Accessing the States of Enhanced Cognition: Implications for military mission preparation

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ABSTRACT

Enhanced Cognitive States (ECSs) have been operationalized as dramatic transient enhancements in temporal and visual-spatial aspects of attention, accompanied by the state of parasympathetic nervous system (PNS) withdrawal-associated arousal. Previous research has shown that ECSs can be elicited during "adrenaline-rush" first-person shooter (FPS) games involving highly adventurous features (e.g., shooting, survival, horror, fantasy). In Experiment 1, we replicated previous experimental results demonstrating the existence of ECSs elicited through playing FPS action video games. In Experiment 2, we examined the role of a player's perspective in reaching the ECSs, by comparing the changes in the performance on the focused attention task and electrocardiographic (EKG) data of expert video gamers who played, on two different days, first-person and third-person adventurous video games (Unreal Tournament and Metal Slug, respectively). The results suggest that a combination of the "adrenaline-rush" nature of the game with the first-person perspective is critical for accessing the ECSs, as the players experienced the ECSs only during the Unreal Tournament but not Metal Slug. Furthermore, we showed that the level of PNS withdrawal-associated arousal correlated significantly with focused attention enhancements during ECSs experiences experimentally induced via gaming, suggesting that arousal represents a physiological marker of the ECSs. The project results suggest possibilities for consciously accessing latent resources of our brain to temporarily boost our cognitive capacities on demand, such as providing military personnel with specific simulation training before short-burst military missions.

ABOUT THE AUTHORS

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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 experimental psychology and neuroscience. Phenomenological literature termed these states as "flow" (Csikszentmihalyi, 1975, 1990) 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.. These enhanced mental 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), and visual artists (Nakamura & Csikszentmihalyi, 2002). Flow states have also been reported to occur in the context of coping with stress (Csikszentmihalyi, 1992), particularly during life-threatening experiences (Wilson, 1972), such as fighting on a battlefield or engaging in an extremely dangerous task (e.g., defusing a bomb).

Due to the spontaneous nature of the enhanced mental states and the fact that they usually occur during highly challenging situations, it has been difficult to create conditions to capture them experimentally. Thus, there have been only very few experimental studies suggesting the existence of such states and their transient nature. In these few studies, significant temporary enhancements in visual-spatial focused attention have been reported as a result of specific styles of Tibetan meditation, which involve self-identifying oneself with powerful religious figures (deities), wearing garlands of skulls, holding severed heads, and stepping on corpses, while aiming at destroying internal obstacles to self-realization (Amihai & Kozhevnikov, 2014; Kozhevnikov et al., 2009). Other studies also discussed potential applications of Tibetan meditation styles and East Asian martial art techniques for accessing and maintaining these states voluntarily, using emotionally charged visual imagery and/or special breathing practices (Krein & Ilundain, 2014; Kozhevnikov et al., 2019).

More recently, Kozhevnikov et al. (2018) focused more closely on investigating the cognitive aspects of these enhanced states induced by 30 minutes 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 aspects of focused attention, which result from specific environmental conditions (active gaming engagement at an optimally matched skill-challenge level), resonant with what has been described in early phenomenological literature as "flow". In another study, Kozhevnikov et al. (2022) demonstrated that collaborative Escape room games, either played in a real-world setting or in immersive virtual reality, also induced the ECSs in a team of players as long as these games were "survival" type of games. According to Kozhevnikov et al. (2018, 2022), it is autonomic arousal [i.e., a withdrawal from relaxation and stimulating to action, as indicated by parasympathetic nervous system (PNS) activity towards 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 gaming, which underlies the ECSs and lead to the observed focused attention enhancements.

Arousal corresponds to the state of high wakefulness and readiness to respond to the stimuli 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 cognitive functions (Lacey & Lacey, 1978; Jennings et al., 2015), which are necessary to meet the urgent demands of struggle, fight, or escape. Indeed, previous research has demonstrated that the amount of pre-stimulus arousal exhibited by non-human primates and humans predicts the probability of success on a number of visual tasks, including attention and memory tasks (Hasegawa et al., 2000; Robbins, 2005). This evidence suggests that arousal might serve as a unifying mechanism underlying focused attention enhancements during ECSs, occurring as a result of various activities.

Considering the significance of ECSs for advancing human performance and their potential implications for training military personnel, 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. Previous HCI research has shown that the "adrenaline-rush" nature of the video game [i.e., 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)] is an important gaming dimension to induce the state of flow, as the violent content of FPS games significantly increases arousal (Barlett et al., 2008). However, as recent research suggests (Kozhevnikov et al., 2022), the "adrenaline-rush" nature of the video game alone is not sufficient to induce ECSs, and the effect of the player's perspective might be critical. In video gaming, two fundamentally different perspectives from which the player views the scene are typically implemented, first vs. third-person perspective. 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. Previous HCI research demonstrated that players' perspective influences the level of engagement and associated arousal, which was more pronounced following the instruction to shoot from an egocentric vs. allocentric perspective (Petras et al., 2016). Similarly, in the study of Kozhevnikov et al. (2022), only first-person "adrenaline-rush" games led to the ECSs, as measured by improvement on the attentional blink task (ABT), reflecting enhancements in temporal aspects of attention.

Neuroimaging studies also prove that the egocentric perspective contributes to PNS withdrawal-associated arousal (Beissner et al., 2013). While allocentric representations are used for recognizing objects and scenes and do not involve direct interaction with the environment, egocentric representations are tightly coupled to the body's sensory-motor system during goal-directed object manipulation (Milner & Goodale, 2008). In this sense, egocentric representations 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, 2003, 2004). Therefore, interacting with a game environment from a first-person egocentric perspective might engage the players' motor system directly and, as a consequence, result in more pronounced autonomic nervous system (ANS) modulations (Beissner et al., 2013).

RESEARCH GOALS

The overarching goal of this study was to examine further the role of PNS withdrawal-associated arousal as an underlying mechanism of the ECSs, and how it relates to the player's perspective.

Our first objective was to validate the previous findings of Kozhevnikov et al. (2018, 2022) on the existence of ECSs. In Experiment 1, we replicated the phenomenon of ECSs by comparing the changes in ABT performance and corresponding arousal level in video gamers who played *Unreal Tournament 2004* (UT, FPS) vs. control participants who were resting or doing unrelated cognitive tasks during this period. Our second objective was to examine the role of a player's perspective in accessing the ECSs. In Experiment 2, all the participants played both an egocentric game (UT) and an allocentric game (Metal Slug, MS). In addition to having similar contact, both games, UT and MS, have 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. In terms of the requirement for cognitive processing, both games required a fast speed of processing and focusing attention on one specific task (to shoot opponents).

In both Exp. 1 and 2, following 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 be the result of figuring out the effective strategy to perform the ABT (e.g., attention diffusing when a distracting secondary task is carried out, Arend et al., 2006; Wierda et al., 2010), significant improvements on the ABT due to attention diffusing strategies are rare and of limited magnitude (Arend et al., 2006). It is generally found that individual A.B. magnitude cannot be significantly reduced by simply practicing the task (Tang et al., 2014, for a review). In Experiment 1, ABT was administered to participants before and immediately after 30 min gaming. In Experiment 2, to examine whether the ECS dissipates within 30 minutes 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 minutes of rest.

Furthermore, in both Experiments 1 and 2, we used electrocardiography (ECG) methodology to examine the role of PNS withdrawal-associated arousal in accessing the ECSs. ECG measures are shown to be reliably related to the activity of the ANS, including its PNS and SNS divisions (Camm et al., 1996). Specifically, an ECG marker indicative of PNS activation (relaxation) is the increase in HF HRV (Pomeranz et al., 1985). According to recent research (Toledo et al., 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 of 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 et al., 2018). Based on the results of 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 ECSs experiences, experimentally induced via gaming.

EXPERIMENT 1

Method

Participants

Twenty-six participants (18 males) were recruited for Experiment 2 through social media advertising for cash remuneration (age, M = 31.25, SD = 6.08). The participants were expert gamers (i.e., video gaming for at least 1 hour/day, 4 days/week for the last 6 months) in FPS games.

First-Person Shooter Video-Game Unreal Tournament (UT)

The action video game chosen for this study was an FPS game, specifically Unreal Tournament 2004 (UT 2004) by Atari. The player sees 3D graphics on a computer screen from the perspective of their avatar in the game. The player must accurately aim his or her weapon and shoot opponents by maneuvering and clicking the mouse. At the same time, the player uses the keyboard to move the avatar in all directions to successfully dodge the bullets and proceed through the game's terrain. To achieve optimal skill-challenge balance, similar to previous research (Green & Bavelier, 2006), the difficulty level was raised when the participant exceeded a kill-death (KD, number of kills and deaths in the game) 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].

Attentional Blink Task (ABT)

Attentional blink refers to a phenomenon in which a participant exhibits a significant drop in performance when instructed to identify two target letters in a rapid serial visual presentation. Specifically, when two targets are presented within approximately 200-500 ms of one another, identification of the second target tends to be impaired. We adopted an ABT task from Raymond, Shapiro & Arnell (1992) using E-prime 1.0 software. Participants were positioned 63 cm from a Dell 17-inch monitor. They viewed a rapid sequence of letters (approximately 0.82° × 0.82°) on a gray background at the center of the screen (see Figure 1) and were asked to report: (a) the identity of the one white letter (T1) in a sequence of black letters and (b) whether or not a letter 'X' (T2) was present after the white letter (50% of trials). Each letter appeared for 16.7 ms, followed by an 83.3 ms inter-stimulus interval (ISI). The sequence varied in length from 16 to 22 letters, with the white letter appearing unpredictably anywhere from the 7th to the 15th position in the sequence" (Figure 1).

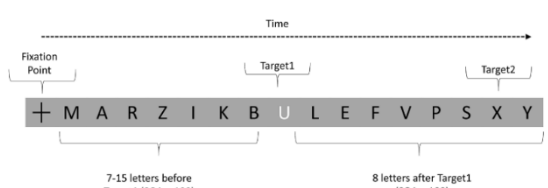

Figure 1. Illustration of an Attentional Blink Trial. T1 is a white letter embedded in the stimulus stream (A-Z), and T2 is a black X presented (50% of trials) at a variable serial position after T1.

Procedure

The group of video gamers played UT (Unreal Tournament 2004) for 30 minutes, 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-minute 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 using the NeXus-10 device and BioTrace+ software (Version V2012C, Mind Media, Netherlands) at a sampling rate of 256 Hz. All participants were pre-and post-tested on the ABT. Each participant performed an adapted version of the Attentional Blink Task (ABT) (Raymond et al., 1992), consisting of 96 trials, twice: immediately before (ABT pre-test) and after (ABT post-test) video-gaming session. The control group filled out a cognitive style questionnaire in-between the ABT pre-test and ABT post-test. ABT was run in E-Prime 1.0 software, with participants at approx. 63 cm distance from the computer monitor.

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 frequencies ranging from 0.15-0.40 Hz (HF) and 0.04-0.15 Hz (LF), according to heart rate variability (HRV) analysis standards (Camm et al., 1996).

Results

We excluded five participants (2 from the experimental group and 3 from the control group) as these participants did not show the expected AB effect (non-blinker) based on the criterion proposed by Martens et al. (2006).

ABT performance

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 T2|T1 accuracy collapsed across lags 2, 3, and 4 as the dependent variable. The results showed that experimental and control groups did not significantly differ on the ABT pre-test, $F(1,38) = 1.07$, $p = .31$. To access the change in ABT performance from pre-test to post-test, we used a 3X2X2 Mixed ANOVA with Lag (lag 2, lag 3, lag 4), Time (ABT pre-test, ABT post-test) as within-subjects factors, and Group [UT, Rest] as a between-subjects factor,

The main effect of Lag was significant, $F(2,74) = 43.14$, $p = .001$, $\eta_p^2 = .54$, and pairwise comparisons using the Bonferroni correction indicated increased accuracy with each lag (lag 7 > lag 4 > lag 3, all *ps* < .05, and lag 3 > lag 2, $p = .08$), replicating the classic AB effect (Raymond et al., 1992). The effect of Time was also significant, $F(1,37) = 7.20.9$, $p = .01$, $\eta_p^2 = .16$, indicating more accurate performance on ABT post-test than on pre-test. Importantly, the interaction between Group and Time was significant, $F(1,37) = 28.91$, $p < .001$, $\eta_p^2 = .44$. Follow-up ANOVAs revealed significant improvements from ABT pre-test to ABT post-test in the experimental (UT) group [$F(1,18) = 53.67$, $p = .000$, $\eta_p^2 = .74$], but not in the control group, $F(1,18) = 2.53$, $p = .13$]. The results for the experimental group are shown in Figure 2.

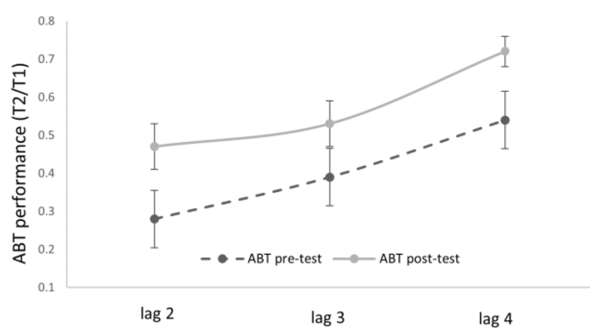

Figure 2. Changes in ABT performance by Lag from pre- to post-test for the experimental group.

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 all of them did not show any significant improvements from the ABT pre-test to post-test. None of the other effects were significant, including Lag X Time X Group interaction, all *Fs* < 1, suggesting similar ABT improvements in the experimental group at each lag (see Fig. 2).

Thus, only the experimental group showed a significant improvement on the ABT task after playing the FPS videogame, while the participants in the control group demonstrated similar levels of ABT performance before and after the rest period.

HRV analysis

HRV data of 2 participants (1 from the control group and 1 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 from Time-1 to Time-2 (first and last 5 minutes of 30-minute gaming/resting period), we performed a within-subjects ANOVA, with Time (Time 1, Time 2) as within-subject factor and Group (UT, Rest) as between-subject factor. The results yielded a significant effect of Time, $F(1,34) = 7.45$, $p = .01$, $\eta_p^2 = .18$, with HF HRV decreasing from Time 1 to Time 2. Importantly the effect of Group X Time interaction was significant, $F(1.34) = 4.10$, $p = .050$, $\eta_p^2 = .11$. While there was a significant reduction in HF between the two time points for the UT group, $F(1,19) = 10.86$, $p = .004$, $\eta_p^2 = .36$, 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 and LF/HF yielded insignificant effects of Time (*ps*> .40) and insignificant Group X Time interactions (*ps* >.19), suggesting that only the video gamers who played the UT developed the state of arousal, but no changes in the ANS state were observed for the control group.

EXPERIMENT 2

Method

Unreal Tournament (UT) – Egocentric game

See the description of the game in Exp 1.

Metal Slug (MS) – Allocentric game

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 the difference in its allocentric perspective. In this game, the player views 2D graphics viewed from the third-person perspective of their avatar (Fig. 3 shows screenshots from UT and MS games).

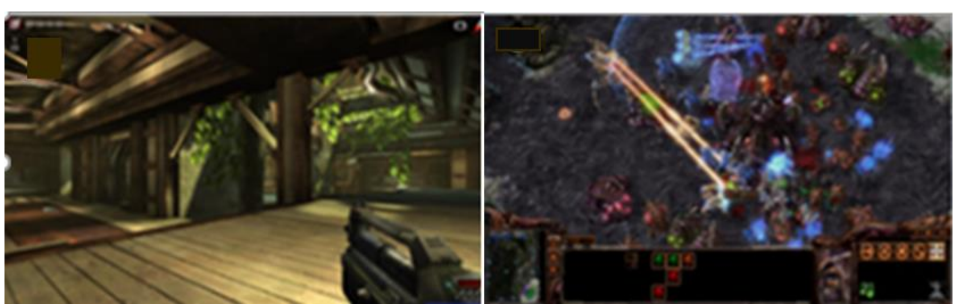

Figure 3. Screenshots of the UT (left) and MS (right) games

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 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 6 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.

Attentional Blink Task (ABT)
See the description of the AB task in Exp 1.

Presence Questionnaire (PQ)
The 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 that asks individuals to rate their 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).

Participants
Twenty-six participants (18 males) were recruited for Experiment 2 through social media advertising for cash remuneration (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 hour/day, 4 days/week for the last 6 months) in the games used in this experiment (UT and MS).

Procedure
All participants were exposed to both conditions (UT and MS), for two consecutive days, and each session lasted for 2 hours. 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 Attentional Blink Task – ABT pre-test. After that, they played either UT or MS to get through as many levels as possible. After 5 minutes of gaming, the difficulty level was moderated to match the participant's ability. We stopped them strictly after 30 minutes of game play. Then they completed the second Attentional Blink Task – ABT post-test1. After that, the participants were asked to rest for another 30 minutes. 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-minute rest period, subjects completed the Attentional Blink Task for the third time – ABT post-test2.

Results
Six participants were removed from all statistical analyses for the following reasons: 2 of the participants were non-blinkers (i.e., not displaying the AB effect), one of the participants did not show up for the second session, 3 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 2 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.

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 non-significant, $t(19) < 1$, $p = .90$.

Based on the results of Experiment 1 that playing the UT video game led to comparable improvements across all the lags within the AB window (with the highest percentage of accuracy improvement for lag 2), in this experiment, the ABT performance changes were calculated as the absolute difference in T2]T1 /accuracy between the ABT pre- and post-gaming averaged over lag-2 only. Paired samples t-test (two-tailed) revealed that T2|T1 accuracy at lag 2 on the ABT pre-test was significantly lower than at lag 7, $t(19) = 8.64$, $p < .001$.

ABT Performance

The changes between the ABT pre-test and ABT post-test1 (∆ABT1), a between the ABT pre-test and ABT post-test2 (∆ABT2) for each game, are plotted in Fig. 4A. A 3X2 repeated measures ANOVA with Time (ABT pre-test, ABT post-test1, ABT post-test2) and Perspective (egocentric, EGO; allocentric, ALLO) as within-subjects factors revealed a significant main effect of time, $F(2, 36) = 8.71$, $p = .001$, $\eta_p^2 = .31$, 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 no significant differences between the ABT pre-scores for the EGO and ALLO games, $F(1,19) = 2{,}97$, p =.10.

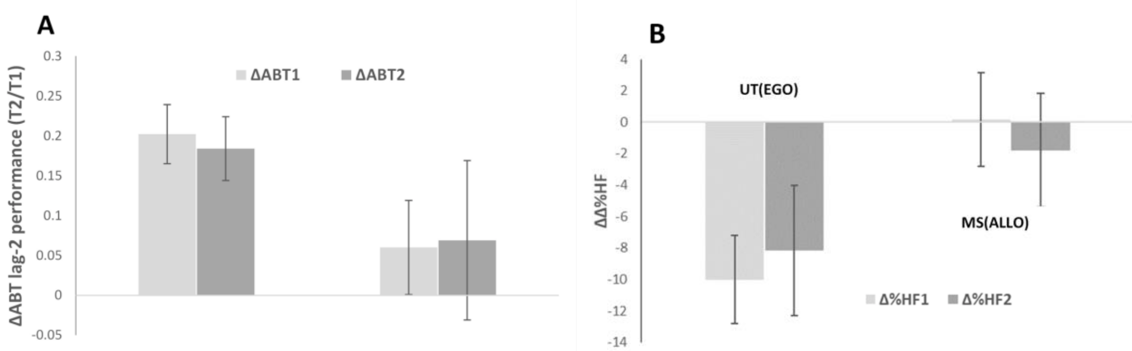

Figure 4 ABT and HRV Changes. (A) ∆ABT1 and ∆ABT2 change due to gaming (EGO vs. ALLO). (B) ∆%HF1 and ∆%HF2 changes due to EGO vs. ALLO games. Bars represent mean values ± SEM.

There was, however, a significant interaction between Perspective and Time, $F(2,36)$.= 3.59, $p = .037$, $\eta_p^2 = .16$. For EGO game, the follow-up repeated measures ANOVA with Time (ABT pre-test, ABT post-test1, ABT post-test2) yielded a significant effect of Time, $F(2,38) = 8.91$, $p = .001$, $\eta_p^2 = .32$ and pairwise comparisons, showed that ABT performance during post-test1 was significantly more accurate relative to the pre-test (p < .001; *M*pre = .27, *SD* = .21; *M*post-test1 = .47, *SD* = .28] as well as during post-test2 relative to the pre-test (*p* =.18, *M*post-test2 = .41, *SD* = .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, ABT post-test2) showed a non-significant 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 (*M*pre = .40, *SD* = .35; *M*post-test1 = .47, *SD* = .28; *M*post-test1 = .38, *SD* = .26). Thus, participants exhibited significant improvements on the ABT task 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 minutes of rest, the UT (EGO) group still showed significant improvements on the ABT are consistent with the results reported by Kozhevnikov et al. (2018). When comparing performance of the participants, however, between ABT pre-test taken on Day 1 and Day 2, their performance showed no significant difference, paired-samples *t* test (two-tailed), $t(19) = -1.09$, $p = .28$, *M*pre Day 1 = .29, *SD* = .29; *M*pre Day 2 = .38, *SD* = .30, suggesting that the ECS does last more than 30 minutes but dissipates by the next day.

HRV Analysis

For both EGO and ALLO conditions, ∆%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, ∆%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 3X2 repeated measures ANOVA with Time (HF pre-test, HF post-test1, HF post-test2) and Perspective (EGO, ALLO) as within-subjects factors (see Fig. 4B). 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, HF post-test2) yielded a significant effect of Time [F(2,38) =8.49, *p* =.001], $\eta_p^2 = .32$ 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, HF post-test2) yielded no significant effect of Time, F< 1, *p* =.5. Overall, the results indicate significant decrease in both Δ%HF1 (Δ*M* = -10.01, *SD* =12.53), and Δ%HF2 (Δ*M* = --8.17, *SD* =13.37) for EGO condition, but no changes in either Δ%HF1 (Δ*M* = -0.17, *SD* =12.53) or Δ%HF2 (Δ*M*=-1.78, *SD* =15.30) for ALLO condition.

To examine LF changes, we performed a 3X2 repeated measures ANOVA with Time (LF pre-test, LF post-test1, LF post-test2) and Perspective (EGO; ALLO) as within-subjects factors. The main effects of Perspective, F < 1, *p* = 0.9) and Time, *F*(2.38)= 0.8, *p* =.11 as well as interaction between Perspective and Time (*F* < 1, *p* =.85) were non-significant. Overall, the changes in %LF were non-significant, either for the EGO condition (Δ*M* = -0.03, SD = 17.95) or ALLO conditions (Δ*M* = -1.84, SD =18.22). In addition, we performed repeated-measures ANOVA with Time (LF/HF pre-test, LF/HF post-test1, LF/HF post-test 2) and Perspective (EGO, ALLO). The main effects of Perspective and Time, as well as the interaction between Perspective and Time, were non-significant (Fs < 1, all *p*s > .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 an unchanging LF/HF ratio for the egocentric condition indicates arousal - a reduction in PNS activity with a shift in the balance towards relative sympathetic enhancement (Toledo et al., 2003). The unchanging HF, LF, and LF/HF patterns for the allocentric condition indicate no ANS-related changes 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 minutes of rest.

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 (Exp. 1) and UT(EGO) condition (Exp, 2). As the linear relationship between ABT improvements and HF HRV changes holds true 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 decreases with LF and LF/HF remaining unchanged were interpreted as generated by PNS withdrawal associated arousal (Chalmers et al., 2014; von Rosenberg et al., 2017), which is different from the state of stress, during which a decrease in PNS response could be accompanied by increases in LF (SNS activation). Therefore, we removed 3 players from Exp. 1 and 4 players from Exp. 2 who exhibited HF increases (relaxation). In addition, 3 players from Exp. 1 and 2 players from Exp. 2 were also removed, as they exhibited LF increases of more than 20% (more than 1.5SD of the mean LF) of their corresponding group, suggesting that they experienced the state of stress. For the remaining 25 players [13 players from the UT group (Exp. 1) and 12 players from the egocentric condition (Exp. 2) with a complete 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 (**Fig. 5**).

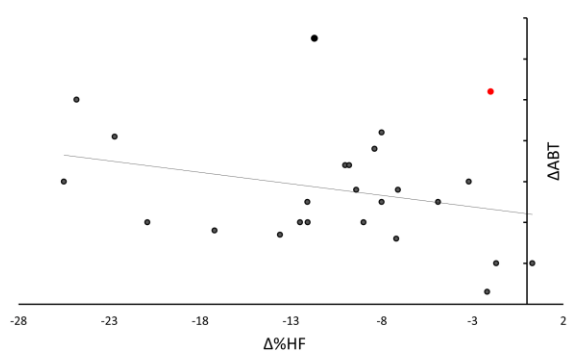

Figure 5. ABT Performance Changes from Pre-test to Post-test (ΔABT) vs. Pre-test to Post-test %HF Changes. The red dot indicates a data point, removed from the analysis as influential, based on Cook's Distance.

The initial regression, however, was not significant [$R = .28$, $R^2 = .08$, $F(1,24) = 1.95$, $p = .17$]. One of the data points (indicated by the red dot in Fig 5), however, was identified as being influential based on its Cook's Distance (0.32), which was more 6 times 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 (.06). However, his performance at both ABT post-test1 (.52) and post-test2 (.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 in the pre-test. After removal of this data point, the regression was significant 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, 2 other players experienced the ECS only in the allocentric condition. Interestingly, these 4 players were the only competition level gamers in our sample, with 2 of those who accessed the ECSs specializing in Metal Slug arcade types of games. These results suggest that a high level of expertise might facilitate access to ECSs from the allocentric game perspective.

DISCUSSION

Our results are consistent with previous findings of Kozhevnikov et al. (2018), and they demonstrate that playing 30 minutes of action video games induces the ECS, characterized by significant ABT increases (representing a behavioral marker of the ECSs) and HF HRV decreases (representing a physiological marker of the ECSs). Furthermore, after combining the data from Experiments 1 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 PNS withdrawal-associated arousal. These findings further support the existence of ECSs, and that these states are sub-served by PNS withdrawal-associated arousal, which is directly related to the level of focused attention enhancements and, therefore, the degree to which ECSs are experienced.

Although threat coping strategies and associated arousal might seem as a negative phenomenon leading to stress, according to polyvagal theory (Porges, 2007), PNS withdrawal associated arousal is an intermediate state between a state dominated by PNS influences facilitating social interactions in situations that are safe from danger, and a state dominated by SNS influences reducing a fight-or-flight response in situations of imminent danger. While in the case of real-life challenges of more general nature (e.g., car accidents, fights, exams), due to optimal challenge, individuals without any expertise might exhibit PNS withdrawal associated arousal, in the case of domain-specific challenges (e.g., extreme sport, chess-playing, military missions), 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, the “loss of control” mode predominantly involves the cortico-adrenal 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.

Furthermore, according to our results, although “adrenaline-rush” activity is critical, it might not be sufficient by itself, without the egocentric perspective, to elicit the ECS. 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 arousal level required to access the ECS, it seems important for the “adrenaline-rush” activity to have direct relevance to oneself, which is facilitated by playing a game from an egocentric perspective. Overall, the results suggest that ECSs cannot be easily included by passively watching someone else’s activities (e.g., watching TV). To induce ECSs, an activity should directly engage an individual (from an egocentric perspective) and be associated with a high level of emotional involvement (e.g., performing surgery, playing chess, composing). On a more general level, outside of the gaming context, our findings suggest that all activities contributing to the state of PNS 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), intense skeleton muscular 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). 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, the level of expertise), beyond immediate physical danger or survival threat, may also contribute to enhancing the level of arousal, thus leading to the experience of ECSs.

Considering that ECSs, as any biological, mental, or physical state, usually take a certain amount of time to develop, peak, and dissipate, it does not end instantaneously after the supporting activity has stopped but persist for some time (dissipation period). Our results suggest that although enduring for longer than initially suggested (30 minutes, 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. According to Exp. 2, ECSs did not dissipate 30 minutes after completing the supporting activity. Importantly, HF decreases 30 min post-gaming relative to baseline were also significant, indicating that PNS withdrawal associated arousal persisted even after 30 minutes 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 PNS withdrawal associated arousal.

Implications for military mission preparation

Although ECSs are transient, a temporary boost in cognition (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. Most research on training cognitive skills has targeted long-term training and involved prolonged training procedures. This includes long-term video-gaming research (Dale et al. 2020) as well as research on training of basic combat soldiers' mental skills (Adler et al, 2015). While the effects of long-term training procedures might be durable, they are small (Adler et al., 2015). Therefore, while research on long-term training informs us that cognition can be improved over time, within certain limits, as a result of specific training, the current 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.

Therefore, from a more practical perspective, this study proposes a tool, which has the potential to dramatically boost military personnel's mental skills in preparation to short-burst missions. If ECSs could be activated in military personnel using 30 min "adrenaline-rush" type of simulations, the content of which can be designed to resemble the requirements of their upcoming missions, this could lead to dramatic enhancements of their cognitive capacities and unprecedented performance for the duration of the follow-up mission. Based on our previous research on ECSs (Kozhevnikov et al., 2022), immersive 3D VR simulations could be the most effective environment to train military personnel to access the ECSs. Not only does immersive VR provide a relatively realistic and immersive environment for individuals and teams that can simulate dangerous and highly challenging egocentric activities, but it also affords concurrent neurophysiological data collection and rigorous control of variables, which is impossible to achieve in the real world. For example, heart-rate monitoring devices worn by trainees in such VR environments, by providing information about the HRV changes, would allow real-time updates of the trainees' ANS states, particularly whether individuals are optimally aroused, over-challenged (stressed), or under-challenged. However, more research is required to identify different aspects of such immersive VR simulations that can facilitate quick and efficient access to the ECSs. Our pilot interviews with professional gamers, for example, suggest additional aspects of gaming activity, such as attentional focus (i.e., engaging in focused vs. divided attention activity), may be essential to access the ECSs. None of the participants playing StarCraft in Kozhevnikov et al. (2022) was able to access the ECS, as according to their informal reports, multitasking required by this game "drained" their energy and made them tired. Anecdotally, in competitive FPS team games, such as Counter-Strike: Global Offensive (CS: GO), to mitigate the multitasking load (strategy design and implementation), a designated team member instructs and directs the other players' activities so that other players can focus on a single goal, for example, to kill enemies. In addition, other dimensions, such as 2D versus 3D game presentation, the uncertainty of risk estimation, or the complexity of movements, should also be examined in future research, as they may also contribute to accessing ECSs.

One of the most significant challenges in designing such a training procedure is to allow experiencing ECSs in a "sparing mode", that is, to consciously maintain its required level and safely exit the state. As experiencing a prolonged or high-intensity state of arousal is not safe and might lead to the system's chronic over-activation, resulting in hypertension and coronary artery disease, or even heart failure (Johnson, 2013), control over ECSs implies expertise in manipulating the level of arousal as well as quicker return to the baseline HRV state. Indeed, there have been cases of visual artists who continued to persist on painting “single-mindedly, disregarding hunger, fatigue, and discomfort” for days (Nakamura & Csikszentmihalyi, 2002) or athletes (runners) who were pushing their limits during the Olympics until they collapsed. In this respect, the knowledge of Eastern martial arts and Tibetan practices involving special breathing exercises might be helpful. Research suggests that the breathing techniques employed by these practices, by manipulating tidal volume, respiratory frequency, the ratio between the length of inspiration and expiration, and period of breath-holding, all affect HRV markers and might help to increase or decrease the intensity of arousal, prolong its duration, and allow a quick return to the state of relaxation (Telles et al., 2011). In combination with modern technological advances (egocentric immersive VR simulations) aimed at allowing efficient access to the ECSs, the breathing techniques can facilitate maintenance and control of these states. Future research should further investigate the temporal dynamics of ECSs, particularly when combined with different breathing patterns, including the recovery time from PNS withdrawal associated arousal, to lead to quick but safe access, maintenance, and exit from these states.

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