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Accessing the States of Enhanced Cognition in a Gaming Context: The Importance of Psychophysiological Arousal

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Abstract

The goal of this study was to examine activities and experiences where enhanced cognitive states (ECSs), characterized by dramatic boosts in focused attention, could be elicited under specific gaming contexts. In Experiment 1, expert gamers were tested on the attentional blink task before and after playing games of different genres, varying on four game design dimensions (perspective, "adrenaline-rush," immersivity, and collaborative vs. individual context) and two cognitive dimensions (speed of processing and attentional focus). In Experiment 2, using ECG-HRV methodology, we examined the physiological markers of gaming dimensions found to be critical for accessing ECSs in Experiment 1. The findings suggest that ECSs are a universal phenomenon that demands focusing one's attention on a single task from the egocentric perspective, and ought to involve an adventurous "adrenaline-rush" type of activity. Furthermore, the results demonstrated that an underlying physiological mechanism of ECSs includes parasympathetic nervous system (PSNS) withdrawal-associated arousal. Specifically, the gaming dimensions leading to greater PSNS withdrawal-associated arousal resulted in greater improvements on the attentional blink task during ECSs. These findings suggest that individuals can transcend what was hitherto assumed to be a limitation of human cognition, granting new prospects for eliciting exceptional human performance.

Keywords: Enhanced cognitive states; Autonomic arousal; Video games; Escape rooms; Electrocardiogram

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1. Introduction

The existence of enhanced mental states, in which an individual is fully absorbed in an activity, exhibiting exceptional perceptual and attentional functioning, colloquially known as "flow" or "being in the zone," has been extensively described in phenomenological and human–computer interaction (HCI) literature, but had until recently been overlooked in cognitive psychology and neuroscience. Phenomenological literature termed these states as "flow" (Csikszentmihalyi, 1975) or "peak experiences" (Maslow, 1962) and has provided striking reports of the state properties, such as intense concentration, distraction-less focus, distorted sense of time, and an autotelic sense of self-realization (Csikszentmihalyi, 1975, 1990, 1997). These enhanced states seem to be a universal phenomenon, as they have been reported by experts from a wide range of domains, such as elite athletes (Kotler, 2014), gamers (e.g., in basketball or chess, Csikszentmihalyi, 1975), surgeons (Colaianni, 2020), and visual artists (Nakamura, Csikszentmihalyi, Snyder, & Lopez, 2002). What seems common to all the reports is that the activities leading to them inherently require intense concentration along with their alleged capacity to induce an "adrenaline-rush," which figuratively refers to a surge of strength and energy brought on by a stressful or highly emotional situation, as if induced by adrenaline.

Due to the spontaneous nature of the enhanced mental states and the fact that they usually occur during highly challenging situations, it has been extremely challenging to create conditions to capture them experimentally. Thus, there have been only very few cognitive psychology and neuroscience studies suggesting the existence of such mental states and their transient nature. In these few studies, significant temporary enhancements on visual-spatial and temporal aspects of attention have been reported as a result of specific styles of meditation, which involve focusing on emotionally significant images of selected people or religious figures (Kozhevnikov, Louchakova, Josipovic, & Motes, 2009; May et al., 2011). According to Amihai and Kozhevnikov (2014), it is psychophysiological arousal (i.e., a withdrawal from parasympathetic nervous system [PSNS] activity toward enhanced sympathetic nervous system [SNS] tone), reflected by a decrease in high-frequency (HF) components of the heart-rate variability (HRV) power spectrum, developed during these mediation styles that led to the observed cognitive enhancements. Similarly, although not consistently replicated, improved performance on spatial reasoning tasks and temporal aspects of attention, as measured by the attentional blink task (ABT), were observed after listening to a Mozart sonata for 10 min (e.g., Ho, Mason, & Spence, 2007; Rauscher, Shaw, & Ky, 1993, Thompson, Schellenberg, & Husain, 2001; but see Chabris, 1999 for a critical review). Indeed, the "Mozart effect" disappeared when arousal caused by the music itself was statistically controlled for (Thompson et al., 2001). In a more recent study, Kozhevnikov, Li, Wong, Obana, and Amihai (2018) focused more closely on investigating the cognitive aspects of these enhanced states, induced by 30 min of playing first-person shooter (FPS) action video games. The elicited states were termed "enhanced cognitive states" (ECSs) and operationalized as transient enhancements in temporal and visual-spatial aspects of focused attention, which result from specific environmental conditions (active gaming engagement at an optimally matched skill-challenge level).[1] Furthermore, according to Kozhevnikov et al. (2018), HF-HRV decreases during FPS video gaming were directly proportional to the magnitude of the focused attention enhancements, as measured by ABT performance.

Despite the preliminary evidence for ECSs, the reports on their existence are sporadic, and it is not clear under what conditions the ECSs could be consistently replicated. Furthermore, occurrences of ECSs have been treated as isolated cases of cognitive enhancements due to specific activities (e.g., listening to music, meditation, or action video gaming) rather than a universal phenomenon with a common mechanism. Considering the significance of ECSs for advancing human performance, it is important to start formulating scientific models of exceptional cognitive functioning, which could explain the mechanisms allowing an individual to exhibit higher levels of cognitive performance than normally available. The goal of this research is to identify activities and experiences critical for inducing these states and consequently to investigate the common nature of these conditioning pre-ECS experiences. In particular, in the current study, we examine the induction of ECSs in the context of gaming, which, according to cognitive (Kozhevnikov et al., 2018) and HCI (Bian et al., 2016; Raphael, Bachen, & Hernández-Ramos, 2012) research, might be the only way to induce states of enhanced cognition under laboratory conditions through the simulation of "adrenaline-rush" real-life situations. Based on previous studies that suggested a link between heightened arousal and states of enhanced cognition (Amihai & Kozhevnikov, 2014; Kozhevnikov et al., 2018; Thompson et al., 2001), we hypothesized that arousal serves as a unifying physiological mechanism underlying the occurrence of ECSs.

First, we replicated the results reported by Kozhevnikov et al. (2018), demonstrating the existence of ECSs elicited through playing FPS action video games (Experiment 1A). Second, we conducted an exploratory study to examine a variety of games from different genres, characterized by differences in game design, including gameplay styles and game mechanics (e.g., shooter, adventure, puzzle-solving, and escape rooms) to identify aspects of gaming activities that are critical to access ECSs (Experiment 1B). In particular, we chose games that varied across four different dimensions related to game design, which have been reported to lead to ECSs according to the three different types of studies: (1) phenomenological literature based on qualitative analyses of narrative reports describing subjective experiences of these states (usually termed "flow"), (2) HCI literature examining conditions leading to the state of flow as a result of the use of technology, based on self-report flow questionnaires, and (3) our in-depth pilot interviews with expert video gamers who reported ECS experiences. The four game dimensions were:

1.1. Perspective

In video gaming, two fundamentally different perspectives from which the player views the scene are typically implemented. These are the egocentric and allocentric perspectives, which rely on egocentric and allocentric spatial frames of reference, respectively. The egocentric reference frame specifies the location and orientation with respect to the self (e.g., to the "right" or "left"), whereas the allocentric reference frame specifies location and orientation with respect to elements and features of the environment independently of the viewer's position (e.g., "next to") (Klatzky, 1998). FPS video games adopt a first-person egocentric perspective where the player views the game environment from the direct perspective of the controlled avatar. In contrast, video games from genres such as real-time strategy (RTS) adopt a third-person allocentric perspective, where the game environment is presented to the player either from a top-down or isometric perspective.[2] Previous HCI research suggests that players' perspective influences the level of engagement and associated arousal. The latter was measured by a greater ERP N100 component (arousal and attention-related evoked potential), which was more pronounced following the instruction to shoot from an egocentric versus allocentric perspective (Petras, ten Oever, & Jansma, 2016).

1.2. "Adrenaline-rush"

The colloquial phrase "adrenaline-rush" is applied to the feeling of exhilaration experienced in highly stressful or exciting situations.[3] A variety of factors might contribute to an "adrenaline-rush" experience, such as a person's intrinsic motivation, personality traits, or the elements of competitiveness. For the purpose of this study, to classify the games according to the "adrenaline-rush" dimension, we refer to the level of game violence and elements of survival, as reflected in the game narrative (e.g., life-threatening situations), audio (e.g., screams of pain), and graphics (e.g., virtual blood). According to this classification, "adrenaline-rush" games may vary from low "adrenaline-rush" games, such as safe and emotionally neutral puzzle games (Tetris), to games involving the elements of adventure and survival (e.g., escape rooms), and finally to more violent high "adrenaline-rush" FPS video games. Specifically, the main objective of many high "adrenaline-rush" FPS games includes killing enemy players while avoiding gunfire, where the player is constantly prepared to cope with an emergency under immediate defense reaction pressure. Indeed, HCI literature suggests that the violent content of FPS games, in particular a large amount of virtual blood and screams of pain, may significantly increase arousal (Anderson & Bushman, 2001; Anderson et al., 2010; Barlett, Harris, & Bruey, 2008; Jeong, Biocca, & Bohil, 2012).

1.3. Immersivity of a gaming environment

Being an interactive part of a game scene, the act of "looking out" (physical immersion) includes a higher level of interactivity and realism inherent in 3D immersive environments than "looking into" the game scene, as presented on a 2D computer screen. According to HCI literature, more naturalistic environments (e.g., real-world escape rooms, in which players solve a series of puzzles meeting specific criteria or immersive virtual reality [VR] games) might facilitate the sense of presence, and thus lead to the state of flow, characterized by a deep sense of immersion into the activity (Sherry, 2004). Applying VR as gaming media has been suggested to amplify flow experiences by increasing vividness, interactivity, and telepresence to a greater extent than traditional 2D computer screens (Kim & Ko, 2019). Similarly, in our pilot interview, a majority of gamers reported experiencing more "aroused" or "stimulated" in more realistic escape rooms, more fully identifying themselves with the game character, and acting directly within the game environment.

1.4. Collaborative versus individual game context

Phenomenological and HCI research on flow has, so far, mainly discussed these as experiences in individuals rather than occurring when individuals are gaming in a team. There are reports, however, that games in a team context, involving direct social interactions, might let individuals experience the state of flow (Lim & Lee, 2009; Raphael et al., 2012). While HCI literature on the role of social interactions in flow is scarce, this literature does show that players are more emotionally immersed and report more enjoyable experiences when playing in a social setting (Gajadhar, De Kort, & IJsselsteijn, 2009). Indeed, the flow state has been reported by players to be more pronounced when playing together in each other's physical presence than playing an online multiplayer game without immediate social communication in physical proximity (Gajadhar et al., 2009).

Since most of the activities reported in phenomenological literature (i.e., chess, extreme sports, and surgery) leading to the state of flow are time-constrained and require intense concentration on a given task, in addition to the four game design dimensions, we were also interested in exploring how such cognitive aspects of gaming as processing speed (fast vs. slow) and the type of attentional processes (focused vs. divided) might affect the access to ECSs. Different games may vary significantly in terms of the attentional demands involved. For instance, most "action" video games require fast processing speed, high visuo-motor coordination, and a high level of focused attention (i.e., keeping the focus on one activity). Other games, however, do not necessitate decision making under such severe time constraints (e.g., escape rooms) and might require divided attention (i.e., multitasking) instead.

In Experiment 2, we examined the nature of the gaming dimensions found critical for accessing ECSs in Experiment 1, particularly their relation to psychophysiological (PSNS withdrawal-associated) arousal. At the biological system level, arousal corresponds to the induction of neuroendocrine signaling cascades, enabling an individual to organize adaptive behavior; that is, to cope with a survival threat emergency. During arousal, various visceral, respiratory, and hormonal changes altogether contribute to the maximum efficiency of an organism to mobilize resources, including particular cognitive functions (Jennings, Allen, Gianaros, Thayer, & Manuck, 2015; Lacey & Lacey, 1978; Lindsley, 1951; Sokolov, 1990), which are necessary to meet the urgent demands of struggle or escape. Indeed, previous research has demonstrated that the amount of prestimulus arousal exhibited by rats, nonhuman primates, and humans predicts the probability of success on a number of visual tasks, including attention and memory-guided delay tasks (Hasegawa, Blitz, Geller, & Goldberg, 2000; Robbins, 1997, 2005). Therefore, we hypothesized that only those game dimensions that contribute to heightened arousal would lead to experiences of ECSs. Finally, based on Kozhevnikov et al. (2018), where HF HRV-associated arousal has been shown to significantly correlate with changes in focused attention due to FPS video gaming, we expected to find a relationship between HF-HRV decreases and focused attention enhancements during the ECS experiences, experimentally induced via gaming.

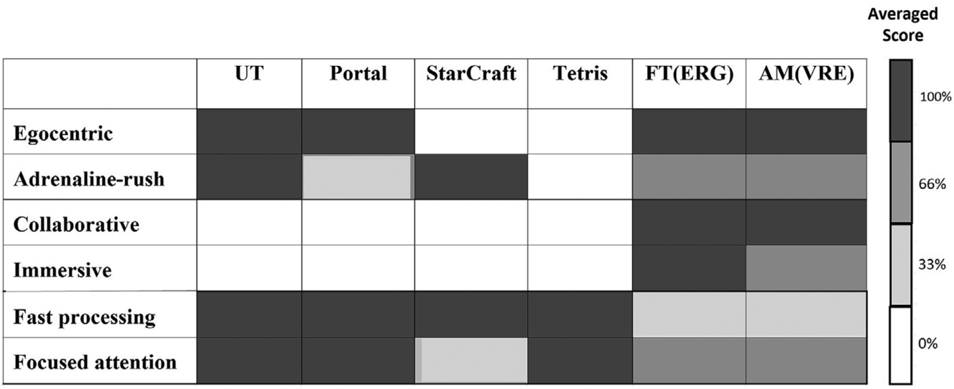

Fig. 1. Classifications of the games according to the gaming and cognitive processing dimension.

2. Experiment 1

Experiment 1 was designed to (1) validate the existence of ECSs (Experiment 1A) by comparing the changes in ABT performance and corresponding arousal level in video gamers who played *Unreal Tournament 2004* (UT, FPS) versus control participants who were resting during this period, and (2) contrast the changes in the ABT performance between participants playing six separate games of different genres (Experiment 1B). The six games in Experiment 1B included four video games of different genres, such as *UT* (FPS), *Portal* (Platform), *StarCraft II* (RTS), *Tetris* (Puzzle), and two immersive escape room games, a collaborative physical puzzle game, *Forgotten Temple* (FT(ERG)), and a collaborative 3D immersive VR escape game, *Abandoned Mine* (AM(VRE)). All the games in Experiment 1B had common features, which were emphasized as important in previous phenomenological and HCI research to access the flow state, such as (1) engagement in the activity that requires full attention from players; (2) goal-directed action; and (3) appropriate level of challenge with immediate feedback. We asked three professional video gamers and one escape room designer to rate the chosen games according to the four dimensions discussed above (perspective, "adrenaline-rush," immersivity, and collaborative vs. individual context) as well as on the speed of processing and attentional focus. Inter-rater reliability was 86%, but all the raters fully agreed on the classification illustrated in Fig. 1, after a discussion.

The measures of focused attention, used by previous experimental research that reported dramatic temporary enhancements in attentional capacities due to specific activities (e.g., listening to music, meditation, or action video gaming), were either related to temporal aspects of focused attention (ABT, Gilleta, Vrbancic, Elias, & Saucier, 2003; Ho et al., 2007; Kozhevnikov et al., 2018; May et al., 2011; Olivers & Nieuwenhuis, 2005; Rauscher et al., 1993) or visual-spatial focused attention (e.g., visual working memory and visual reasoning tasks, Amihai & Kozhevnikov, 2014; Kozhevnikov et al., 2018; Nantais & Schellenberg, 1999; Thompson et al., 2001). In this study, in accordance with Kozhevnikov et al. (2018), we used the changes in ABT performance as a behavioral marker of an ECS. Although in some cases, ABT enhancements might simply be the result of figuring out the effective strategy to perform on the ABT (e.g., attention diffusing when a distracting secondary task is carried out, Arend, Johnston, & Shapiro, 2006; Wierda, Rijn, van, Taatgen, & Martens, 2010), the reasons to consider ABT enhancements as a behavioral marker of ECSs are twofold. First, significant improvements on the ABT due to attention diffusing strategies are rare and of limited magnitude (Arend et al., 2006; Falcon, 2007; Moore & Wiemers, 2018), and it is generally found that individual AB magnitude cannot be significantly reduced by simply practicing the task, even when attention diffusing strategies are applied (Beanland & Pammer, 2012; Braun, 1998; Dale & Arnell, 2013; Falcon, 2007). Second, even though video gamers, as a group, exhibit higher scores on the ABT (Green & Bavelier, 2003), due to either self-selection or prolonged video-game training, it is unlikely that someone would develop ABT enhancements within 30 min as a result of video gaming (unless individuals are experiencing an ECS). This contrasts with most visual-spatial tasks, such as mental rotation or paper folding, which exhibit significant practice effect, even after the first exposure (Lohman & Nichols, 1990), thus making it difficult to differentiate the attention enhancements due to an ECS from test-retest effects.

Furthermore, in Experiment 1A, we used electrocardiography (ECG) methodology to compare the level of PSNS-withdrawal associated arousal in the group of video-game players versus the control group. As PSNS-withdrawal associated arousal could be used reliably as a physiological marker of the ECS, we expected only the group playing an FPS video game to exhibit significant level of arousal, along with associated ABT enhancements, but not the control group. ECG measures are shown to be reliably related to the activity of the autonomic nervous system (ANS), including its PSNS and SNS divisions (Camm et al., 1996). Specifically, an ECG marker indicative of PSNS activation (relaxation) is the increases in HF HRV (Pomeranz et al., 1985). According to recent research (Chalmers, Quintana, Abbott, & Kemp, 2014; Toledo, Gurevitz, Hod, Eldar, & Akselrod, 2003; von Rosenberg et al., 2017), HF HRV decreases can be viewed as generated by the state of arousal, assuming that there are no changes in low-frequency (LF) components of the HRV power spectrum or in the ratio LF/HF. The most frequently reported HRV factor associated with stress (increase in SNS tone) is a decrease in HF HRV accompanied by an increase in LF HRV (Kim, Cheon, Bai, Lee., & Koo, 2018).

2.1. *Methods*

2.1.1. *Participants*

In Experiment 1A, an experimental group of 22 video gamers (17 males), between the ages 20–26 ($M = 21.90$, $SD = 1.68$) and a separate control group of 22 participants (16 males), ages 19–24 ($M = 20.76$, $SD = 1.30$) were recruited from the National University of Singapore (NUS). All participants in the experimental group were required to have a minimum gaming experience of 1 h/day, 4 days a week for at least 6 months in the FPS genre (specifically in playing *Unreal Tournament*—UT) to be considered experts, similar to criteria adopted in other research of expert gamers (Castel, Pratt, & Drummond, 2005). Their total video-gaming experience ranged between 1 and 6 years ($M = 4.05$, $SD = 1.19$). Thirteen participants in the control group also met the requirement of an expert video gamer in the FPS genre ($M = 3.98$, $SD = 1.50$).

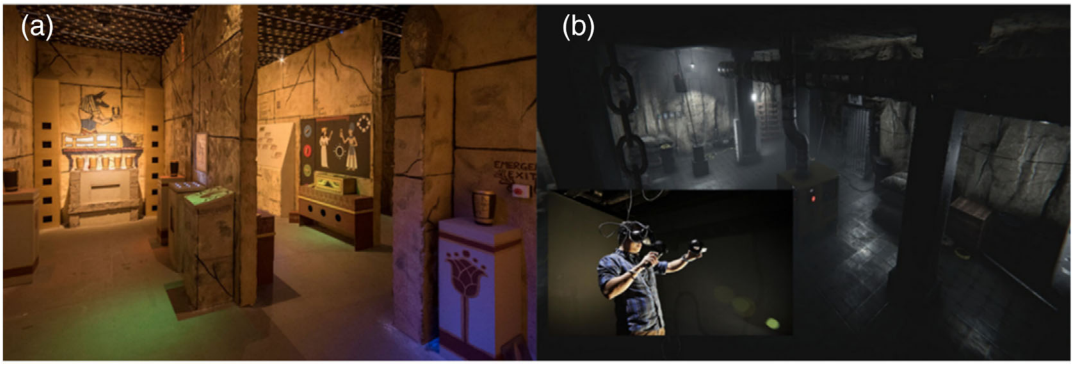

Fig. 2. Screenshots of the games FT(ERG) (A) and AM(VRE) (B).

In Experiment 1B, there were six separate experimental groups (two escape games and four video games) as described below, with a total sample size of 145 participants.

2.1.2. Group 1: Escape games

This first group comprised 58 participants (32 males), between the ages 19 and 36 ($M = 26.34$, $SD = 4.12$). For the FT(ERG) real-world collaborative game, participants were recruited through online advertisement at the NUS campus. To ensure that the participants will experience optimal challenge during escape games, we invited only those who had played at least once in escape rooms and reported to enjoy it. Ensuring players were comfortable, we encouraged them to form a group with their friends in the advertisement. To standardize group performance, we then let the 24 participants (14 males) sign up for the FT(ERG) in teams of four players each. For the AM(VRE) condition, 34 participants ($N = 18$ males) were recruited as part of their NUS class activities and were subsequently asked to form teams of three or four players each. Twenty-eight of these participants reported having had prior exposure to immersive VR and having played escape room games multiple times.

2.1.2.1. Escape room game FT(ERG): We selected the theme of "the Forgotten Temple" from one of the ERG operators in Singapore (lockdown room, Fig. 2A) for this adventure game. In this plot, a group of treasure-hunters (recommended 3–5 players) are locked in a two-room structure resembling an ancient temple. The goal of FT(ERG) is to find the exit door key in 1 h. There are eight stages of problem solving, that is, intermediate goals, each linked to the next in a particular sequence, that lead the players to the key. Teamwork is implied to complete the task. In order to avoid drastically different times taken for a successful escape, players were given a portable phone and were entitled to a maximum of five calls for hints. FT(ERG) is a fully immersive game happening in a real-world setting.

2.1.2.2. Virtual reality escape AM(VRE): The collaborative VR game ("Abandoned Mine," see Fig. 2B) was set up in a VR equipped room (navigation space 1 m^2) with 3D HMD (head-mounted displays), head position, and orientation tracking. In this plot, the Yokon rock

Table 1
Video game expertise and optimal skill-challenge criteria

Game	Expertise criteria	Optimal skill-challenge criteria
FT(ERG)	Played at least once in ER and had enjoyed it	Escape within 1 h
AM(VRE)	Experience with VR and ERG	Escape within 1 h
UT	Expert video gamer	Maintain kill/death ratio between 1:2 and 2:1
Portal	Expert video gamer	Complete at least 15/19 levels in single player mode
StarCraft	Expert video gamer	Defeat both players at minimum level 5/7
Tetris	Expert video gamer	Attain at least level 5 (no max level exists)

mine is closed due to a landslide, with people and gold forever lost inside, and according to the legend, the miners trapped inside protect the gold ever since as "living-dead." The goal of this adventure VR game is to discover an old corridor that descends into the depths of the mine and then to identify the still working old elevator to get out as quickly as possible under conditions of low oxygen. Due to the limited position-tracking possibilities of this game (the tracked area was only 1 m^2), we considered the AM(VRE) game as partially immersive.

2.1.3. Group 2: Video games

The second group included 77 ($N = 62$ males) expert video gamers between the ages of 19 and 30 ($M = 22.64$, $SD = 2.11$) recruited for the study from the NUS campus. All participants in this group were expert video gamers (gaming for at least 1 h/day, 4 days a week for at least the last 6 months, as measured using a self-report prescreening questionnaire) in the specific games used in this study (i.e., UT, Portal, StarCraft II, or Tetris, see Table 1). Participants were assigned the game condition in which they had the most experience. Total video gaming experience ranged between 1 and 17 years ($M = 7.32$, $SD = 4.95$). Specifically, the UT group included 23 participants (20 males) who did not participate in Experiment 1A. The Portal group included 15 participants ($N = 13$ males), the StarCraft group included 15 participants (all males), and 24 participants ($N = 14$ males) were in the Tetris group.

2.1.3.1. Unreal Tournament, First-Person Shooter: UT: In this experiment, the FPS game was *Unreal Tournament 2004* (UT2004, Atari see Fig. 3A). In this game, the player views 3D graphics on a computer screen from the first-person perspective of his or her avatar. The player must navigate the UT2004 virtual terrain and accurately aim their weapon to shoot enemies by maneuvering with the computer keyboard and mouse while successfully dodging enemies' bullets. The "Single Player" game mode was set, resulting in an increase of enemies and the geographical complexity of the terrain every time the player meets the requirements of each game level. Additionally, to achieve optimal skill-challenge balance according to the kill/death (KD) ratio, that is, the number of kills and deaths in the game, the game's difficulty level was adjusted after the player had been gaming for 5 min. Similar to previous research (Green & Bavelier, 2006; Kozhevnikov et al., 2018), the level of difficulty was raised when the participant exceeded a KD ratio of 2:1 and reduced when the ratio went below 1:2. The optimal challenge to skill balance was defined as maintaining a KD ratio within the interval (1:2; 2:1).

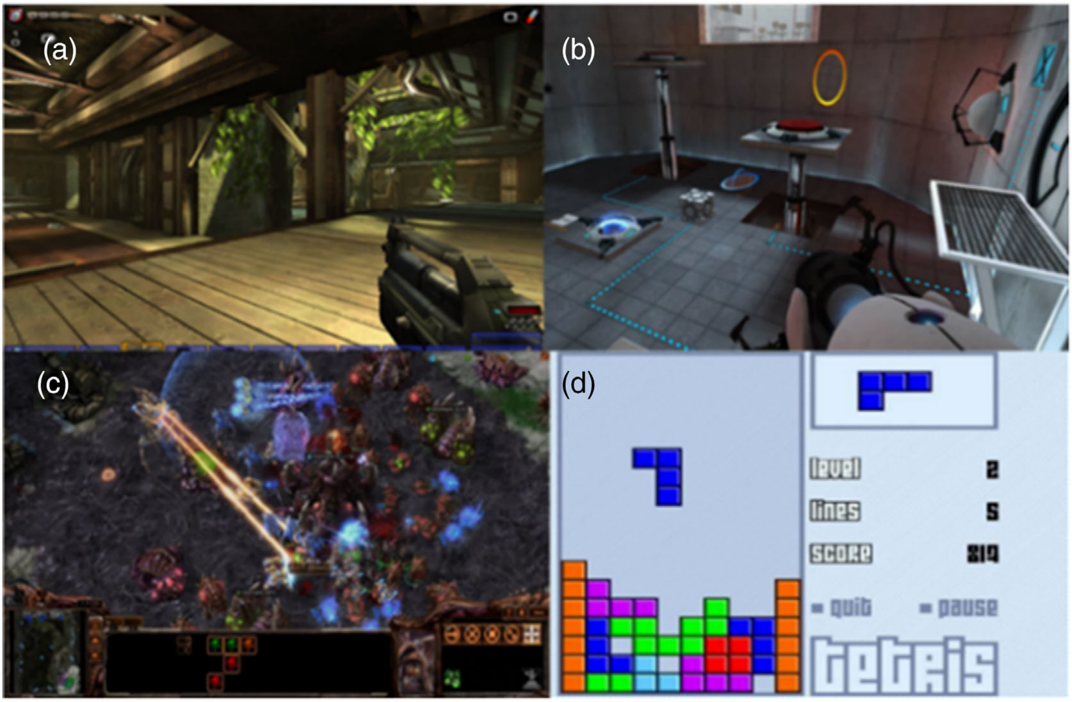

Fig. 3. Screenshots of the UT (A), Portal (B), StarCraft II (C), and Tetris (D).

2.1.3.2. Portal: Portal (Valve Corporation, Fig. 3B) is very similar to FPS games, where the player also maneuvers the environment from the avatar's first-person perspective. However, instead of shooting/killing opponents in an open (i.e., free to explore) environment, the game involves solving puzzles to navigate the environment, that is, moving between chambers. Players must fire a gun to aim at two surfaces of the chamber to create a temporary portal between them, to be able to move between these two spatial locations. This game mainly requires spatial manipulations to solve puzzles, and it has previously been classified as a puzzle game (Nelson & Strachan, 2009). The difficulty of the puzzles in each chamber automatically increases in complexity as players progress in this game; therefore, it was impossible to adjust the difficulty level manually. Hence, no preassessment phase was included in this game, and each participant started the game at the first level.

2.1.3.3. StarCraft II: Heart of the Swarm: The StarCraft II: Heart of the Swarm (Blizzard Entertainment, Fig. 3C) is an RTS game, where players take an allocentric bird's eye perspective of the battlefield. Commands are given via the mouse and keyboard. The goal of the game is to establish a base that allows players to gather resources, therefore, building military units. Subsequently, these units can be used to secure areas of the battlefield to gather more resources or destroy the opponents' units and buildings. Destroying all of the opponents' units and buildings is the overall goal of the game, serving as the equivalence to

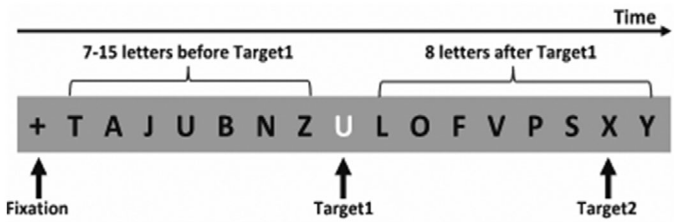

Fig. 4. ABT paradigm.

killing opponents in FPS (Green & Bavelier, 2006; Nelson & Strachan, 2009). The custom game mode was used in which participants played against the computer. Every participant included in this study had achieved at least a gold ranking on the Battle.net online league, indicating that they were sufficiently skilled to play at high difficulty successfully (i.e., at least level 4 out of 7). Due to the nature of the game (i.e., the game lasts a variable amount of time depending on the strategy used by the player), a preassessment phase was not feasible for this game condition. However, at the end of the first game, the experimenter checked if the participant had defeated the computer bot, and if so, the difficulty level was increased by one level for the next game. In cases where the participant had been defeated by the bot, the difficulty level was decreased for the next game session.

2.1.3.4. Tetris: In this game (Tetris by Palmantics, Fig. 3D), geometric shapes made up of four orthogonally connected squares fall one at a time from the top and settle at the bottom of the game area, causing later blocks to stack above previous ones. The player is required to control the location and orientation of landing blocks to succeed. We used the single-player marathon mode in this study, the only available mode of the Tetris version. Participants saw the preview block, rendering them attentive to a wider part of the screen, which is similar to how visual attention is spatially distributed across the screen in StarCraft to screen for additional information that would improve successful gaming. The game was played until the speed of the falling blocks was too fast, resulting in “Game over.” The game was then reset back to level 1 for the next round, and Tetris was played for as many rounds as possible within the allotted time limit of 30 min.

2.1.4. Attentional blink task

Attentional blink (AB) is the phenomenon, which occurs as the result of the “temporal limits of the deployment of selective attention” (Dux & Marois, 2009, p. 1683). During the ABT, participants viewed a rapid sequence of black letters on a gray background at the center of the screen (Fig. 4) and were required to report: (1) the identity of the only white letter (T1) and (2) whether the letter “X” (T2) was presented after the white letter (50% of trials). Each letter was presented for 16.7 ms, followed by an 83.3 ms ISI.

The letter sequence length varied from 16 to 24 letters, with the white letter appearing unpredictably anywhere from the 8th to the 16th position in the sequence. In this experiment, four ABT lags (2, 3, 4, and 7) were applied, where T2 appeared after T1 at the respective lag time (lag-2, 200 ms; lag-3, 300 ms; lag-4, 400 ms; and lag-7, 700 ms). The AB window has been identified to be approx. 500 ms (Shapiro, Raymond, & Arnell, 1997), thus while lag-2 to lag-4 fell inside this AB window, lag-7 occurred outside of it. Overall, the ABT consisted of 96 trials (24 trials per lag). The ABT was scored for the accuracy of Target2 (T2) detection, given that Target1 (T1) had been correctly detected, denoted as T2 | T1 accuracy.

2.2. Procedure

In Experiment 1A, the group of video gamers played UT (Unreal Tournament 2004) for 30 min, which is the length of time necessary to access the ECS (Kozhevnikov et al., 2018). During the same period, the control group performed a 30-min intervening task, consisting of filling out self-report cognitive style questionnaire measuring their visual and verbal preferences in information processing (Blazhenkova & Kozhevnikov, 2009). Participants' ECG data were continuously recorded throughout the entire Experiment 1A using the NeXus-10 device and BioTrace+ software (Version V2012C, Mind Media, Netherlands) at a sampling rate of 256 Hz. In Experiment 1B, all participants in group 2 (video games) played the corresponding video game (UT, Portal, StarCraft, or Tetris) for 30 min. Due to the nature of the games in group 1 (escape games), FT(ERG) and AM(VRE) were played for approx. 1 h. All the gamers in Experiments 1A and 1B were expected to meet a performance criterion as detailed in Table 1 during the game intervention to ensure that they were optimally challenged by the game.

All participants were pre- and post-tested on the ABT, and our setting ensured that all players, in both Experiments 1A and 1B, would be able to perform the ABT immediately after their gaming/escaping to capture the effect of the ECS. Each participant performed an adapted version of the ABT (Raymond, Shapiro, & Arnell, 1992), consisting of 96 trials, twice: immediately before (ABT pre-test) and after (ABT post-test) video-gaming session. The control group (Experiment 1A) filled out a cognitive style questionnaire in-between ABT pretest and ABT post-test. ABT was run in E-Prime 1.0 software, with participants at approx. 63 cm distance from the computer monitor. All gamers in Experiments 1A and 1B were interviewed for 10–15 min on their gaming experiences after the ABT post-test to ensure that their perceived (subjective) level of challenge experienced during gaming corresponded to the optimal skill-challenge criteria.

2.2.1. ECG data analyses

During ECG data analyses, inter-beat interval (IBI) artifacts were removed and replaced by interpolated data. Fast Fourier transform-based spectral analysis of the ECG-derived IBIs was performed with Biotrace+ software. Relative spectral power (in %) was extracted in the frequencies ranging from 0.15 to 0.40 Hz (HF) and 0.04 to 0.15 Hz (LF), according to HRV analysis standards (Camm et al., 1996).

2.2.2. Statistical analyses

The ABT and HRV data in Experiment 1A were analyzed using a $3 \times 2 \times 2$ mixed ANOVA with Lag (lag 2, lag 3, and lag 4) and Time (ABT pre-test and ABT post-test) as within-subjects factors, and Group (UT and Rest) as a between-subjects factor. The ABT data in Experiment 1B were analyzed using a mixed 2 × 6 ANOVA with Time (ABT pre-test and ABT post-test) as a within-subjects factor and Game (FT(ERG), AM(VRE), UT, Portal, StarCraft, and Tetris) as a between-subjects factor. A-priori power analysis was conducted using G*Power 3 statistical software package (Faul, Erdfelder, Lang, & Buchner, 2007), with an effect size set to 0.30 (based on the previous study of Kozhevnikov et al., 2018), alpha level of 0.05, correlation between repeated measures of 0.5, and statistical power of 80%, yielding a minimum size of 39 participants for Experiment 1A and 114 participants for Experiment 1B.

2.3. Results: Experiment 1A

We excluded five participants, two from the experimental (video gaming) group and three from the control group, as these participants did not show the expected AB effect (nonblinker) based on the criterion proposed by Martens, Munneke, Smid, and Johnson (2006).

2.3.1. ABT performance

In Experiment 1A, the ABT performance changes were calculated as the absolute difference in T2 | T1 accuracy averaged across lags 2, 3, and 4. To ensure that both groups started at a similar level of ABT performance, we ran a one-way ANOVA with average ABT pre-test T2|T1 accuracy collapsed across lags 2, 3, and 4 as the dependent variable. The results showed that the experimental and control groups did not significantly differ, $F(1,38) = 1.07$, $p = .31$. Similarly, both groups did not significantly differ in their ABT pre-test lag-7 T2 | T1 accuracy, $F < 1$, $p = .50$. The results of a repeated-measures ANOVA with Lag (2, 3, 4, and 7) as within-subject factor yielded a significant effect of Lag, $F(3,111) = 85.72$, $p < .001$. Pairwise comparisons using the Bonferroni correction indicated increased accuracy with each lag (lag 7 > lag 4 > lag 3, *ps* < .01, and lag 3 > lag 2, $p = .10$), replicating the classic AB effect (Dux & Marois, 2009; Raymond et al., 1992; Shapiro, Raymond, & Arnell, 1994).

To access the change in ABT performance from pre-test to post-test, we used a 3 × 2 × 2 mixed ANOVA with Lag (2, 3, and 4), Time (ABT pre-test and ABT post-test) as within-subjects factors and Group (UT and Rest) as a between-subjects factor. The main effect of Lag was significant, $F(2,74) = 43.14$, $p = .001$, $\eta_p^2 = 0.54$, with T2 | T1 accuracy increasing with each lag (lag 4 > lag 3, $p < .05$, and lag 3 > lag 2, $p = .08$, Bonferroni). The effect of Time was also significant, $F(1,37) = 7.20.9$, $p = .01$, $\eta_p^2 = 0.16$, indicating more accurate performance on ABT post-test than on pre-test. Importantly, the interaction between Group and Time was significant, $F(1,37) = 28.91$, $p < .001$, $\eta_p^2 = 0.44$. Follow-up ANOVAs revealed significant improvements from ABT pre-test to post-test in the experimental (UT) group (Fig. 5A, *M*pre = 0.40, $SD = 0.04$, *M*post = 0.57, $SD = 0.05$; $F(1,18) = 53.67$, $p = .000$, $\eta_p^2 = 0.74$), but not in the control group (Fig. 5B, *M*pre = 0.37, $SD = 0.04$, *M*post = 0.31, $SD = 0.05$; $F(1,18) = 2.53$, $p = .13$). There was also no significant difference between the participants in the control group with and without gaming expertise, $F(1,17) < 1$, $p = .76$, where both groups did not show any improvements from the ABT pre-test to post-test. None of the other effects were significant, including Lag X

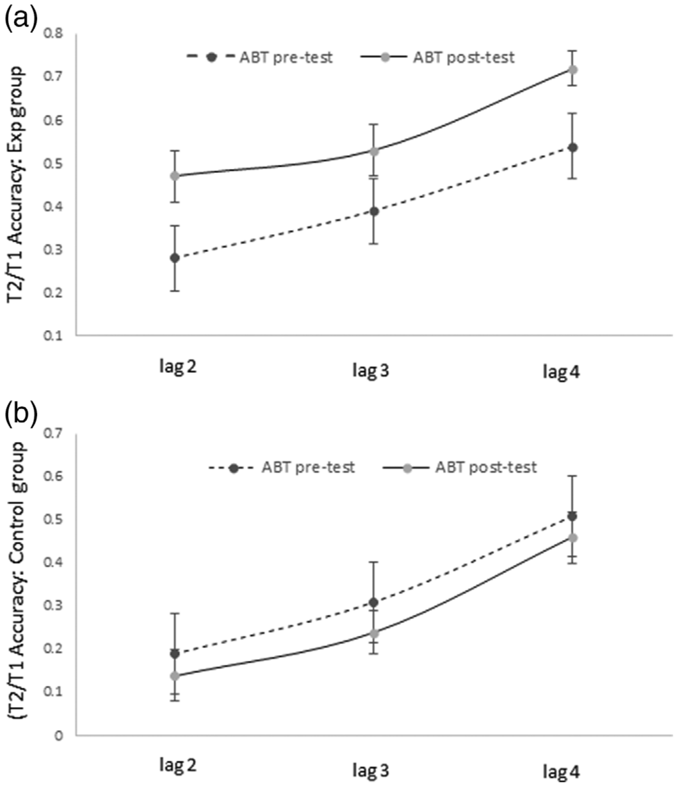

Fig. 5. T2│T1 Accuracy changes from ABT pre-test to ABT post-test for the experimental (A) and control (B) groups by lag. Bars represent mean ± SEM.

Time X Group interaction (all *Fs* < 1), suggesting similar ABT improvements in the experimental group at each lag, with about 20% T2│T1 accuracy improvements at lag 2, 14% improvements at lag 3, and 17% improvements at lag 4.

2.3.2. HRV analysis

HRV data of two participants (one from the control group and one from the experimental group) were removed due to high signal-noise levels and replaced by the mean of the corresponding group in the HRV analysis below.

To analyze the changes in HF HRV from Time-1 to Time-2 (first and last 5 min of 30-min gaming/resting period), we performed a within-subjects ANOVA, with Time (Time 1 and Time 2) as within-subject factor and Group (UT and Rest) as between-subject factor. The results yielded a significant effect of Time, $F(1,34) = 7.45$, $p = .01$, $\eta_p{}^2 = 0.18$, with HF HRV decreasing from Time 1 to Time 2. Importantly, the effect of Group X Time interaction was significant, $F(1.34) = 4.10$, $p = .050$, $\eta_p{}^2 = 0.11$. While there was a significant reduction in HF HRV between the two timepoints for the UT group (*M*pre = 33.75, $SD = 14.31$, *M*post = 24.10, $SD = 11.90$, $F(1,19) = 10.86$, $p = .004$, $\eta_p{}^2 = 0.36$), no changes in HF HRV were observed for the control group, $F < 1$, $p = .54$. Other within-subjects ANOVAs, conducted to analyze the changes LF HRV and LF/HF, yielded insignificant effects of Time ($ps > .40$) and insignificant Group X Time interactions ($ps > .19$). The results suggest that only the experimental group, who played the UT game, developed the state of arousal, but no changes in the ANS state were observed for the control group.

2.4. Results: Experiment 1B

In group 1, we excluded three participants (one participant from FT(ERG) and two participants from AM(VRE)) from all further statistical analyses. Two of these participants did not show the expected AB effect (nonblinker), based on the criterion proposed by Martens et al. (2006), and another one could not continue to play and withdraw from the AM(VRE) game due to the feeling of motion sickness, resulting in a total of 23 participants in the FT(ERG) and 32 in the AM(VRE) condition. In group 2, a total of five participants (one from UT, one from StarCraft, two from Portal, and one from Tetris) were removed from all further statistical analyses. Two of these participants (from the UT and Tetris conditions) did not show the attentional blink effect, and three others (one from the StarCraft and two from the Portal condition) did not meet the performance criterion set during the experiment as detailed in Table 1. Thus, the remaining sample in group 2 consisted of a total of 72 participants, of which 22 participants participated in the UT(FPS), 13 in the Portal, 14 in the StarCraft, and 23 in the Tetris conditions.

The FT(ERG) condition had six groups of players, five of which were able to escape within the allotted 1 h. One FT(ERG) group included in the analyses requested an additional 15 min, after which they could escape successfully. There were difficulties for AM(VRE) groups to escape in the allotted 1 h, due to the required time to learn operating within VR, that is, navigate in the game environment and grab objects (which according to AM(VRE) players' reports could range from 10 to 20 min). Thus, we revised our initial criterion to escape in 1 h, and all AM(VRE) groups were given an additional 30 min to escape (90 min in total), during which they were able to escape successfully. We retained all of the AM(VRE) groups in the analysis. However, due to practical constraints (i.e., learning time to operate VR varied between individuals and groups), we could not measure how long it took each AM(VRE) group to escape.

2.4.1. ABT performance

Considering the exploratory nature of this experiment, we calculated the ABT performance changes as the absolute difference in T2 | T1 accuracy between the ABT pre- and post-gaming averaged over lag-2 only. Consistent with the results of Experiment 1A that playing the UT video game leads to comparable improvements across all the lags within the AB window (with the highest percentage of accuracy improvement for lag 2), previous experimental research demonstrated that lag 2 is the most challenging lag to show any improvements (Oei & Patterson, 2015), but when achieved, the improvements on this lag are often the most pronounced (Green & Bavelier, 2003; Nieuwenstein & Potter, 2006). Paired samples *t*-test (two-tailed) revealed that T2 | T1 accuracy at lag 2 was significantly lower than at lag 7 ($t(125) =$

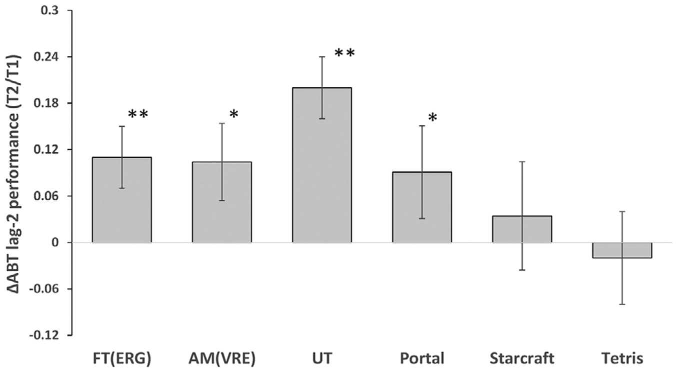

Fig. 6. T2|T1 Accuracy changes between ABT pre-test and ABT post-test per gaming condition in Experiment 1. Bars represent mean ± SEM. ** $p < .01$, * $p < .05$.

19.75, $p < .001$), replicating the AB phenomenon of sharply impaired performance at lag 2 compared to lag 7 (Dux & Marois, 2009; Shapiro et al., 1994).

First, to ensure that there was no difference between the pre-test performance between the groups, one-way ANOVA was conducted on the groups' ABT prescores. The analysis revealed no significant difference between the groups, $F(5, 125) = 1.09$, $p = .36$. Second, 2 × 6 mixed-design repeated measures ANOVA with Time (ABT pre-test and ABT post-test) as a within-subjects factors and Game (FT(ERG), AM(VRE), UT, Portal, StarCraft, and Tetris) as a between-subjects factor revealed a significant main effect of Time ($F(1,120) = 20.93$, $p < .001$, $\eta_p^2 = 0.15$). There was no significant main effect of Game ($F(5,120) < 1$, $p = .50$), but there was a significant interaction between Game and Time ($F(5,120) = 2.70$, $p = .02$, $\eta_p^2 = 0.10$). Follow-up tests (simple effects), comparing the ABT changes between the pre- and post-test, conducted for each game separately, yielded a significant increase in ABT performance for the UT($F(1,21) = 12.97$, $p = .002$, $\eta_p^2 = 0.38$), FT(ERG) ($F(1,23) = 12.50$, $p = .002$, $\eta_p^2 = 0.36$), AM(VRE) ($F(1,31) = 5.72$, $p = .023$, $\eta_p^2 = 0.16$), and Portal ($F(1,12) = 4.86$, $p = .04$, $\eta_p^2 = 0.28$). No significant changes in ABT pre-test and post-test were observed for StarCraft ($F < 1$, $p = .49$) or Tetris ($F < 1$, $p = .67$). The changes between ABT pre-test and post-test (ΔABT) for each game are plotted in Fig. 6. Thus, the largest effect sizes for lag-2 T2|T1 accuracy improvements were observed in UT (20% increase, effect size $\eta_p^2 = 0.37$) and FT(ERG) (15% increase, effect size $\eta_p^2 = 0.36$), followed by AM(VRE) and Portal (about 10% increase, effect sizes $\eta_p^2 = 0.28$ and $\eta_p^2 = 0.16$, respectively), with no significant changes for StarCraft (3% increase) and Tetris (2% decrease).

To ensure that the results were not affected by gender, we added Gender as an additional between-subject variable into the above 2 × 6 mixed ANOVA. However, neither the effect of Gender nor the interaction between Time X Gender was significant, $Fs < 1$. For the FT(ERG) condition, we found a significant negative correlation ($r = -.82$, $p < .05$) between the escape time and Group ΔABT, calculated as the average of that group participants' ABT improvements. We could not investigate the relationship between the escape time and Group ΔABT for the AM(VRE) condition, since as mentioned above, it was impossible to control the exact time it took each AM(VRE) group to escape due to different learning curves to operate a VR set for different players.

Furthermore, planned contrasts were performed for each game dimension (perspective, adrenaline-rush, immersivity, and collaborative context) to examine which dimensions contribute to significant ABT improvements. For each game dimension, the mean ΔABT score of each gaming condition was weighted (according to judges' classifications, presented in Fig. 1), combined into the two groups, representing the opposite characteristics of the gaming dimension (e.g., first vs. third perspective, collaborative vs. individual game context), and then compared using two-tailed *t*-test. Levene's test was conducted to assess the homogeneity of variance, which yielded $p = .07$, assuming equal variance across the six gaming conditions. For Perspective, the four first-person games (UT, Portal, FT(ERG), and AM(VRE)) were combined (each weighted by +1) and compared with third-person games (StarCraft and Tetris, each weighted by –2). The resulting contrast yielded a significant effect of Perspective, $t(121) = 2.98$, $p = .004$, so that first-person perspective games led to significantly greater ABT improvements than the third-person games. For adrenaline-rush, the five adrenaline-rush games (UT, Portal, StarCraft, FT(ERG), and AM(VRE)) were combined and weighted by +1,+1/3, +1, +2/3, and +2/3, respectively, and subsequently compared to Tetris, weighted by –11/3. The resulting contrast was significant, $t(121) = 3.03$, $p = .003$, such that "adrenaline-rush" games led to significantly greater ABT improvements than neutral Tetris. There was no significant difference between collaborative and individual games (FT(ERG) and AM(VRE), each weighted by +1, were compared to four other games, each weighted by –1/2, $t(121) = 1.088$, $p = .23$). There was also no significant difference between immersive and nonimmersive games (FT(ERG) and AM(VRE) weighted by +1 and +2/3, respectively, compared to four other games, each weighted by –5/12, $t(121) = 0.76$, $p = .45$).

Similar contrast analyses were performed for cognitive processing dimensions, which yielded no significant difference either between fast and slow processing (four video games, each weighted by +1/2, were compared to two escape games, each weighted by –1, $t(121) = 0.78$, $p = .44$) or between focused and divided attention (UT, Portal, and Tetris, each weighted by +1, combined with two escape rooms, each weighted by +2/3, were compared to StarCraft, weighted by –13/3, $t(121) = 1.06$, $p = .29$).

2.5. *Discussion*

The results of Experiment 1 are consistent with previous findings of Kozhevnikov et al. (2018), which showed that playing 30 min of FPS action video games produces significant ABT increases, representing a behavioral marker of the ECSs. Both groups that played the UT game in Experiments 1A and 1B showed about 20% lag 2 increase in their ABT performance, while the control group (Experiment 1A) did not show any changes. Moreover, in contrast to the control group, the UT group in Experiment 1A developed a significant level of PSNS withdrawal-associated arousal, representing a physiological marker of the ECS. The significant increase in ABT performance and a significant decrease in HF-HRV in the participants who played the UT game support previous findings regarding the existence of ECSs.

Furthermore, the results of Experiment 1B suggest that both dimensions, the egocentric perspective and "adrenaline-rush," might be the most critical dimensions allowing access to ECSs. Indeed, all first-person egocentric games (UT, Portal, FT(ERG), and AM(VRE)) led to significant ABT enhancements, while the allocentric games (StarCraft and Tetris) did not. Furthermore, all the games showing significant increases in ABT were adventurous "survival" games involving at least some "adrenaline-rush" experience. We did not find, however, the level of game violence to be related to the magnitude of ABT enhancements. For instance, Portal led to significant ABT enhancements, while StarCraft did not. Although Portal involves gameplay elements that induce at least some level of "adrenaline-rush" (e.g., players are required to move over obstacles and jump between portals while encountering dangerous traps involving lava pits, electrocution chambers, laser turrets, and hostile robots), it does not involve the same level of violence as StarCraft. Escape games (FT(ERG) and AM(VRE)), which involved some elements of violence (e.g., images of blood and skeletons) and threatened the player's survival to a greater degree than Portal but lesser than UT, also led to significant ABT enhancements, comparable in their effect size to either UT (as in the case of FT(ERG)) or Portal (as in the case of AM(VRE)).

In addition, according to our results, although "adrenaline-rush" activity is critical, it is not sufficient by itself to elicit the ECS. StarCraft, which was classified as a high "adrenaline-rush" game, involving a more violent type of activities (i.e., kill enemy units and destroy enemy buildings) than Portal or escape games, did not lead to significant ABT enhancements, suggesting that other factors may have counteracted with the effect of "adrenaline-rush." The main difference between StarCraft and other games that led to ABT enhancements is their perspective. The former is an allocentric game, and it is possible that its allocentric nature prevented StarCraft players from experiencing an ECS (as it will be examined further in Experiment 2). Another possible reason that StarCraft did not lead to an ECS is that it was the only game that required divided attention due to the need for multitasking throughout most of the game (e.g., building one's base and training soldiers while checking maps; tracking timer, resources, and enemy movements). Although, according to the results of Experiment 1B, the effect of attentional focus on ABT improvements was not significant, the effect of focused versus divided attention while gaming was not formally controlled for in Experiment 1B. In comparison to other games in this study, StarCraft, a game that requires the highest amount of multitasking, also involves an allocentric perspective, which alone might prevent players from accessing ECSs. We did not include any game, which would be both first-person and high "adrenaline rush," and require multitasking, thus allowing us to isolate the effect of perspective from an attentional focus on accessing the ECS. While escape rooms, in general, require an attentional focus to be maintained on a single activity (i.e., players spend a significant amount of time focusing on deciphering individual clues, even as they shift their attention from one clue to another while proceeding with the game), the beginning stages of AM(VRE) game in this experiment, however, also required some level of multitasking from the players while they were learning how to operate VR. These multitasking demands might explain why AM(VRE) players exhibited lower ABT enhancements compared to FT(ERG) players.

When elaborating on the game experience during the semistructured informal interview, a StarCraft player reported, "after I play StarCraft, even if the game is quite easy, it still drains me because there are many things to be done at the same time… I have to focus on attacking and building my units and so on." (StarCraft also caused other participants to subjectively feel fatigued, as 7 out of 11 participants reported in the interview that they felt tired after the game.) Similar to StarCraft players, AM(VRE) players reported being drained at the beginning of the game while trying to multitask (i.e., learn how to operate VR and play the game). The results that constant multitasking demands within the game may prevent the development of the ECS are consistent with previous phenomenological research (e.g., Csikszentmihalyi, 1975), according to which keeping an attentional focus on a single task while ignoring all the relevant distractors has been suggested to be one of the defining characteristics of flow experiences in phenomenological literature (described as "intense concentration," "distraction-less focus," or "total absorption," Csikszentmihalyi, 1975).

Overall, we cannot disregard the importance of the attentional focus dimension in allowing one to access the ECS.

As for other gaming dimensions, such as speed of processing, immersivity, and collaborative game setting, although they may have facilitated access to ECSs, they were less critical compared to perspective and "adrenaline-rush." Despite being time-limited, both FT(ERG) and AM(VRE) do not require a fast response from the players as compared to the other four video games. These games, however, did lead to ABT improvements, in contrast to Tetris, which did not lead to ABT improvements but required fast processing speed during gameplay. In contrast to long-term video gaming (LTVG) research, according to which only the video games requiring intense speed of processing might lead to improvements on lag 2 (Oei & Patterson, 2015), our findings indicate that speed of processing is not essential for accessing the ECS, suggesting that attentional enhancements due to ECSs and LGVT rely on different mechanisms.

Similarly, neither immersivity nor a collaborative gaming nature has been found to be a critical factor in inducing an ECS. Indeed, both immersive and nonimmersive, as well as both collaborative and individual games, have been shown to result in significant ABT improvements. The result that both FT(ERG) and AM(VRE) led to significant ABT improvements, with FT(ERG) and UT having comparable effect sizes, may seem surprising, as, despite FT(ERG) and AM(VRE) being egocentric and "adrenaline-rush" games, their visual content is by far less violent than that of UT. In addition, although most of the players had prior experience with playing escape rooms, precise control of optimal skill-challenge criteria in these games was not possible. The novelty effect of these games, especially in the case of AM(VR), which involved a learning curve related to familiarization with VR equipment, could only have diminished the magnitude of ABT increases. Similarly, the longer duration of FT(ERG) and AM(VRE) gameplay, in comparison with UT (1-h vs. 30 min), is also an unlikely explanation of ABT enhancements, where the magnitude of ABT enhancements correlated negatively with longer escape time. The combination of factors, such as the realistic nature of the escape games, their first-person perspective, and the elements of "adrenaline-rush," is more likely to have significantly contributed to ABT enhancements during these games.

In conclusion, the results of Experiment 1 suggest that an egocentric perspective and "adrenaline-rush" are the most critical factors contributing to accessing the ECS. In Experiment 1, however, high "adrenaline-rush" StarCraft involved both an allocentric perspective and multitasking. To isolate the effect of perspective from "adrenaline-rush" on accessing the ECS, in Experiment 2, we address this issue by choosing two high "adrenaline-rush" shooter games, both requiring a high level of focused attention but differing in their perspective (egocentric vs. allocentric).

3. Experiment 2

In Experiment 2, we used a within-subject design. All the participants played an egocentric game (UT) and an allocentric game (Metal Slug, MS). In contrast to StarCraft in Experiment 1, Metal Slug does not require multitasking and its content is very similar to the egocentric UT game. Furthermore, to examine whether the ECS dissipates within 30 min of rest after the supporting activity (video gaming) has stopped, we administered the ABT post-test twice: ABT post-test1 immediately after video gaming and ABT post-test2 after 30 min of rest. ECG methodology was used throughout the whole experiment to assess the changes in arousal due to playing egocentric UT *(Unreal Tournament 2004*) versus allocentric MS *(Metal Slug: Super Vehicle*).

3.1. Methods

3.1.1. Participants

Twenty-six participants (18 males) were recruited for Experiment 2 through social media advertising for cash remuneration and from the online portal for research participation at the Department of Psychology of the National University of Singapore (age, $M = 31.25$, $SD = 6.08$). The participants were expert gamers (according to the same criterion as in Experiment 1, i.e., video gaming for at least 1 h/day, 4 days/week for the last 6 months) in the games used in this experiment (UT and MS).

3.1.2. UT (egocentric game)

The egocentric game in Experiment 2 was Unreal Tournament 2004 (UT 2004, Atari Inc.; UT), the same as used in Experiment 1 (see Methods of Experiment 1 for more details).

3.1.3. MS (allocentric game)

The allocentric game in Experiment 2, Metal Slug: Super Vehicle-001 (SNK 1996), is a run-and-gun platformer game. It was chosen due to its similar gaming content relative to the UT game, except for its allocentric perspective. In this game, the player views two-dimensional graphics viewed from the third-person perspective of their avatar (Fig. 7).

Similar to UT, the player must navigate the MS game environment to shoot opponents, dodge bullets, and maneuvering the virtual terrain via moving back, forth, up, and down through inputs on the computer keyboard. The virtual avatar respawns after being killed, but

Fig. 7. Computer screenshots of the Metal Slug: Super Vehicle-00.

only up to three times. The “Arcade” gaming mode was used, where the number of enemies and their difficulty to be killed increases as the player progresses to the next level. The player can reach the next level by killing a series of opponents. “Game over” is shown after the player has been killed thrice, where players must restart the game at level 1. Each participant started the game at the “Medium” difficulty level, with six difficulty levels in total. To match the player’s optimal skill-challenge balance, the difficulty level was decreased if “Game over” occurred at levels 1–3, while it was maintained if it occurred at levels 4–6 and increased when there was no “Game over” in the first 5 min of gaming.

3.1.4. ABT

See Experiment 1 for ABT description.

3.1.5. Presence Questionnaire

The Presence Questionnaire (PQ) questionnaire was developed to measure the degree to which individuals experience presence (defined as the subjective experience of being in a virtual environment, even when one is physically situated in another) and the influence of possible contributing factors (control, sensory, distraction, and realism) on the intensity of this experience (Witmer & Singer, 1998). The PQ consists of 32 items, which ask an individual to rate his/her experience on a 7-point scale. Examples of the items are: “How compelling was your sense of objects moving through space?” and “How aware were you of events occurring in the real world around you?" The internal reliability (Cronbach's alpha) of the PQ is 0.8 (Witmer & Singer, 1998).

3.1.6. Procedure

All participants were exposed to both conditions (UT and MS) for 2 consecutive days, and each session lasted for 2 h. The order of the games was counterbalanced. Participants were randomly assigned to those who played the UT or MS video game in the first session. After participants completed the demographic questionnaire, to record the ECG, three electrodes were attached to the right and left collarbone, and beneath the left rib cage. Participants then completed the first ABT—ABT pre-test. After that, they played either UT or MS to get through as many levels as possible. After 5 min of gaming, the difficulty level was moderated to match the participant's ability. We stopped them strictly after 30 min of game play. Then, they completed the second ABT—ABT post-test1. After that, the participants were asked to rest for another 30 min. During the rest period, participants were interviewed on their experience during video gaming (e.g., how difficult was the game, whether they enjoyed it or felt tired) and were permitted to engage in leisure activity (on the phone, laptop, tablet, or otherwise). They were also asked to complete the Immersive Tendency Questionnaire (Witmer & Singer, 1998), administered to control the realism of these two games. Following a 30-min rest period, subjects completed the ABT for the third time (ABT post-test2).

To analyze the changes in ABT performance as well as in HRV measures, we conducted a 3 $\times$ 2 repeated measures ANOVA with Time (ABT pre-test, ABT post-test1, and ABT post-test2) and Perspective (egocentric, EGO; allocentric, ALLO) as within-subjects factors. A priori power analysis for a 3 $\times$ 2 repeated measures ANOVA, conducted using G*Power 3, with an effect size set to 0.30, alpha level of 0.05, correlation between repeated measures of 0.5, and statistical power of 80% yielded a minimum size of 20 participants.

3.2. Results

Six participants were removed from all statistical analyses for the following reasons: two of the participants were nonblinkers (i.e., not displaying the AB effect), one of the participants did not show up for the second session, and three other participants did not meet the performance criterion set for the optimal skill-challenge (e.g., when a kill-death ratio below 1:2) at least for one of the games (UT or MS). The ECG data of additional two participants were removed due to technical problems with ECG recordings and high signal noise levels. Their HRV data were replaced by the means in the corresponding group for the HRV analysis described below. Thus, the remaining sample consisted of a total of 20 participants.

For the ABT pre-test, the results of a repeated-measures ANOVA for Lag (2, 3, 4, and 7) as within-subject factor yielded a significant effect of Lag, $F(1{,}19) = 93{,}77.72$, $p < .001$. Pairwise comparisons using the Bonferroni correction indicated increased accuracy with each lag (lag 7 > lag 4 > lag 3, $ps < .01$, and lag 3 > lag 2, $p = .01$), replicating the AB effect. To ensure that UT and MS are, indeed, similar in terms of realism, immersivity, and presence, we ran a paired-samples t-test (two-tailed) to compare the differences in the participants' self-reports on the PQ (Witmer & Singer, 1998), which was nonsignificant, $t(19) < 1$, $p = .9$.

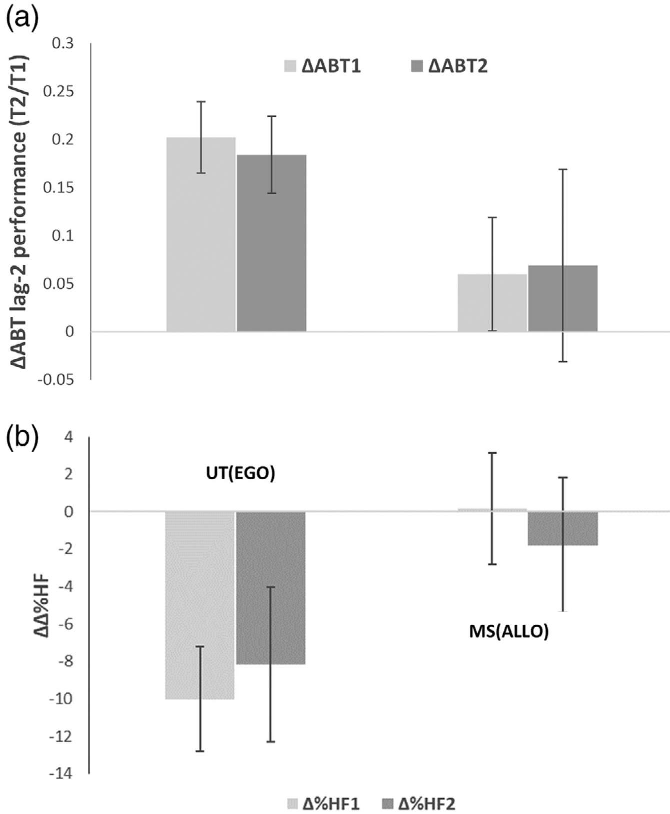

Fig. 8. Attentional blink task and heart rate variability changes. (A) ABT performance improvements due to gaming (EGO vs. ALLO) from ABT pre-test to ABT post-test1 (ΔABT1) and from ABT pre-test to ABT post-test2 (ΔABT2). (B) %HF decreases due to EGO versus ALLO games; from the first 5 min of game to the last 5 min of game; (Δ%HF1) and from the first 5 min of game to 5 min measured 30 min after game (Δ%HF2). Bars represent mean values ± SEM.

3.2.1. ABT changes

First, similar to Experiment 1B, the changes in ABT performance in this experiment were calculated as the absolute difference in T2 | T1 accuracy between the ABT pre- and post-tests, averaged over lag 2 only. The changes between ABT pre-test and ABT post-test1 (ΔABT1) as well as between ABT pre-test and ABT post-test2 (ΔABT2) for each game are plotted in Fig. 8A. A 3 × 2 repeated measures ANOVA with Time (ABT pre-test, ABT post-test1, and ABT post-test2) and Perspective (egocentric, EGO; allocentric, ALLO) as within-subjects factors revealed a significant main effect of time, $F(2, 36) = 8.71$, $p = .001$, $\eta_p^2 = 0.31$, indicating a significant difference in performance between ABT pre-test, post-test1, and post-test2. There was no significant main effect of Perspective, $F < 1$, $p = .48$. There were also no significant differences between the ABT prescores for EGO and ALLO game, $F(1,19) = 2{,}97$, $p = .10$. There was, however, a significant interaction between Perspective and Time, $F(2,36) = 3.59$, $p = .037$, $\eta_p^2 = 0.16$. For EGO game, the follow-up repeated measures

ANOVA with Time (ABT pre-test, ABT post-test1, and ABT post-test2) yielded a significant effect of Time (F(2,38) = 8.91, p = .001), $\eta_p^2 = 0.32$, and pairwise comparisons showed that ABT performance during post-test1 was significantly more accurate relative to the pre-test (p < .001; Mpre = 0.27, SD = 0.21; Mpost-test1 = 0.47, SD = 0.28) as well as during post-test2 relative to the pre-test (p = .18, Mpost-test2 = 0.41, SD = 0.27), albeit the performance during post-test1 and post-test2 did not significantly differ (p = .30). For ALLO game, the follow-up repeated measures ANOVA with Time (ABT pre-test, ABT post-test1, and ABT post-test2) showed a nonsignificant effect of Time (F(2,38) = 2.05, p = .14), so that there were no changes in ABT performance between pre-test, post-test1, and post-test2 (Mpre = 0.40, SD = 0.35; Mpost-test1 = 0.47, SD = 0.28; Mpost-test1 = 0.38, SD = 0.26).

Second, we conducted similar analyses for the ABT performance changes calculated as the absolute difference in T2 | T1 accuracy averaged across lags 2, 3, and 4. A 3 × 2 repeated measures ANOVA with Time (ABT pre-test, ABT post-test1, and ABT post-test2) and Perspective (egocentric, EGO; allocentric, ALLO) as within-subjects factors yielded a significant effect of Time, F(2, 36) = 20.08, p < .001, $\eta_p^2 = 0.53$, insignificant effect of Perspective, F < 1, p = .54, and marginal Perspective X Time interaction, F(2,36) = 2.88, p = .069, $\eta_p^2 = 0.14$. Follow-up repeated measures ANOVA yielded a significant effect of Time for EGO game, (F(2,38) = 15.04, p < .001), $\eta_p^2 = 0.44$, and pairwise comparisons (Bonferroni) showed that ABT performance during post-test1 was significantly more accurate relative to the pre-test (p < .001; Mpre = 0.44, SD = 0.19; Mpost-test1 = 0.60, SD = 0.16), and there was a marginal decline from ABT post-test 1 to ABT post-test 2 (p = .08; Mpost-test2 = 0.55, SD = 0.19). For ALLO game, the follow-up repeated measures ANOVA with Time (ABT pre-test, ABT post-test1, and ABT post-test2) showed only marginal effect of Time (F(2,38) = 3.13, p = .06), with pairwise comparisons (Bonferroni) showing no significant difference between the ABT pre-test and post-test (p = .21, Mpre = 0.50, SD = 0.23; Mpost-test1 = 0.56, SD = 0.28; Mpost-test1 = 0.38, SD = 0.26), but a significant decline from post-test1 and post-test 2 (p = .02, Mpost-test1 = 1.49, SD = 0.18).

Thus, in both cases (for lag2-accuracy only or averaged accuracy across lags 2, 3, and 4), participants exhibited significant improvements in the ABT performance only for the EGO condition, while for the ALLO condition, they demonstrated similar levels of ABT performance before and after the video game. The findings that after 30 min of rest, the UT (EGO) group still showed significant (lag 2) or marginal (averaged lags 2, 3, and 4) improvements on the ABT are consistent with the results reported by Kozhevnikov et al. (2018). When comparing performance of the participants on lag 2, however, between ABT pre-test taken on Day 1 and Day 2, it showed no significant difference, paired-samples t-test (two-tailed), t(19) = –1.09, p = .28, Mpre Day 1 = 0.29, SD = 0.29; Mpre Day 2 = 0.38, SD = 0.30, suggesting that the ECS does last more than 30 min but dissipates by the next day.

3.2.2. HRV analysis

The results of HF HRV analysis are presented in Fig. 8B. For both EGO and ALLO conditions, Δ%HF1 was calculated as the relative (in %) HF difference between the last 5 min of video game playing (HF post-test1) and the first 5 min (HF pre-test). Similarly, Δ%HF2 was calculated as the relative difference in HF between the last 5 min of the 30 min rest period after video gaming (HF post-test2), compared to the first 5 min of the game (HF pre-test).

We performed a 3 × 2 repeated measures ANOVA with Time (HF pre-test, HF post-test1, and HF post-test2) and Perspective (EGO and ALLO) as within-subjects factors. There was neither significant effect of Time, $F<1$, $p = .52$ nor Perspective, $F(2.38) = 2.04$, $p = .17$. The effect of interaction between perspective and Time was significant, $F(2.38) = 4.62$, $p = .02$. For EGO game, the follow-up repeated measures ANOVA with Time (HF pre-test, HF post-test1, and HF post-test2) yielded a significant effect of Time ($F(2,38) = 8.49$, $p = .001$), $\eta_p{}^2 = 0.32$, and pairwise comparisons showed that HF pre-test was significantly higher in comparison with both HF post-test1 ($p = .001$) and HF post-test 2 ($p = .002$), but there was no difference between HF post-test1 and HF post-test2 ($p = .12$). For ALLO game, the follow-up repeated measures ANOVA with Time (HF pre-test, HF post-test1, and HF post-test2) yielded no significant effect of Time, $F< 1$, $p = .5$. Overall, the results indicate significant decrease in both Δ%HF1 ($\Delta M = –10.01$, $SD = 12.53$) and Δ%HF2 ($\Delta M = –8.17$, $SD = 13.37$) for EGO condition, but no changes in either Δ%HF1 ($\Delta M = –0.17$, $SD = 12.53$) or Δ%HF2 ($\Delta M = –1.78$, $SD = 15.30$) for ALLO condition.

To examine the changes in LF, we performed a 3 × 2 repeated measures ANOVA with Time (LF pre-test, LF post-test1, and LF post-test2) and Perspective (EGO; ALLO) as within-subjects factors. The main effects of Perspective, $F < 1$, $p = .9$) and Time, $F(2.38) = 0.8$, $p = .11$ as well as interaction between Perspective and Time ($F < 1$, $p = .85$) were nonsignificant. Overall, the changes in %LF were nonsignificant, either for the EGO condition ($\Delta M = –0.03$, $SD = 17.95$) or ALLO condition ($\Delta M = –1.84$, $SD = 18.22$). In addition, we performed repeated-measures ANOVA on the LF/HF ratio with Time (LF/HF pre-test, LF/HF post-test1, and LF/HF post-test 2) and Perspective (EGO and ALLO) as within-subject factors. The main effects of Perspective and Time and the interaction between Perspective and Time were nonsignificant (Fs < 1, all ps > .49). There were no changes in LF/HF ratio either for the EGO ($M = 2.90$, $SD = 1.93$) or ALLO ($M = 2.86$, $SD = 2.23$) conditions.

Altogether, the pattern of HF decreasing and LF remaining unchanged with unchanging LF/HF ratio for the egocentric condition indicates arousal—a reduction in parasympathetic activity with a shift in the balance toward relative sympathetic enhancement (Toledo et al., 2003). The unchanging HF, LF, and LF/HF patterns for the allocentric condition indicate no ANS-related changes happening while playing the allocentric video game. Furthermore, the results showed no significant differences between Δ%HF1 and Δ%HF2 for both EGO conditions, suggesting that HF has not returned to the baseline after 30 min of rest.

3.2.3. Relationship between HF HRV and ABT changes

To analyze the relationship between ABT improvements and HF HRV changes, we combined the ABT data from the UT group (Experiment 1A) and UT(EGO) condition (Experiment 2). As the linear relationship between ABT improvements and HF HRV changes holds only for individuals who experience the ECSs (Kozhevnikov et al., 2018), all the players who exhibited the state of stress or relaxation instead of arousal were excluded from the regression analysis below. Only HF HRV decreases with LF HRV and LF/HF remaining unchanged were interpreted as generated by PSNS withdrawal-associated arousal (Billman, 2011; Chalmers

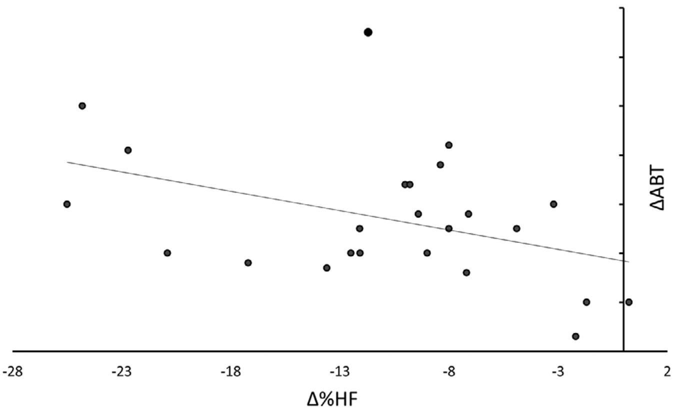

Fig. 9. ABT performance changes from ABT pre-test to post-test (ΔABT) versus %HF pre-test to post-test changes.

et al., 2014; von Rosenberg et al., 2017), which is different from the state of stress, during which a decrease in parasympathetic response could be accompanied by increases in LF HRV (SNS activation). Therefore, we removed three players from Experiment 1A and four players from Experiment 2, who exhibited HF HRV increases (relaxation). In addition, three players from Experiment 1A and two players from Experiment 2 were also removed, as they exhibited LF HRV increases of more than 20% (more than 1.5 SD of the mean LF) of their corresponding group, suggesting that they experienced the state of stress. Although to control optimal challenge, all the UT players were required to maintain KD ratio between 1:2 and 2:1, about one-third of the players in both experiments, consistent with their HRV data, reported either being overchallenged while managing to maintain the required KD ratio or, in contrast, being able to maintain it while not playing to their full capacity.

For the remaining 25 players (13 players from the UT group [Experiment 1A] and 12 players from the egocentric condition [Experiment 2] with a full set of HRV data), we computed the linear regression of ΔABT, representing changes in ABT performance from pre-test to the post-test, against the corresponding changes in %HF changes. The initial regression, however, was not significant ($R = .28$, $R^2 = .08$, $F(1,24) = 1.95$, $p = .17$).

One of the data points, however, was identified as being influential based on its Cook's distance (0.32), which was six times more than the mean (0.05) and greater than $4/n$ (0.16), where n is the number of observations. Further examination of this participant's data revealed that his ABT pre-test score was very low (0.06). However, his performance at both ABT post-test1 (0.52) and post-test2 (0.42) was relatively high, suggesting that the large improvements on the ABT at post-test1 might have been due to a misunderstanding of the task instructions at pre-test. After removal of this data point, the regression was significant (Fig. 9), with Δ%HF significantly predicting ΔABT ($R = .41$, $R^2 = .17$, $F(1,23) = 4.33$, $p = .048$).

Interestingly, 2 out of the 12 players who could access the ECS in the egocentric condition while playing UT (Experiment 2) were also able to access the ECS in the allocentric condition while playing MS. In addition, two other players experienced the ECS only in the allocentric condition. These results suggest that even though it is less likely to occur than the egocentric game perspective, the ECS can also be elicited from the allocentric game perspective.

3.3. Discussion

In Experiment 2, we matched two video games (UT and MS) for their content, attentional focus, feeling of presence, and "adrenaline-rush" level to examine the effect of game perspective (egocentric vs. allocentric) and its effect on the capacity to access an ECS. This approach allowed us to demonstrate that despite being similar on the above parameters, the "adrenaline-rush" egocentric UT game led to significantly larger HF HRV decreases and greater attentional enhancements than the allocentric MS game of a similar "adrenaline-rush" level. Although a few participants reached the required threshold of PSNS withdrawal-associated arousal to access the ECS during the allocentric "adrenaline-rush" MS game, in most cases, "adrenaline-rush" activity alone was not sufficient to induce notable HF HRV decreases and associated ABT enhancements. Indeed, although defense reactions that individuals employ to cope with threats during "adrenaline-rush" type of activities have long been known to lead to the state of arousal (Hilton, 1982), to trigger the required arousal level, it seems critical for the "adrenaline-rush" activity to have direct relevance to oneself, which is facilitated by playing a game from an egocentric perspective. The contribution of the egocentric perspective to PSNS withdrawal-associated arousal can be explained by the difference in cognitive and neurological processes governing egocentric versus allocentric spatial processing (Klatzky, 1998; Zaehle et al., 2007). While allocentric representations are used for recognizing objects and scenes and do not involve direct interaction with the environment (Hu & Goodale, 2000; Milner & Goodale, 2008), egocentric representations are tightly coupled to the body's sensory-motor system during goal-directed object manipulation (Gilmore & Johnson, 1997), and in this sense, they are closely associated with motor control processes. Indeed, neuroimaging studies have provided evidence of higher activity of the somatosensory cortex during spatial tasks requiring participants to take the perspective of the self as opposed to the perspective of someone else (Ruby & Decety, 2001, 2003, 2004). Therefore, interacting with a game environment from a first-person egocentric perspective would engage the players' motor system directly, and as a consequence, result in more pronounced ANS modulations, as demonstrated by the previous studies that showed the association of somatosensory cortex and supplementary motor areas with sympathetic regulation (Beissner, Meissner, Bär, & Napadow, 2013; Dum, Levinthal, & Strick, 2016).

In summary, the results of Experiment 2 support our hypothesis that game features leading to ECS experiences are those contributing to PSNS withdrawal-associated arousal. Together with the observed linear relationship between the level of PSNS withdrawal-associated arousal and ABT improvements, our findings suggest that PSNS withdrawal-associated arousal serves as a psychophysiological mechanism of the ECSs. To access the ECS, one needs to develop a sufficient level of arousal. A combination of "adrenaline-rush" gaming activity with its egocentric perspective allows one to develop greater PSNS withdrawal-associated arousal, compared to "adrenaline-rush" activity alone.

Another finding of Experiment 2 is that, after 30 min of rest post-gaming, no significant decline in ABT performance was found in participants who had experienced the ECS.

Importantly, HF decreases 30 min post-gaming relative to baseline were also significant, indicating that PSNS withdrawal-associated arousal persisted even after 30 min of rest. Considering that HF HRV decreases are proportional to the ABT enhancements, this might explain why ABT performance was still enhanced at ABT post-test2 relative to baseline. On the next experimental day, both ABT enhancements and the associated HF-HRV decreases, observed in the UT condition, had returned to baseline, suggesting that the ECS can persist for more than 30 min but not until the next day, depending on the time needed for an individual to recover from PSNS withdrawal-associated arousal. Although enduring for longer than initially suggested (30 min, Kozhevnikov et al., 2018), the ABT performance improvements and associated HF decreases are transient and reflect a state, not long-lasting improvements in focused attention.

4. General discussion

The first goal of this research was to investigate the nature of the activities and experiences critical in inducing ECSs in the context of gaming. Experiment 1B examined four different dimensions of game design (perspective, "adrenaline-rush" type of activity, immersivity, and collaborative vs. individual gaming) and two dimensions related to cognitive aspects of gaming activity (speed of processing and attentional focus), all of which were hypothesized to facilitate accessing ECSs. The results show that the egocentric perspective and the "adrenaline-rush" nature of the game are the most critical gaming dimensions for experiencing an ECS. In addition, the findings of Experiment 1B are the first to show experimentally that it is possible to experience an ECS not only in individual game settings but also in group game settings. Although immersivity and collaborative versus individual game context do not seem to be as critical as perspective and "adrenaline-rush," both collaborative escape room games led to the experience of ECSs. The results of Experiment 1B also suggest that processing speed required by a game is not a critical factor for accessing ECSs, while attentional focus (i.e., engaging in focused vs. divided attention activity) may still be essential. Future experimental research should examine the importance of focusing attention on a single task versus multitasking in inducing ECS experiences. Anecdotally, in competitive FPS team games, such as Counter-Strike: Global Offensive (CS: GO), a designated team member instructs and directs the other players' activities, hence, other players are able to focus on a single goal, for example, to kill enemies. In a way, this team leader mitigates the multitasking load, for example, strategy design and implementation. Investigating individual FPS games versus team FPS games and whether team leaders might be unable to achieve ECSs due to multitasking might shed more light on the importance of attentional focus dimension. In addition, it should be noted that other gaming dimensions, beyond those examined in this research, such as 2D versus 3D game presentation, the uncertainty of risk estimation, or complexity of movements, should also be examined in future research, as they may also contribute to accessing ECSs.

Our second goal was to examine the common aspects of the gaming dimensions that lead to the ECS experiences and explore the relationship between ABT enhancements and

PSNS withdrawal-associated arousal. According to the results of Experiment 2, it is a combination of egocentric game perspective together with "adrenaline-rush" type of activity, rather than each of these dimensions separately, that allows one to access the ECS by developing a corresponding level of PSNS withdrawal-associated arousal. Furthermore, consistent with our predictions, after combining the data from Experiments 1A and 2, we observed a linear relationship between the magnitude of the ABT enhancements and HF HRV decreases in those players who developed the state of PSNS withdrawal-associated arousal. These findings further support the existence of ECSs, and that these states are subserved by PSNS withdrawal-associated arousal, the level of which is directly related to the level of focused attention enhancements, and therefore, the degree at which ECSs are experienced.

On a more general level, outside of the gaming context, the findings of this study suggest that all activities, which contribute to the state of PSNS withdrawal-associated arousal, would also contribute to accessing the ECSs. Indeed, most activities reported to induce enhanced mental states are associated with either a high level of emotional involvement (e.g., performing surgery, playing chess, composing, or listening to emotional music), intense skeletomuscular as well as respiratory system engagement (e.g., extreme sport and dancing), or a combination of both (e.g., advanced Tibetan meditative practice that involves both emotional visualization and intense breathing techniques, Minvaleev, Bogdanov, Bogdanov, Bahner, & Marik, 2013). It should be noted, however, that in real life, not only the "adrenaline-rush" dimension (classified as a level of violence in this study) and egocentric perspective, but also other factors that require significant emotional involvement and/or intrinsic motivation (e.g., situations of high competitiveness), beyond immediate physical danger or survival threat, may also contribute to enhancing the level of arousal, thus leading to the experience of ECSs. For example, Tetris players participating in highly competitive Tetris tournaments may also experience the ECS, as some of our participants in Experiment 1B reported during informal interviews, although by itself Tetris is not an egocentric or high adrenaline-rush game.

Although threat coping strategies and associated arousal might seem as a negative phenomenon leading to extreme stress, according to polyvagal theory (Porges, 2007), PSNS withdrawal-associated arousal is an intermediate state between a state dominated by parasympathetic influence facilitating social interactions in situations that are safe from danger, and a state dominated by sympathetic influence facilitating a fight-or-flight response in situations of imminent danger. That is, PSNS withdrawal-associated arousal occurs when attention is drawn to a stressor because of its potential threat or novelty and accompanied by the reduction of parasympathetic system activity so that the sympathetic system can be triggered quickly if it turns out to be necessary. Upon detecting a stressor (in real life or virtual simulation), individuals then exert threat-coping strategies. Depending on cognitive resources and expertise in a given domain, ANS modulations may then differentially affect cognitive performance and the potential to access an ECS, mainly because individuals tend to appraise stressful situational demands as either a challenge within their control or as a threat outside their abilities or resources for coping. The former "control" case seems to elicit a withdrawal from parasympathetic activity, as opposed to a sole increase in sympathetic activity, as in the latter "loss of control" case (Epel, McEwen, & Ickovics, 1998). This might explain why an "optimal challenge" condition is critical to experience an ECS (i.e., the person should have sufficient resources to cope with a situation presenting a challenge). While in the case of real-life challenges of more general nature (e.g., car accidents, fights, and exams), due to optimal challenge, individuals without any particular expertise might exhibit PSNS withdrawal-associated arousal, in the case of domain-specific challenges (e.g., extreme sport or chess playing), expertise is usually needed to exert control over these challenges. While the neuroendocrine signaling cascade of the "control" coping mode involves the sympatho-adrenal system, as characterized by increases in noradrenaline, gonadotropins, testosterone, and oxytocin, the "loss of control" mode predominantly involves the corticoadrenal system, related to increases in cortisol and decreases in testosterone (Cardinali, 2018). Noradrenaline, released in forebrain structures, is suggested to facilitate sensory processing and enhance executive functions in the frontal cortex (Sara & Bouret, 2012). As such, ECSs are likely mediated by the sympatho-adrenal system and associated neurobiological mechanisms. What remains to be addressed in future research is the brain mechanisms which provide an individual with extraneous focused attention capacities observed during an ECS as a result of PSNS withdrawal-associated arousal.

An additional question to be addressed by further research is the duration of ECSs. A biological state, mental or physical, usually takes a certain amount of time to develop, peak, and dissipate. Similarly, an ECS, which has been operationalized as a state that occurs in the course of the supporting activity, does not end instantaneously after the activity has stopped but persists for some time (dissipation period). Similar to Kozhevnikov et al. (2018), we found that ECSs do not dissipate 30 min after completing the supporting activity but fade out by the next day. Future research should further investigate the temporal dynamics of ECSs, particularly the duration of their dissipation period. This includes the recovery time from PSNS withdrawal-associated arousal, which, along with other factors (e.g., the level of challenge experienced during the activity, baseline attentional capacities, and health condition), might affect the ECS duration.

The current research has a number of important theoretical and practical implications. From a theoretical perspective, it provides experimental evidence for the existence of universal ECSs—states characterized by dramatic temporary improvements in focused attention, with PSNS withdrawal-associated arousal serving as their underlying physiological mechanism. While there is substantial evidence that LGVT also contributes to improved cognitive performance (see Dale, Joessel, Bavelier, & Green, 2020; Green & Bavelier, 2003 for reviews), it should be noted that their effects are very different from those of ECSs. LTVG does not explicitly benefit task-oriented focused attention but instead increases the ability to ignore task-irrelevant information and the distribution of spatial attention over the entire visual field. ECSs, however, boost the temporal and visual-spatial aspects of focused attention. Moreover, the enhancement of cognitive functions through LTVG has been reported to be dependent on common demands between the game and transfer task (Oei & Patterson, 2015) and thus limited to the task or performance requiring the same cognitive functions. The current research suggests that the ECS, in contrast, is a universal phenomenon, and its benefits to focused attention are generalizable even outside the context of the specific game or activity that brought on the ECS. In Experiment 1, FT(ERG) resulted in similar ABT improvements to UT, although this game simulates real-world activities immersed in a physical space and does not share many features with action video gaming (such as requirements for fast responses and high visuo-motor coordination) that have been previously suggested to affect the performance of action video gamers on attentional tasks (Bavelier & Green, 2019; Dale et al., 2020; Green & Bavelier, 2003). The implications of the LTVG and ECS studies are also very different. LTVG studies inform us that human cognition can be improved over time with specific training that can be generalized to other situations, whereas the ECS research implies that we can temporarily transcend what was assumed to be an ordinary human capacity in cognition under the right conditions and with relevant expertise.

From a more practical perspective, this study proposes a tool (gaming) to investigate ECSs experimentally. Examining ECSs in controlled settings will contribute significantly to modern psychology and neuroscience, where the areas of enhanced cognition and exceptional human functioning have been understudied due to difficulties in designing experimental conditions to induce such cognitive changes or finding subjects with exceptional cognitive capacities. Unlike other real-world activities that could be rather dangerous (rock-climbing or other extreme sports) or require very high levels of expertise (e.g., visual art or surgery), gaming is an activity that not only has the potential to activate ECSs but can also be readily applied and studied under controlled laboratory conditions. In this respect, VR gaming could be the most effective. Not only does it provide a relatively realistic and immersive gaming environment for individual players and teams that can simulate dangerous and highly challenging activities, but it also affords concurrent neurophysiological data collection (Bian et al., 2016) and rigorous control of variables, which is impossible to achieve in the real world. Furthermore, the content of games can be designed to suit the intrinsic interests of individuals and is widely accessible to the public, creating a great potential for games to be used as the tool through which individuals can experience such ECSs once they are sufficiently skilled in the game. Finally, although ECSs are transient, a temporary boost in focused attention can, nevertheless, be utilized to enhance performance dramatically during critical periods. While coaching athletes to set world records and perform beyond their limits is not unusual in sports, no comparable techniques to teach experts to go beyond and above their current achievements exist in cognitive domains (e.g., art, science, or music) despite numerous reports by members of such professions on their spontaneous experiences of ECSs. Research on ECSs and the ways to induce them might show how cognitive capacities can be boosted upon demand potentially resulting in unprecedented levels of human cognitive performance in different creative domains.

Acknowledgments

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Notes

1 While ECSs have been shown to resonate with the state of flow, where significant relationships were reported between some of the self-assessed dimensions of flow questionnaires and ECSs (Experiment 1, Kozhevnikov, Li, Wong, Obana, & Amihai, 2018), the term "flow" refers to experiential aspects of mental states, whereas the term "ECS" reflects the objective state of enhanced focused attention capacities, as characterized by behavioral (improvement on focused attention tasks) and physiological (PSNS withdrawal-associated arousal) markers.

2 We will refer to the egocentric perspective only in cases where the perspective of the player is both first-person and aligns with the egocentric frame of reference. However, there are video games, such as third-person shooter (TPS) games that apply a third-person viewpoint, fixed behind the shoulder of a character from an egocentric spatial reference frame that aligns with a coordinate system relative to the character not environment.

3 In this paper, the terminology "adrenaline-rush" type of activity has been borrowed from colloquial language and the HCI literature for the practical purpose of game classification only.

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