**Universidade de Aveiro** Departamento Educação e Psicologia
**2017**

**Joana da Silva Dias**

# Processamento Atencional Inconsciente e Adaptação ao Conflito em Jogadores de Videojogos

# Unconscious Attentional Processing and Adaptation to Conflict in Videogame Players

**Universidade de Aveiro** Departamento de Educação e Psicologia
**2017**

**Joana da Silva Dias**

# Processamento Atencional Inconsciente e Adaptação ao Conflito em Jogadores de Videojogos

# Unconscious Attentional Processing and Adaptation to Conflict in Videogame Players

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Psicologia da Saúde e Reabilitação Neuropsicológica, realizada sob a orientação científica da Professora Doutora Sandra Cristina de Oliveira Soares, Professora Auxiliar do Departamento de Educação e Psicologia da Universidade de Aveiro, e a coorientação do Professor Doutor Samuel de Sousa Silva, Investigador no Instituto de Engenharia Eletrónica e Telemática de Aveiro (IEETA) da Universidade de Aveiro.

Dedico este trabalho aos meus pais, Maria dos Anjos e Paulino, ao meu irmão, Rafael, e familiares mais próximos que me ajudaram a crescer e a lutar pelos meus objetivos. Sem vocês, eu nunca teria conseguido alcançar os meus sonhos.
Dedico também este trabalho a toda a comunidade gamer pois, se não fosse a minha paixão pelos videojogos, este trabalho poderia nunca ter existido.

"A famous explorer once said, that the extraordinary is in what we do, not who we are. I'd finally set out to make my mark; to find adventure. But instead adventure found me. In our darkest moments, when life flashes before us, we find something; Something that keeps us going. Something that pushes us."
*Lara Croft in TombRaider (2015).*

**o júri**

presidente

Professora Doutora Anabela Maria Sousa Pereira
Professora Associada com Agregação do Departamento de Educação e Psicologia da Universidade de Aveiro

Professor Doutor Daniel Ruivo Marques
Investigador no Instituto de Imagem Biomédica e Ciências da Vida (IBILI) da Faculdade de Medicina da Universidade de Coimbra

Professora Doutora Sandra Cristina de Oliveira Soares
Professora Auxiliar do Departamento de Educação e Psicologia da Universidade de Aveiro

**agradecimentos**

Gostaria de agradecer a todas as pessoas que me apoiaram e me incentivaram a prosseguir o meu sonho, mesmo quando a dúvida e a incerteza estiveram presentes.

Em primeiro lugar, um especial agradecimento à Doutora Sandra Soares por me ter permitido estudar um tema que me era querido e que não fazia parte da sua zona de conforto. Obrigada pela sua orientação, disponibilidade, compreensão e palavras de conforto e incentivo, mesmo nos momentos em que tudo parecia estar a correr mal. Ao Doutor Samuel, por ter trabalhado incansavelmente para realizar a parte experimental da tarefa aqui apresentada, ainda quando surgiam diversos obstáculos à sua execução, e pela sua coorientação ao meu trabalho. Ao Fábio, meu colega de tese, por ter contribuído para a realização da mesma e por me ter ajudado sempre que precisei de orientações.

A todos os colegas que encontrei ao longo da minha vida e, em especial, nestes 5 anos de trabalho árduo pela área que sempre me preencheu o coração, um obrigada sincero por terem feito esta experiência única
Em especial, às minha colegas de curso e amigas do coração, Ana Cláudia e Ana Filipa, por terem sido o meu pilar nestes últimos 5 anos e que espero que o sejam para a vida. Muito obrigada pelas partilhas durante toda esta fase da nossa vida: desde as horas a falar sobre estatística a horas de palavras de carinho e incentivo e a horas a falar sobre séries e filmes. Conheço-vos como a palma da minha mãe e agradeço que me tenham deixado entrar dessa forma nas vossas vidas. À Bruna, por ter sido uma grande companheira de curso e amiga, apesar do último ano de curso nos ter separado em termos geográficos. À Maria João, que, apesar de alguns momentos menos felizes, vai ser sempre uma pessoa importante. À Camila, por simplesmente me aturar sempre com um sorriso nos lábios. Por último, à Margarida, amiga de secundário, por me ter apoiado sempre e por ser das amigas que mais estimo.

A toda à minha família, mas, em especial: aos meus pais, Maria dos Anjos e Paulino, por me terem dado a possibilidade desta experiência única, por me incentivarem a alcançar os meus objetivos de vida e pelo amor e compreensão; ao meu irmão, Rafael, por, sem saber, alegrar-me e pelas suas curiosidades pela minha futura profissão; aos meus avós, Maria Virginia, Altino e Maria Augusta, pelas palavras sábias e de orgulho pela pessoa que me tornei; por último, à minha tia/madrinha, por ser a minha segunda mãe e por me tratar como uma filha.

Ao João, companheiro de todas as horas, por todo o carinho, suporte e paciência, especialmente nos momentos de dúvida. Graças a ti ganhei mais confiança em mim e aprendi a encarar a vida com outros olhos.

À minha professora de psicologia de secundário, Teresa Amaral, por me ter incentivado a prosseguir a minha paixão por psicologia, quando a maioria achava que essa era uma má opção para arranjar emprego no futuro.

Por último, um obrigada a todos os participantes e à AlienTech, por ter oferecido equipamento gaming, utilizado no sorteio.

**palavras-chave**

controlo executivo, adaptação ao conflito, processamento insconsciente, videojogos, CFF, tarefa de flankers.

**resumo**

A rede de controlo executivo é crucial para detetar e lidar com a interferência ou conflito resultante da competição entre diferentes estímulos, mesmo a um nível inconsciente. Para testar esta rede, pode ser usada a *Eriksen Flanker Task*, onde é apresentado um alvo com *flankers,* que podem ser congruentes ou incongruentes com o alvo. Esta tarefa também nos dá efeitos de compatibilidade que mostram a adaptação ao conflito. Recentemente, a pesquisa sobre os efeitos dos videojogos tem crescido, sugerindo melhorias nas habilidades de atenção em jogadores de videojogos (VGPs) em comparação com não jogadores de videojogos (NVGPs). No entanto, nenhum dos estudos analisou a rede de controlo executivo a um nível inconsciente. A tarefa *Chromatic Flicker Fusion* (CFF) é uma técnica recente que parece permitir interferência e adaptação ao conflito em condições inconscientes. O presente estudo utilizou uma Tarefa de *Eriksen Flanker Task* e CFF para comparar 31 VGPs e 29 NVGPs nos tempos de reação (RTs) e taxa de precisão. Os VGPs foram mais rápidos e mais precisos do que os NVGPs. Os resultados também sugerem que ambos os grupos têm um padrão igual em condições mascaradas (CFF) e visíveis. A condição mascarada não produziu a mesma interferência da condição visível, contrariamente às nossas previsões. Ambos os grupos apresentaram adaptação ao conflito, apresentando RTs mais baixas e maiores taxas de precisão quando os blocos apresentavam alta frequência de conflito. Os resultados sugerem que as habilidades melhoradas nos VGP ao nível do controlo executivo não se restringem ao processamento consciente.

**keywords**

executive control network, adaptation to conflict, unconscious processing, videogames, CFF, flanker task.

**abstract**

The executive control network is crucial to detect and deal with the interference or conflict that results from the competition between different stimuli, even at an unconscious level. To test this network, an Eriksen Flanker Task can be used, where a target and flankers, that can either be congruent or incongruent with the target, are presented. This task also gives us compatibility effects that show us adaptation to conflict. In recent years, research on the effects of videogames has been growing, suggesting improvements in attentional skills in videogame players (VGPs) compared to non-videogame players (NVGPs). However, none of the studies analysed the executive control network at an unconscious level. Chromatic Flicker Fusion (CFF) is a recent technique that seems to allow interference and conflict adaptation in unaware conditions. The present study used an Eriksen Flanker Task and CFF technique to compare 31 VGPs and 29 NVGPs in reaction times (RTs) and accuracy rates. VGPs were faster and more accurate overall than NVGPs. The results also suggest that both groups have an equal pattern in masked (stimuli with CFF) and visible conditions. The masked condition did not produce the same interference as the visible condition, contrary to our predictions. Both groups showed adaptation to conflict, presenting lower RTs and higher accuracy rates when the blocks had high frequency of conflict. Results suggest that VGPs' improved skills in executive control are not restricted to conscious processing.

**Index**

## List of figures



## List of tables

## 1. Introduction

Given the myriad of information that constantly impinge our vision, our ability to select goal-relevant stimuli and filter out the distractor information (i.e., endogenous attention), is crucial for an adaptive executive control system (Pashler, Johnston, & Ruthruff, 2001; Posner & Petersen, 1990). Given the limited capacity of our attentional system, executive control plays a crucial role in detecting and dealing with the interference or conflict that results from the competition between the enormous sources of stimulation (Posner, & Rothbart, 2007; Posner, Snyder, & Davidson, 1980). This function is critical for dynamic adjustments between cognition (such as attention) and behaviour in response to our environment demands (Fan, McCandliss, Sommer, Raz, & Posner, 2002).

The executive control network is usually studied by tasks, such as the Eriksen Flanker (Eriksen & Eriksen, 1974), Stroop (Stroop, 1935), dual (Pashler, 1994), and priming tasks (Lombardi, Higgins, & Bargh, 1987), in which participants are asked to respond to a particular feature of a target (or task-relevant) stimulus, while distractor (or task-irrelevant) stimuli are presented and the congruency between target and distractors is varied. For instance, in one of the most commonly used task, the Eriksen Flanker task (Eriksen & Eriksen, 1974), participants are presented with a target and flankers (i.e., distractors) that can either be congruent, e.g., arrows pointing in the same direction of that of a target arrow, or incongruent with the target, e.g., arrows pointing in the opposite direction of a target arrow. When the target is presented alongside with congruent stimuli, response times tend to be faster and more accurate than when these are incongruent (Hasegawa & Takahashi, 2014; Larson, Kaufman, & Perlstein, 2009). The overall attention given to distractor stimuli is demonstrated by the index of compatibility effect or congruency effect, which is calculated by subtracting the performance obtained in incongruent trials from that obtained in congruent trials (Verguts & Notebaert, 2009).

Importantly, the executive control of attention plays a critical role in modulating the way the distractor stimuli are attended, by either dampening or promoting their priority in visual processing, mostly as a function of previous experience regarding the distractors' congruency (i.e., congruent vs incongruent distractors) (Botvinick, Braver, Barch, Carter & Cohen, 2001). This effect, which mirrors the flexibility of executive control (Ravizza, & Carter, 2008), is known as *conflict adaptation* or *Gratton effect* (Gratton, Coles, & Donchin, 1992), and acts to allow adjustments in behaviour in order to maintain goal-directed performance and, ultimately, to promote predictability over the environment (Bombeke, Langford, Notebaert, & Boehler, 2017). Conflict adaptation is reflected in subtle adjustments in the way distractors in a current trial are processed (by either promoting or inhibiting them) according to their previously perceived task-related value. In other words, an incongruent trial will lead to a desensitization of the distractors presented in the following trial, and a congruent trial will result in an enhancement of the distractors shown in the following trial (for a review, see Duthoo, Abrahamse, Braem, Boehler, & Notebaert, 2014; Gratton et al., 1992). Importantly, visual attention selectivity seems to be modulated by the frequency of conflict associated with a given presentation, such that tasks with an overall higher level of incongruency will lead to lower compatibility effects (i.e., attendance given to the distractors), as opposed to a high congruency task, where most of the trials give a positive association between target and distractors, hence increasing their attendance (Kuratomi & Yoshizaki, 2013; Mayr & Awh, 2009). Conflict adaptation can be calculated, for instance, via the compatibility effect index derived from compatibility ratios in a block-wise adaptation task, since this index is a measure of conflict solving or, in other words, adaptation to conflict (Verguts & Notebaert, 2009). The compatibility effect index observed when congruent trials appear as frequently as incongruent ones in a trial block (i.e., balanced frequency of conflict) is greater than that when congruent trials appear infrequently (i.e., high frequency of conflict), presenting a block-wise conflict adaptation effect (Hasegawa & Takahashi, 2014; Snodgrass & Shevrin, 2006). Thus, conflict adaptation can be seen as the behavioral effects of previously confronted conflict by a reaction to the proportion of valuable information presented in the current task (block-wise; Mansouri et al., 2009).

Expertise in action videogame playing has been consistently associated with improvements in attentional skills. Action videogame players play for many hours and over long periods of time, with this training modulating the way objects are selected from the environment (Chisholm, Hickey, Theeuwes & Kingstone, 2010). Moreover, in action videogames there is often a great penalty for either failing to process a target or allowing irrelevant information to interfere with the processing of the potential target, which make these players good candidates for developing a highly efficient executive control of attention (e.g., Green & Bavelier, 2006). In fact, in the last decades, playing video games has become a very popular activity. Accordingly, the interest in studying the impact of expertise in playing videogame on cognitive abilities, such as on attentional effects, has been exponential (e.g., Karle, Watter, & Shedden, 2010). Overall, the results of these studies suggest that expert action video game players (VGPs) are better in a variety of attention tasks, compared to non-video game players (NVGPs), namely by showing: lower reaction times (Castel, Pratt & Drummond, 2005; Dye, Green & Bavelier, 2009a), enhanced spatial and temporal abilities (Green &

Bavelier, 2003; Green & Bavelier, 2006; Green & Bavelier, 2007; West, Stevens, Pun & Pratt, 2008), greater attentional resources (Green & Bavelier, 2003; Dye, Green, & Bavelier, 2009a), enhanced change detection (Clark, Fleck, & Mitroff, 2011), improved target detection (Feng, Spence & Pratt, 2007; Green & Bavelier, 2006), faster recovery from attentional capture (Chisholm et al., 2010), faster switch between tasks (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Karle et al., 2010) and, most importantly to the current study, better suppression of irrelevant, potentially distracting information (Chisholm et al., 2010; Hubert-Wallander Green, Sugarman, & Bavelier, 2011; Mishra, Zinni, Bavelier, & Hillyard, 2011). However, none of these studies have investigated conflict adaptation in VGPs, which is likely to be enhanced given their expertise in successfully adapting to opposing patterns of response (for a review, see Dye, Green, & Bavelier, 2009b).

Although much research has argued against unconscious processing of executive control (for a review, see Desender, & Van den Bussche, 2012), a large bulk of studies have accumulated evidence that this network may indeed be elicited by unconscious visual stimuli, i.e., may not require intention or voluntary control processing (for a review, see Kiefer, 2012). Consistent with this, some recent studies have demonstrated that processes associated with goal pursuit (i.e., striving for a desired outcome, such as those involved in videogame playing) can be activated and altered without awareness (e.g., Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001; Marien, Custers, Hassin, & Aarts, 2012; Van Gaal, Lamme, & Ridderinkhof, 2010). For instance, cues that are processed without awareness seem to increase the neural activity associated to executive control networks, suggesting that higher cognitive functions are not exclusively processed in aware conditions (e.g., De Pisapia, Turatto, Lin, Jovicich, & Caramazza, 2012). However, despite the continued growth regarding the implications of action videogames experience in attention skills, a further topic that remains unexplored is whether the overall outperformance of VGPs is also observed when the target stimuli are presented under unaware conditions.

In the present study, we will rely on the Chromatic Flicker Fusion (CFF) technique (Hoshiyama, Kakigi, Takeshima, Miki, & Watanabe, 2006) to render the distractor stimuli invisible. This technique seems to engage frontal and temporal regions (e.g., Fogelson, Kohler, Miller, Granger, & Tse, 2014), hence recruiting the brain networks involved in the executive control of attention (Badre & Wagner, 2004; Egner & Hirsch, 2005; Nelson, Reuter-Lorenz, Sylvester, Jonides, & Smith, 2003). Using an Eriksen Flanker task, VGPs will be compared to NVGPs in blocks of presentations either involving suppressed (i.e., invisible) or visible flankers (arrows) that can be either congruent (i.e., point in the same direction) or incongruent (i.e., point in the opposite direction) with the target stimulus. Moreover, conflict adaptation will be manipulated by varying the frequency of conflict in a given block (50%/50% or 80%/20%, respectively for balanced frequency of conflict and high frequency of conflict). Consistent with previous studies, we expect a) an overall facilitated effect for congruent, compared to incongruent trials, reflected in faster response times and higher accuracy to the target in both masked and visible blocks; b) an enhancement of the compatibility effect for presentation blocks with balanced frequency of conflict, compared to the ones with high frequency of conflict (i.e., lower and higher ratio of incongruent trials, respectively), associated with adaptation to conflict; and c) facilitation effects of congruency, as well as conflict adaptation effects, to be more pronounced in VGPs, compared to NVGPs.

## 2. Material and methods

### 2.1. Participants

Sixty-six university students, with ages ranging between 18 and 27 years old, were recruited to take part in the study. However, the data from six participants were excluded due to improper initial calibration of the luminance levels, resulting in an insufficient suppression by the Chromatic Flicker Fusion (CFF) technique, or technical software problems. Hence, our final sample included 60 participants (42 males and 18 females), with ages ranging between 18 and 27 years (M = 21.88; SD = 2.38). Thirty-one of these participants were videogame players (VGPs; 27 males and 4 females) and 29 non-videogame players (NVGPs; 15 males and 14 females).

The selection of the participants to each of these groups was based on the responses to an online questionnaire (see Appendix A), in which they were asked to define the frequency of action video game usage in the prior 12 months. Besides the frequency of playing, participants were also asked to name all video games they have played in the last 12 months. Moreover, they reported the videogames they had been playing for the last month, as well as the frequency each one they had played in such period (Dye et al., 2009a). The criterion to be considered a VGP was a minimum of 5 h per week (on average) of action videogame play in the previous year (Bavelier, Achtman, Mani, & Föcker, 2012). Note that only action video games, which have “fast motion, require vigilant monitoring of the visual periphery, and often require the simultaneous tracking of multiple targets” (Green & Bavelier, 2006, p. 3), were considered for the selection. Hence, other types of games reported by the participants, such as board, puzzle, card, strategy or social games, were not regarded. The most reported games by the VGP group were *Counter Strike: Global Offensive* and *League of Legends* (see Appendix B for a list of the action video games reported by the participants in the prior month of the experiment). The recruited VGPs played an average of 15,8 hours per week of action video games. The criterion to be considered a NVGP was one or less hours per week of action video game play over the previous year. Participants that did not qualify to either of these two groups were not included in the study. Participants who were eligible to take part in the experiment were then selected to one of the two groups, i.e., videogame players (VGPs) or non-videogame players (NVGPs).

All participants had normal or corrected-to-normal vision (this included not having color blindness) and had no physical or psychological problems.

### 2.2. Apparatus and stimuli

Chromatic Flicker Fusion (CFF) (Hoshiyama et al., 2006), was used in order to suppress the flanker stimuli, hence allowing for the assessment of interference and conflict adaptation in unaware conditions. This technique consists of alternating a low contrast red and green arrows (opponent colors), through the coloring of initially black and white arrows (Moutoussis & Zeki, 2002). The background, where the stimuli appeared, was an alternating red and green checkerboard pattern with a black mesh, enabling an easier flicker fusion (Hoshiyama et al., 2006). The red/green alternated with each other in a sequence animated at 30Hz, above the chromatic fusion threshold, which is between 15Hz and 20Hz. This caused the flankers to fuse with the background, creating a yellowish solid background (Fogelson et al., 2014; Zou, He, & Zhang, 2016) (for an example of the technique, see Figure 1). The target arrow was presented in every trial, regardless of the condition or block, and was not affected by the CFF. A blue fixation cross was located at the center of the screen to guide the participant's focus of attention to this area, where the target arrow appeared in every trial.

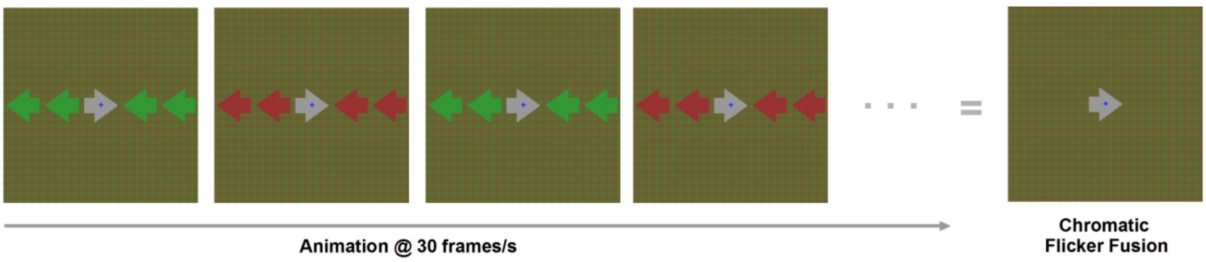


*Figure 1*. Example of the CFF technique.

The experimental task was performed in a 21-in LCD monitor (Dell brand), with a 1920x1080 display resolution and a 60Hz frame rate. The screen's brightness and contrast was kept at 50% throughout the study and the lab's environment light conditions were the same for all participants. Each trial was introduced by the sound of a beep, played through headphones (Sony MDR-XD150). The viewing distance of the frame presented in each trial was 16º and the arrows with the flankers of 2.8º wide. Participants were sat at a distance of 50cm from the screen.

Each trial started with a beep sound immediately followed by a fixation cross, presented for 200ms, followed by a ramping up of 300ms to 1200ms of stable stimuli presentation (see Figure 2). After the 1200ms, a new trial was presented.

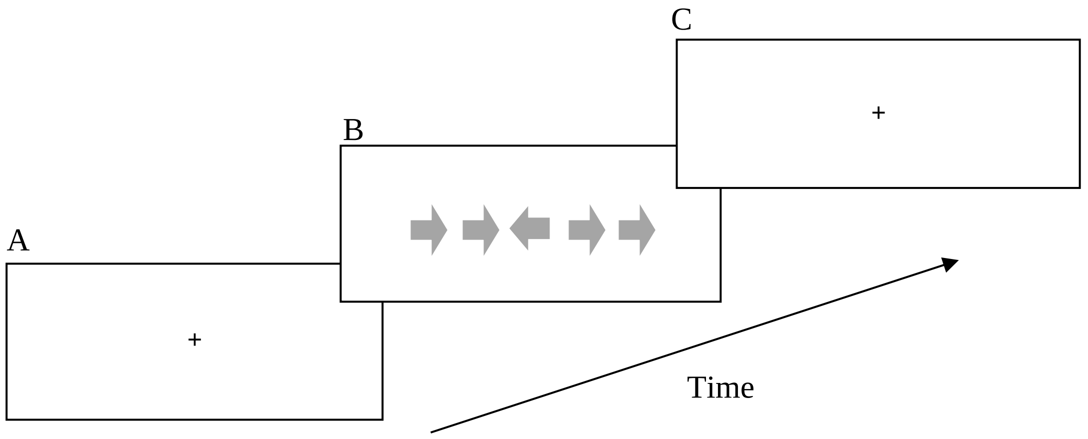


*Figure 2*. Example of a trial. A – fixation cross presented for 200ms; B – beep sound and 300ms to 1200 of stimuli presentation in which participants should give an answer; C – next 200ms of fixation time, followed by the beginning of a new trial.

**2.3. Procedure**

While arriving at the laboratory, participants were first asked to respond to a questionnaire regarding sociodemographic information. They also filled the state form (Y-1) of the Portuguese version (Silva, 2006) of the State-Trait Spielberg Anxiety Inventory (STAI; Silva & Spielberger, 2007), to evaluate their level of anxiety before the experiment. This reasoning behind this measure was to control for possible impairments in intention-based attentional allocation, which could have led to a greater distractibility during the selection of attentional information (Sänger, Bechtold, Schoofs, Blaszkewicz, & Wascher, 2014). The responses were given on a Likert scale, ranging from 1 (nothing) to 4 (very), with the scoring of the questionnaire ranging between 20 and 80 points, with higher scores indicating higher levels of state anxiety. Since the total mean score of our participants before the experimental task was 31.15 (SD = 7.759), which is within the expected average for the Portuguese population (Silva, 2006), and because this factor was not of theoretical interest in our study, no additional analyses considering this variable were performed.

Given the possible existence of slight variations in the calibration of the display and individual differences in the participants' color perception, a calibration task was run before the experimental task, in order to ensure the best possible masking of the flankers. We used stimuli that were structurally similar to the stimuli used in the experimental task, but replaced the arrows with plain squares to avoid revealing the content of the stimuli that would be masked. This calibration task, heterochromatic flicker photometry (Lee, Martin, & Valberg, 1988), allows participants to change the luminance of one of the colors (green in our case), during the color flickering. Participants were instructed to change their luminance color by pressing the up or down keyboard arrows, experiencing the different levels of perceptual luminance attainable, so that they can then adjust and choose the most suitable level for them. After experiencing all the different flicker frequencies, participants were then asked to choose the one in which the colors seemed to fuse and the flickering was most close to reduction as possible. When they encountered this point, they were instructed to press the enter key, thus defining their ideal luminance level, which would be used throughout the main task. This prior procedure was essential for preventing the awareness of stimuli suppressed by the CFF, since it reduced the flickering sensation evoked by the technique and allowed a more solid impression of a fused color between the stimuli and the background (Jiang, Zhou, & He, 2007; Lee, at al., 1988). Following the calibration procedure, participants underwent a 20-trial practice phase, allowing them to get accustomed to the task. During the practice, only the target arrow was shown, i.e., no flankers were presented. Moreover, none of the targets during the practice were presented in unaware conditions (i.e., the CFF was not employed). Further clarifications on the task instructions were provided, if needed.

In the experimental task, the stimuli were presented in three conditions: masked, visible and in a control condition (with only the target arrow, absent of flankers and in aware conditions, i.e., without the use of the CFF technique). The masked condition consisted of the presentation of flanker arrows around the center target arrow, suppressed by the CFF technique (i.e., unnoticeable to the human eye; Hoshiyama et al., 2006). In the visible condition, stimuli were not presented under the CFF technique, hence being presented in aware conditions, i.e. the target arrow was surrounded by the visible flanker arrows. In the control condition, there was only the target arrow, without any flankers surrounding it.

Specifically, the task included five different blocks (see Figure 3, that illustrates the different conditions). In the first block (A), both target arrows and masked flanker arrows were presented. The direction of the masked flanker arrows (the same for all four arrows) was either the same as the direction of the target arrow (congruent condition) or the opposite (incongruent condition). In this block, there was a balanced frequency of conflict, i.e., the proportion of congruent and incongruent trials was 50%/50% (50 congruent and 50 incongruent trials). In the next presented block (B) target arrows and masked flanker arrows were also shown but with a high frequency of conflict, i.e., in a proportion of 20%/80% congruent and incongruent flankers, respectively (i.e., 20 congruent trials and 80 incongruent trials). In the next block (C), the target arrow was presented alone, with no flankers (control condition). The subsequently presented block (D) included a target arrow and visible flanker arrows with a balanced frequency of conflict (50 congruent and 50 incongruent trials); this block was similar to block A, only differing in the visibility of the flankers (visible, in this case). Finally, we also included a block (E) in which was presented a target arrow and visible flanker arrows with a high frequency of conflict (20 congruent and 80 incongruent trials); this block was similar to block B, again only differing in the visibility of the flankers. Since each block included a total of 100 trials, participants were presented with a total of 500 trials in the main experimental task.

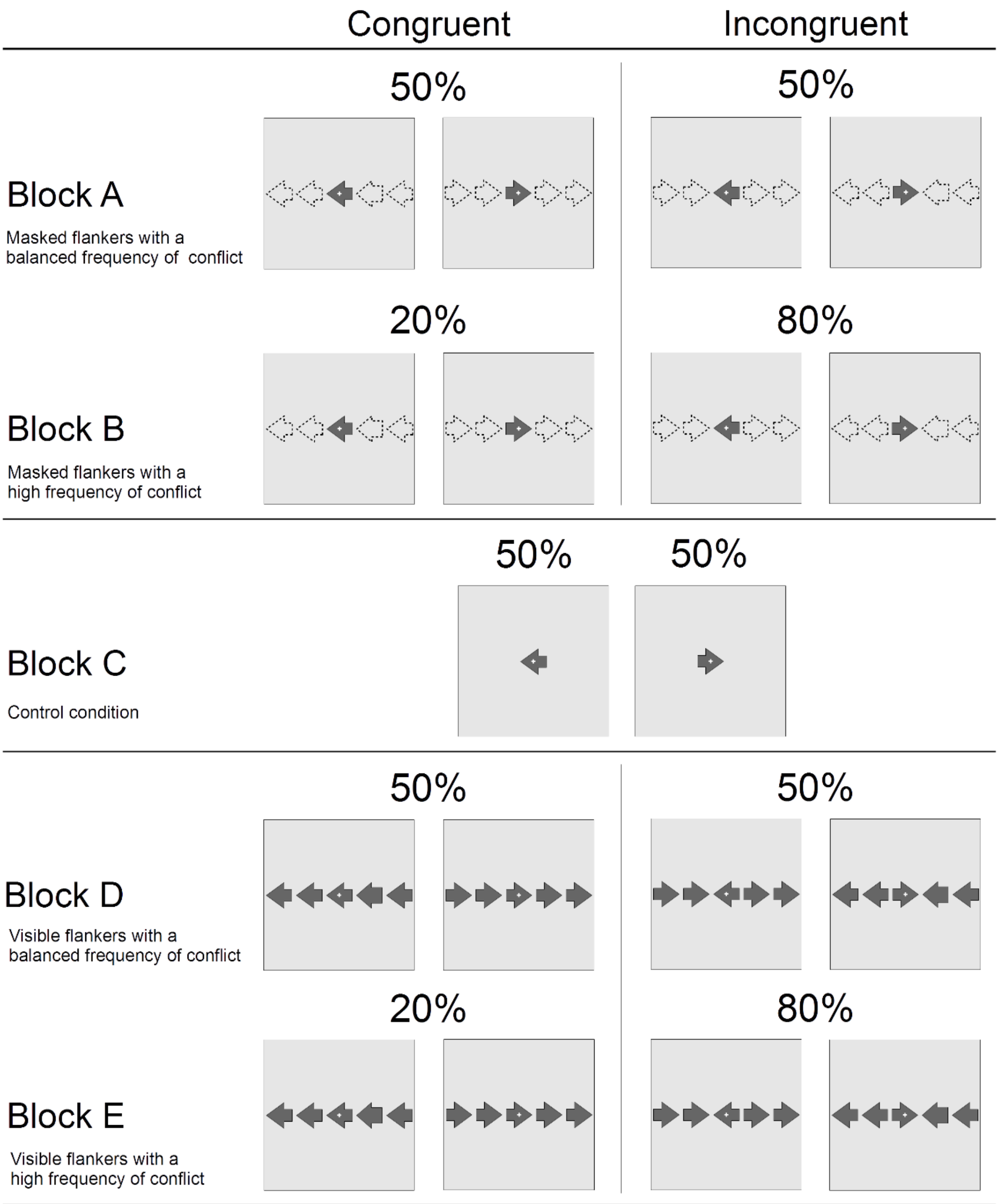


*Figure 3*. Distribution of the different conditions (congruency, visibility of the flankers and frequency of conflict) through the different blocks of the experiment.

The experiment begun with the masked condition (i.e., blocks A and B). Block C was introduced as a control condition, to serve as a baseline between the masked and the visible condition and to avoid a possible bias between masked and visible blocks. The last two blocks (D and E), with flanker arrows presented in visible conditions, were then presented. Participants had breaks in the middle of each block (i.e., after 50 trials) and between blocks.

They were told they could rest the time they needed in each break and that they should press the space bar whenever they were ready to return to the task.

At the end of the experiment, we asked participants if they were aware of any flanker arrows in the masked blocks (A and B), which they rarely did, thus indicating that the CFF was successful in rendering the stimuli invisible.

## 3. Results

Statistical analyses were performed using IBM SPSS Statistics 22. Analyses of Variance (ANOVAs) and t-tests were run for RTs and accuracy. The level of statistical significance was set at $p < 0.05$. Multiple comparisons with Bonferroni adjustment were used for post-hoc tests and Students T-tests were run to test for specific hypotheses.

For the RT analysis, and following standard approaches in attentional tasks (e.g., Green & Bavelier, 2006), those above or below two standard deviations from the mean of each participant were excluded. Response times from incorrect responses trials were also excluded.

### 3.1. Response Times

*Effects of the visibility of the flankers*

We started by performing a mixed Analyses of Variance (ANOVAs) for RTs with the visibility of the flanker (masked, visible, and control) as a within-subjects factor and the group (VGPs and NVGPs) as a between-subjects factor. The results showed that participants were significantly faster in the control (*M* = 880.24; *SD* = 46.59) and masked conditions (*M* = 882.97; *SD* = 47.43) than in the visible condition (*M* = 929.34; *SD* = 49.30) ($p_s < 0.001$), $F(2,116) = 169.83$, $p < 0.001$, partial $\eta^2 = 0.75$. There was also a main effect of group, with VGPs being overall faster than NVGPs, $F(1,58) = 4.01$, $p < 0.05$, partial $\eta^2 = 0.65$. However, no significant interaction between the visibility of the flankers and the group was revealed, $F(2,116) = 0.42$, $p = 0.66$, partial $\eta^2 = 0.01$.

However, and because it was important to understand if there were differences between the groups in any of the conditions, T-tests were performed to compare both groups in each of the visibility of the flankers' conditions (masked, control and visible). The results showed statistically significant differences between groups in the masked, $t(58) = 2.00$, $p = 0.51$, and visible conditions, $t(58) = 2.06$, $p < 0.05$, with VGPs showing faster RTs (masked: *M* = 871.47; *SD* = 46.94; visible: *M* = 917.00; *SD* = 45.12) than NVGPs (masked: *M* = 895.26; *SD* = 45.56; visible: *M* = 942.53; *SD* = 50.91). However, no difference between groups was shown for the control condition, $t(58) = 1.70$, $p = 0.09$.

*Congruency effects, visibility of the flankers and frequency of conflict*

Given the observed significant differences between the visible and control conditions, we ran an ANOVA without the control condition. This ANOVA included three within-subjects' variables (congruency – congruent and incongruent trials; visibility of the flankers– masked and visible; and frequency of conflict - balanced frequency of conflict and high frequency of conflict - 50/50 congruency x 20/80 congruency). The mean RTs from both groups (VGPs and NVGPs) across the three conditions (congruency, visibility of the flankers and frequency of conflict) are displayed in Table 1.

Table 1

*Mean response time and standard deviation (in milliseconds) across the three conditions (congruency, visibility of the flankers and frequency of conflict) for both VGPs and NVGPs.*

| | Masked | | | | Visible | | | |
|---|---|---|---|---|---|---|---|---|
| | Congruent | | Incongruent | | Congruent | | Incongruent | |
| | Block A | Block B | Block A | Block B | Block D | Block E | Block D | Block E |
| VGPs | 870.05 | 879.51 | 867.18 | 873.06 | 883.40 | 887.68 | 944.05 | 929.97 |
| | (48.96) | (40.46) | (49.56) | (49.09) | (45.39) | (46.57) | (47.82) | (46.08) |
| NVGPs | 897.07 | 899.14 | 895.72 | 892.97 | 907.27 | 907.93 | 974.27 | 955.77 |
| | (52.72) | (46.59) | (50.16) | (43.05) | (53.72) | (53.40) | (57.67) | (51.52) |

The results showed a main effect of visibility of the flankers, with participants displaying shorter RTs when the flankers were masked *(M* = 882.97; *SD* = 47.43), compared to when the flankers were visible (*M* = 929.34; *SD* = 49.30), $F(1,58) = 173.17$, $p$ <0.001, partial $\eta^2 = 0.75$. The results also showed a main effect of congruency, as predicted, $F(1,58) = 366.76$, $p$ <0.001, partial $\eta^2 = 0.86$, with participants showing overall faster RTs for the congruent (*M* = 891.13; *SD* = 47.59) rather than incongruent trials (*M* = 916.19; *SD* = 47.11). There was a two-way interaction between congruency and visibility of the flankers, $F(1,58) = 366.37$, $p <$ 0.001, partial $\eta^2 = 0.86$, where in masked blocks (i.e. A and B) participants were faster in the incongruent trials (*M* = 881.83; *SD* = 49.22) compared to congruent trials (*M* = 886.10; *SD* = 50.71), contrarily visible blocks (i.e., D and E), where participants were faster in congruent trials (*M* = 896.21; *SD* = 50.61), compared to incongruent trials (*M* = 950.56; *SD* = 52.31).

Moreover, a further two-way interaction between congruency and frequency of conflict, $F(1,58) = 27.47$, $p < 0.001$, partial $\eta^2 = 0.32$, showed that although RTs for congruent, compared to incongruent trials, were faster for both balanced frequency of conflict (*M* =

889.02; *SD* = 49.07; *M* = 919.82; *SD* = 49.92, respectively for congruent and incongruent trials) and high frequency of conflict (*M* = 893.23; *SD* = 48.21; *M* = 912.56; *SD* = 46.41, respectively for congruent and incongruent trials), this effect was enhanced for the former, consistent with previous literature (e.g. Gratton et al., 1992). The results also showed a two-way interaction between frequency of conflict and visibility of the flankers, revealing shorter RTs, in the masked presentation blocks, for balanced frequency of conflict (*M* = 882.04; *SD* = 51.40) compared to high frequency of conflict (*M* = 885.84; *SD* = 47.28), while the reverse effect was observed for the visible block conditions (*M* = 926.80; *SD* = 51.89; *M* = 919.95; *SD* = 49.22, for balanced and high frequency of conflict, respectively), $F(1,58) = 8.35$, $p < 0.01$, partial $\eta^2 = 0.01$.

Finally, a three-way interaction between congruency, visibility of the flankers, and frequency of conflict was shown, $F(1,58) = 13.77$, $p < 0.001$, partial $\eta^2 = 0.19$. Specifically, participants were faster in congruent trials in masked balanced frequency of conflict (i.e., block A), compared to visible ones with balanced frequency of conflict (i.e., block D) (*ps* < 0.005). The same pattern was observed for masked and visible conditions with high frequency of conflict (*ps*< 0.05). Regarding incongruent trials, participants were faster in the masked balanced frequency of conflict block (i.e., block A), compared to visible balanced frequency of conflict one (i.e., block D) (*ps* < 0.001). The same pattern was produced by masked and visible blocks with high frequency of conflict, in incongruent trials (*ps* < 0.001). However, in the high frequency of conflict masked block (i.e., block B), participants were faster in the incongruent rather than in the congruent trials, contrarily to the balanced frequency of conflict masked trials (i.e., block A), where no significant difference between congruent and incongruent trials was observed and in the balanced and high frequency of conflict in the visible blocks (i.e., blocks D and E), where participants were faster in congruent trials (*ps*< 0.05) (see Figure 4).

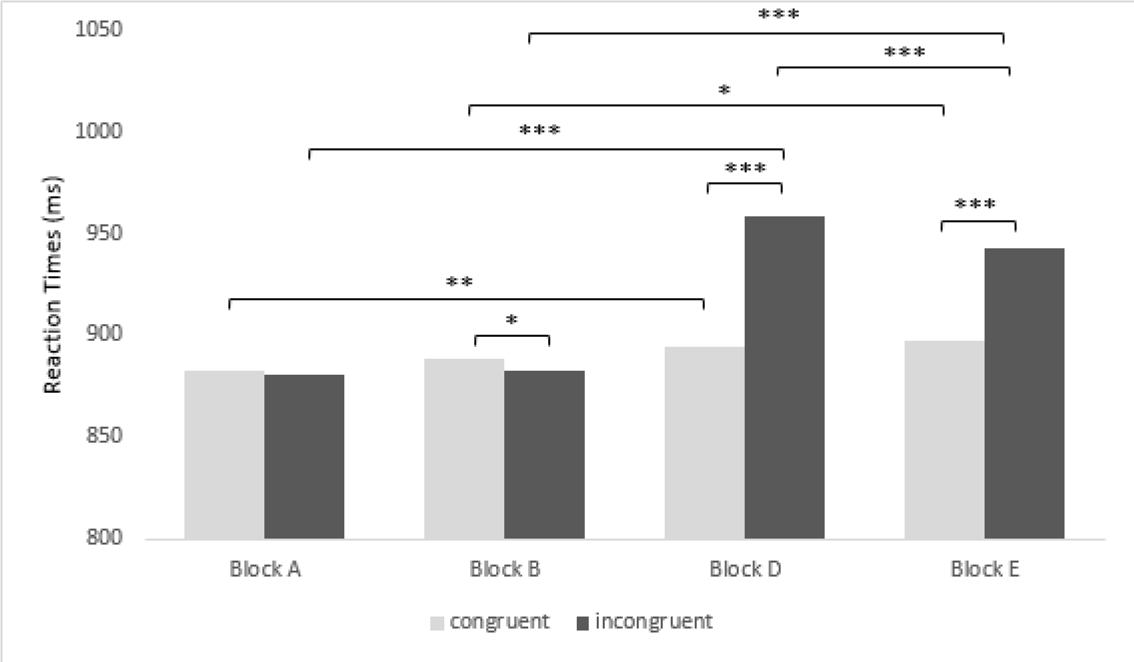


*Figure 4.* Mean response time (in milliseconds) across all conditions. Block A and block B – masked trials; block D and block E – visible trials. Block A and D – balanced frequency of conflict; block B and E – high frequency of conflict. Statistical differences are indicated (**p* <0.05; ***p* <0.01; ****p* <0.001).

Importantly, a main effect of group was observed, $F(1,58) = 4.25$, $p < 0.05$, partial $\eta^2 = 0.07$, indicating that VGPs were faster overall ($M$ = 886.32; $SD$ = 44.60) than NVGPs ($M$ = 909.48; $SD$ = 44.93), consistent with previous literature showing an outperformance in attentional skills in this group (e.g. Bavelier et al., 2012; Dye et al., 2009a; Green & Bavelier, 2003; Green & Bavelier, 2006; Green, Pouget, & Bavelier, 2010). However, and contrarily to our predictions, no significant interaction with group was observed.

*Compatibility effects and conflict adaptation*

An ANOVA with compatibility effects for frequency of conflict (balanced and high frequency of conflict) as a within-subjects' factor and group (VGPs and NVGPs) as a between-subject's variable, was run.

Although frequency of conflict did not produce a main effect in mean RTs (see section above), compatibility effects (RT on the incompatible trials minus RT on the compatible trials) were computed for the visible blocks, given the significant differences between incongruent and congruent trials in these blocks (D and E, i.e., balanced frequency of conflict and high frequency of conflict, respectively). The results showed a lower compatibility effect in the high frequency of conflict block (i.e., block E; $M$ = 942.44; $SD$ = 50.09), compared to the balanced frequency of conflict one (i.e., block D; $M = 958.66$; $SD = 54.52$), $F(1,58) = 58.24$, $p < 0.001$, partial $\eta^2 = 0.50$. No significant differences in the compatibility effect were shown between VGPs and NVGPs, $F(1,58) = 0.001$, $p = 0.98$, partial $\eta^2 = 0.00$ nor an interaction between these two factors, $F(1,58) = 0.21$, $p = 0.65$, partial $\eta^2 = 0.004$. In Figure 5, compatibility effects for both groups are shown.

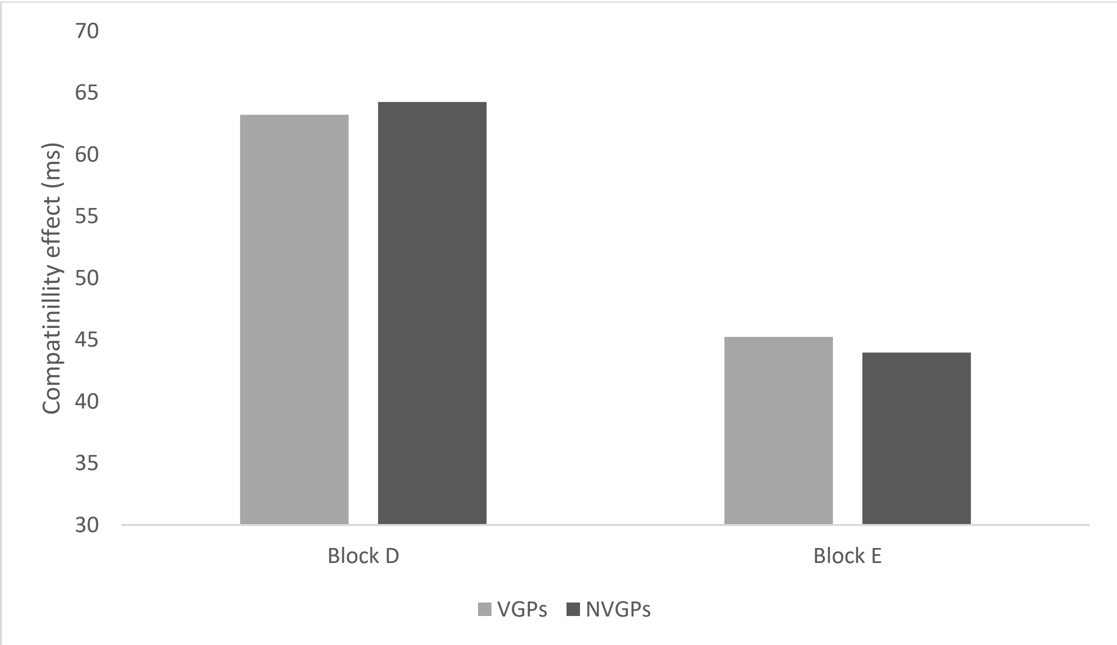


*Figure 5*. Compatibility effects for response time in blocks D and E, for both VGPs and NVGPs. Block D: visible trials with balanced frequency of conflict; block E: visible trials with high frequency of conflict.

Regarding conflict adaptation, which is calculated by subtracting the compatibility effect from high frequency of conflict trials and balanced frequency of conflict trials (i.e., blocks E and D, respectively), the results did not reveal differences between VGPs (-17.992ms) and NVGPs (-20.286ms), $t(58) = -0.46$, $p = 0.65$, contradicting our predictions.

### 3.2. Accuracy

For the accuracy data, we used the same statistical analyses than for the RT data, i.e., ANOVAs and T-tests for specific predictions.

*Effects of the visibility of the flankers*

Consistently with the RT's results, we performed an ANOVA with the visibility of the flanker (masked, visible, and control) as a within-subjects factor and the group (VGPs and

NVGPs) as a between-subjects factor. A main effect of the visibility of the flankers was observed, with participants being more accurate in the masked (*M* = 98.76; *SD* = 1.20) and control conditions (*M* = 98.40; *SD* = 1.70), compared to the visible ones (*M* = 97.50; *SD* = 1.97), $F(2,118) = 15.72$, $p < 0.001$, partial $\eta^2 = 0.21$. There was also a marginal main effect of group, where VGPs were overall more accurate than NVGPs, $F(1,58) = 3.04$, $p = 0.087$, partial $\eta^2 = 0.50$. Like in the RTs, there was no significant interaction between the visibility of the flankers and the group, $F(2,116) = 0.51$, $p = 0.60$, partial $\eta^2 = 0.01$. However, the groups demonstrated a different pattern: while in VGPs there was a difference between the control and the visible condition, where they were more accurate in the control condition, NVGPs presented a difference between the control condition and the masked one, being more accurate in the masked condition, *ps* < 0.05 (see Figure 6).

In line with the RTs' results, we used t-tests to investigate if VGPs and NVGPs differed in each condition of the visibility of the flankers. The results showed that VGPs (*M* = 98.77; *SD* = 1.43) were only (marginally) more accurate than NVGPs (*M* = 98.00; *SD* = 1.43) in the control condition, $t(58) = -1.81$, $p = 0.075$.

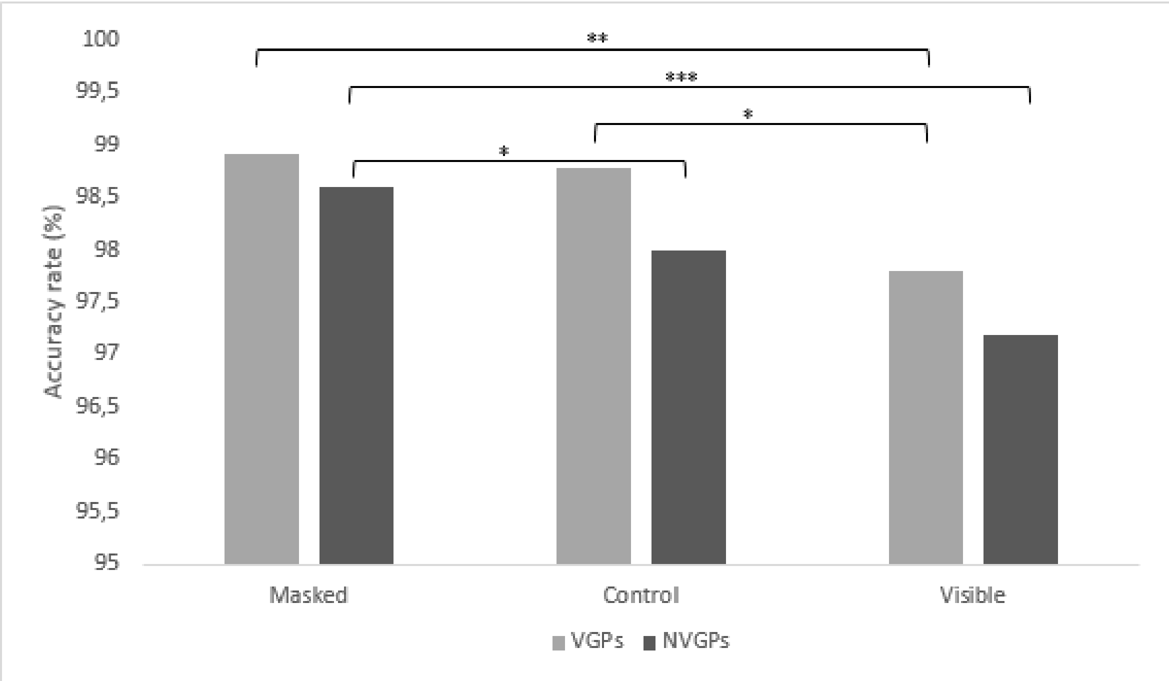


*Figure 6.* Mean accuracy rates (in percentage) across masked, control and visible condition for both VGPs and NVGPs. Statistical differences are indicated (*$p$ <0.05; **$p$ <0.01; ***$p$ <0.001).

*Congruency effects, visibility of the flankers and frequency of conflict*

Same analysis as the RTs' were performed. The mean accuracy rates for both groups (VGPs and NVGPs) across the three conditions (congruency, visibility of the flankers and frequency of conflict) are displayed in Table 2.

Table 2.

*Mean accuracy rate and standard deviation (in percentage) across the three conditions (congruency, visibility of the flankers and frequency of conflict) for both VGPs and NVGPs.*

| | Masked | | | | Visible | | | |
|---|---|---|---|---|---|---|---|---|
| | Congruent | | Incongruent | | Congruent | | Incongruent | |
| | Block A | Block B | Block A | Block B | Block D | Block E | Block D | Block E |
| VGPs | 99.03 | 99.35 | 98.45 | 99.03 | 99.87 | 99.84 | 96.55 | 96.77 |
| | (1.54) | (1.70) | (2.30) | (0.95) | (0.50) | (0.90) | (3.81) | (3.62) |
| NVGPs | 98.89 | 98.97 | 98.47 | 98.40 | 99.17 | 99.31 | 94.85 | 96.85 |
| | (1.58) | (2.06) | (2.05) | (1.56) | (1.56) | (1.76) | (6.08) | (2.69) |

A main effect of visibility of the flankers showed that participants were more accurate in the masked conditions (*M* = 98.76; *SD* = 1.20), compared to visible ones (*M* = 97.50; *SD* = 1.97), $F(1,58) = 18.17$, $p < 0.001$, partial $\eta^2 = 0.24$. Moreover, and also in line with the RT results', a main effect of congruency revealed that congruent trials produced higher accuracy rates (*M* = 99.31; *SD* = 0.89) than incongruent trials (*M* = 97.43; *SD* = 2.00), $F(1,58) = 65.25$, $p < 0.001$, partial $\eta^2 = 0.53$. The congruency effects were again modulated by the visibility of the flankers, with participants being more accurate in congruent trials in both masked (congruent: *M* = 99.07; *SD* = 1.37; incongruent: *M* = 98.59; *SD* = 1.49) and visible conditions (congruent: *M* = 99.56; *SD* = 1.04; incongruent: *M* = 96.27; *SD* = 3.08), but with this effect being more pronounced in the latter (i.e., visible) conditions. This effect was reflected in a significant interaction between congruency and the visibility of the flankers, $F(1,58) = 51.25$, $p < 0.001$, partial $\eta^2 = 0.47$.

Contrarily to the RT results', frequency of conflict produced a marginal main effect in accuracy, with participants being more accurate in the high frequency of conflict blocks (*M* = 98.57; *SD* = 1.13) than in balanced frequency of conflict blocks (*M* = 98.17; *SD* = 1.86), $F(1,58) = 3.16$, $p = 0.08$, partial $\eta^2 = 0.05$. Neither an interaction between visibility of the flankers and frequency of conflict $F(1,58) = 0.76$, $p = 0.39$, partial $\eta^2 = 0.01$ nor an interaction between these two factors and congruency (three-way interaction) was found, $F(1,58) = 1.41$, $p = 0.24$, partial $\eta^2 = 0.02$. Also, in contrast with the RTs, no main effect of the group was observed, $F(1,58) = 2.38$, $p = 0.13$, partial $\eta^2 = 0.04$.

*Compatibility effects and adaptation to conflict*

Consistently with the RT results', we computed the compatibility effects for the visible blocks, with the results revealing a marginally significant effect between the balanced frequency of conflict block (i.e., block D; M = - 3.80; SD = 4.85) and high frequency of conflict one (i.e., block E; M = -2.78; SD = 3.21), $F(1,58) = 3.31$, $p = 0.074$, partial $\eta^2 = 0.54$. Again, there were no overall differences between VGPs and NVGPs, $F(1,58) = 0.01$, $p = 0.93$, partial $\eta^2 = 0.00$, nor the compatibility effects differed as a function of group, $F(1,58) = 0.50$, $p = 0.48$, partial $\eta^2 = 0.01$. Figure 7 shows the module of the compatibility effects in accuracy rate, in both VGPs and NVGPs, to facilitate interpretation.

Finally, adaptation to conflict did also not differ as a function of the group: -1.40% for VGPs and -0.60% for NVGPs, $t(58) = 0.705$, $p = 0.483$

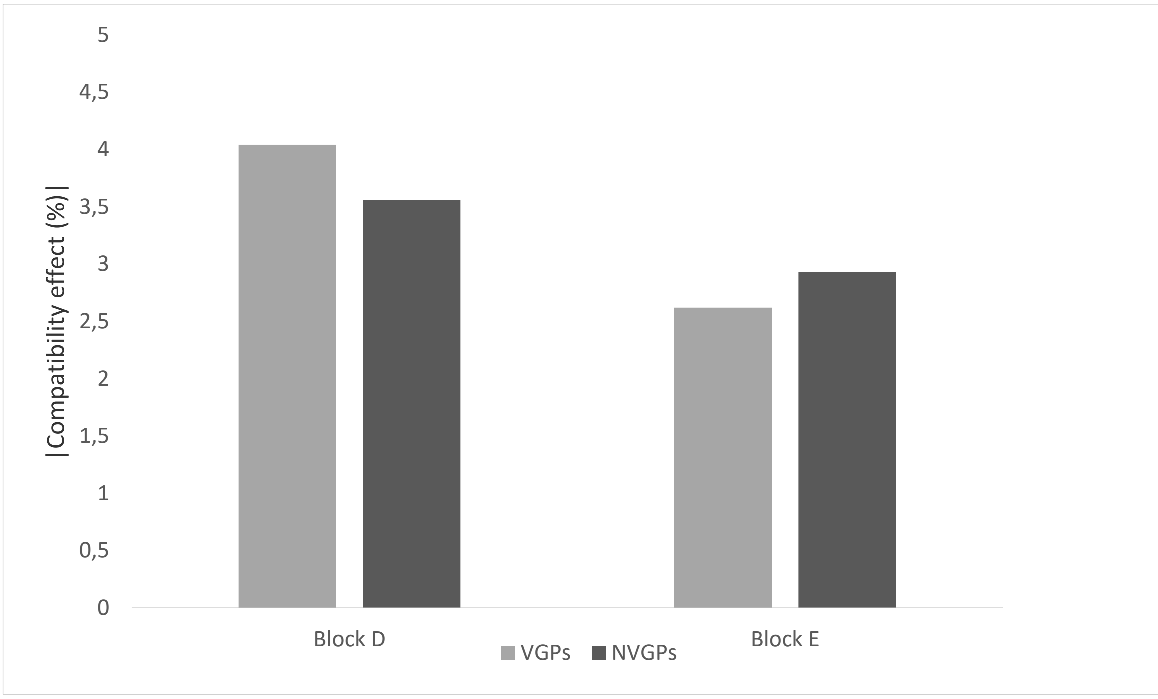


*Figure 7.* Compatibility effects for accuracy rate in blocks D and E, for both VGPs and NVGPs. Block D: visible trials with balanced frequency of conflict; block E: visible trials with high frequency of conflict.

## 4. Discussion

The present research was designed to study unconscious attentional processing and adaptation to conflict as a function of action videogame expertise. For this purpose, we used an Eriksen Flanker task and the Chromatic Flicker Fusion (CFF) technique to investigate congruency effects in both masked and visible conditions. We also varied the frequency of the conflict to investigate if participants adjusted their responses according to the frequency of incongruent trials. By doing so, we would have a measure of conflict adaptation, calculated via the compatibility effect index in a block-wise conflict adaptation effect. Our goal was to study the executive control network, which is known to direct our attention towards task-relevant stimuli and inhibits the processing of distractor items, resorting to the Eriksen Flanker Task.

Consistently with previous findings (e.g., Bugg, 2008; Davelaar & Stevens, 2009; Eriksen & Eriksen, 1974), our results showed that participants were faster and more accurate in congruent trials than in incongruent ones, suggesting that the executive control network detected conflict when the incongruent flankers were presented. Indeed, we know that the presentation of flankers results in an automatic activation, leading to fast correct responses in the congruent condition and fast incorrect responses in the incongruent condition. However, in the latter, the executive control network, in order to minimize the incorrect responses, takes precedence in the incorrect automatic activation, resulting in slow but correct responses (Davelaar & Stevens, 2009).

Importantly, this pattern of results was only evident in the visible conditions, contrarily to our prediction. Moreover, this effect was reversed (i.e., participants were significantly faster in incongruent, rather than in congruent trials) in the high frequency of conflict (with only 20% of congruent trials) of the masked condition (block B). Thus, it seems that when flankers with the same orientation as the central arrow had a higher unexpected occurrence (congruent flankers), incongruent trials were more efficient in capturing attention, even in an unconscious level. Accordingly, studies have shown that the more unexpected the occurrence of a stimulus, the higher the attentional resources it captures (e.g., Houtman et al., 2012; Notebaert et al., 2009), which corresponds to a phenomenon known as the "orienting response" (Sokolov, 1963). Indeed, the orienting response can be elicited in early stages of the attentional processing, even in an unconscious level (Lamme, 2003; Lu et al., 2012; McCormick, 1997), extracting high-level information that leads to categorization, conceptual integration and conducting reflex-like responses (e.g. Mudrik, Breska, Lamy, & Deouell, 2011; for a review, see Mulckhuyse & Theeuwes, 2010). Moreover, some authors (Callejas, Lupiàñez, & Tudela, 2004; Fan, McCandlis, Fossella, Flombaum, & Posner, 2005), suggest that orienting seems to promote the enhancement and activation of the executive network, which is the network elicited by the Eriksen Flanker task. Accuracy results showed a consistent pattern to that of RTs, i.e., participants were more accurate when the flankers were congruent than when they were incongruent, most likely because incongruent trials produce a higher response conflict than congruent ones, leading to higher error rates (Gratton et al., 1992). Nevertheless, overall, participants showed higher accuracy rates in the masked, compared to the visible trials, independently of the congruency between the flankers and the target arrow. Given the lack of interference caused by the flankers in the masked condition, stimuli were probably not reaching higher cognitive areas (i.e. executive control), hence not evoking cognitive conflict, which would explain the lack of a decrement in the accuracy rates. Although we were expecting the masked condition to produce the same interference as the visible condition, the results for both conditions produced the same pattern for both VGPs and NVGPs, as we were expecting.

One of the main goals of this study was based on the assumption that a similar pattern of responses would be observed between the masked and visible conditions, since the CFF has been shown to allow residual neural processing of stimuli that are invisible to the observer (Fang & He, 2005; Jiang et al., 2007; Sterzer, Haynes, & Rees, 2008) and to decode category information from temporal and frontal regions (Fogelson et al., 2014). Indeed, CFF technique has been pointed to constitute a more perceptive way of allowing unconscious information to reach critical neural parts for executive control (Fogelson et al., 2014; Wu et al., 2015). Therefore, although stimuli were presented under the CFF technique, i.e., below the threshold of awareness, we expected flankers to produce a similar interference as that expected in the visible condition. However, this was not the case since, overall, no differences between the masked and control conditions, compared to the visible ones, were shown. These findings are, however, in line with the ones from Wu and colleagues (2015), where masked flankers showed no interference and were indistinguishable from the condition where flankers were absent. In the same line as that proposed by these authors, it is possible that the innocuous nature of the stimuli may be at the core of these findings. Indeed, emotional flanker stimuli, such as threatening stimuli, can be perceived without reaching awareness (e.g. Lin, Murray, & Boynton, 2009). Since quickly responding to threat-related stimuli can be critical for survival, our organism is empowered with a preattentive unconscious detector system that automatically scans the environment for threat stimuli, independently of its conscious perception (Blanchette, 2006; Phelps, 2006; Öhman, 2005; Vuilleumier & Schwartz, 2001). Importantly, and consistent with this idea, we found no significant interactions with videogame expertise.

The lack of significant interactions between action videogame expertise and congruency effects in both masked and visible conditions, and balanced and high frequency of conflict conditions, may be due to the nature of the stimuli used in our study. In action videogames, specific objects attract more attention because of their high impact on action selection (Castel et al., 2005). If we think in first person shooters, we could speculate that weapons, bombs and colour outfit codes, for example, would be probably considered as threat stimuli to the player's survival. We encourage future studies to use flanker stimuli that are more easily encountered in action videogames, as these are emotionally-relevant and may, therefore, evoke a more effective action of the executive control system in this group. Moreover, and in order to draw firmer conclusions on the executive attentional network of VGPs, future studies should also rely on electrophysiology to study the time course of attention processing. According to Bavelier and colleagues (2012), the higher the increase in difficulty in search tasks, the lesser the recruitment of the fronto-parietal network and visual areas in VGPs, compared to NVGPs, which is indicative of a more effective executive attentional network control.

Regarding the compatibility effect and adaptation to conflict, our results also showed that both groups reported similar compatibility effects, as well as decreased compatibility effects in the high frequency of conflict block (i.e., block E). These results are congruent with the model proposed by Botvinick and collaborators (2001), that suggests that once a conflict is detected, an automatic recruitment of attentional control activities is triggered. The conflict elicited by an incompatible stimulus is reduced following an incompatible trial, and when these trials are very frequent, the compatibility effect is lessened. An alternative view also suggests that the modulation of the compatibility effect is determined by practice with specific stimulus characteristics or feature-response contingencies (Wendt & Luna-Rodriguez, 2009). Again, and since no interactions with the group were found in our study, it is likely that the task may have had not been challenging enough for VGPs since no specific elements of videogames were introduced, hence suggesting that the VGPs superior executive attentional control may be dependent on contextual stimuli.

Finally, our results confirmed our prediction that VGPs would be overall faster to respond to the target stimulus and supress the flankers, thus replicating previous reports in the literature showing the outperformance of VGPs in several attentional domains (Bavelier et al., 2012; Dye et al., 2009a; Green, et al., 2010; Green & Bavelier, 2003; Green & Bavelier, 2006). The accuracy results showed no overall differences between VGPs and NVGPs, which is indicative that VGPs are not more likely to make speed-accuracy trade-offs, i.e., responding faster but less accurately. In fact, speeded processing of visual information in VGPs without a decrease in accuracy has been reported by several investigators (e.g., Castel et al., 2005; Dye et al., 2009a, Green & Bavelier, 2006).

VGPs are trained to be faster and more accurate in the presence of specific stimuli in order to “survive” in rapidly changing and hostile virtual environments (Castel, et al., 2005). Moreover, our results support the idea that attentional improvements in VGPs cannot be simply explained by the fact that they are better at pressing keys in response to visual activation (for a review, see Dye, et. al., 2009a) since in the control trials participants only had to respond to one stimuli without any concurrent (or distractor) ones. According to Castel and colleagues (2005), VGPs display an overall RT advantage since they can better produce an appropriate response when a stimulus is detected. However, in some tasks, like visual search tasks, high levels of arousal and greater vigilance in VGPs are observed, most likely due to their resemblance with videogame characteristics. This may indicate that the outperformance of VGPs may be restricted to conditions where they feel challenged, which would then enable their increased awareness of the surroundings and, consequently, trigger faster responses to relevant stimuli. Consistent with this notion, Hubert-Wallander and colleagues (2011) have proposed that in search tasks with a limited number of items, VGPs and NVGPs do not differ, given the reduced challenge involved in the task. In the present study, given that the control condition was a simple task involving the indication of the direction of an arrow (left or right), we can speculate that the low challenged and cluttered environment (i.e., absence of flankers) may explain the lack of differences between groups. Importantly, thought, and as previously alluded, VGPs were significantly faster than NVGPs when flankers were presented, independently of whether these were masked or visible, which suggests that the improved skills of VGPs in executive control are not restricted to conscious processing.

The present work was the first, to our knowledge, investigating attentional unconscious processing in videogame players. Although many other studies have tried to understand the attentional processing in VGPs, very few have tried to understand the processing behind the behaviour, focusing more on the results rather than the process itself. For instance, it is still unclear whether the improved attentional skills in VGPs represent a superior ability to control the allocation of selective attention or represent a better cognitive control ability in task switching. Also, it is interesting to keep exploring the process behind the improved attentional skills, since some authors pointed out a benefit of a top-down process and others a bottom-up process for VGPs. Further investigations in the attentional skills in videogame players is encouraged in order to optimize its benefits, already suggested, for example, in rehabilitation and in retarding the decline in perceptual, cognitive, and motor function of the natural process of aging (e.g. Basak, Boot, Voss, & Kramer, 2008; for a review see Lohse, Shirzad, Verster, Hodges, & Van der Loos, 2013) as well as in professions that demand improved attentional function as jet pilots, military professionals and surgeons (e.g. Gopher, Weil, & Bareket, 1994; Rosser et al., 2007). These improvements are possible since studies (e.g. Green & Bavelier, 2003; Green & Bavelier, 2006; Green & Bavelier, 2007) have already shown that NVGPs, trained with videogames, improve their performance in task involving spatial resolution, vision and efficient distribution of visual attention. Also, action videogame training seems to reduce or eliminate the typical gender gap in the outperform of males' spatial abilities, that has been associated with success in science and mathematics (Feng et al., 2007). Finally, future studies should better investigate the transfer of action videogame improved skills to complex real-world tasks (for example, driving).

**References**

Badre, D., & Wagner, A. D. (2004). Selection, integration, and conflict monitoring: Assessing the nature and generality of prefrontal cognitive control mechanisms. *Neuron, 41*(3), 473-487. doi:10.1016/S0896-6273(03)00851-1

Bargh, J. A., Gollwitzer, P. M., Lee-Chai, A., Barndollar, K., & Trötschel, R. (2001). The automated will: Nonconscious activation and pursuit of behavioral goals. *Journal of Personality and Social Psychology, 81*(6), 1014-1027. doi:10.1037/0022-3514.81.6.1014

Basak, C., Boot, W. R., Voss, M. W., & Kramer, A. F. (2008). Can training in a real-time strategy video game attenuate cognitive decline in older adults?. *Psychology and Aging, 23*(4), 765-777. doi:10.1037/a0013494

Bavelier, D., Achtman, R. L., Mani, M., & Föcker, J. (2012). Neural bases of selective attention in action video game players. *Vision Research, 61*, 132-143. doi:10.1016/j.visres.2011.08.007

Blanchette, I. (2006). Snakes, spiders, guns, and syringes: How specific are evolutionary constraints on the detection of threatening stimuli?. *The Quarterly Journal of Experimental Psychology, 59*(8), 1484-1504. doi:10.1080/02724980543000204

Bombeke, K., Langford, Z. D., Notebaert, W., & Boehler, C. N. (2017). The role of temporal predictability for early attentional adjustments after conflict. *PloS One, 12*(4), e0175694. doi:10.1371/journal.pone.0175694

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica, 129*(3), 387-398. doi:10.1016/j.actpsy.2008.09.005

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*(3), 624. doi:10.1037/0033-295X.108.3.624

Bugg, J. M. (2008). Opposing influences on conflict-driven adaptation in the Eriksen flanker task. *Memory & Cognition, 36*(7), 1217-1227. doi:10.3758/MC.36.7.1217

Castel, A. D., Pratt, J., & Drummond, E. (2005). The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search. *Acta Psychologica, 119*(2), 217-230. doi:10.1016/j.actpsy.2005.02.004

Callejas, A., Lupiáñez, J., & Tudela, P. (2004). The three attentional networks: On their independence and interactions. *Brain and Cognition, 54*(3), 225-227. doi:10.1016/j.bandc.2004.02.012

Chisholm, J. D., Hickey, C., Theeuwes, J., & Kingstone, A. (2010). Reduced attentional capture in action video game players. *Attention, Perception, & Psychophysics, 72*(3), 667-671. doi:10.3758/APP.72.3.667

Clark, K., Fleck, M. S., & Mitroff, S. R. (2011). Enhanced change detection performance reveals improved strategy use in avid action video game players. *Acta Psychologica, 136*(1), 67-72. doi:10.1016/j.actpsy.2010.10.003

Colzato, L. S., van den Wildenberg, W. P., Zmigrod, S., & Hommel, B. (2013). Action video gaming and cognitive control: playing first person shooter games is associated with improvement in working memory but not action inhibition. *Psychological Research, 77*(2), 234-239. doi:10.1007/s00426-012-0415-2

Davelaar, E. J., & Stevens, J. (2009). Sequential dependencies in the Eriksen flanker task: A direct comparison of two competing accounts. *Psychonomic Bulletin & Review, 16*(1), 121-126. doi:10.3758/PBR.16.1.121

De Pisapia, N., Turatto, M., Lin, P., Jovicich, J., & Caramazza, A. (2011). Unconscious priming instructions modulate activity in default and executive networks of the human brain. *Cerebral Cortex*, *22*(3), 639-649. doi:10.1093/cercor/bhr146

Desender, K., Van Lierde, E., & Van den Bussche, E. (2013). Comparing conscious and unconscious conflict adaptation. *PLoS One, 8*(2), e55976. doi:10.1371/journal.pone.0055976

Duthoo, W., Abrahamse, E. L., Braem, S., Boehler, C. N., & Notebaert, W. (2014). The heterogeneous world of congruency sequence effects: An update. *Frontiers in Psychology, 5*(1001), 1-9. doi:10.3389/fpsyg.2014.01001

Dye, M. W., Green, C. S., & Bavelier, D. (2009a). The development of attention skills in action video game players. *Neuropsychologia*, *47*(8), 1780-1789. doi:10.1016/j.neuropsychologia.2009.02.002

Dye, M. W., Green, C. S., & Bavelier, D. (2009b). Increasing speed of processing with action video games. *Current Directions in Psychological Science, 18*(6), 321-326. doi:10.1111/j.1467-8721.2009.01660.x

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience, 8*(12), 1784–1790. doi:10.1038/nn1594

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Attention, Perception, & Psychophysics, 16*(1), 143–149. doi:10.3758/BF03203267

Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks. *Neuroimage, 26*(2), 471-479. doi:10.1016/j.neuroimage.2005.02.004

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*(3), 340-347. doi:10.1162/089892902317361886

Fang, F., & He, S. (2005). Cortical responses to invisible objects in the human dorsal and ventral pathways. *Nature Neuroscience, 8*(10), 1380-1385. doi:10.1038/nn1537

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science, 18*(10), 850-855. doi:10.1111/j.1467-9280.2007.01990.x

Fogelson, S. V., Kohler, P. J., Miller, K. J., Granger, R., & Tse, P. U. (2014). Unconscious neural processing differs with method used to render stimuli invisible. *Frontiers in Psychology, 5*, 601. doi:10.3389/fpsyg.2014.00601

Gopher, D., Well, M., & Bareket, T. (1994). Transfer of skill from a computer game trainer to flight. *Human factors, 36*(3), 387-405. doi:

Gratton, G., Coles, M. G., & Donchin, E. (1992). Optimizing the use of information: strategic control of activation of responses. *Journal of Experimental Psychology: General, 121*(4), 480. doi:10.1037/0096-3445.121.4.480

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*(6939), 534-537. doi:10.1038/nature01647

Green, C. S., & Bavelier, D. (2006). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 32*(6), 1465. doi:10.1037/0096-1523.32.6.1465

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science, 18*(1), 88-94. doi:10.1111/j.1467-9280.2007.01853.x

Green, C. S., Pouget, A., & Bavelier, D. (2010). Improved probabilistic inference as a general learning mechanism with action video games. *Current Biology, 20*(17), 1573-1579. doi:10.1016/j.cub.2010.07.040

Hasegawa, K., & Takahashi, S. (2014). The role of visual awareness for conflict adaptation in the masked priming task: comparing block-wise adaptation with trial-by trial adaptation. *Frontiers in Psychology, 5*(1347), 1-6. doi:10.3389/fpsyg.2014.01347

Hoshiyama, M., Kakigi, R., Takeshima, Y., Miki, K., & Watanabe, S. (2006). Priority of face perception during subliminal stimulation using a new color-opponent flicker stimulation. *Neuroscience Letters, 402*(1–2), 57–61. doi:10.1016/j.neulet.2006.03.054

Houtman, F., Castellar, E. N., & Notebaert, W. (2012). Orienting to errors with and without immediate feedback. *Journal of Cognitive Psychology, 24*(3), 278–285. doi:10.1080/20445911.2011.617301

Hubert-Wallander, B., Green, C. S., Sugarman, M., & Bavelier, D. (2011). Changes in search rate but not in the dynamics of exogenous attention in action videogame players. *Attention, Perception, & Psychophysics, 73*(8), 2399-2412. doi:10.3758/s13414-011-0194-7

Jiang, Y., Zhou, K., & He, S. (2007). Human visual cortex responds to invisible chromatic flicker. *Nature Neuroscience, 10*(5), 657–662. doi:10.1038/nn1879

Karle, J. W., Watter, S., & Shedden, J. M. (2010). Task switching in video game players: Benefits of selective attention but not resistance to proactive interference. *Acta Psychologica, 134*(1), 70-78. doi:10.1016/j.actpsy.2009.12.007

Kiefer, M., & Pulvermüller, F. (2012). Conceptual representations in mind and brain: Theoretical developments, current evidence and future directions. *Cortex, 48*(7), 805-825. doi:10.1016/j.cortex.2011.04.006

Kuratomi, K., & Yoshizaki, K. (2013). Block-wise conflict adaptation of visual selectivity: Role of hemisphere-dependent and location-specific mechanisms: Block-wise conflict adaptation of visual selectivity. *Japanese Psychological Research, 55*(4), 315-328. doi:10.1111/jpr.12015

Lamme, V. A. (2003). Why visual attention and awareness are different. *Trends in Cognitive Sciences, 7*(1), 12–18. doi:10.1016/S1364-6613(02)00013-X

Larson, M. J., Kaufman, D. A. S., & Perlstein, W. M. (2009). Neural time course of conflict adaptation effects on the Stroop task. *Neuropsychologia, 47*(3), 663–670. doi:10.1016/j.neuropsychologia.2008.11.013

Lee, B. B., Martin, P. R., & Valberg, A. (1988). The physiological basis of heterochromatic flicker photometry demonstrated in the ganglion cells of the macaque retina. *The Journal of Physiology, 404*(1), 323–347. doi:10.1113/jphysiol.1988.sp017292

Lin, J. Y., Murray, S. O., & Boynton, G. M. (2009). Capture of attention to threatening stimuli without perceptual awareness. *Current Biology, 19*(13), 1118-1122. doi:10.1016/j.cub.2009.05.021

Lohse, K., Shirzad, N., Verster, A., Hodges, N., & Van der Loos, H. M. (2013). Video games and rehabilitation: Using design principles to enhance engagement in physical therapy. *Journal of Neurologic Physical Therapy, 37*(4), 166-175. doi:10.1097/NPT.0000000000000017

Lombardi, W. J., Higgins, E. T., & Bargh, J. A. (1987). The role of consciousness in priming effects on categorization: Assimilation versus contrast as a function of awareness of the priming task. *Personality and Social Psychology Bulletin, 13*(3), 411-429. doi:10.1177/0146167287133009

Marien, H., Custers, R., Hassin, R. R., & Aarts, H. (2012). Unconscious goal activation and the hijacking of the executive function. *Journal of Personality and Social Psychology, 103*(3), 399–415. doi:10.1037/a0028955

Mayr, U., & Awh, E. (2009). The elusive link between conflict and conflict adaptation. *Psychological Research, 73*(6), 794-802. doi:10.1007/s00426-008-0191-1

McCormick, P. A. (1997). Orienting attention without awareness. *Journal of Experimental Psychology: Human Perception and Performance, 23*(1), 168-180. doi:10.1037/0096-1523.23.1.168

Mishra, J., Zinni, M., Bavelier, D., & Hillyard, S. A. (2011). Neural basis of superior performance of action videogame players in an attention-demanding task. *Journal of Neuroscience, 31*(3), 992-998. doi:10.1523/JNEUROSCI.4834-10.2011

Moutoussis, K., & Zeki, S. (2002). The relationship between cortical activation and perception investigated with invisible stimuli. *Proceedings of the National Academy of Sciences, 99*(14), 9527–9532. doi:10.1073/pnas.142305699

Mudrik, L., Breska, A., Lamy, D., & Deouell, L. Y. (2011). Integration without awareness: expanding the limits of unconscious processing. *Psychological Science, 22*(6), 764-770. doi:10.1177/0956797611408736

Mulckhuyse, M., & Theeuwes, J. (2010). Unconscious attentional orienting to exogenous cues: A review of the literature. *Acta Psychologica, 134*(3), 299-309. doi:10.1016/j.actpsy.2010.03.002

Nelson, J. K., Reuter-Lorenz, P. A., Sylvester, C. Y. C., Jonides, J., & Smith, E. E. (2003). Dissociable neural mechanisms underlying response-based and familiarity-based conflict in working memory. *Proceedings of the National Academy of Sciences, 100*(19), 11171-11175. doi:10.1073/pnas.1334125100

Notebaert, W., Houtman, F., Opstal, F. V., Gevers, W., Fias, W., & Verguts, T. (2009). Post-error slowing: An orienting account. *Cognition, 111*(2), 275–279. doi:10.1016/j.cognition.2009.02.002

Öhman, A. (2005). The role of the amygdala in human fear: automatic detection of threat. *Psychoneuroendocrinology, 30*(10), 953-958. doi:10.1016/j.psyneuen.2005.03.019

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116*(2), 220-244. doi:10.1037/0033-2909.116.2.220

Pashler, H., Johnston, J. C., & Ruthruff, E. (2001). Attention and performance. *Annual Review of Psychology, 52*(1), 629–651. doi:10.1146/annurev.psych.52.1.629

Phelps, E. A. (2006). Emotion and cognition: Insights from studies of the human amygdala. *Annual Review of Psychology, 57*, 27-53. doi:10.1146/annurev.psych.56.091103.070234

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*(1), 25-42. doi:10.1146/annurev.ne.13.030190.000325

Posner, M. I., & Rothbart, M. K. (2007). Research on attention networks as a model for the integration of psychological science. *Annual Review of Psychology, 58*(1), 1-23. doi:10.1146/annurev.psych.58.110405.085516

Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, *109*(2), 160-174. doi:10.1037/0096-3445.109.2.160

Ravizza, S. M., & Carter, C. S. (2008). Shifting set about task switching: Behavioral and neural evidence for distinct forms of cognitive flexibility. *Neuropsychologia, 46*(12), 2924-2935. doi:10.1016/j.neuropsychologia.2008.06.006

Rosser, J. C., Lynch, P. J., Cuddihy, L., Gentile, D. A., Klonsky, J., & Merrell, R. (2007). The impact of video games on training surgeons in the 21st century. *Archives of Surgery, 142*(2), 181-186. doi:10.1001/archsurg.142.2.181

Sänger, J., Bechtold, L., Schoofs, D., Blaszkewicz, M., & Wascher, E. (2014). The influence of acute stress on attention mechanisms and its electrophysiological correlates. *Frontiers in Behavioral Neuroscience, 8*(353), 1-13. doi:10.3389/fnbeh.2014.00353

Silva, D. R. (2006). O Inventário de Estado-Traço de Ansiedade (STAI). In M. M. Gonçalves, M. R. Simões, L. S. Almeida & C. Machado (Eds.), *Avaliação Psicológica: Instrumentos Validados para a População Portuguesa* (Vol. 1). Coimbra: Quarteto.

Silva, D. R., & Spielberger, C. D. (2007) *Manual do Inventário de Estado-Traço de Ansiedade (STAI).* Publicado por Mind Garden, Inc., www.mindgarden.com

Snodgrass, M., & Shevrin, H. (2006). Unconscious inhibition and facilitation at the objective detection threshold: Replicable and qualitatively different unconscious perceptual effects. *Cognition, 101*(1), 43-79. doi:10.1016/j.cognition.2005.06.006

Sokolov, E. N. (1963). Higher nervous functions: The orienting reflex. *Annual Review of Physiology, 25*(1), 545–580. doi:10.1146/annurev.ph.25.030163.002553

Sterzer, P., Haynes, J. D., & Rees, G. (2008). Fine-scale activity patterns in high-level visual areas encode the category of invisible objects. *Journal of Vision, 8*(10), 1-12. doi:10.1167/8.15.10

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*(6), 643-662. doi:10.1037/h0054651

Van Gaal, S., Lamme, V. A., & Ridderinkhof, K. R. (2010). Unconsciously triggered conflict adaptation. *PloS one*, *5*(7), e11508.

Verguts, T., & Notebaert, W. (2009). Adaptation by binding: A learning account of cognitive control. *Trends in Cognitive Sciences*, *13*(6), 252-257. doi:10.1016/j.tics.2009.02.007

Vuilleumier, P., & Schwartz, S. (2001). Beware and be aware: Capture of spatial attention by fear-related stimuli in neglect. *Neuroreport, 12*(6), 1119-1122. doi:10.1097/00001756-200105080-00014

Wendt, M., & Luna-Rodriguez, A. (2009). Conflict-frequency affects flanker interference: Role of stimulus-ensemble-specific practice and flanker-response contingencies. *Experimental Psychology, 56*(3), 206-217. doi:10.1027/1618-3169.56.3.206

West, G. L., Stevens, S. A., Pun, C., & Pratt, J. (2008). Visuospatial experience modulates attentional capture: Evidence from action video game players. *Journal of vision, 8*(16), 1-9. doi:10.1167/8.16.13

Wu, Q., Lo Voi, J. T. H., Lee, T. Y., Mackie, M.-A., Wu, Y., & Fan, J. (2015). Interocular suppression prevents interference in a flanker task. *Frontiers in Psychology, 6*, 1010. doi:10.3389/fpsyg.2015.01110

Zou, J., He, S., & Zhang, P. (2016). Binocular rivalry from invisible patterns. *Proceedings of the National Academy of Sciences, 113*(30), 8408–8413. doi:10.1073/pnas.1604816113

**Appendix A**

*Online questionnaire (sociodemographic and health information and frequency of action video game usage in the prior 12 months).*

Gamers vs Non Gamers

O estudo que pretendo realizar no âmbito da minha dissertação de mestrado em Psicologia da Saúde e Reabilitação Neuropsicológica, orientada pela Prof. Doutora Sandra Soares, pretende perceber se existem diferenças em questões atencionais em jogadores ávidos de videojogos de ação e não jogadores.

Para percebermos se se enquadras em algum destes grupos, gostaria que preenchesse o seguinte questionário. Caso seja selecionado(a), será contactado(a) para a tarefa experimental (com data a definir entre o experimentador e o participante), ficando ainda habilitado(a) a ganhar um dos 3 prémios que temos para lhe oferecer (headset, teclado e rato - oferecidos pela Alientech)

1. Email
2. Idade
3. Sexo
    a. Feminino
    b. Masculino
4. Habilitações Académicas
    a. 12º ano
    b. Licenciatura
    c. Mestrado
    d. Doutoramento
5. Tem algum problema de saúde física? Se sim, indique qual.
6. Tem algum problema de saúde mental? Se sim, indique qual.
7. Está a tomar alguma medicação (medicação prescrita, suplementos vitamínicos ou outros)? Se sim indique qual/quais?
8. Tem algum problema visual? (se estiver corrigido considere que não tem)
    a. Sim
    b. Não

9. Costuma jogar videojogos de ação*? (considere SIM se no último ano jogou em média, por semana, 5 horas; considere NÃO se no último ano jogou, em média, por semana, menos de 1 hora; considere ÀS VEZES se no último ano jogou, em média, por semana, entre 1 a 5 horas)
   * jogos que destacam os reflexos do jogador, a coordenação olho-mão e o tempo de reação
   a. Sim
   b. Não
   c. Às vezes

Regularidade com que joga videojogos de ação

1. Centre-se no ÚLTIMO ANO. Indique quais os videojogos de ação que jogou, colocando-os por ordem decrescente de frequência (i.e, o que mais jogou em primeiro lugar e o que menos jogou em último)
2. Centre-se no ÚLTIMO MÊS. Em média, quais videojogos de ação jogou e com que frequência semanal (exemplo: Call of Duty – 10 horas semanais; League of Legends – 7 horas semanais; Overwatch - 5 horas semanais)?

**Appendix B**

*List of games categorized as action video games and played in the last month by VGPs.*

Battlefield, Castlevania, Counter-Strike Global Offensive, Dark Souls 3, Destiny, Dishonored, Fallout 4, Final Fantasy XIV, Grand Theft Auto 5, H1Z1, Halo, League of Legends, Mass Effect, Overwatch, Rainbow Six Siege series, Rocket League, Saints Row 2, Skyrim, Titanfall 2, Tomb Raider series, Uncharted 4.