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THE EFFECTS OF REWARD AND EXPERIENCE VALENCE IN A VIDEOGAME-TASK DESIGNED TO EVALUATE RESPONSE INHIBITION

Efectos de la recompensa y valoración de la experiencia en una prueba basada en videojuegos diseñada para evaluar inhibición de respuesta

Efeitos da recompensa e da valência da experiência em uma tarefa de videogame concebida para avaliar a inibição da resposta

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Keywords: Delay Aversion; Reward Processing; Motivation; Response Inhibition; Video game.

Palabras clave: Aversión al retraso; Procesamiento de recompensas; Motivación; Inhibición de la respuesta; Videojuego.

Palavras-chave: Aversão ao atraso; Processamento de Recompensas; Motivação; Resposta Inibitória; Videogame.

A B S T R A C T

Objective: To evaluate the impact of the valence of experience during gameplay (VEG) and rewards on a new video game task designed to assess response inhibition. **Participants and Methods:** Adolescents (n=101) aged between 10-12 years-old with typical development were evaluated in several measures, such as: attention, hyperactivity and impulsivity symptoms, game proficiency; game related performance, and VEG. Based on VEG, participants were divided into two groups: positive (ExpP) or negative (ExpN). Bayesian statistical group comparisons and Bayesian repeated measures analysis (rmBANOVA) were employed. **Results:** rmBANOVA showed a difference between groups only during the two halves of the task were ExpN made a higher number of commission errors. Total of commission errors was negatively correlated with the total time on task. Path analysis revealed a positive influence of VEG on rewards gain, which was negatively related to commission errors. The best-fit mediation model considered the rewards as having a causal impact on total number commission errors. **Conclusions:** Results shed light on the importance of motivation and rewards during tasks that involve cognitive and motivation control processing.

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R E S U M E N

Objetivo: Evaluar el impacto de la valoración de la experiencia durante el juego y las recompensas en una novedosa tarea de videojuegos diseñada para evaluar la inhibición de la respuesta. **Participantes y Método:** Adolescentes (n=101) de entre 10 y 12 años de edad con un desarrollo típico fueron evaluados en varias medidas, tales como: atención, hiperactividad y síntomas de impulsividad, competencia en el juego; desempeño relacionado con el juego y valoración de la experiencia. Basándose en la valoración de la experiencia, los participantes se dividieron en dos grupos: positivo (ExpP) o negativo (ExpN). Se emplearon comparaciones estadísticas bayesianas de grupos y análisis de medidas repetidas bayesianas (rmBANOVA). **Resultados:** rmBANOVA mostró una diferencia entre los grupos sólo durante las dos mitades de la tarea donde ExpN hizo un mayor número de errores de comisión. El total de errores de comisión se correlacionó negativamente con el tiempo total de la tarea. Los análisis de senderos revelaron una influencia positiva de la valoración de la experiencia en la ganancia de recompensas, que se relacionó negativamente con los errores de comisión. El modelo de mediación más adecuado consideró que las recompensas tenían un impacto causal en el número total de errores de comisión. **Conclusiones:** Los resultados arrojan luz sobre la importancia de la motivación y las recompensas durante las tareas que implican un procesamiento cognitivo y de control de la motivación.

R E S U M O

Objetivo: Avaliar o impacto da valência das recompensas e da experiência (VEG) durante sessões de jogo em uma nova tarefa em formato de jogo, desenvolvida para avaliar resposta inibitória. **Participantes e Métodos:** Adolescentes (n=101) com idade entre 10-12 anos, com desenvolvimento típico foram avaliados em diversas medidas, tais como: sintomas de desatenção, hiperatividade e impulsividade, proficiência geral em jogos, desempenho na tarefa e VEG. Baseado no desempenho em VEG, os participantes foram divididos em dois grupos em relação a sua experiência positiva (ExpP) ou negativa (ExpN). Comparações estatísticas Bayesianas entre grupos e analyses medidas repetidas Bayesianas foram utilizadas (rmBANOVA). **Resultados:** rmBANOVA mostrou uma diferença entre os grupos apenas durante as duas metades da tarefa onde ExpN cometeu um maior número de erros de comissão. O total de erros de comissão foi negativamente correlacionado com o tempo total na tarefa. A análise de caminhos revelou uma influência positiva do VEG no ganho de recompensas, que foi negativamente relacionada a erros de comissão. O modelo de mediação de melhor ajuste de curvas considerou as recompensas como tendo um impacto causal no número total de erros de comissão. **Conclusão:** Os resultados lançam luz sobre a importância da motivação e recompensas durante tarefas que envolvem processamento cognitivo e de controle motivacional.

Introduction

Processes related to cognitive control are crucial for adaptation to a sophisticated environment. Its development since childhood is associated to success in school (Duckworth, Taxer, Eskreis-Winkler, Galla, & Gross, 2020; Giovannetti, Pietto, Segretín, & Lipina, 2020), social relationships (Federico, 2020), resilience capacity (Moumne, Hall, Böke, Bastien, & Heath, 2020) and in adulthood to work performance (de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012), health self-care (Duke & Harris, 2014) and even with family relationships (Crandall, Ghazarian, Deater-Deckard, Bell, & Riley, 2018). Cognitive control depends on several neuropsychological processes, and mainly on executive functions. According to Diamond (2013), executive functions are processes related to intentional behavior. These functions include core processes as working memory, inhibitory control, and cognitive flexibility, which serve as a basis for complex executive functions as planning, problem-solving, and fluid intelligence. According to some authors, it is proposed that there are two linked executive functions, but of a different nature. Thus, the so-called "cold" executive functions are associated with problem-solving, planning, concept formation, strategy development and implementation, working memory, verbal reasoning, sequencing, selective attention, resistance to interference, cognitive flexibility, and impulse inhibition. While "hot" executive functions are comprised of coordination of cognition and emotion/motivation, such as regulation of social behavior and decision making about those events that have a significant emotional consequence (Montero et al., 2017; García-Arias, 2012). In this sense, delay discounting is classified as “hot” executive function (Chequer de Castro Paiva, de Souza Costa, Fernandes Malloy-Diniz, Marques de Miranda, & Jardim de Paula, 2019)

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Inhibitory control involves the capacity to prevent automatic responses, interrupt responses, which are leading to a failure on our avoid intrusion' effect (Barkley, 1997; Tiego, Testa, Bellgrove, Pantelis, & Whittle, 2018). Some authors argue that they fail in inhibitory control is a crucial role in understanding the symptomatology of ADHD (van Rooij et al., 2015; Nigg, 2017). Nonetheless, some argue that motivational processes present a strong influence in inhibition processes (Chequer de Castro Paiva, de Souza Costa, Fernandes Malloy-Diniz, Marques de Miranda, & Jardim de Paula, 2019; Dovis, Van der Oord, Huizenga, Wiers, & Prins, 2015; Fosco, Hawk, Rosch, & Bubnik, 2015; Modesto-Lowe, Chaplin, Soovajian, & Meyer, 2014). It has been documented that, for instance, children with ADHD are under-stimulated by reinforcements from their typically developing child peers. Therefore, it is presumed that the deficits associated with executive functioning in these children are the result of an abnormal increase in sensitivity. Thus, under evaluation conditions of a non-stimulating nature, children with ADHD would be incompetent to motivate themselves and develop tasks efficiently, resulting in poor performance. According to Haenlein and Caul (1987), children with this pathology may perform efficiently; however, they have a higher threshold concerning detection of reinforcements, unlike typically developing children. Thus, for example, Kohls, Herpertz-Dahlmann, and Konrad (2009) compared the impact of different forms of reinforcement on executive performance between children with and without ADHD. They found that children with ADHD showed an abnormal response to executive performance reinforcement during a socially rewarding condition, but not during a financially rewarding condition. Sonuga-Barke (2002, 2003) proposes that in addition to the executive dysfunction, difficulties based on motivational and reward processing could be impairing the goal-oriented behavior (see also Rabinovici, Stephens, & Possin, 2015, for an updated review on this topic). Delay discounting refers to the human preference for smaller-but- sooner over larger-but-later recompenses, which occurs due to subjective valuation of rewards as a function of the delay to their delivery (Patros et al., 2016). Specifically, ADHD subjects have a sub-optimal level of reward processing, which leads to a reward delay discounting that is manifested as attempts to escape or avoid delay (Lytle, Hammer, & Booth, 2020; Méndez Oehninger et al., 2015). The finding that children with ADHD do not respond efficiently is perhaps not due to deficits in inhibitory control, but raises the question of the extent to which this is the case for the executive function considered most deficient in these children. In this sense, motivational aspects, as well as delayed rewards, have recently been suggested as two critical constructs in ADHD (Ceceli, Natsheh, Cruz, & Tricomi, 2020). A recent study by Yu and Sonuga-Barke (2020) compared the performance of children with ADHD on hypothetical and real-time reinforcement delay tests. Children with ADHD showed a greater temporary discount on real-time delay tasks, but not on hypothetical delay tasks. These findings suggest that the experience of waiting before reward delivery is an important determinant of the greater temporal discount in ADHD.

The tools employed to assess inhibitory control involve tasks in which participants need to stay long periods responding to repetitive target stimuli and inhibiting responses to specific non-target stimuli. One of the most employed tools is those that involve continuous performance, such as the Conners Continuous Performance Test (CCPT; Conners, Epstein, Angold, & Klaric, 2003). Both ADHD adolescents (Cleminshaw, DuPaul, Kipperman, Evans, Sarno Owens, 2020; Rivero, Miranda & Bueno, 2013) and adults (Malloy-Diniz, Fuentes, Borges Milk, Correa, & Bechara, 2007; Philipsen & Döpfner, 2020) show impairment in several measures of CCPT, such as more significant reaction time variability during the task and a higher number of omission and commission errors when compared to controls. Since CCPT requires high levels of vigilance and attentional control (for distractors) during long periods, several authors propose that this task involves high levels of anxiety (Ter-Stepanian et al., 2017), stress (Palma, Fernandes, Muskat, & Calil, 2012), and discomfort (Lee, Lin, Liu, Lu, & Hsieh, 2016; Shaked et al., 2019), which could affect the interpretation of the result.

On the other hand, several studies show that when ADHD subjects play video games, during a task which also involves a high degree of repeatability and for long periods, their results do not differ from subjects with typical development (Rivero, 2016). Shaw, Grayson, and Lewis (2005) submitted ADHD patients in two versions of a continuous performance test, a commercial one (CCPT) and another version built by the authors, which contained game elements (Pokemon CPT). The results showed that children with ADHD made fewer commission errors and were more attentive in the Pokemon CPT than the commercial version. These results can be causally related to the motivational potential that video games have in their design, such as audio-visual reinforcements, challenges, narrative, aesthetic, rewards, clear targets, and other game-specific elements. In this direction, Peijnenborgh et al. (2016) conducted a study evaluating the feasibility of a battery composed of 6 serious mini-games (with fantasy elements, as well as other video game elements) to evaluate "cold" executive functions, time perception, and reinforcement mechanisms in typically developing children, as well as with ADHD. These aspects are known to be deficient in such pathology. Discriminant analyses after the intervention with the game revealed that children with ADHD were adequately classified by the video game, suggesting a high sensitivity and specificity of the instrument evaluated.

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For instance, Crepaldi et al. (2020) describe the planning and implementation of a serious game for the improvement of attention skills in children with (ADHD) to promote, accurately, adequate management of inhibitory control. This serious game, called *Antonyms*, consists of a series of activities, each of which causes the tendency to respond immediately and inappropriately, based on the model proposed by Sonuga-Barke, above exhibited. The children must block this tendency, reflect on the situation, and find the non-intuitive solution to encourage the capacity for self-regulation. Researchers expected outcome is an increased ability to inhibitory control in irrelevant stimuli. These characteristics may contribute to normalizing the engagement and persistence in tasks that require sustained cognitive control (Choi et al., 2020).

However, studies linked to the use of video games as an experimental paradigm for measuring variables associated with motivational and delayed gratification aspects are incipient. Most of the studies we cite in this section focused on other experimental paradigms. Improving our understanding of delay gratification in ADHD, using well-designed video games for this purpose, is essential for elucidating the etiology of this highly prevalent disorder and for informing the development of effective treatments. These procedural aspects, previously stated, can have an impact on impulsive decision making if, for example, the participant is more motivated to finish the task instead of earning more points or if he or she is not making accurate decisions because he or she is not receiving the reward. Thus, the present study aims to correct aspects that have not been appropriately addressed by previous studies, and that could have a significant impact on ADHD, clarifying the role of motivation in the completion of tasks that involve delay gratification.

Considering that motivational processing plays on self-regulated behavior control, this study presents the initial results of a game that combines the use of progressive rewards during a task that demands the ability of inhibitory control. The relation between the subjective valence experience during the gameplay and the reward gain, inhibition control, and total time on task, also was explored.

Methods

Participants

Participants, from both genders, were recruited in a private school in São Paulo, Brazil. Their parents filled a health condition questionnaire to check health conditions, psychotropic medication use, or any sensorial, developmental, or neurological disorders. The school informed if any student repeated a school year. If any of these conditions were detected, she was excluded from this study. The final sample comprised of 101 adolescents with similar demographic characteristics. They were 52 females, mean age was 10.9 (SD=0.3, range=10-12 years old), and presented six years of formal education. This study was approved by the' Institutional Ethical Committee Review Board under the registration number (CAAE) 00751612.7.0000.5505. Primary caregivers signed informed consent forms.

Measures

A video game designed to evaluate behavioral inhibition

The Dragon Hunter Task (DHT) is a self-paced video game-based task specifically developed for this study. It is a 10-min continuous performance task-like where motor responses have to be executed (or inhibited) depending on the presence of a specific element (magical aura) on the screen. This response inhibition task was embedded in the context of an adventure game where the participant had to recover 12 sapphires stolen by mighty dragons. These dragons hold a magical aura that protects them from any type of attack. Each magical aura possesses specific inter stimuli intervals (ISI 3, 4, 5, 6, 7, 8, 9 seconds), signaling the participants to suppress any type of motor activity (i.e., attack the dragons). The game was divided into 12 stages. In each step, the participant had nine trials to achieve five correct hits (attack when the magical aura is disappeared), not necessarily sequential. If the participant produced five correct answers, the game rewards one of the 12 sapphires, and the stage is over. However, if the participant made five errors, she failed the scene, advancing to the next and was not rewarded.

The online platform keeps records of several measures: a) *commission error*: the number of spacebar presses while the magical aura is still active; b) *omission error*: the number of times that the participant did not press the spacebar when the magic aura was not present; c) *correct hits*: the number of times that the participant presses the spacebar when the magic aura disappears; d) *total time on task in seconds*: the sum of the seconds that the participant took to complete each of the 12

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2021, Vol. 15 Nº2 135 - 149 ISSN: 0718-4123
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DHT phases; and e) *amount of rewards for each stage*: the amount of rewards that the participant won during the game, whereas the maximum value is one per stage, totaling a maximum of 12 rewards.

The DHT was constructed using the parameters of a continuous performance task (see figure 1), such as the Conners Continuous Performance Test (Conners, Epstein, Angold & Klaric, 2003) which is recognized to be sensitive to detect ADHD alterations related to reaction time variability and inhibition (Berger, Slobodin, & Cassuto, 2017; Egeland & Kovalik-Gran, 2008; Gu, Gau, & Tzang, 2013; Tallberg, Rästam, Wenhov, Eliasson, & Gustafsson, 2018). Besides the continuous performance elements, we added two others in the DHT that allowed us to investigate the reward processing: the *amount of rewards gain during the task* and the *escaping choice* (i.e., the participant could commit errors to finish the task earlier). These elements were added further to investigate reward delay and delay aversion during the assessment.

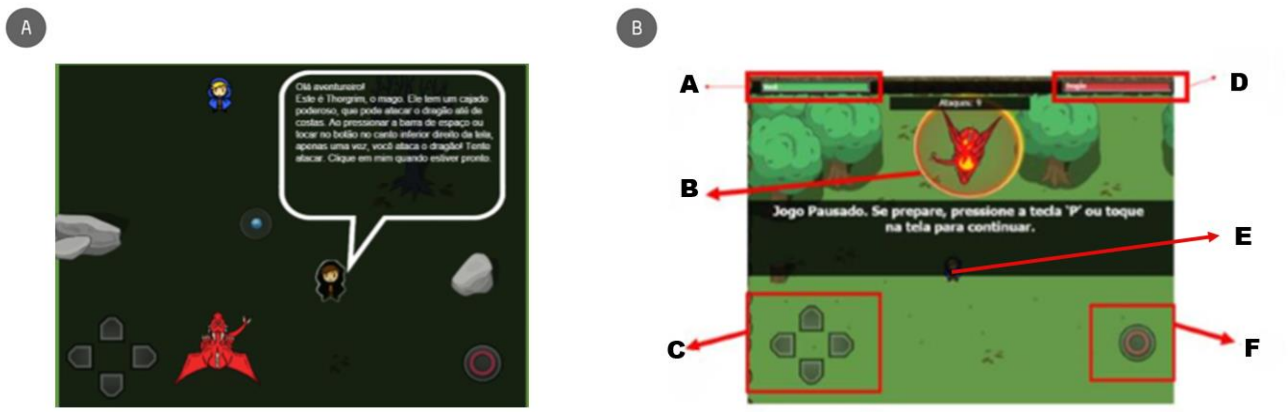

Figure 1: Dragon Hunter Game screenshots (A) Tutorial screen where the participant can interact with the game mechanics and its elements, such as the dragon, the sapphire, and the main character (the blue one). Also, it is possible to experiment with video game controls. (B) Main game screen. Each game element represents essential information during the gameplay; (A) participant's life, (B) Magical Aura, (C) Directional arrows to move the character, (D) Dragon's life, (E) Participant character and (F) action button, allows to participant attack the dragon.

Revised Gameplay Questionnaire (RGQ; Parnell, 2009)

RGQ is a self-reported questionnaire composed of 26 items related to four subdomains of the gameplay experience. The questionnaire was scored on a seven-point Likert scale: 1=Strongly Disagree; 7=Strongly Agree. Higher global scores indicate a positive experience with high emotional engagement, better focus on the game, and few usability and gameplay barriers (Parnell, 2009). Besides the global score, Parnell (2009) found four subdomains factors: Emotional experience (items 1, 4, 10, 22*, 24*, 26), focus (2, 3, 6, 9, 13*, 18, 19, 20*, 23), playability barriers (12* ,14, 15*, 16, 25) and usability barriers (5, 7, 8, 11, 17*, 21*). In the present study, we employed a translated and adapted version to a Brazilian young adult population (Rivero et al., 2015). We proceed with a cognitive debriefing process to adapt the instrument to adolescents. The sample was composed of 10 adolescents, five females, 12 y/o, and six-year of education. These subjects had to point out items there were inadequate to the context or items that were incomprehensive. We excluded five items: 2 that were incomprehensive to the participants (item 18 "I found the game mechanics to be varied enough" and 20 "My field of view made it difficult to see what was happening in the game") and three items because they did not apply to the videogame (item 11 "I knew how to change the settings in the game", "I found the game's menus to be cumbersome" and 21 "I found using the options screen to be difficult").

Note: The items with * are negative questions with scoring reversed.

SNAP-IV - Attentional, Hyperactivity-Impulsive, and Oppositional Symptoms Scale.

The short version of the SNAP-IV (MTA SNAP-IV Brazilian version; Mattos, Serra-Pinheiro, Rodhe Pinto, 2006) is a checklist based on DSM-IV (Diagnostic and Statistical Manual of Mental Disorders) to evaluate symptoms related to inattention (items 1 to 9), and hyperactivity/impulsivity (10 to 18). Ordinal categories can vary from 0 to 3 (0=not at all; 1=must a little; 2=quite a bit; 3=very much). The total score ranged from 0 to 54 points. Severity was evaluated by summing the total score on the scale. Everyday difficulties were evaluated, for example: question 1 - "Often fails to give close attention to details or makes careless mistakes in schoolwork, work, or other activities"; Question 9 - "Often is forgetful in daily activities"; Question 18 -

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"Often interrupts or intrudes on others (e.g., butts into conversations/games)". SNAP-IV's reliability coefficient (Cronbach's alpha) for overall parent ratings was .94. For the inattentive, hyperactive/impulsive subdomains were .90 and .79, respectively (Bussing et al., 2008). Internal consistency estimates did not increase with the removal of any item; specifically, ranges of alpha (if item deleted) for the inattentive, hyperactive/impulsive subdomains were .88 to .89 and .76 to .80 (Bussing et al., 2008). Data from a community sample showed that SNAP-IV has predictive validity for Concern Level. SNAP-IV parent subscale scores were significantly higher for children who met ADHD criteria on the DISC-IV than for those who did not ($p < .0001$) (Bussing et al., 2008).

Previous videogame proficiency

The prior game experience was assessed using summing up the answers of two open-ended questions modified from Green, Sugarman, Medford, Klobusicky, and Bavelier (2012). The items appeared as follows: "In a typical week, how many hours do you play videogames?" and "In a typical weekend, how many hours do you play videogames?".

Data collection proceedings

The DHT assessment session occurred collectively in the student's classroom. Before starting the application, the examiner asked the participants if they already have any experience in the use of video games and tablets. The complete research proceeding lasted 50 minutes. The participants were submitted to four steps: 1) DHT tutorial; 2) Previous videogame proficiency questions; 4) DHT assessment; 4) and RGQ.

Data analysis

Bayesian inference was employed. To verify the dimensionality and to understand the factor structure of RGQ, Bayesian exploratory factor analysis (BEFA) was run through Mplus *software.* The resultant one-factor F-scores (latent trait) from the bayesian confirmatory factor analysis (BCFA) of the SNAP-IV and RGQ were employed as independent continuous variables to construct the bayesian path analysis models. Path analysis was used to estimate the linear regression system in which all variables are observable.

Two groups were created: one related to a more negative experience (ExpN) and another with a more positive experience (ExpP) during the gameplay, both based on the RGQ result percentile. The ExpN group (N=26) was obtained with the scores using the 25th percentile as the cutoff point and the ExpP group (N=26) with higher scores using the 75th percentile. The difference between groups was calculated using t-distribution for robust estimates (which better accommodates outliers) and the standard deviation indirectly controlled through the 'normality parameter' (nu). We employed the syntaxes suggested by Kruschke (2015) through the software Stan (version 3) combined with the "rstan" package (version 2.21.1, Stan Development Team, 2020). For the normality parameter v be stable in the analysis, only a single parameter was estimated to describe both groups. Priori values for the parameters were defined as an exponential distribution with a mean of 29 (nuMinusOne ~dexp (1/29)).

Repeated measures analysis of bayesian variance (rmBANOVA) was used because of its advantages in working with limited samples and missing data. Also, the Bayes factor (BF) is considered a more robust and sophisticated alternative to the null-hypothesis significance testing (NHST), and the arbitrary cutoff of .05 in *p*-value (Jarosz & Wiley, 2014). Besides, it provides a more precise estimate of the amount of evidence present in the data (Kruschke, 2015).

Because of the inherently subjective nature of the prior model odds, the emphasis of Bayesian hypothesis testing is on the amount by which the data shift one's beliefs, that is, on the Bayes factor. Thus, when the Bayes factor BF_{10} equals 3.5, the data are 3.5 times more likely under H_1 than under H_0. When the Bayes factor BF_{10} equals 0.2, the data are five times more likely under H_0 than under H_1. According to Jeffreys (1961), evidence categories for Bayes factors can be interpreted as following: < 0.01 decisive evidence for H_1; 0.01 to 0.033 very strong evidence for H_1; 0.033 to 0.1 strong evidence for H_1; 0.1 to 0.33 substantial evidence for H_1; 0.33 to 1 anecdotal evidence for H_1. If the Bayes factor is equal to 1, there is no evidence at all. On the other side, BF ranging from 1 to 3 has anecdotal evidence for H_0; 3 to 10 substantial evidence for H_0; 10 to 30 strong evidence for H_0; 30 to 100 very strong evidence for H_0; and > 100 decisive evidence for H_0.

Robust bayesian correlations were made between total time on complete tasks, rewards, and commission of errors. Finally, bayesian mediation analyzes were carried out between the reward, VEG, and C-errors.

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Results

Dimensionality evidence of the RGQ

Bayesian exploratory (BEFA) and confirmatory factor analysis (BCFA) results suggest that the theoretical model proposed by Parnell (2009) is unidimensional, after excluding the five items of the original scale. Factorial items loaded higher than 0,3, with RGQ raw values ranging from 25 to 125 points.

Comparison between positive and negative experience groups

Table 1 shows the parameters posterior medians and 95% credibility intervals (high-density interval, HDI). Minimum and maximum values were commission errors, 5 to 56; rewards, 0 to 12; previous game proficiency, 0 to 13 hours; SNAP-IV, 0 to 51; and the total time on task, 156 to 754 sec. The commission errors, rewarding, and the total time on task normality parameters logarithms (log10 *v*) suggested normal distributions (values near 1.47). However, on SNAP-IV (Severity), *v*=0.5 indicating long tails when comparing groups. The effect size (η^2) was higher in reward (η^2=-1.5 [-2.2 to -0.8]), C-errors (η^2=1.0 [0.3 to 1.7]), and total time on task (η^2=-1.0 [-1.9 to -0.3]). ExpP had better results (higher total rewards and lower total C-errors and a longer total time on task) than the ExpN group. Both previous game proficiency (η^2=-0.3 [-0.8 to 0.3]) and SNAP-IV (Severity) (η^2=0.6 [-0.2 to 1.4]) showed no differences between groups since these results cross zero in the credibility interval.

Table 1 – Posterior medians and high-density interval of the robust parameters of the negative (n=25) and positive (n=26) game experience groups.

	C-errors	Rewards	Time (hours)	SNAP-IV (1 to 18)	Time (seconds)
	Median [95% HDI]	Median [95% HDI]	Median [95% HDI]	Median [95% HDI]	Median [95% HDI]
$\mu_{(ExpP)}$	17.7 [12.6 to 22.9]	6.8 [5.6 to 8.1]	5.1 [3.7 to 6.6]	8.7 [5.7 to 11.8]	557.9 [517.9 to 593.6]
$\mu_{(ExpN.)}$	31.1 [25.1 to 37.0]	2.6 [1.5 to 3.7]	4.2 [2.9 to 5.5]	10.6 [8.6 to 12.8]	434.8 [372.5 to 498.3]
$\mu_{(Diff.)}$	13.3 [5.1 to 2.9]	-4.2 [-5.9 to -2.5]	-.9 [-2.9 to 1.1]	4.5 [2.6 to 6.5]	-121.6 [-193.3 to -47.7]
$\sigma_{(ExpP.)}$	11.7 [7.9 to 16.4]	3.0 [2.2 to 4.1]	3.6 [2.7 to 4.8]	1.9 [-1.8 to 5.7]	85.6 [40.1 to 125.6]
$\sigma_{(ExpN.)}$	14.0 [1.3 to 19.0]	2.6 [1.8 to 3.6]	3.2 [2.2 to 4.3]	6.5 [3.9 to 9.5]	143.0 [88.2 to 200.9]
$\sigma_{(Diff.)}$	2.4 [-3.4 to 8.6]	-.4 [-1.8 to .8]	-.4 [-2.0 to 1.1]	-2.0 [-5.4 to 1.0]	57.9 [2.2 to 121.1]
ν	26.6 [1.5 to 94.8]	26.8 [1.9 to 95.1]	3.3 [2.6 to 98.6]	4.0 [1.2 to 8.0]	13.0 [1.0 to 76.0]
log10(v)	1.4 [.6 to 2.1]	1.4 [.7 to 2.1]	1.5 [.8 to 2.1]	.5 [.2 to .9]	1.1 [.25 to 1.9]
η2	1.0 [.3 to 1.7]	-1.5 [-2.2 to -.8]	-.3 [-.8 to .3]	.4 [-.4 to 1.1]	-1.0 [-.1.9 to -.3]

Note: HDI = high density interval; ExpN. = negative experience group; ExpP. = positive experience group; μ = mu (central tendency parameter of the t-distribution), σ = sigma (spreading parameter of the t-distribution); v = nu (normality parameter) η^2 = difference effect size μ (Diff.).

Longitudinal between groups analysis

Considering a within-between subject factors design and 12 repeated measures factors separated by game stages, rmBANOVA was used to model comparisons. Table 2 shows all possible models and information about their relative adequacy: the null model (A_0), the model with a main effect of C-errors (A_1), the model with a main effect of groups (A_2), the model with a main effect of C-errors, the main effect of groups (A_3), and interaction between C-errors and groups (A_4). The "P(M)" column shows the prior model probabilities, the "P(M|data)" column shows the posterior model probabilities, and the "(BF_M)" column shows the change from prior to posterior model odds. Finally, the "(BF_{10})" column lists the Bayes factor for each model against the null model (equal zero).

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Table 2 also shows that in the first half of the game (stages 1 to 6), the main effect (model A3, BF_{10}=0.02) and interaction (A4, BF_{10}=0.03) had substantial evidence for H_1 (no difference in C-errors between ExpN and ExpP). Still, in the 2nd half (stages 7 to 12), the main effect (model B3, BF_{10}=403.6) and interaction (B4, BF_{10}=439.40) had decisive evidence for H_0 (i.e., the difference in C-errors between ExpN and ExpP).

Table 2 – Model comparison using bayesian repeated measures ANOVA (rmBANOVA).

Models	P(M)	P(M|data)	BF_M	BF_{10}	% error
A_0. *Null model*	.2	.65	7.48	1.00	-
A_1. CoE (stages 1 to 6)	.2	.04	.15	.06	.51
A_2. Groups (1st half)	.2	.28	1.55	.43	.84
A_3. CoE + Groups (1st half)	.2	.02	.07	.02	3.89
A_4. CoE + Groups (1st half) + CoE ✻ Groups (1st half)	.2	.02	.07	.03	1.04
B_0. *Null model*	.2	8.54 x10^{-4}	.00	1.00	-
B_1. CoE (stages 7 to 12)	.2	.00	.00	1.21	.39
B_2. Groups (2nd half)	.2	.28	1.54	325.31	.81
B_3. CoE + Groups (2nd half)	.2	.35	2.11	403.62	1.79
B_4. CoE + Groups (2nd half) + CoE ✻ Groups (2nd half)	.2	.38	2.40	439.38	1.11

Note. All models include subject. CoE = commission errors. Groups = ExpN and ExpP. 0="Null" model (only participants have effects); 1="Only stages" (1. + main effect of stages); 2="Only group" (1.+ main effect of group); 3="Main effects" (1. + main effects of both); 4="Interaction" (4. + interactions). In a model: if an effect is null, its effect is exactly 0; if an effect is not null, its effect needs a prior distribution.

Information on specific effects can be seen in Table 3 (see supplementary). Cauchy distribution was used as prior to the single effect parameter. In the two-factor design, we have five models but only three effects: stages, group, and stages:group (: means interaction). The first few columns of the output of the effects were based on model averaging. In model averaging, the evidence for the presence of an effect is combined across models that include that effect. For instance, in the two-factor design the effect A features in three out of the five models; therefore, the prior inclusion probability "P(incl)" equals 0.2 + 0.2 + 0.2 = 0.6. Thus, the prior inclusion probability is the sum of the prior probabilities of all models that include the effect. Similarly, the posterior inclusion probability "P(incl|data)" is the sum of the posterior probabilities of all models that include the effect.

The factor-inclusion parameter, analogous to predictor-inclusion parameters for variable selection in multiple linear regression, was used to compute the posterior probability that there is a nonzero deflection somewhere among the groups. The factor-inclusion parameters are given Bernoulli priors that express the prior probability of including the factors (Kruschke, 2015). The inclusion of Bayes factor "($BF_{Inclusion}$)" is the change from prior to posterior inclusion odds. The remaining columns of the output of the effects are based on including and excluding specific effects in a way that is similar to backward and forward regression (stepwise). Specifically, "$BF_{Backward}$" considers the most significant model with the effect (but without an interaction including the effect) and compares this model against the same model that excludes the effect. For the two-factor setup, "$BF_{Backward}$" for effect A means that the model with A+B is compared against a model that only has B. Thus, a high value for "$BF_{Backward}$" signifies support for the inclusion of the effect. Finally, "$BF_{Forward}$" is obtained by comparing the model with only the effect of interest (even if it is an interaction) against the null model. In our two-factor setup, for A, this means comparing the model with A against the null model; for A:B, this involves comparing the model with only A:B against the null model. Again, a high value of "$BF_{Forward}$" signifies support for the inclusion of the effect.

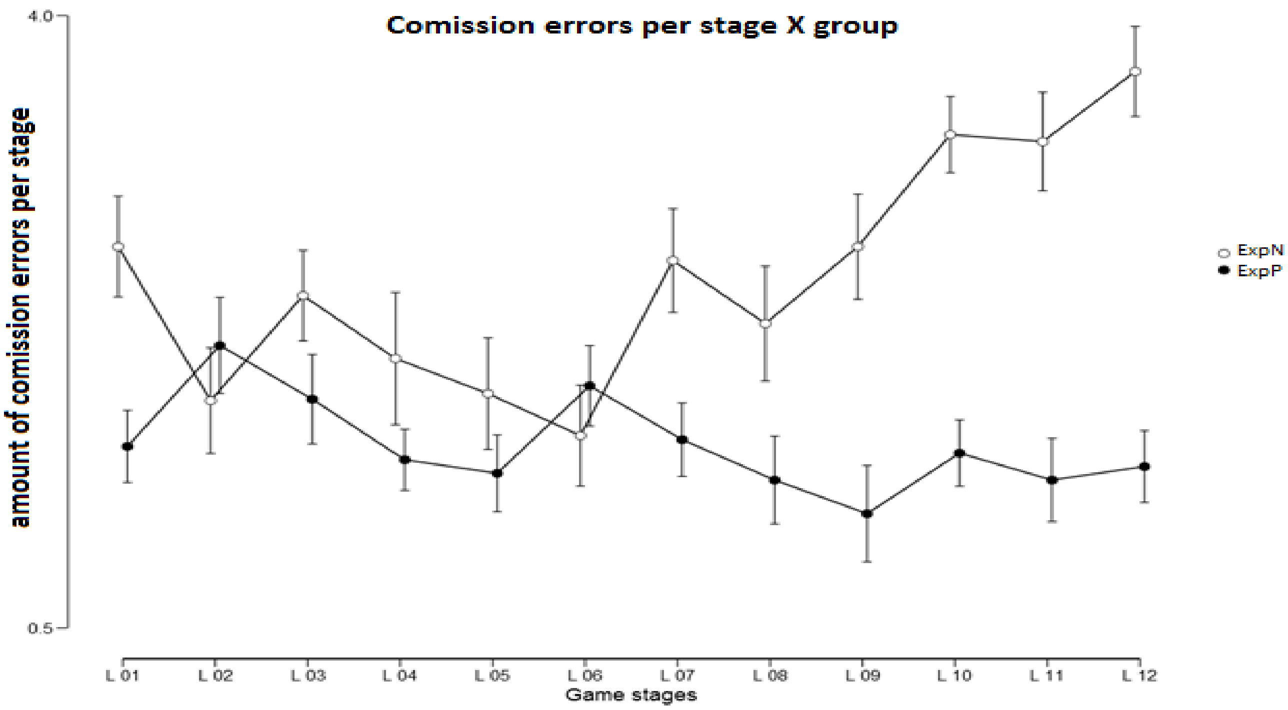
ISSN: 0718-4123
DOI: 10.7714/CNPS/15.2.211

Table 3. Comparison between ExpN and ExpP groups in RGQ stages 1-6 and RGQ stages 7-12.

Effects	P(incl)	P(incl|data)	BF $_{Inclusion}$	BF $_{Backward}$	% errorB	BF $_{Forward}$	% errorF
Commission error	.6	.84	3.52	3.64	1.91	3.50	.29
Reward groups	.6	1.00	$2.73\ 10^{10}$	$3.05\ 10^{10}$	1.64	$2.94\ 10^{10}$	1.02
Commission error ✻ Reward groups	.2	.26	1.42	$3.05\ 10^{10}$	1.64	.45	2.05
RGQ (Stages 1 to 6)	.6	.07	.05	.06	3.98	.06	.51
ExpP	.6	.31	.30	.45	3.92	.43	.84
RGQ ✻ ExpP	.2	.02	.07	.45	3.92	1.07	4.03
RGQ (Stages 7 to 12)	.6	.72	1.73	1.24	1.96	1.21	.39
ExpN	.6	1.00	352.74	334.11	1.83	325.31	.81
RGQ ✻ ExpN	.2	.38	2.40	334.11	1.83	1.09	2.10

According to Table 3, decisive evidence for H_0 was seen in AA2 ($BF_{Forward}$>100), and substantial evidence for H_0 was found in B2 (3<$BF_{Forward}$<10). This evidence can be seen in Figure 2. Figure 2 shows the groups. Group 1 shows that, after the intervention with the video game, it evidences a high positive affective valence. Group 2, meanwhile, shows a negative affective valence. More explanatory, it is observed that group 1, the higher the frequency of play, the higher the efficiency in inhibitory control. For group 2, with negative affective valence, response inhibition remains the same or declines.

Figure 2. The impact of positive (ExpP) and negative (ExpN) experience on a task on response inhibition (12 game stages).



 ISSN: 0718-4123
DOI: 10.7714/CNPS/15.2.211

Correlation between total time on task, reward, and C-errors variables

To understand the relationship between variables, a robust bayesian correlation was performed using t-distribution with median and mad parameters as a priori values. The correlation between total time on task and rewards was 0.53 ([CI 95% = 0.37 to 0.66], nu=48.9 [11.8 to 132.0]), and between total time on task and C-errors was -0.81 ([-0.88 to -0.73], nu=26.8 [6.2 to 88.3]). These results indicate that participants who spent less time on task gained few rewards and made more C-errors, which is related to failure in response inhibition.

Influence of reward and valence of experience on DHT

The results obtained from the bayesian path analysis showed that the RGQ F-score was inversely proportional to C-errors (R^2=-0.39, [-0.53 to -0.21]) and directly proportional to the number of rewards obtained during the task (R^2=0.41 [0.24 to 0.56]). Participants who reported positive experiences on DHT, had more rewards and lower C-errors, while those with negative experiences had fewer rewards and higher C-errors. The total amount of received rewards and committed C-errors were negatively correlated with each other (ρ=-0.56 [-0.68 to -0.41]).

Figure 3 shows that the previous game proficiency did not affect the amount of C-errors (R^2=0.05 [-0.13 to 0.23]) neither on the total number of rewards obtained (R^2=0.01 [0.16 to 0.19]). Furthermore, the SNAP-IV f-score did not relate to C-errors (R^2=0.06 [-0.12 to 0.24]) or to rewards (R^2=0.04 [-0.15 to 0.21]).

Figure 3. Bayesian path analysis

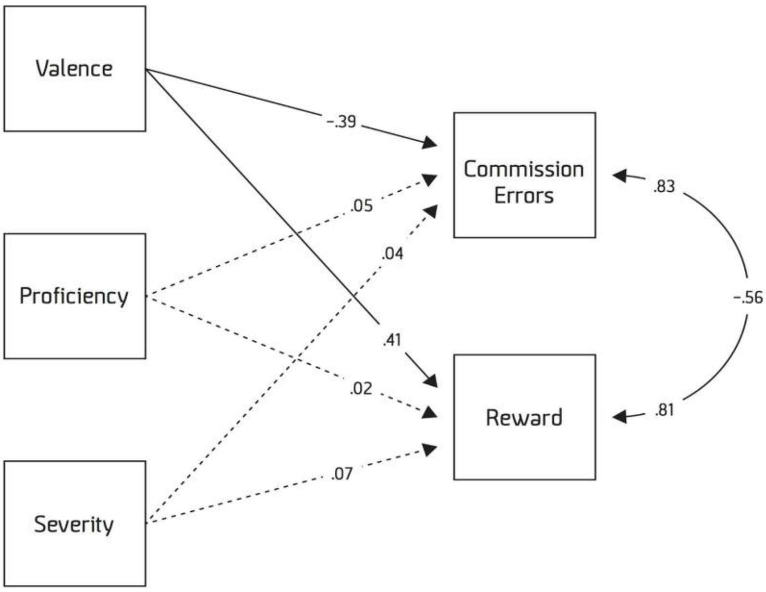


Figure 3: The unidirectional arrows indicate the relationship between IVs and DVs. The bidirectional arrow indicates a correlation between DVs. The dark lines indicate a significant effect. Markov chain Monte Carlo was used for resampling. Two-MCMC channels (PX1 Gibbs algorithm) with 10,000 iterations were employed. Model fitting information: DIC = 517.73; BIC=546.73; pD=10.80; PPp=0.486 (PPC=-11.92 to 14.68).

Mediation analysis of VEG and reward variables

The mediation analysis was used to understand how a causal agent X transmits its effect to Y. In Figure 3, there are two following variables Y and M and two antecedent variables X and M, with X having a direct effect on Y and M, and X having an

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ISSN: 0718-4123
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indirect effect on Y through M (mediating variable). This indirect effect shows how Y is influenced by X through a causal effect, in which X affects M, which in turn influences Y.
In Figure 4-A, Bayesian path analysis were calculated. VEG is the mediating variable (M) that receives the reward effect (X). The relationship that has emerged shows that C-errors (Y) are directly affected by rewards (X), regardless of the influence of VEG (M), thus the causal mechanism proposes that in our sample, the more rewards earned, the fewer C-errors committed (R^2=-0,56 [-0,68 to -0,41]). However, as seen in Figure 4-B, C-errors (Y) do not receive the influence of VEG (X) when mediated by rewards (M) (R^2=-0,16), within the events chain.

Figure 4. Mediation models to explain the causal effect of experience and rewards on inhibition control.

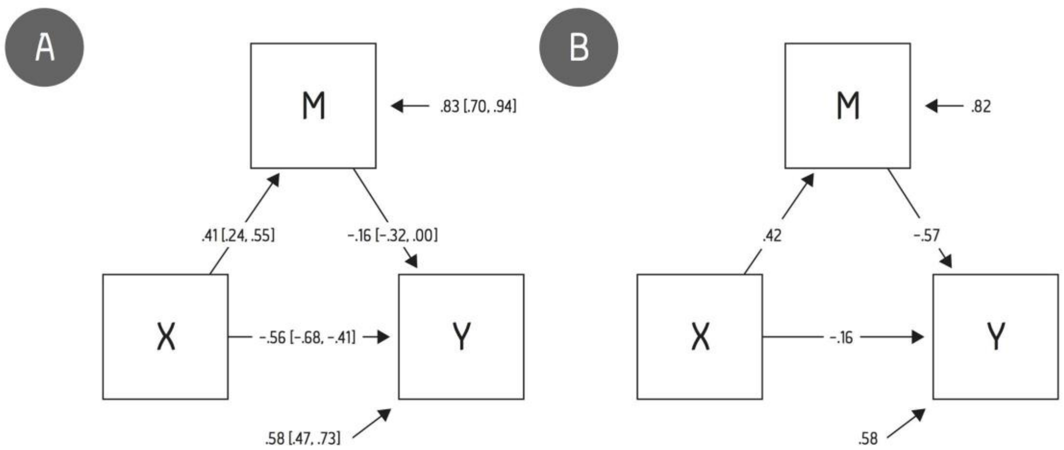

Figure 4: (A) VEG is mediator (M), Reward is independent variable (X) and C-errors is dependent variable (Y). DIC = 1016,56; BIC = 1034,56; pD = 7,1 (PPp = 0,469; X2=-10,11 to 10,90). (B) Reward is mediator (M), VEG is independent variable (X) and C-errors is a dependent variable (Y). AIC = 1277,63; BIC = 1295,94; SABIC = 1273,83 (X2 = 75,47; g.l.=3).

Discussion

The present study reinforces the relationship between motivation and inhibitory control. As we hypothesized, adolescents that reported a more positive game experience during the task earned almost three times the amount of rewards. They had nearly two times more response inhibitions and remained more time on task when compared to adolescents that reported a more negative game experience.
The adolescents that had a more negative game experience had the inverse performance, with less total time on task, fewer rewards, and more response inhibition, specifically in the second half of the task. This data points out that participants with a negative experience adopted a delay avoidance strategy during the second half of the task, which seems to be related to deficits in reward processing. These deficits can be explained by a reward devaluation, after the processing of predictive cues of reward delay, during the first half of the task, which consequently contributed to the delay avoidance strategy implementation. Analyzing an ADHD sample, Sonuga-Barke, De Houwer, De Ruiter, Ajzenstzen, & Holland (2004) proposes that these subjects had a sensitivity to delays and develop an attentional bias to cues related to delay.

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The above results must be understood in the light of DHT characteristics. The task was built to evaluate response inhibition through a continuous performance paradigm (Conners, 2003) while assessing the effect of reward gain during the task. All DHT stages had the same number of possible trials, and ISI was randomized, and the reward gain happens if the participants win the stage, which occurs when 5 in 9 trials are correct responses. This necessity to make five correct answers to earn a reward could diminish the reward magnitude. Prelec and Loewenstein (1991) defined reward magnitude as the amount and frequency that a reward occurs. It can be understood as the personal understanding of how much compensation will be gain concerning the judgment of the amount of time that she needs to wait to receive it (delay). It is known that for a reward to influences behaviors, the individual must attribute personal values to it, even before the occurrence of it. This prior valoration directly depends on reward magnitude, amount of delay time and the probability to receive it or not, a phenomenon that occurs in both animal and non-animal humans (Green & Myerson, 2004; in human animals: Mok et al., 2020; as a non-human animals: McDevitt, Dunn, Spetch, & Ludvig, 2020).

The reward devaluation that happened through DHT stages could be related not only to a change in reward magnitude calculation but also to a perception of employed effort. This change in effort perception in comparison to the attributed rewards values during the initial stages is known as effort discounting (Botvinick, Huffstetler & McGuire, 2009; Gershman & Bhui, 2020; Harmon-Jones, Willoughby, Paul, & Harmon-Jones, 2020). This effort cutting contributed to the implementation of the above-cited delay aversion avoidance strategy seen during the two half of the task, which increased the number of commission errors and diminished the total time on task

Our data seem to point out that even in a sample of typical development adolescents, rewards, and valence of experience during the gameplay are essential to adequate response inhibition. In his seminal paper about delay aversion, Sonuga-Barke (1994) shows that impulse control deficits could be more related to preference not to wait than an incapacity to wait. The same pattern can be seen in our task since it is a choice task, where the participants can reduce the time on the mission by making errors.

A clear relationship between rewards gain, total time on task, and valence of experience during the gameplay during the task was established to the number of commission errors. This relationship revealed that the most positive experiences have led to a higher gain rewards and better response inhibition, and the latter was directly correlated with the highest number of reward gain. Besides, the bayesian mediation analysis showed the causal mechanism between the rewards gained, during the DHT, and commission errors. A clear relationship between positive reinforcement and errors was observed in the task results; the more rewards were earned, the few commission errors were committed.

These data are consistent with the dual pathways model proposed by Sonuga-Barke (2002), where impulsive errors could be related to motivational processing problems, rather than just high-order executive control (Sonuga-Barke, 2002). These kinds of motivational fails are commonly seen in patients with ADHD (Sonuga-Barke, 2002, Sjöwall, Roth, Lindqvist, & Thorell, 2013; Sjöwall, Bohlin, Rydell, & Thorell, 2017). However, in this study, it is possible to see the centrality of reward processing failures in subjects with typical development.

No difference was found between groups on previous game proficiency and attention/hyperactivity traits measured by SNAP-IV severity. Considering the role of last video game, proficiency did not change the amount of correct response inhibition answers. Several studies demonstrated that previous ability on the video game, influences on several cognitive skills, such as inhibition control (He, Turel, Wei, & Bechara, 2020; Hutchinson, Barrett, Nitka, & Raynes, 2016; Ruiz-Marquez et al., 2020) and attention control (Benzing & Schmidt, 2019; Cardoso-Leite & Bavelier, 2015; Chisholm & Kingstone, 2015). Furthermore, some studies found an essential connection between participants who had experience in video game skills and better performance on continuous performance tests (Alves & Carvalho, 2010; Chan & Rabinowitz, 2006). These results always brought some concerns about the use of continuous performance tests as tools to measure cognitive skills, maybe because it resembled a video game (i.e., fast-paced task, visual stimuli, and challenge level). However, the present data indicate that participants' video game skills did not affect DHT.

No differences in the measure of behavioral symptoms severity reported by parents were found. This could be related to the sample characteristics, mainly due to the hyper normality sample. All students belonged to a private school with a critical self-selection method, which influences the interpretation of our results. A more heterogeneous sample must be evaluated to understand the influence of behavior symptoms on response inhibition concerning valence of experience during the gameplay and rewards. For its novelty aspect, it is essential to proceed with more studies to evaluate the validation criteria of DHT. Crucial to these future steps are the study of populations where the primary impairments are related to response inhibition, such as ADHD and Bipolar Disorder.

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Finally, we believe it is relevant to contextualize these results in the context of education, in order to design video games with the purpose of increasing students' intrinsic motivation. It has been systematically reported that video game-based tools could increase inhibitory control in various populations (Bavelier & Shawn Green, 2019; Kristjánsson, 2013; Ramos & Garcia, 2019). In this sense, it is feasible to hypothesize that this study contributes to develop educationally attractive video games based on positive rewards that increase intrinsic motivation and learning, as opposed to traditionalist teaching approaches. In this sense, the optimization of inhibitory control is associated with better educational performance in school-age adolescents (Girard, Ecalle, & Magnan, 2013; Squire, 2005). Overall, the present study provides evidence in the field of neuropsychology, particularly as a precursor to the development of new technologies based on video games for the training of inhibitory control and associated reward regulation. At the same time, the study suggests guidelines for understanding the motivational and rewarding mechanisms underlying the teaching-learning processes in educational contexts. That is, the present study is based on the assumption of non-traditionalist learning alternatives that could be useful to achieve the best educational performance in, for example, populations with ADHD. Therefore, in the 21st century, video games are considered a key resource that guarantees the success of teaching-learning processes.

Conclusion

Our study suggests that valence of experiment and the amount of reward seem to have an essential role in regulating response inhibition behavior. In other words, adolescents who had a decreased delay rewards gradient developed a greater aversion to delay. These subjects established avoidance and escape strategies to minimize the time spent on tasks that demand involvement for extended periods. These strategies seem to be related to impulsive behavior and can play a vital role in the establishment of an engagement reduction pattern on task.

There is now growing, though not yet conclusive evidence, that altered reinforcement mechanisms are implicated in ADHD. Understanding the specific nature of those deficits could provide a platform for innovative environmentally-mediated therapies for ADHD. These factors must be considered during the design of new video game instruments for evaluation and rehabilitation. More studies should employ DHT to evaluate subjects with impulse control deficits, such as ADHD and Bipolar Disorder patients.

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