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Research article

The role of individual differences in attentional blink phenomenon and real-time-strategy game proficiency

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ABSTRACT

The impact of action videogame playing on cognitive functioning is the subject of debate among scientists, with many studies showing superior performance of players relative to non-players on a number of cognitive tasks. Moreover, the exact role of individual differences in the observed effects is still largely unknown. In our Event-Related Potential (ERP) study we investigated whether training in a Real Time Strategy (RTS) video game StarCraft II can influence the ability to deploy visual attention measured by the Attentional Blink (AB) task. We also asked whether individual differences in a psychophysiological response in the AB task predict the effectiveness of the video game training. Forty-three participants (non-players) were recruited to the experiment. Participants were randomly assigned to either experimental (Variable environment) or active control (Fixed environment) group, which differed in the type of training received. Training consisted of 30 h of playing the StarCraft II game. Participants took part in two EEG sessions (pre- and post-training) during which they performed the AB task. Our results indicate that both groups improved their performance in the AB task in the post-training session. What is more, in the experimental group the strength of the amplitude of the P300 ERP component (which is related to a conscious visual perception) in the pre training session appeared to be predictive of the level of achievement in the game. In the case of the active control group in-game behaviour appeared to be predictive of a training-related improvement in the AB task. Our results suggest that differences in the neurophysiological response might be treated as a marker of future success in video game acquisition, especially in a more demanding game environment.

1. Introduction

1.1. Video games and cognitive functioning

Playing video games (VG) is undoubtedly one of the most popular leisure activities in today's society. However, besides being an engaging form of entertainment, playing video games has been also discussed recently in the context of its potential consequences on attentional and perceptual skills (e.g., Bavelier et al., 2011; Franceschini et al., 2013; Green and Bavelier, 2003; Toril et al., 2014). Particularly video games defined as “action video games” are thought to exert a significant influence on human cognitive functioning. According to Green and Bavelier (2003) video games that can be classified to this category need to: “have fast motion, require vigilant monitoring of the visual periphery, and often require simultaneous tracking of multiple targets”. In fact, the cumulative evidence suggests that expert action VG players outperform non-players in a number of cognitive tasks measuring such skills as visual attention, some aspects of cognitive control, general processing speed or working memory (e.g., Blacker and Curby, 2013; Castel et al., 2005; Colzato et al., 2013; Dye et al., 2009a, b; Green and Bavelier, 2003, 2006, 2007; Strobach et al., 2012). What is more, according to recent investigations, even relatively short training in action VG playing (e.g., 10 h) can improve subjects' performance in a subsequent cognitive examination (e.g., Basak et al., 2008; Feng et al., 2007; Li et al., 2010).

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Given that, in the light of recent meta-analyses (e.g., Dougherty et al., 2016; Guye and von Bastian, 2017; Melby-Lervåg et al., 2016; Sala and Gobet, 2019), traditional cognitive-training programs (e.g. . Jaeggi et al., 2010) bring little benefits and have minimal effect on domain-general cognitive skills, it comes as no surprise that VGs have started to be seen as a potentially promising new tool for enhancing cognitive skills. The resemblance of game-environment and its dynamics to real-world complexity as well as their inherently motivating character are currently considered as their greatest assets that could be profitable in the process of both restoring cognitive functions following brain impairments and in preventive cognitive interventions (Achtman et al., 2008).

The impact of VG playing on cognitive functioning has also become the subject of a heated debate among scientists, with some of them even undermining the relation between VG experience and cognitive abilities (Unsworth et al., 2015). Indeed, there is a plethora of studies showing also either none or weak impact of video-game playing on cognitive functions such as working memory or selective attention (e.g., Boot et al., 2008; Irons et al., 2011; Murphy and Spencer, 2009; Unsworth et al., 2015). Those discrepancies can, however, result from numerous methodological and statistical shortcomings, such as very small samples, extreme-groups designs, lack of standardized trainings, no active control groups and lack of independent replications (Bisoglio et al., 2014; Boot et al., 2011; Unsworth et al., 2015), which are present in the field. Aiming to overcome the limitations of previous study designs, a number of new approaches towards research on video games have emerged.

1.2. New trends in research on video games

First of all, it has been acknowledged that so-called "action video games", which in the light of numerous studies have been identified as the most beneficial for cognitive functioning, are, in fact, a loosely defined category. Indeed, as demonstrated by Dobrowolski et al. (2015), expertise in two games, both classified as action video games - namely real-time strategy (RTS) and first-person shooter (FPS), can have differential impact on cognitive functioning, with RTS players - in contrast to FPS players - showing greater performance in task measuring abilities such as visual attention and task-switching as relative to non-players (Dobrowolski et al., 2015). Those results suggest that VG play benefits might be a function of the type of actions performed within the game (Dobrowolski et al., 2015). Therefore, it seems that both, the gameplay mechanics and its demands on cognitive functions as well as individual's behaviour in the game environment, has to be taken into consideration during planning and analysis of studies in the field.

Furthermore, numerous investigations suggesting the positive impact of video games on cognitive functioning based their evidence on comparisons between expert video gamers and non-gamers. Those studies are therefore correlational in nature. It is likely that the mechanisms through which playing certain video-games influences cognitive functions are more complex, with multiple factors contributing to the observed differences. One of such factors might be a self-selection effect, as it is possible that future video game experts demonstrate superior perceptual, attentional, and cognitive skills from the very beginning of their gaming adventure and these initial predispositions promote video game expertise (Boot et al., 2008). In fact, as demonstrated by Kramer and Erickson's research group (Erickson et al., 2010), variability in performance in demanding video games can be predicted from variations in the pre-training volume of striatum. We found a similar pattern of results (Kowalczyk et al., 2020). These results seem to suggest that neuroanatomical differences can serve as effective predictors of procedural learning and cognitive flexibility during complex skill acquisition. What is more, similar effects have been also observed, for example, in the context of hippocampal volume and effectiveness of memory training (Engvig et al., 2012) and the value of such predictive models in the field of cognitive neuroscience has been already recognized as well (Gabrieli et al., 2015). This shows how important it is to employ a training design to investigate the impact of VG playing on cognition.

1.3. Present study

In our study we wanted to further investigate the mechanism through which playing video games might exert influence on cognitive functioning. Given that numerous studies emphasize not only the superior performance of action video game players as relative to non-players in attention-demanding tasks (e.g., Chisholm et al., 2010; Dye et al., 2009a, b; Hubert-Wallander et al., 2011), but also differences in neural strategies and mechanisms employed by those two populations during such tasks (e.g., Bavelier et al., 2012; Krishnan et al., 2013; Mishra et al., 2011), we decided to focus our research on changes in attentional skills. Aiming to precisely track the process of gaining those skills in the game environment, we designed a training procedure during which participants were learning to play a real-time strategy (RTS) game. To provide participants with both a cognitively-demanding and ecologically valid training environment, we chose RTS video game StarCraft II (SC2) – described as bearing close resemblance to "the messiness of the real world" (Vinyals, 2016) – for a training tool.

Furthermore, in order to assess post-training change in attentional skills and, at the same time, take into account individual differences in this domain, we measured participants' performance in the same cognitive task before and after the training. We chose Attentional blink (AB) task as a pre- and post-training measure for two main reasons: (i) AB paradigm has been widely investigated in the VG players population and, in the light of current research, is considered to be an adequate measure of temporal aspects of attentional processing (e.g., Green and Bavelier, 2003; Luck et al., 2000; Vul et al., 2008) (ii) its behavioural effects and neurophysiological underpinnings have been extensively studied and described in the existing literature (review: Martens and Wyble, 2010). Therefore, by examining the susceptibility of AB effects to the RTS video game training, we could not only test the influence of RTS training on attention but also contribute to the wealth of knowledge in this field.

Finally, while participants were completing both pre- and post-training measurements, their brain activity was recorded with the use of electroencephalography (EEG) technique, which served us as a benchmark for obtained behavioural results and allowed us to create individual profiles of subjects also on a neurophysiological level. Similarly to other studies (e.g., Koivisto and Revonsuo, 2008; Kranczioch et al., 2003; Mishra et al., 2011; Sergent et al., 2005), we applied an Event-Related-Potential (ERP) technique to analyze collected EEG data.

1.3.1. Attentional blink task

The attentional blink (AB) phenomenon is defined as a transitory impairment of attention appearing when multiple targets need to be processed in close temporal proximity. In laboratory settings this phenomenon is usually studied by task described as rapid serial visual presentation (RSVP). The Attentional Blink task, originally presented by Raymond et al. (1992), described the RSVP paradigm as consisting of a series of stimuli which are displayed at a single location with a frequency of about 10 per second. In the stream of stimuli two are defined as targets. The second target (T2) is presented at various time lags following the first target (T1). Within this framework, the AB phenomenon manifests itself as the inability of subjects to report on the second target (T2) when it is presented between 200-500 ms after the first one (T1) (Kranczioch et al., 2003).

Invariant and stable as it seemed at first, in the light of current investigations, the AB effect appears to be surprisingly susceptible to individual differences, with its magnitude varying from one individual to another (Martens et al., 2006). What is more, as revealed by recent studies, certain experiences can attenuate AB effect (review: Martens and Wyble, 2010). Frequent playing in action video games has been shown to be one of such experiences, with video game players outperforming non-video game players in detecting stimuli in the AB time window. The difference in performance between these two populations is thought to result either from faster target processing or increased ability to maintain several attentional windows in video-game players (Green and Bavelier, 2003; Oei and Patterson, 2013).

Despite numerous studies addressing factors influencing AB phenomenon, its neurophysiological underpinnings are still a matter of debate. Recent studies seem to suggest, however, that targets presented in the AB time window can reach working memory, which is reflected at the neurophysiological level in the modulation of the P300 ERP component (Kranczioch et al., 2003).

P300 is an ERP component with the peak latency varying from 250 to 650 ms after stimulus. It is thought to represent the activity of the widespread fronto-parietal networks and to be related to engagement of attentional resources and working memory processes, which are both crucial for dealing with cognitive tasks (Bonala and Jansen, 2012; Verleger et al., 2016). In the studies employing AB paradigm, the P300 component - in contrast to earlier ERP components such as P1 or N1 - has been shown to be evoked only by targets which were detected during blink interval (Kranczioch et al., 2003; Sergent et al., 2005; Sessa et al., 2007). As Kranczioch et al. (2003) suggested, such results can be interpreted as the evidence that relevant information presented during the AB time window is not entirely lost, but, one the contrary, in some trials, can be compared with templates held in working memory. In the light of those investigations, the P300 component might be thus considered as a marker indicating the depth of information processing. Furthermore, it can also act as a reliable neurophysiological measure of changes in cognitive functioning since its latency and amplitude have been shown to be sensitive to cognitive impairments, such as for example memory loss (Lai et al., 2010). To the best of our knowledge, however, its role in marking post-training changes in stimuli processing in the AB task has not yet been investigated.

1.3.2. StarCraft II

StarCraft II is a real-time strategy game, which is considered to be an excellent research platform for studying complex skills acquisition. A rich and dynamic task environment, accurate measures of motor performance, attentional allocation and perceptual processing, entertaining character, large datasets with numerous variables and many levels of expertise are listed as its main advantages (Thompson et al., 2013). The game itself is cognitively challenging, as it requires precise timing (taking action as soon as it is available), speed (issuing as many actions as possible) and spatial precision (targeting the right place, structure or unit). What is more, according to studies in the field, extensive and long-term RTS experience can induce neuroplastic changes. Particularly, RTS players appear to have significantly more total white matter connections between occipital and parietal areas and within occipital areas as compared to non-players (Kowalczyk et al., 2018). Accordingly, behavioural studies indicate enhanced visual and spatial skills in RTS players (Dobrowolski et al., 2015; Kim et al., 2015). The expertise in the game is also associated with an increase in the number of attentional shifts that occur within a set time frame (Thompson et al., 2013) and training in SC2 has been reported to have a positive effect on cognitive functioning (Glass et al., 2013). Importantly, StarCraft II allows for creating various game environments differing in the amount of cognitive effort the playing requires. This way, similarly to the video-game training employed in the study of Erickson et al. (2010), it is possible to create two groups – experimental promoting cognitive flexibility by encouraging the use of numerous different strategies (in our study called: Variable) and the active control in which optimal strategy is not to prioritize different aspects of task flexibly, but rather to use “flat” priority approach (in our study called: Fixed).

1.4. Research goals

Our study employed two versions of StarCraft II video game as cognitive training in order to determine if we can observe different outcomes depending on the level of game complexity (Variable versus Fixed). We posed two kinds of research questions to frame our current study. Firstly we were interested how our participants will change after training at the behavioural level. Would we be able to observe a bigger improvement in the post-training relative to the pre-training performance in the AB task (i.e. higher accuracy in detecting T2 in the AB time window) in the experimental (Variable) group compared to the active control (Fixed)? Secondly, we wanted to look at the variables on the electrophysiological level and see if we can observe the P300 ERP component in response to the detected targets presented in the AB time window (T2) and, if so, whether a post-training improvement in the AB task would be reflected on the neurophysiological level (i.e. difference between sessions and difference between groups in the mean amplitude of the P300 ERP).

We were also interested in the predictive power of our behavioural and psychophysiological variables. Would we be able to predict the performance of players in the game based on initial variability in cognitive indicators (i.e. the accuracy in the AB task in the pre-training examination)? Can we predict the performance of players in the game based on initial psychophysiological indicators (i.e. the magnitude of P300 component amplitude in the pre-training session)? And, what is most important, which of these predictors will be stronger in regards to training's effectiveness. We have also asked a question about in-game behaviour (which we treat as a proxy for the training's impact) as a predictor of a post training cognitive gain (measured as a difference between pre- and post-training performance in the AB task).

2. Methods

2.1. Participants

A total of 70 participants were initially recruited online via a covert questionnaire (Sobczyk et al., 2015). As a result of (1) resignation (n = 8), (2) wrong hardware configuration (n = 7), (3) failure to meet all training objectives (n = 4), (4) bad quality of data (n = 7) or (5) lost data (n = 1) only 43 of participants were included in analyses reported here. Participants were randomly assigned to two training groups: experimental - Variable (n = 21; 13 males; M_{age} = 24.71, SD = 3.15) and active control - Fixed (n = 22; 10 males; M_{age} = 25.13, SD = 2.96). The participants reported normal or corrected-to-normal visual acuity, normal color vision, and normal hearing. They were right-handed and reported not being on any medications, no history of neurological or psychiatric disorders and injuries, including no previous head trauma, no previous head or neck surgery and no brain tumors. All participants declared less than 5 h of video games played per week over the past six months and no experience with Real Time Strategy or First Person Shooter games. Informed consent was obtained from each participant before the start of the experimental procedure. Initially, we had 34 participants additionally assigned to a passive control (PC) group (n = 16, 8 males; M_{age} = 24.69, SD = 2.87) or additional active control (AAC) group (n = 18, 10 males, M_{age} = 25.11, SD = 3.88). As a result of (1) resignation (PC: n = 1; AAC: n = 4), (2) failure to meet all training objectives (AAC: n = 2) (3) bad quality of data (PC: n = 2; AAC: n = 2), and (4) lost data (PC: n = 4; AAC: n = 1) we excluded passive control and additional active control groups from analyses and focused on comparisons of our two RTS training groups [experimental (Variable) and active control (Fixed)]. Then it is important to mention that dropout is a common problem in longitudinal, training studies (e.g. Moore et al., 2017). Furthermore, our study employed restrictive recruitment criteria, which finally resulted in an inability to re-complete the control groups.

2.2. Procedure

Ethics Committee of the SWPS University of Social Sciences and Humanities approved the study design and the informed consent form. The research consisted of three steps: (1) Pre-training measurement of cognitive function via Attentional Blink task, (2) Training sessions, and

(3) Post-training measurement (Figure 1). Experimenters were present in all meetings. Measurement and training sessions took place in the laboratories of the SWPS University in Warsaw.

2.3. Experimental procedure

Prior to the beginning of the experiment, participants were verbally instructed as to what they would be experiencing and were shown what the procedure of EEG electrode mounting entails. Then, after signing a consent form, participants were brought into a laboratory setting and seated in front of a 24 inch BenQ XL2411Z computer monitor (1920 × 1080 resolution, 100Hz refresh rate) at a distance of 60 cm. Electrodes were then mounted and participants were briefly shown the EEG signal and explained how it is affected by eye blinks and muscular movements, which was a part of the procedure aimed at minimizing the amount of artifacts in the signal. The procedure was then started, and upon its completion subjects were provided with a place to wash their hair. The entire procedure lasted no more than 2 h and was identical during both measurements. All subjects, who fulfill training requirements and participated in both measurement sessions, were compensated for their participation with approx. 184 USD after post-training measurement.

2.4. Experimental task – attentional blink paradigm

The experimental task was based on the procedure outlined by Kranczioch et al. (2003). In each trial, a stream of either 16 or 19 letters (1.0–1.8 deg. x 1.3 deg.) appeared in a sequence on a white background. Participants were asked to detect two types of targets in the stream of letters: T1 and T2 (see Figure 1b). T1 appeared as a green capital letter that could be either a vowel (all except for I) or a consonant (all except for F, K, Q, X, Z). T2 was always a black capital letter X. The remaining non-targets were randomly chosen black consonants (except F, K, Q, X, Z), with the restriction that two adjacent letters in a stream could not be identical. In the case of 16 letter trials T1 would always appear as the fourth letter, and for 19 letter trials it would appear as the seventh. T2 could appear at a "lag" of one, two, or seven items after T1. At the end of each stream participants were asked to indicate: (1) if a vowel was present in the letter stream and (2) if the letter X appeared in the stream. Responses were given as "yes" or "no". Stream length, T1 type (vowel or consonant), and T2 lag were evenly split across 16 practice trials and four blocks of 64 trials, within randomization of trial order within each block. No T2 appeared in 25% of the trials. As the presented paradigm represents the most classic AB task model, it allows us to compare our findings with the results obtained by previous research.

2.5. Training

2.5.1. StarCraft II training

The StarCraft II (SC2) training consisted of 30 h of training time over a four-week period. Training consisted of playing matches (approx. 20 minutes each) against SC2's artificial intelligence (AI), and all matches were played at our laboratory. Participants were required to train a

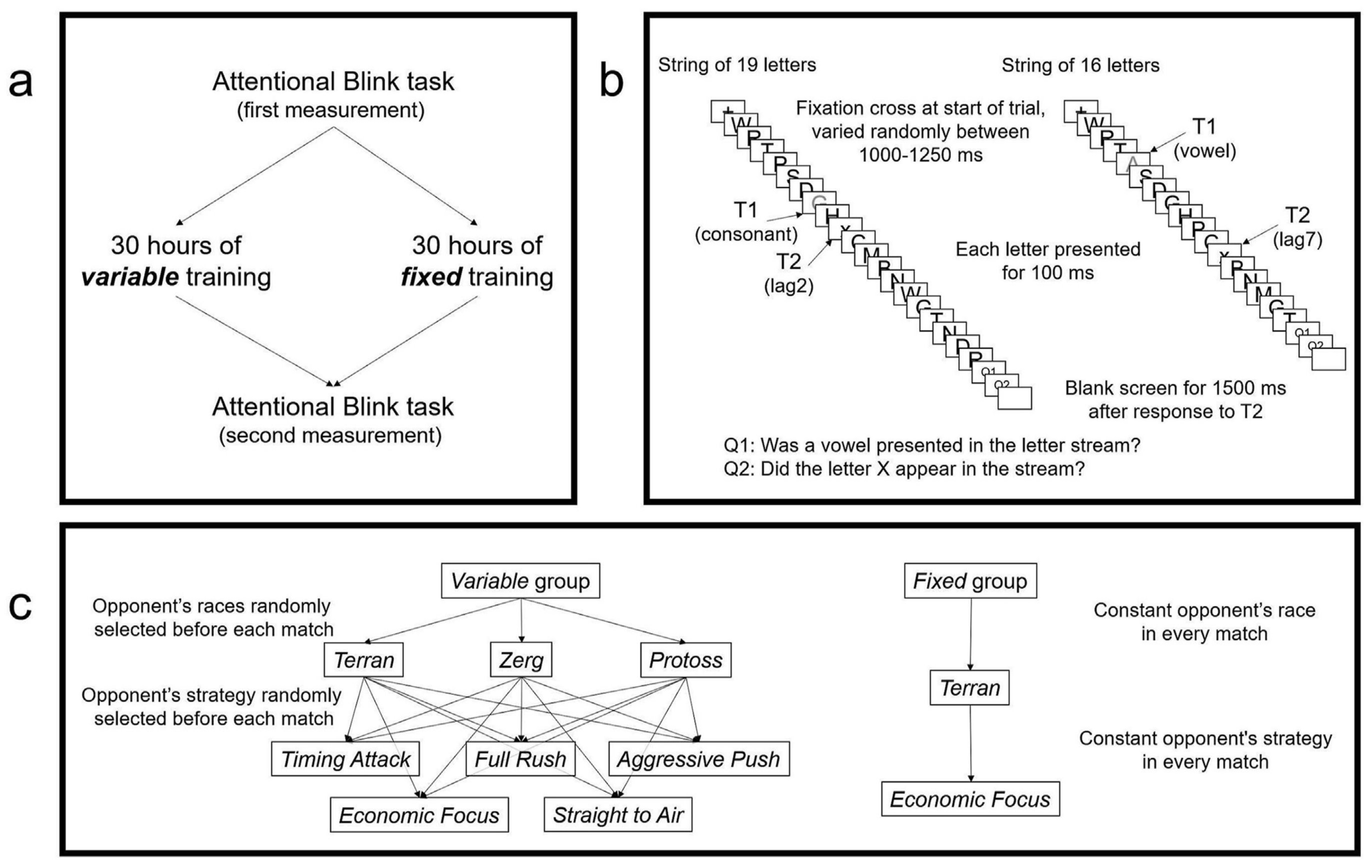

Figure 1. (a) Study design: two measurement sessions were carried out during the study (pre-training and post-training). Training included 30 h of playing in the real-time strategy game (*StarCraft II*), spread over 4 weeks. Training varied depending on the group. (b) Example of two trials of Attentional blink task. The first trial consists of 19 letters. T1 is presented as a green letter G, and the "X" (T2) appears in Lag 2. The second trial consists of 16 letters, where T1 is presented as a green A letter, and "X" (T2) appears in Lag 7. Each trial started with a fixation cross after which a string of (16 or 19) letters was presented. Each letter was presented for 100 ms and then participants were asked about the type of T1 and the presence of T2. Each trial ended with a blank screen presented for 1500 ms after response to the second question. (c) While all of the participants played as a Terran faction during training, the opponent's race and strategy varied according to the training group type. Participants from the Variable group could match three factions, from each could use one of five strategies. The faction and the strategy were randomly selected before each match for the Variable group. In the case of a Fixed group, participants always played against the Terran faction, which used an economic strategy.

minimum of 10 h per week, but no more than 5 h per day. This was done to avoid excessive skew in the distribution of training hours across the training period. There were also two possible training types: Fixed and Variable. The exact differences between the types of the training are described below and were presented in Figure 1.

Participants had to access an online platform before each match in order to receive configuration parameters; the parameters consisted of the difficulty setting, the opponent's faction, the opponent's strategy, and the game map. Participants from both groups played all of their matches as a Terran faction. While the map was randomly selected from 14 maps before each match in both - Fixed and Variable - training versions, the opponent's faction and strategy only varied in the Variable group. The Fixed group always faced the same faction (Terran), and their opponent always applied a more passive “Economic Focus” strategy. The Variable group could face any of the three factions (each with their own unique units and abilities) and also any of five opponent strategies: Full Rush, Timing Attack, Aggressive Push, Economic Focus, Straight to Air. Game difficulty was set adaptively for both training types spanning across seven levels. The online platform software recorded the number of wins (+1) and losses (-1) and each time the total passed the multiple of 4 threshold, the difficulty was increased by one. The difficulty decreased whenever the total dropped below the multiple of 4 threshold. The training was preceded by an introduction phase designed to familiarize participants with the core concepts of the game and basic gameplay mechanics (see next section).

2.5.2. StarCraft II introduction

The introductory phase consisted of eight parts: (1) a short text describing the goals of the meeting; (2) a text and video based description of the overall game; (3) a video introduction to the Terran faction, its units and buildings; (4) a text based description of the fundamental game concepts and in-game interface; (5) an AI guided tutorial that introduces the gameplay in real time, allowing participants experience the game for the first time; (6) a quiz requiring that the correct labels be attached to each of the five basic unit and building types that are available to the Terran faction, which was intended to check if participants were attentive to the training materials; (7) two films (25 min each) describing basic strategies and explaining the various stages that each match progresses through; and (8) a three-match series in which the game progressively increased its difficulty, speed and available units, with no specific guiding instructions. The entire introduction lasted approx. 2.5 h, and did not count into the required 30 h of training. It was also automated and self-paced, with experimenters only providing assistance when needed and also during part 8 of the introduction where assistance was provided to keep up the pace and direction of each training game. Upon completion of this introduction, participants were free to begin training on the following day.

2.6. Data reduction and analysis

All analyses were conducted using IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp., R Statistical Software (Foundation for Statistical Computing, Vienna, Austria) and MATLAB custom scripts.

2.6.1. Telemetric data

Independently of the group, training created in the study resulted in 8 levels of matches' difficulty: (1) Very Easy, (2) Easy, (3) Medium, (4) Hard, (5) Harder, (6) Very Hard, (7) Elite and (8) Cheater. The level of difficulty corresponded to the win ratio of previously played matches, which enabled steady progress in the game environment. Due to the fact that only four of participants could reach the top two levels, Elite and Cheater levels were excluded from further analyses. Maintain levels were later divided into three categories: the easiest levels (Very Easy level, Easy level), the middle levels (Medium level, Hard level) and the hardest levels (Harder level, Very Hard level). The game performance of two experimental groups was compared through a series of *t* tests.

2.6.2. Behavioural data

Accuracy rates for each lag were calculated. To reveal attentional blink effect, detection rates at specific lags were compared with *t* tests for dependent measures. To calculate Lag, Session and Group effects, $4 \times 2 \times 2$ ANOVA for repeated measures was created.

2.6.3. EEG data

A 64-channel SynAmps RT Neuroscan EEG amplifier and Brain-Products actiCap Ag/AG-Cl active electrode set were used to record brain activity during task performance. All channels were recorded at 1000 Hz sampling rate. Impedances were held below 5 kΩ. All data were pre-processed offline using MATLAB environment and EEGlab (Delorme and Makeig, 2004), and ERPlab (Lopez-Calderon and Luck, 2014) software packages. The signal was initially re-referenced to a common average and then down-sampled to 250 Hz, followed by a band-pass filter between 0.1 and 40 Hz. Data epochs between -0.2 and 0.996 s (with zero being the T2 presentation) were extracted, and all epochs with incorrect behavioral responses were rejected. The remaining epochs were manually filtered for eye-blinks/movements and excessive muscle activity, and then averaged.

The P300 component mean amplitudes were extracted from 375-625 ms time window after T2 presentation, which is a standard window for P300 from AB task (see literature: Barry et al., 2020; Dell'acqua et al., 2003; Kranczioch et al., 2003) and activity observed on the corresponding topographical maps of the scalp. It was analyzed with a 3 (Lag: lag 1 vs lag 2 vs lag 7) x 2 (Sessions: pre-training vs post-training) x 2 (Group: Fixed vs Variable) repeated-measures ANOVA, with Lag and Sessions as the within-subjects factor and Group as the between subjects factor.

2.6.4. Moderation analyses

Multiple moderation models were estimated through the PROCESS macro (Hayes, 2018) for SPSS Statistics. All of the used variables were standardized to avoid multicollinearity and to make interpretations more straightforward.

3. Results

3.1. Game performance

We started by calculating the average time spent in the game and the mean number of played matches. Although there were no significant difference between groups in time spent playing SC2 ($p = 0.816$), participants from Variable group were able to played more matches in that time period (Variable group: Mean = 100.19, SD = 23.997; Fixed group: Mean = 82.545, SD = 12.078); $t(29) = 3.024$, $p = .005$ (Figure 2c and Figure 2b). It is a result of the fact that participants from Variable group played more matches on Harder level (Variable group: Mean = 22.762, SD = 19.621; Fixed group: Mean = 8.545, SD = 16.387); $t(39) = 2.573$ $p = .014$ and on Very Hard level (Variable group: Mean = 11.143, SD = 13.016; Fixed group: Mean = 3.727, SD = 10.152); $t(37) = 2.077$, $p = .045$. On the other side, participants from Fixed group played more matches on Medium level [Variable group = 20.857, SD = 13.074; Fixed group = 29.773, SD = 17.498); $t(38) = -1.898$, $p = .065$] what is shown in Figure 2a.

3.2. Behavioral results

Previous investigations have shown that subjects often fail to report T2 when it is presented within 200–500 ms after T1, whereas when the interval is longer, both targets are usually reported correctly (Chun and Potter, 1995; Raymond et al., 1992; Ward et al., 1997). Importantly, when T1 and T2 are presented about 100 ms apart, subjects quite often

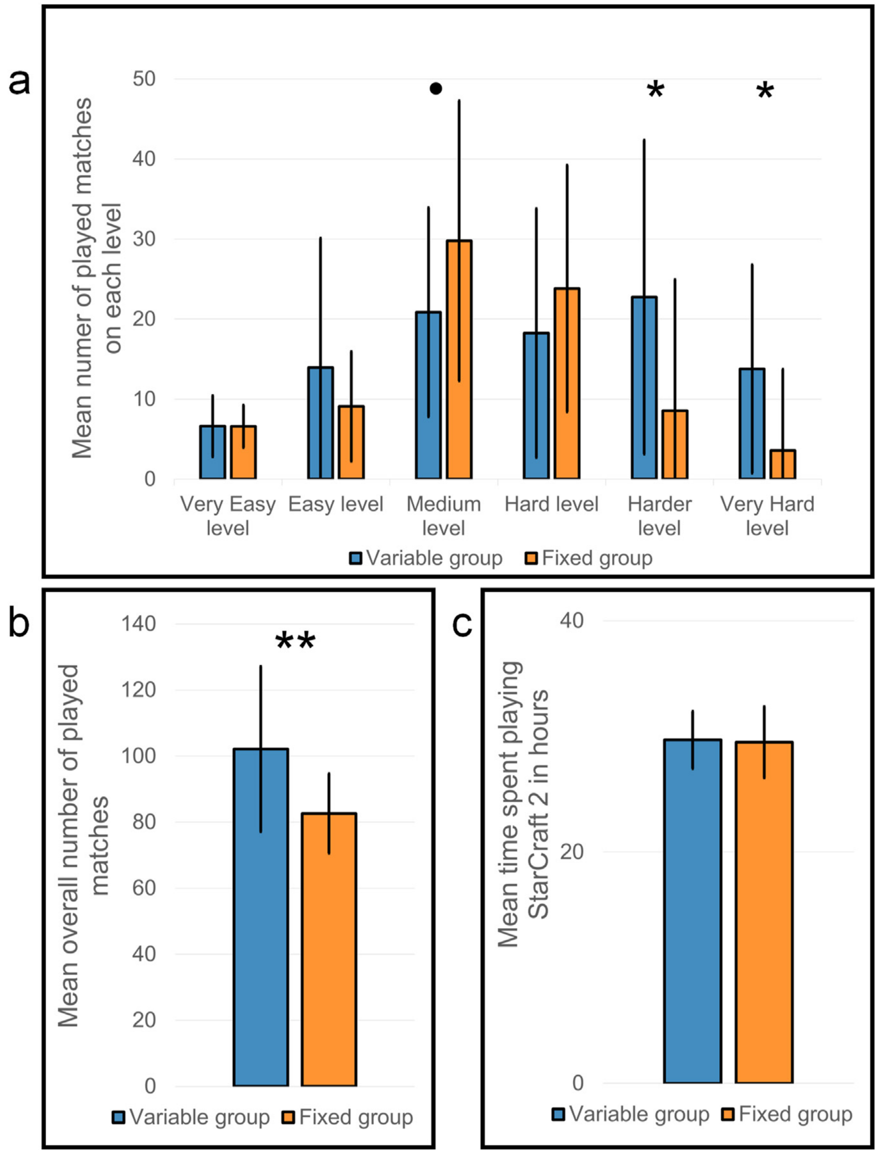

Figure 2. (a) Mean number of matches played on each level during training for Variable and Fixed groups. (b) Mean overall number of matches played during training for Variable and Fixed groups. (c) Mean overall time spent in training for Variable and Fixed groups. Asterisks indicate statistical significance: • p = .07, * p < .05, ** p < .01, *** p < .001.

report both targets. So, we started our analysis from checking whether these two basic trends occurred in our study (Figure 3).

An attentional blink effect was detected with mean T2 detection rates from both sessions at Lag 2 being lower than at Lag 1, $t(83) = -3.746$, $p < .001$, 95% CI of Lag 2/Lag 1 difference [24.198, -7.415], and at Lag 7, $t(83) = -5.955$, $p < .001$, 95% CI of Lag 2/Lag 7 difference [31.119, -15.438], which stands in agreement with the literature (e.g. Constable et al., 2018; Kranczioch et al., 2003). Due to the fact that attentional blink effect was confirmed, behavioral data were analyzed using a 4 (Lag: lag 1 vs lag 2 vs lag 7 vs No T2) x 2 (Sessions: pre-training vs post-training) x 2 (Group: Fixed vs Variable) repeated-measures ANOVA, with Lag and Session as the within-subjects factors, Group as the between subjects factor and accuracy as a dependent variable. It revealed main effects of Lag [$F(3,39) = 34.316$, $p < .001$, $\eta^2 = .474$] and Session [$F(1,41) = 11.217$, $p = .002$, $\eta^2 = .215$) as well as a Lag × Session interaction [$F(3, 39) = 5.744$, $p = .002$, $\eta^2 = .306$] what is depicted in Figure 3a. No interaction effect with the Group was found (Lag x Group: $F(3, 39) = 1, 027$, $p = .391$, $\eta^2 = .073$; Session x Group: $F(1, 41) = 1.583$, $p = .215$; $\eta^2 = .037$; Lag x Session x Group: $F(3, 39) = .652$, $p = .586$, $\eta^2 = .048$] and we observed a similar pattern of improvement after training in both groups (Figure 3). .

3.3. Psychophysiological results

As P300 component is associated with conscious processing of stimuli, previous investigations have shown not only that P300 component evokes as a result of item detection, but also may be significantly more positive in some Lag conditions in the AB task. We wanted to investigate if the positivity of P300 - as a reaction to the visual stimuli - will increase after complex cognitive training, which should affect a number of cognitive skills involved in stimulus detection. ANOVA analyses revealed that there were neither main effects of Lag [$F(2, 40) = .720$, $p = .488$, $\eta^2 = .003$, Session [$F(1, 41) = .906$, $p = .342$, $\eta^2 = .002$], interaction between them [$F(2, 40) = .574$, $p = .565$, $\eta^2 = .002$], Lag × Group-interaction [$F(2, 40) = .270$, $p = .764$, $\eta^2 = .001$] or Lag x Session × Group interaction [$F(2, 40) = .800$, $p = .45$, $\eta^2 = .003$]. Still, variable group increased their P300 amplitude power in the post-training measurement, while Fixed group's P300 decreased, which resulted in

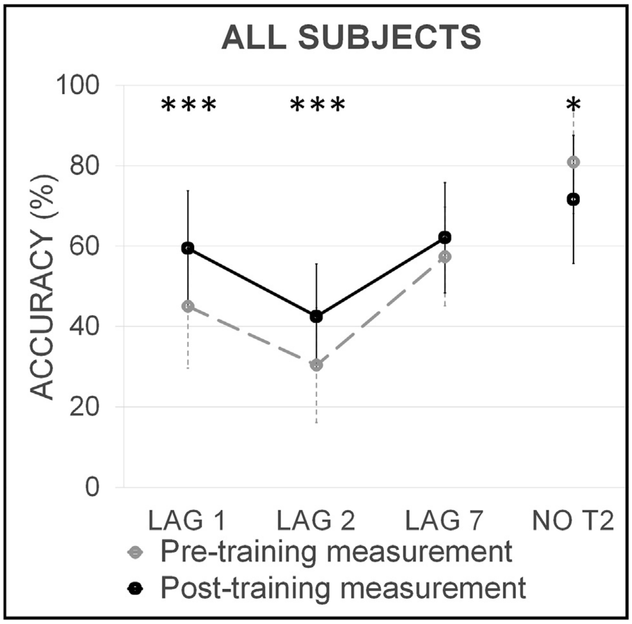

Figure 3. (a) Comparison of accuracy from attentional blink task between sessions at every Lag condition and in No T2 appearance condition for each training group. We observed very similar changes for lag conditions in both groups but all effects were stronger in a Variable group (b) than in Fixed group (c). Asterisks indicate statistical significance (• $p = .09$, * $p < .05$, ** $p < .01$, *** $p < .001$).

significant Session × Group interaction [F(2, 40) = 5.722, p = .018, η^2 = .012] and which is visible in Figure 4a and b.

3.4. Moderation analyses

3.4.1. The mean P300 amplitude from the pre-training measurement as a predictor of the number of matches played on the hardest levels

In order to better understand the observed differences in game performance between our training groups, we started looking for behavioral or neurophysiological predictors of game performance. In order to test the predictive value of the initial neurophysiological index of attention in each of our training groups we performed a series of analysis with indicators describing how well our participants dealt with the game's requirements serving as dependent variables. Separate moderation analyses were performed to clarify whether initial mean P300 amplitude predicted the number of matches played on each difficulty level and whether this relationship was moderated by the training type. As there were no differences between Lag conditions in the mean P300 component, we used mean P300 amplitude which were averaged across all lags.

We created a model containing mean amplitude of a P300 component from the pre-training measurement as a predictor, Group as a moderator variable and mean number of matches played on the hardest levels (Harder and Very hard combined) as a dependent variable (Figure 5a). Created model turned out to be significant [F(3, 39) = 4.617, p = .007, R^2 = .262] and contained significant influence of the Group [b = -.352, t(39) = -2.546, p = .015] and interaction between mean P300 component from pre-training measurement and Group [b = -.3704, t(39) = -2.508, p = .016]. Next, it was revealed that while for the Fixed group there was no relationship between initial P300 component amplitude and number of matches played on the hardest levels (p = .318), for the Variable environment group we saw a significant positive relationship: the stronger initial P300 amplitude the more matches one played on the hardest levels of the game (one unit increase in the average P300 component's amplitude from pre-training measurement resulted in an increase of .56 in a number in matches played on that levels [t(39) = 2.359, p = .023]).

Then two subsidiary models were created for both: Harder and Very Hard levels (Figure 5b). Both models turned to be significant [Harder level: F(3, 39) = 3.94, p = .015, R^2 = .232; Very Hard level:. F(3, 39) = 4.33, p = .01, R^2 = .25] and both presented same tendencies: (1) influence of the Group [Harder: b = -.354, t(39) = -2.512, p = .016; Very Hard: b = -.296, t(39) = -2.124, p = .04] (2) interaction between P300 component recorded during pre-training measurement and Group [Harder level: b = -.304 t(39) = -2.018, p = .05; Very Hard level: b = -.42, t(39) = -2.826, p = .007], (3) through for the Fixed group both relationship turned to be truly insignificant (Harder level: p = .599; Very Hard level: p = .118), there was positive relationship between P300 component and number of matches played on each level for the Variable group [Harder Level: b = .509, t(39) = 2.101, p = .042; Very Hard level: b = .559, t(39) = 2.331, p = .025].

Further analyses did not show a similar relationship for other levels, which were available in the game. All subsequent analyses, attempting to predict the number of matches played on a given level, turned out to be insignificant.

3.4.2. Number of matches played on the easiest levels as a predictor of attentional blink task's improvement

Due to the fact that the game environment was varied and cognitively challenging through the training, games on specific levels should differently influence cognitive abilities of the subjects. Although participants from both groups spent on average the same number of hours playing SC2, their post training performance varied significantly. In order to elucidate the variation seen in behavioural results, we decided to include indicators from the game (number of matches played on a given level) environment in our analysis. As easy levels were the least cognitively demanding, we assumed that time spent on the easiest levels may adversely affect potential progress in the task and time spent on the harder levels may promote it.

We created a model with the number of matches played on the easiest levels as a predictor, Group as a moderator variable and difference in AB's task accuracy before and after training as a dependent variable (Figure 6a). Created model turned out to be significant [F(3, 39) = 3.38, p = .028, R^2 = .206] and contained significant influence of the mean number of matches played on the easiest levels [b = -.4, t(39) = -2.09, p = .043] and interaction between number of matches played on the easiest levels and Group [b = -.549, t(39) = -2.87, p = .007]. Next, it was revealed that for the Variable environment group there were no relationship between predictor and training-related changes in the behavioral task (p = .34), but for the Fixed environment group we saw a negative relationship - the more matches played on the easiest level the weaker the improvement [b = -.93, t(39) = -2.717, p = .009].

Then again, two subsidiary models were created for both: Very Easy and Easy levels (Figure 6b). Both models turned to be significant [Very Easy level: F(3, 39) = 2.852, p = .049, R^2 = .179; Easy level: F(3, 39) = 2.885, p = .047, R^2 = .182] and both presented tendencies, which were revealed in the model described above: (1) there were interactions between number of matches played on each levels and Group [Very Easy level: b = -.387, t(39) = -2.498, p = .017; Easy level: b = -.535, t(39) = -2.62, p = .012], and (2) through for the Variable group both relationship turned out to be truly insignificant (Very Easy level: p = .402; Easy Level: p = .358), there was a negative relationship between number of matches played on each level and difference in the accuracy from behavioral task for the Fixed group [Very Easy Level: b = -.615, t(39) = -2.464, p = .018; Easy level: b = -.909, t(39) = -2.453, p = .019].

Further analyses did not show a similar relationship for other levels available in the game. All subsequent analyses, attempting to predict difference in task accuracy, turned out to be insignificant.

4. Discussion

The initial aim of this study was to test the possibility of improving attention with an RTS video game. Our data show that playing RTS video-

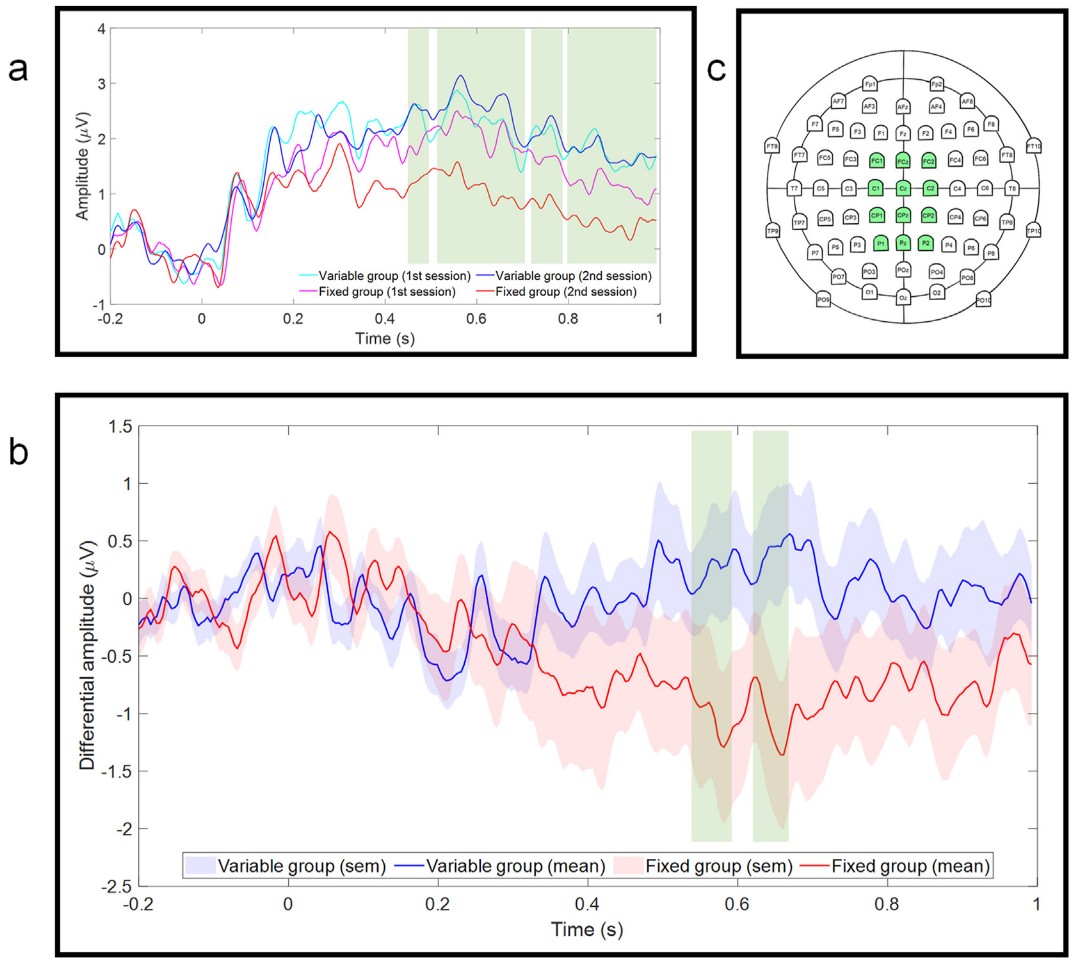

Figure 4. (a) Averaged brain activity recorded on the Cz electrode during attentional blink task, with 0 point being T2 presentation moment. Waves represent each group and measurement session separately, and waves were averaged over all lags. The green color specifies time when significant differences between Variable and Fixed groups were observed (in the 2nd session, so it was a difference between dark blue line and dark red which yield the significant effect). (b) Differential waves (2nd session minus 1st session) for each training group, with 0 point being T2 presentation moment. We can clearly observe opposite effects in amplitude change after training. (c) Localization of electrodes with indication from which electrodes we took signal for our analyses. Note that in graph 4a we are showing signals from a single electrode (Cz).

game can indeed enhance attentional skills, independently of the variant of game being trained. Our results, however, differ from the results obtained e.g. in studies comparing gamers and non-gamers, where expert gamers showed attenuated attentional blink relative to non-experts (see e.g. Wong and Chang, 2018). We did not observe change in the shape of attentional blink, we have rather seen an overall, non specific improvement in task performance. And, what is more important in the light of our hypotheses, this improvement was not dependent on the training type. We did, however, observe training specific effects on the physiological level, the P300 amplitude showed opposite changes in amplitude in fixed and variable training groups. What was even more interesting, the strength of the initial (pre-training) P300 component's mean amplitude appeared to be predictive of the in-game performance for the group playing a more demanding variant of the game (Variable group).

So we can ask: does a specific brain training protocol change every one's brain? Or does the training efficiency depend on an individual's brain? Our analysis indicates that the stronger the initial P300 amplitude the better was the progress of subjects in the game as measured by the number of matches played at most difficult levels. Importantly, this effect was visible only in participants subjected to a varied training regimen. As the P300 ERP component is usually related to such cognitive processes as focusing attention or conscious processing and acting (Bonala and Jansen, 2012; Verleger et al., 2016), its mean amplitude could correspond to participant's individual cognitive resource in that field. Since RTS games also place heavy emphasis on both - quick and well-suited - conscious reacting, it seems likely that this type of action video games is applicable for attention skills training. Then, our results imply that even players with existing predispositions can strengthen them by suitable stimulus (e.g proper training model) in order to develop and maximize their results. However, the pre-session behavioural accuracy, contrary to psychophysiological indicators, seems not to be predictive of player's game achievement. It might indicate that neurophysiological reactions are more sensitive and accurate in pinpointing individual differences in cognitive capacities and therefore be related to the broader spectrum of tasks (Ritter and Gaillard, 2000), than behavioural results.

Furthermore, the behaviour in the game environment appeared to be predictive of improvement in the AB task in the fixed game group. Specifically, participants who played more matches on the easiest levels of the game (which means they struggled to get higher and did not have a chance to practice more demanding actions) had worse improvement or even decrease of correctness in the AB task as measured by the difference between post- and pre-training sessions. A recent meta-analysis by Pallavicini et al. (2018) provides evidence that various video-games can have a different impact on many aspects of behaviour (see also: Oei and Patterson, 2015). Although we subjected both groups to the training of the same RTS video-game, the training modes were different (Variable

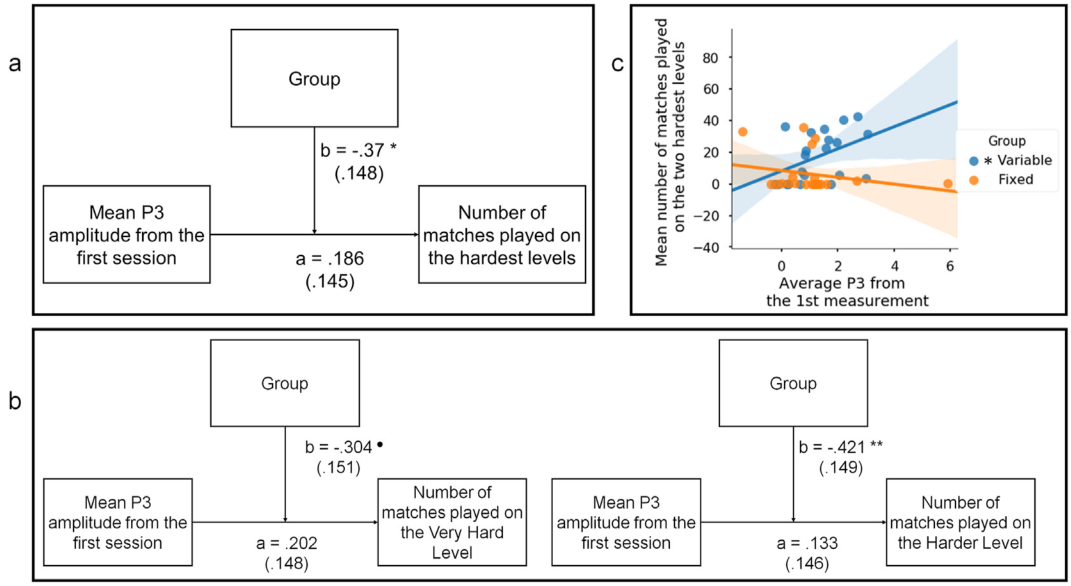

Figure 5. (a) The theoretical moderation model with the P300 component's mean amplitude obtained during pre-training measurement as a predictor, Group as a moderator variable, and the mean number of matches played on the two most difficult levels (which were included in the analyses) as an independent variable. (b) The theoretical moderation models corresponding to the specific levels, which were included in the model presented above. a and b are the path and interaction coefficients (unstandardized regression weights with standard errors in parentheses). Asterisks indicate significant regression paths (• $p < .07$, * $p < .05$, ** $p < .01$, *** $p < .001$). (c) Relationship between P300 component's mean amplitude recorded during pre-training measurement and the mean number of matches played on each of the two most difficult levels. * symbol placed on the legend, corresponds to a significant effect (Variable group: Pearson's coefficient = .445, $p = .043$; Fixed group: Pearson's coefficient = -.242, $p = .278$).

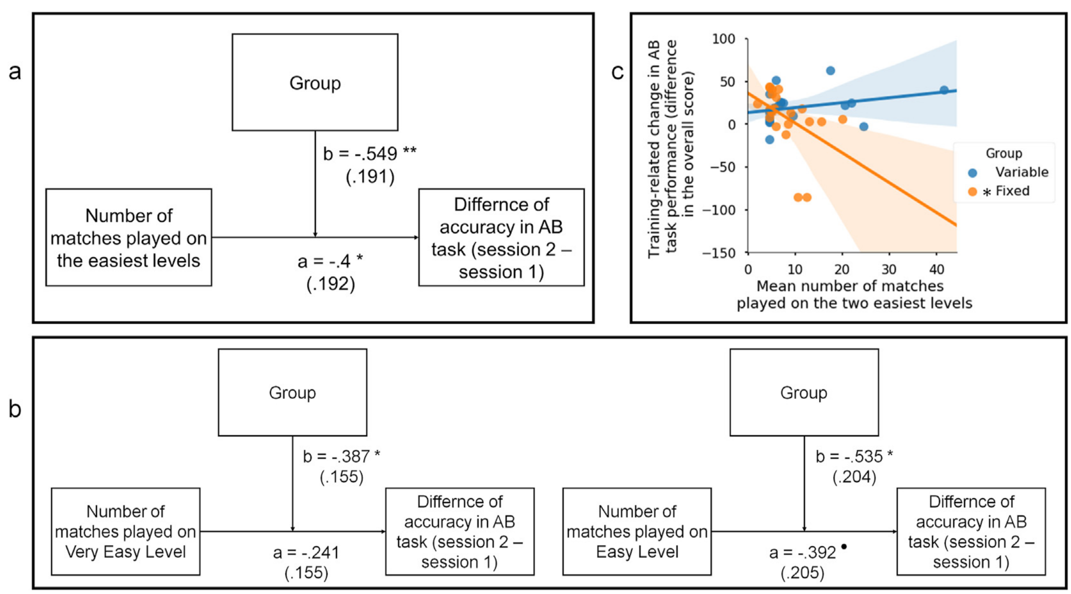

Figure 6. (a) The theoretical moderation model with the mean number of matches played on the two easiest levels as a predictor, Group as a moderation variable, and difference of accuracy in attentional blink task (session 2 accuracy rate – session 1 accuracy rate) as an independent variable. (b) The theoretical moderation models corresponding to the specific levels, which were included in the model presented above. a and b are the path and interaction coefficients (unstandardized regression weights with standard errors in parentheses). Asterisks indicate significant regression paths (• $p < .07$, * $p < .05$, ** $p < .01$, *** $p < .001$). (c) Relationship between the number of marches played on the two easiest levels and task accuracy difference. * symbols placed on the legends correspond to significant conditions. Two versions of correlations were conducted: with the outlier presented on the graph (Fixed group: Pearson's coefficient = -.445, $p = .038$; Variable group: Pearson's coefficient = .304, $p = .181$) and without the outlier (Fixed group: Pearson's coefficient = -.445, p = .038; Variable group: Pearson's coefficient = .174, p = .464).

versus Fixed game environment) depending on the group. While in the Variable group participants had to learn more factions, units and master more strategies to properly develop in the game environment, Fixed group training process was predetermined and not able to be changed, and was depending more on repetition than skills developing. Then, it is understandable that the strength of training's influence was different between the groups. It is also important to realize that the relationship between the player's cognitive abilities and his performance in the game is bilateral. Progress in the game environment should match the level of the player's cognitive abilities, and then if a participant was not able to achieve higher levels of difficulty in the game, he also shouldn't be able to improve his result in the behavioural task.

It is interesting finding that participants subjected to a Variable training model, compared to the Fixed group, played more matches on the most difficult levels. Due to the wide diversity of opponents and their strategies, participants had to develop various strategies and master the most of game rules, which made their task more demanding. This may be partly due to being capable of maintaining their interest and involvement in the training process, which results in maintaining higher motivation. As each opponent required a different approach to the game, it is also possible that a Fixed training scenario, which did not enforce a player's certain behaviours, did not create adequate opportunities for the development of certain skills.

Overall our results suggest that the influence of RTS video-games largely depends on the training model. While the aspects by which games could affect specific cognitive skills, or how long it takes to induce such effect, are widely discussed (e.g. Bediou et al., 2018), previous investigations in that field rarely pay attention to usually limited gameplay and different training modes. Moreover, both - the impact of the game and the game achievements - may depend on the player's individual predispositions.

Considering the fast-growing e-sport industry, the topic of individual predispositions to being a good gamer seems to be exceedingly actual. While in the classic sports methods of measuring player predisposition or development seem to be well validated, in the e-sport such tools and methods are still under-investigated. As game playing is based on a number of cognitive functions, it may be necessary to build a wide range of carefully selected behavioural tasks, and to find their neurophysiological indicators, which may be more sensitive for small changes resulting during training. Then, video games should not be considered solely in terms of their popularity, the possibility of their application as a cognitive training tool in neurorehabilitation, or in terms of how they affect us, but also in terms of player's predispositions to achieve higher scores and methods of inspecting the training process.

In addition, it's important to mention that recent studies are still arguing about the importance of consciously perceiving stimulus in the process of encoding into the working memory (Jones et al., 2020). Then, future investigations should include a wider range of carefully selected tasks and analyses beyond the Attentional Blink paradigm used here. To be able to confirm the importance of the P300 ERP component as a predictor of specific cognitive skills acquisition, study should also include a group of RTS game's experts, whose electrophysiological and behavioural results could be compared to non-player's. Lack of group training another type of video game might be seen as a limitation of this study. Similarly, the fact that we did not compare our results to the control group makes our conclusions limited to the specific type of people.

Declarations

Author contribution statement

Natalia Jakubowska: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Paweł Dobrowolski, Maciej Skorko: Conceived and designed the experiments; Performed the experiments.

Natalia Rutkowska: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Monika Myśliwiec, Jakub Michalak: Performed the experiments.

Aneta Brzezicka: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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