant effect of Stimuli delay ($F(1.6, 48.6) = 17.44$, $p < .0001$, $\eta 2 = .37$) and Age ($F(1, 30) = 4.48$, $p = .043$, $\eta 2 = .13$). Furthermore, the interaction between Stimuli delay and Group presented a significant effect ($F(1.6, 48.6) = 3.63$, $p = .043$, $\eta 2 = .11$) showing that the ADHD group presented significant higher IV for Stimuli delay of 1000 ms ($M = 234.69$; $SD = 83.93$) compared to the Control group ($M = 161.61$; $SD = 66.51$) (Post hoc t-test: $p = .008$) (Figure 2, B).

Figure 2.
Graphics show performance for both groups in delay aversion and time processing games.



Note: (a) Performance during Delay Aversion game as a function of the mean shooting rate. (b) Mean of intraindividual variability for Anticipation game for Stimuli Delay=1000 ms. (c) Absolute Mean Difference of Auditory for longer stimuli delay (1200 ms) for Synchronization game. (d) Absolute Mean Difference of Visual modality for shorter stimuli delay (400ms) for Synchronization game. Standard errors are represented in the figures by the error bars attached to each column. *$p < .05$.

3.3. Synchronization Tapping.

2 (Stimulus duration: 400 ms and 1200 ms) x 3 (Modality: bimodal, visual, auditory) repeated measures ANOVA was computed considering the AMD and IV as dependent variables. *Age* and *Gender* were analysed as covariates. AMD revealed main effects of Stimulus duration ($F(1, 60) = 28.3$, $p <.0001$, $\eta 2 =.49$), Modality ($F(2, 60) = 4.91$, $p = .011$, $\eta 2 =.14$), and an interaction between Stimuli Duration and Age ($F(1, 60) = 6.08$, $p = .02$, $\eta 2 =.168$). Most importantly, a significant effect for the interaction between Stimuli Duration, Modality and *Group* was observed ($F(2, 60) = 4.35$, $p = .017$, $\eta 2 =.1$). A post-hoc analysis of this interaction revealed that the ADHD group was less accurate ($M = 317.52$; $SD = 181.52$) than the Control group ($M = 167.52$; $SD = 151.55$) for the auditory modality in longer Stimulus duration ($p = .014$) (Figure 2, C). Visual modality also showed a significant trend between groups for shorter durations ($p = .053$) where the ADHD group was less accurate ($M = 73.92$; $SD = 46.63$) than the Control group ($M = 47.07$; $SD = 46.63$) (Figure 2, D). Analysis of IV revealed that only Stimulus Duration ($F(1, 60) = 23.3$, $p <.0001$, $\eta 2 =.04$), and the interaction between Stimuli Duration and Age ($F(1, 60) = 8.5$, $p = .007$, $\eta 2 =.22$) showed significant effects. No group effect was found.

3.4. Duration reproduction

A 3 (Modality: visual, auditory and bimodal) repeated measures ANOVA was conducted separately for AMD and IV taking Age as a covariate. There were no significant main effects or interactions for AMD. For IV, only the interaction between Modality and Group presented a reliable trend to significance ($F(1.6, 49.5) = 3.37$, $p = .053$, $\eta 2 =.098$). Post-hoc analysis showed higher IV for the ADHD group in the auditory modality ($M = 0.225$; $SD = 0.158$) than in the control group ($M = 0.137$; $SD = 0.049$) ($p = .037$). No group differences were found for bimodal and visual modalities

3.5. Discriminant analysis.

We included significant variables from each game to perform the discriminant analyses. We obtained a discriminant function that significantly explains the variance between groups (Lambda de Wilks = 0.58, Chi square = 16.05, df = 5, $p = .007$). The relative importance of the independent variables in predicting both groups were: IV for the duration of

1000 ms from the Anticipation game (r function = .585), AMD of both the auditory modality for 1200 ms duration (r function = .543) and the visual modality for the 400 ms duration (r function =.418) from Synchronization game, shooting rate from the Delay Aversion game (r function = -.541) and IV of the auditory modality from the Duration Reproduction game (r function =.453). The classification shows that 82.4% of the cases were correctly classified: 82.4% of the control participants (14 of 17 participants) and 82.4% of the ADHD participants (also 14 of 17 participants).

4. Discussion

Our main goal was to design a screening tool able to identify ADHD potential cases considering temporal processing and delay aversion as clinical markers. In general, the games developed here obtained a valid result. Using the most predictive variables, they were able to provide an efficacy of almost 82.4% correctly classified cases. To our knowledge, no other temporal tasks converted into game-like software have been employed as a screening tool with the aim of detecting possible cases of ADHD.

Window shooting rate from the Delay Aversion game was one of the strongest variables with a powerful function value to discriminate between groups. Children with ADHD chose smaller and sooner over larger and later rewards compared to controls in agreement with existing data (Bitsakou, Psychogiou, Thompson & Sonuga-Barke, 2009; Luman, Oosterlaan & Sergeant, 2005; Marco et al., 2009). In recent research Delay aversion has been described as a strong component of ADHD variability (Castellanos, Sonuga-Barke, Milham & Tannock, 2006; Sonuga-Barke, 2002).

We also observed that motor responses in the estimation of stimulus onset in the Anticipation game seem to be a good predictor for ADHD. This is in agreement with other reported results that show that participants with ADHD have a tendency to anticipate more and higher variability in their response (Rubia et al., 1999). Specifically, our data revealed that a good predictive variable to disentangle both groups was the 1000 ms stimulus.

Furthermore, Synchronization Tapping game showed that children with ADHD had more difficulties to synchronize their motor tapping with a given rhythm, reflected on worse accuracy performance (AMD) but not in variability IV. In the visual modality, impairment was observed for short stimulus duration, while for the auditory modality impairment was observed for long stimulus duration in ADHD children. This does not replicate previous findings in tapping literature where variability but not accuracy discriminates between groups (Rubia et al., 1999; Toplak and Tannock, 2005b). However, inconsistency of findings has been evidenced in tapping and anticipation tasks (Toplak and Tannock, 2005b). We do not attribute the disparity in IV to a low number of trials as our game replicated the same structure as that of Toplak and Tannock (2005b), where they found significantly more intra-individual variability on the visual tapping task (1000 ms) in the ADHD group compared to the control group. Differences in results respect to Toplak and Tannock's study (2005b) might be due to age given that they studied a sample of adolescents from 13 to 18 yo and motor abilities are strongly affected by development. As for accuracy, this study does not report any results. On the other hand, Rubia et al., (1999) found no difference in accuracy. Nevertheless, their task presented a different structure (i.e. there were no uncued trials).

Duration Reproduction game required repetitive responding to several stimuli duration and modalities. We examined whether group and modality (bimodal, visual and auditory) could give account of differences in performance. We found no difference in performance accuracy reported by previous studies (Kerns, McInerney & Wilde, 2001; McInerney & Kerns, 2003). In addition, in line with previous literature, we found that ADHD had more intraindividual variability for auditory stimuli showing a worse performance compared to control group (Toplak et al., 2003). In general, both groups tend to make more errors as stimulus duration increases. Our results show that auditory modality was the only modality that presented a significant effect that disentangled both groups. However, modality was not counterbalanced in our games and this might have had an effect on the results. The auditory modality was always last. Therefore, fatigue might be a component affecting more the performance of the experimental group than that of the control group in the auditory modality. This would explain differences respect to previous literature (Barnett, Maruff, Vance, Luk, Costin, Wood & Pantelis, 2001; Martinussen, Hayden, Hogg-Johnson & Tannock, 2005), which propose that children with ADHD get worse results in visual modality compared to auditory and bimodal modalities during temporal tasks because of the relation between the process of retaining visual information and working memory, systematically reported to be affected in ADHD children.

Present results also seem to indicate differences in perceiving time due to developmental changes as expected (see Droit-Volet, 2013 for a review). Our analysis revealed an effect of age over performance, which is in agreement with other findings (Droit-Volet, 2013) that reported differences in behavior for older children, who are more accurate in estimating and also in motor timing behavior than younger children. Our results show that age affects time processing but not delay aversion.

The present study had a number of limitations. First, ADHD behavioral subtypes were not considered and it has been pointed out that subclinical expressions may be responsible for the failure to test and replicate some pattern choice in temporal tasks. However, literature shows several controversies. Thorell (2007) reported a Delay Aversion task in which children with high hyperactivity choose sooner and smaller versus later and larger, but not the low inattention/overactive group (Thorell, 2007). In contrast, in a Delay Aversion task conducted by Marco and cols. (Marco et al., 2009) with 416 ADHD cases there was no difference in performance due to subtype conditions. Moreover, DSM-V has eliminated subtypes and now considers them as features. Secondly, as mentioned above, the lack of a bigger sample is interpreted as a limitation that might explain the absence of significant results in some of the games. Development affects cognition in several ways at these ages, as was described. A bigger sample would be necessary to decide if age affects each group in different ways, which would require screening tools with different age-dependent thresholds. Moreover, the small sample used does not allow further analyses of correlations with neuropsychological variables related to cognitive or affective aspects of executive functions (Castellanos et al., 2005), or ADHD behavioral or neuropsychological subtypes (as proposed in Sonuga-Barke, Bitsakou & Thompson, 2010), e.g., working memory, which as expected was more impaired in the ADHD group. Finally, we assumed a trade-off between the formal aspects of a psychophysical task and the entertainment and engagement that we could achieve through these four games. Classical tests for cognitive temporal perception usually present almost hundreds of trials turning into demotivating tasks (i.e., Continuous Performance Test, CPT) (Erlenmeyer-Kimling & Cornblatt, 1978). Children with ADHD disengage from long and boring tasks as their attention to non-task related activity increases (Antrop, Stock, Verté, Wiersema, Baeyens & Roeyers, 2006; Sagvolden, Johansen, Aase & Russell, 1998). For this reason, we decided to maintain the minimal number of trials that would enable us to design a reliable screening tool at the expense of experimental rigor.

This current work supports previous results in which ADHD variability is better explained by impairments in different domains (Sonuga-Barke et al., 2010). The percentage of correctly classified cases achieved reveals that a game-like task combining time processing and delay deficit measures could be a potential screening tool for ADHD.

4.1. Conclusions and future research

The results of this study suggest that is it possible to detect true deficits in temporal abilities by employing game-like tasks. Future work must test the screening tool in a bigger sample to assess its power (sensitivity and specificity) and also to compare it with other existing tests, e.g., CPT. In addition, this will be benefited by a better understanding of the nature of ADHD. Future research related to the nature of executive and temporal impairments and ADHD variability will enhance the possibility of more powerful screening tools. Finally, further work must be done to study the different aspects of the conversion into game-like software more rigorously and how this affects the relation between psychopathology and performance. Altogether, our study shows that the combination of videogames assessing cognitive processes is a complex matter that with the necessary experimental controls can become a promising field for healthcare prevention in children.

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Supplementary material

Table s1
T-tests between Game Variables and Standardized Measures for Gender and Group

		ADHD				Control				
Measure	Gender	n	M	SD	*p*	n	M	SD	*p*	
Conners (parents)	M	13	11,85	5,87	0,84	11	5,73	4,24	0,37	
	F	4	12,50	4,36		6	7,67	3,78		
Conners (teacher)	M	13	9,92	6,24	0,28	11	6,55	5,97	0,74	
	F	4	6,25	2,63		6	5,5	6,06		
WISC IQ	M	13	88,77	10,83	0,50	11	95,27	12,55	0,29	
	F	4	92,75	6,24		6	102,5	13,52		
WISC IQ verbal comprehension	M	13	97,00	15,81	0,86	11	102,00	16,60	0,59	
	F	4	98,50	3,87		6	106,17	10,13		
WISC IQ perceptual reasoning	M	13	92,15	14,08	0,55	11	95,82	14,91	0,37	
	F	4	96,75	8,62		6	102,67	13,68		
WISC IQ working memory	M	13	81,69	11,74	0,48	11	90,18	11,12	0,37	
	F	4	86,25	8,06		6	95,17	9,70		
WISC IQ processing speed	M	13	91,23	7,47	0,54	11	92,82	9,70	0,22	
	F	4	93,75	5,12		6	99,83	12,97		
ST AMD for 400 ms	M	13	73,14	35,93	0,25	11	56,79	18,59	0,02	*
	F	4	50,53	17,08		6	33,47	15,80		
ST AMD for 1200 ms	M	13	314,61	140,05	0,14	11	241,74	192,82	0,13	
	F	4	197,03	103,91		6	113,14	41,82		
DA (window shooting rate)	M	13	2,12	0,42	0,12	11	2,51	0,45	0,28	
	F	4	1,75	0,25		6	2,25	0,44		
DR IV for 1000 ms	M	13	297,33	124,75	0,35	11	192,41	90,41	0,58	
	F	4	226,54	142,73		6	164,44	107,17		
DR IV for 5000 ms	M	13	1308,55	702,24	0,75	11	1126,61	703,13	0,88	
	F	4	1171,63	865,63		6	1176,28	543,79		
DR IV for 7000 ms	M	13	2267,87	995,08	0,25	11	1630,18	849,02	0,88	
	F	4	1621,58	754,18		6	1702,64	1153,92		
A IV for 1000 ms	M	13	318,78	116,30	0,84	11	252,43	95,03	0,31	
	F	4	332,39	124,54		6	198,07	113,83		
A IV for 500 ms	M	13	116,54	57,31	0,36	11	157,34	50,68	0,04	*
	F	4	146,78	52,50		6	106,87	29,77		
A IV for 2000 ms	M	13	635,67	184,65	0,35	11	520,87	287,44	0,53	
	F	4	524,47	263,76		6	435,80	199,03		

ST= Synchronization Tapping; DA= Delay Aversion; DR= Duration Reproduction; A= Anticipation; AMD= absolute mean difference; IV= Intra-individual variability. * p<.05

Table s2
T-tests between Game Variables and Standardized Measures for Age and Group

		ADHD					Control			
Measure	Age	n	M	SD	*p*		n	M	SD	*p*
Conners (parents)	6-7 yo	8	11,63	4,57	0,8		8	6,75	3,99	0,76
	8-9 yo	9	12,33	6,36			9	6,11	4,37	
Conners (teacher)	6-7 yo	8	7,13	3,83	0,2		8	6,88	6,56	0,66
	8-9 yo	9	10,78	6,8			9	5,56	5,43	
WISC IQ	6-7 yo	8	91,75	7,4	0,44		8	97,75	11,93	0,98
	8-9 yo	9	87,89	11,86			9	97,89	14,56	
WISC IQ verbal comprehension	6-7 yo	8	99,88	12,3	0,5		8	102,75	13,34	0,85
	8-9 yo	9	95,11	15,4			9	104,11	16,13	
WISC IQ perceptual reasoning	6-7 yo	8	92	7,39	0,8		8	97,38	14,13	0,83
	8-9 yo	9	94,33	16,81			9	99,00	15,54	
WISC IQ working memory	6-7 yo	8	87,63	9,62	0,08		8	92,38	12,78	0,88
	8-9 yo	9	78,44	10,65			9	91,56	9,06	
WISC IQ processing speed	6-7 yo	8	92	8,99	0,92		8	96,25	12,90	0,75
	8-9 yo	9	91,67	5,02			9	94,44	9,96	
ST AMD for 400 ms	6-7 yo	8	79,48	36,82	0,18		8	56,94	22,60	0,12
	8-9 yo	9	57,45	28,25			9	41,12	16,51	
ST AMD for 1200 ms	6-7 yo	8	358,52	146,04	0,04	*	8	275,01	214,43	0,06
	8-9 yo	9	223,32	102,07			9	126,43	60,59	
DA (window shooting rate)	6-7 yo	8	1,94	0,22	0,37		8	2,59	0,47	0,15
	8-9 yo	9	2,12	0,52			9	2,27	0,40	
DR IV for 1000 ms	6-7 yo	8	290,21	142,52	0,78		8	158,69	59,53	0,34
	8-9 yo	9	272,2	122,28			9	203,74	116,62	
DR IV for 5000 ms	6-7 yo	8	1425,9	737,22	0,44		8	1459,96	750,06	0,05
	8-9 yo	9	1143,4	714,18			9	863,41	351,19	
DR IV for 7000 ms	6-7 yo	8	2323,3	1001,4	0,42		8	2018,65	1090,38	0,13
	8-9 yo	9	1931,4	948,47			9	1333,19	668,38	
A IV for 1000 ms	6-7 yo	8	385,77	92,45	0,02		8	273,62	88,27	0,13
	8-9 yo	9	265,28	104,94			9	197,36	104,51	
A IV for 500 ms	6-7 yo	8	116,12	72,94	0,62		8	153,42	48,23	0,29
	8-9 yo	9	130,35	39,33			9	127,17	51,00	
A IV for 2000 ms	6-7 yo	8	748,91	108,3	0,0001	***	8	563,96	274,28	0,28
	8-9 yo	9	485,59	187,04			9	425,85	235,85	

ST= Synchronization Tapping; DA= Delay Aversion; DR= Duration Reproduction; A= Anticipation;