Boosting Cognitive Capabilities through Enhanced States during Gaming

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ABSTRACT

We report on the existence of enhanced cognitive states - states characterized by dramatic temporary improvements in focused attention, as measured by an attentional blink task. In Experiment 1, significant attentional improvements were exhibited by participants who played action video-game (First-Person Shooter), and whose skills matched the level of the video-game (optimal challenge), but not by those who were over challenged or under challenged. Furthermore, using EKG (electrocardiography) methodology, we showed that arousal, indicated by withdrawal from parasympathetic activity and activation of the sympathetic nervous system, is a necessary physiological condition underlying the enhanced cognitive states. In Experiment 2, we showed that participants who played high-arousal collaborative physical puzzle game (such as Escape Room, in which a team of players solve a series of puzzles meeting certain criteria) exhibited similar enhanced cognitive states to the group of FPS video-gamers who were optimally challenged in Experiment 1. In contrast, participants who played a low-arousal computerized puzzle game, such as Tetris, did not exhibit such attentional enhancements, despite their active engagement in the game.

Overall, the findings provide the experimental evidence for the existence of the enhanced cognitive states through high-arousal gaming experiences. In particular, the results suggest that the observed attentional enhancements cannot be simply due to the activity of gaming per se, but might rather represent an enhanced cognitive state resulting from specific conditions (heightened arousal in combination with active engagement and optimal challenge), resonant with what has been described in previous phenomenological literature as "flow" or "peak experience". The enhanced cognitive states are expected to be universal across domains that involve first-person focused attention activities (e.g., painting, drawing, meditation). The finding of this research suggest practical ways for consciously accessing latent resources of our brain to temporarily boost dramatically our cognitive capacities upon demand.

ABOUT THE AUTHORS

Maria Kozhevnikov is an Associate Professor at the National University of Singapore and also a Visiting Associate Professor at Harvard Medical School. Maria Kozhevnikov received her Ph.D. from Technion (Israel) jointly with UC Santa Barbara. Prior to joining the National University of Singapore, she has held faculty positions at Rutgers University (NJ) and George Mason University (VA). In the past two years, she has also served as a Program Director at the US National Science Foundation. Her research interests focus on examining the neural mechanisms of visual/spatial processing as well as in exploring ways to train visual/spatial skills using innovative technologies and gaming.

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INTRODUCTION

The existence of optimal experiences, in which specific cognitive processes (e.g., attention, perception) are dramatically enhanced for limited durations has been suggested by phenomenological research (qualitative analysis of narrative data, Csikszentmihalyi, 1990; Maslow, 1999), but often overlooked in the domain of experimental psychology. Csikszentmihalyi (1975, 1990, 1997) termed such experiences as *flow*, and Maslow (1962) as *peak experiences* (1965), and they defined them as unique, energized yet effortless, states of consciousness, characterized by a number of qualities, such as the merging of action and awareness (the awareness is entirely focused on the activity, and all distracting stimuli are ignored), the loss of awareness of oneself (as a social actor), intense concentration, and distorted sense of time.

These states have been reported during the creative processes of visual artists (Getzels & Csikszentmihalyi, 1976), where they persisted on painting "single-mindedly, disregarding hunger, fatigue, and discomfort" (Nakamura & Csikszentmihalyi, 2002, p.89) as well as during various gaming experiences, such as basketball, chess, or video-gaming (e.g. Keller & Bless, 2008; Moller et al., 2010). Flow has been also reported by top action and adventure sport athletes, while they were achieving their greatest feats (Kotler, 2015). The critical conditions allowing an individual to reach the state of flow in any domain of expertise, identified consistently across the phenomenological research, are: 1) the direct involvement in the activity, so an individual must not just be an observer, but "actively engaged in some form of clearly specified interaction with the environment" (Csikszentmihalyi, 1975, p. 43), and 2) the presence of significant challenge (termed optimal challenge), which pushes one's skills to their limit, but not beyond one's capacities (Csikszentmihalyi, 1975). Flow has also been related to engagement, when the perceived challenge of the task and participants' skills were high and in balance (Shernoff et al., 2003).

Despite a wealth of phenomenological reports on the existence of flow or peak experiences, and the circumstances that produce these experiences, due to the difficulties of capturing them experimentally, there have been only a few experimental studies investigating the existence of these states and their characteristics. For instance, Kozhevnikov, Louchakova, Josipovic, & Motes (2009) reported the existence of temporary meditative states, in which enhancements on a number of visual tasks requiring focused visual attention were observed after specific types of Tibetan meditation (holding the focus of attention on an internally generated image of a Tibetan deity). Similarly, although the so-called "Mozart effect" (Rauscher, Shaw, & Ky, 1993) was not consistently replicated (Chabris, 1999), a more recent study by Ho, Mason, & Spence (2007) observed that listening for 10 minutes to a Mozart sonata resulted in short-term improvement in the temporal aspects of attention as measured by an attentional blink task.

In the area of gaming, and in particular action video-gaming such as First Person Shooter (FPS), a number of researchers have speculated it might induce a state of flow (e.g. Cowley, Charles, Black, & Hickey, 2008; Klasen, Weber, Kircher, Mathiak, & Mathiak, 2011; Procci, Singer, Levy, & Bowers, 2012; Sherry, 2004; Weber, Tamborini, Westcott-Baker, & Kantor, 2009) due to a high level of "absorption" (Weber et al., 2009, p. 403), "intense attentional focus" (p. 397), and "merging action with awareness" (Klasen et al., 2011, p. 2). However, most previous empirical research investigating the influence of gaming on cognition has been focused primarily on the long-term (durable) effects of video gaming (e.g., Dye, Green, & Bavelier, 2009; Green & Bavelier, 2003, 2006a; Green & Bavelier, 2006b; Li, Polat, Makous, & Bavelier, 2009; but see Mayer, 2014, for a review). These studies report that playing FPS games has a long-term positive effect on several aspects of visual attention, such as enhanced peripheral vision (Green & Bavelier, 2003), target discrimination, identification and contrast (Green & Bavelier, 2007; Li et al., 2009), and multiple object tracking capacity (Green & Bavelier, 2006a; Spence & Feng, 2010).

One recent experimental study (Kozhevnikov et al., 2018) focused more closely on the role of action video-gaming in bringing about the enhanced cognitive states, similar to the concept of flow, in which dramatic improvements in certain cognitive capabilities were exhibited by participants who played an FPS videogame. Consistently with the phenomenological literature suggesting that active engagement is indeed critical for the induction of enhanced state, their results showed dramatic improvements on the attentional blink task, a measure of temporal aspects of attention for those participants who actually played the video-game but not the ones who just observed. In addition, analysis of interviews with players identified themes similar to those characterized as “flow” in earlier phenomenological literature. Interviewed players frequently reported experiencing such phenomena as tunnel focus, arousal, and loss of self-awareness, consistent with descriptions of a flow experience. In another experiment, to investigate which particular cognitive processes are enhanced during the above enhanced cognitive states, Kozhevnikov et. al. (2018) presented video-gamers with various tasks measuring capacities of different attentional networks – conflict, orienting, and alerting (Fan et al., 2002) as well as with visual memory and spatial transformation tasks immediately after 30-minute video-gaming and then later after 30 minutes of rest. The results indicated that the participants significantly improved their performance immediately after video-gaming only on the tasks which required visual-spatial focused attention (i.e., visual memory and spatial transformation), however, these improvements were no longer observable after 30 min of rest, suggesting their temporary nature. No improvements were observed on other aspects of attention (conflicting, orienting, and alerting networks).

Taken together the findings of Kozhevnikov et al. (2018) suggested that 1) actively engaging in action video-gaming that was calibrated to one's own skill level for a mere 30 min is associated with dramatic temporary boost of attentional capacities; and 2) the cognitive improvements were limited to temporal and focused visual-spatial aspects of attention, and were not observed for other attentional networks. It is interesting that all previous research suggesting the existence of enhanced cognitive states, whether after listening to a Mozart sonata or following different types of focused meditation, reported improvement on attentional blink and visual-spatial tasks only. It is also worth noting that the cognitive capacities that showed improvements were not the ones that have been shown to improve durably as a result of long-term video-game training (orienting attentional network, e.g., Green & Bavelier, 2003), Thus, the observed enhancement could not be simply explained by video gaming conditions (e.g., optimal skill-demand compatibility during video-gaming) alone. Kozhevnikov et al (2018) suggested the existence of enhanced cognitive states, characterized by significant temporary boost of temporal and spatial aspects of focused attention.

RESEARCH GOALS

The overarching goal of this study is to further investigate the mechanisms of enhance cognitive states and examine conditions under which these states could be elicited.

Our first goal was to investigate the physiological correlates of the enhanced cognitive states resulting from action video-gaming as reported in Kozhevnikov et. al. (2018). Previous physiological studies have associated the state of flow with temporary changes in the autonomic nervous system (De Manzano et. al., 2010), in particular with psychological stress or heightened arousal. In Experiment 1, to assess the changes in activity of the autonomic system as a result of the enhanced cognitive states, we used EKG (electrocardiography) methodology. We analyzed heart rate variability (HRV), and specifically, EKG low-frequencies (LF) and high-frequencies (HF) (Camm et al., 1996; Pagani et al., 1986; Pomeranz et al., 1985; van de Borne et al., 1994; van Dijk et al., 2013). Changes in HF are reliably associated with changes in parasympathetic activity, while changes in the low frequencies (LF) are assumed to reflect both sympathetic and parasympathetic activation (Akselrod et al., 1981; Malliani et al., 1991; Pomeranz et al., 1985). The ratio of LF to HF (LF/HF) have been used to quantify the changing relationship between sympathetic and parasympathetic nerve activities (i.e., the sympatho-vagal balance) (Pagani et al., 1986). Our first hypothesis was that arousal, the act of withdrawing from relaxation and stimulating to action (as indicated by decreased parasympathetic and increased sympathetic activities) is a critical physiological prerequisite for the enhanced cognitive states (as measured by dramatic boost in performance on the attentional blink task).

Our second goal was to investigate the importance of optimal challenge as a condition for achieving the enhanced cognitive states, as has been suggested in phenomenological literature (Csikszentmihalyi, 1975). In Experiment 1, we assigned participants into three groups: Under-challenge (UnC), Optimal-challenge (OpC), and Over-challenge (OvC), in which they were presented with an FPS game of low, average, or high level of difficulty, respectively. Our second hypothesis was that if in fact the improvements on the attentional blink task observed in Kozhevnikov et al.’s

(2018) experiment were the result of an enhanced cognitive state, rather than active video-gaming per se, then only OpC group would exhibit these improvements along with associated arousal.

Our third goal was to further investigate which type of games lead to enhanced cognitive states. Based on previous reports that the state of flow can be induced only during highly adventurous, challenging, and arousing activities (Csikszentmihalyi, 1992; Kotler, 2015; LeFevre, 1988), we examined the effect of high- versus low-arousal games on the attentional enhancements. In Experiment 2, we compared the ABT improvements followed by playing Escape Room Game (ERG), which is a high-arousal collaborative physical puzzle game versus Tetris, a low-arousal computerized puzzle game.

EXPERIMENT 1

Method

Participants

Fifty-six participants (N=39 males) were recruited from the online portal of the Research Participation (RP) Programme in the Department of Psychology at the National University of Singapore (NUS). The participants were naïve to the purpose of the experiment. We required our participants to have some prior and on-going experience and interest in FPS video gaming. Overall, 5 participants reported playing more than 10 hours per week, 11 participants reported playing between 4 to 10 hours, and 40 participants reported playing between 2 and 4 hours of FPS per week.

First-Person Shooter Video-Game

The action video game chosen for this study was a FPS game, specifically Unreal Tournament 2004 (UT 2004) by Atari. The player sees three-dimensional graphics on a computer screen from the perspective of his or her 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 in order to successfully dodge the bullets and proceed through the game's terrain.

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 (e.g. see Dux & Kelly, 2012; Kelly & Dux, 2011), 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).

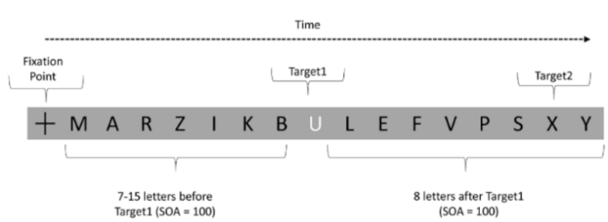

Figure 1. Illustration of an Attentional Blink Trial. T1 is a white letter embedded in the stimulus stream (A-Z) and T2 is a black X presented (50% of trials) at a variable serial position after T1.

Two decades of research has suggested that the attentional blink is a robust phenomenon that is likely attributable to a fundamental limit in sequential object processing, and that the processing limits evidenced in the attentional blink cannot be directly eliminated by brief exposure to the task (see Tang et al., 2014 for a review).

Procedure

Upon arrival, participants were randomly assigned to one of the three groups: UnC, OpC, and OvC. In particular, 16 participants were assigned to the UnC group, 22 participants to the OpC group and 18 participants to the OvC group. The three groups did not differ either in years of video-gaming experience [$F(2,49)=1.76$, $p = .18$] or frequency of playing ($F<1$, $p = 0.73$). First, the experimenter put on the participants the electrodes for EKG recording. Then, the participants were administered the ABT as a pretest, after which they were briefly interviewed about their gaming background, and asked to provide demographic information.

Second, to get participants accustomed to the particular FPS videogame used in the study, they were asked to play Stage 1 – during which the characters and game setting were introduced at the “Experienced” level (Level 3) for 5 min. The participants were told that the aim of the playing session was to enjoy themselves, while trying their best in the game. During this period, the experimenter observed the performance of each participant on the computer screen next door that displayed the same graphics as the participants’ screen, in order to judge the participant’ skills level apropos the group they were assigned. In particular, during this period the experimenter screened the participants to exclude any novices who were unable to play at the “Experienced” level and to identify any extremely skilled practitioners for whom the “Experienced” level was exceedingly easy. As a result of the 5-min screening period, one participant (randomly assigned to the UnC group) was identified as a novice who unable to play at the “Experienced” level, and his data were excluded from all the analyses. Another participant, who exhibited extremely advanced skills during screening, was reassigned from the OvC group to the UnC condition, as it became clear that even the highest levels of the game would not be particularly challenging for this individual. Thus, the resulting tallies for each group were as follows: UnC: 16, OpC: 22, and OvC: 17.

Third, after playing for 5 min, the participants were reassigned to a new game level, according to their experimental manipulation group. In the UnC group, participants were assigned to a lower level of game difficulty, usually “Average” (Level 2) or “Novice” (Level 1). In the OpC group, participants were assigned to “Experienced” (Level 3) or “Adept” (Level 4) levels. Participants in OvC group were assigned to the highest levels of difficulty, usually “Expert” (Level 5) or “Inhumane” (Level 6). All participants played the videogame for 30 min, with the UnC and OpC groups starting at the highest level of difficulty for their group (level 2 for the UnC, level 4 for the OpC group), and lowest level of difficulty (level 5) for the OvC group. During this play, the level of difficulty was readjusted after the end of the first match (about 15 min into the play period) for participants who were not able to achieve the specific KD ratio for their assigned group. Specifically, the difficulty level was decreased if the kill-death (KD) ratio went below 2:1 for participants in the UnC group, and it was increased if KD ratio went above 1:2 for participants in the OvC group, following criteria specified in previous research (Green & Bavelier, 2006a). Participants in the OpC group were expected to maintain a KD ratio between 1:2 and 2:1, and the level of difficulty for this group was raised when a participant exceeded a KD ratio of 2:1 and reduced when the ratio fell below 1:2. Thus, the KD ratio was maintained in the following intervals: UnC $[2{:}1, +\infty]$, OpC $[1{:}2, 2{:}1]$ and OvC $[0, 1{:}2]$. If a participant was unable to achieve the KD ratio required for his/her assigned group at any point during the game (i.e., either at levels 6 or 5 for OvC, 4 or 3 for OpC, and 2 or 1 for UnC), the participant’s data were excluded from all analyses. The group assignment is illustrated in Figure 2. Finally, after the playing session, each participant was given a 2-min self-report questionnaire, consisting of 4 questions, in which they were asked to assess the level of the challenge and its match to their skills on a 5-point scale. This was followed by an additional ABT session (post-test1), followed by 30-min rest period, after which the participants performed the ABT for the third time (post-test 2). The whole experiment lasted about one and a half hours in total.

Figure 2. Group assignment in Experiment 1

EKG recording and protocol

Although various measures (e.g., blood pressure, oxygen consumption, galvanic skin response) have been used to quantify changes in the autonomic system, we chose to use EKG as it is both non-invasive and less sensitive to environmental conditions such as humidity and temperature. Additionally, since the EKG electrodes were placed on the participants' torsos, the signal was less susceptible to motion artifacts induced by arm movement during the game. In the current experiment, the participants had their EKG measured throughout the entire experiment. EKG was recorded using the BioTrace+ Software recording system (Mind Media B.V.), and was sampled at 256Hz, and a high-pass filter of 0.1 was applied to the data. The measures were taken via two electrodes, one placed on the right collarbone and another below the left rib cage, and referenced to the left collarbone.

Heart rate variability (HRV) analysis

HF were computed using Welch's periodogram method (Welch, 1967), and were measured in absolute power (milliseconds squared). The HF frequencies we analyzed were 0.15–0.4Hz, and the LF frequencies were 0.04–0.15Hz, the ranges most commonly used in EKG analysis (Berntson et al., 1997; Bigger et al., 1992; Stein et al., 1993). The HF and LF changes due to videogame playing were calculated as the percent difference between the first and final 5 min of video-game playing, and the ABT performance change was calculated as the percent difference between post-test1 and pre-test performance on lags within the attentional blink window (i.e. 2, 3, and 4).

Results

Three participants were excluded from all analyses because they were unable to achieve the KD ratio required for their group at any point during the game. Two additional participants, who were "non-blinkers" and did not show an attentional blink effect, were also excluded from the analysis. Finally, one participant in the UnC group was excluded from all analyses as an outlier, since this participant showed improvement on ABT (ΔABT=0. 26) greater than 3 SDs above the UnC group mean (ΔABT=−0.02, SD=0.11). Thus, the final data analyses below include 49 participants: 14 in the UnC, 20 in the OpC, and 15 in the OvC group. To ensure that the assignment of the participants tot the three groups corresponded to the intended level of challenge, we compared the participants' assessments of perceived challenge and its match to their skills. There was a significant difference between the three groups in their perceived level of challenge: F(2,49)=19.3, p < .001. Consistently with the experimental manipulation, UnC group participants reported the least degree of challenge (M=10.9, SD=1.50), in comparison to the other two groups (p < .05), while OvC group participants reported the highest degree of challenge (M=15.9, SD=1.89; p < .01). The OpC group participants (M=13.7, SD=2. 87) reported significantly higher challenge than the UC group participants (p < .05) but lower than participants from the OvC group (p < .001).

ABT performance

We conducted a 3 (Time: pretest/post-test1/post-test2) ×4 (Lag: 2, 3, 4, 7) ×3 (Group: UnC, OpC, and OvC) ANOVA using T2|T1 accuracy across lags 2, 3, 4, and 7 as the dependent variable (see Fig. 3).

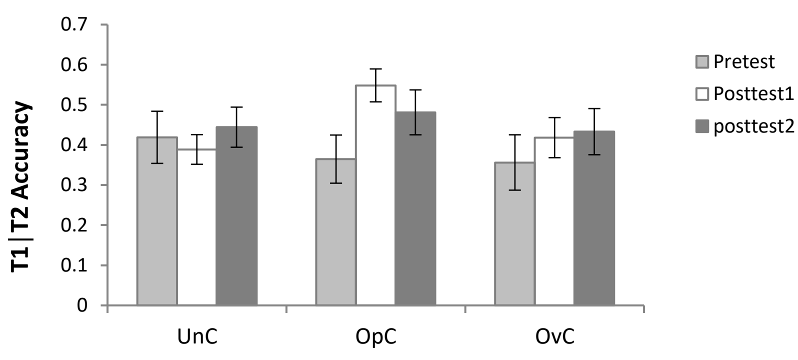

Figure 3. Performance on ABT pre-test, post-test 1, and post-test 2 by Group

As expected, the ANOVA yielded a significant main effect of Lag [F (3,47) =18.55, p < .001, ηp2=0.60], demonstrating a linear increase in accuracy with increasing lags (Lag 7 > Lag 4 > Lag 3 > Lag 2). The main effect of Group was not significant F(2,46)=0, 41, p=.67), however, there was a significant effect of Time, F (2,465)=11, 41, p < .01, ηp2=0.24). Also, there was a significant interaction between Time and Group, F(4,92)=7.11, p < .001, ηp2=0.24). The follow-up ANOVA for the UnC group yielded a non-significant effect of Time, F(2,26)=1.361, p=.022.

The UnC group did not show significant improvements in their ABT performance either from the pretest to post-test1 (Mpre=0.44, SD=0.24; Mpost1=0.40, SD=0.24; p=.12) or from the post-test1 to posttest2 (Mpost2=0.47, SD=0.27; p=.11). The ANOVA for the OpC group yielded a significant effect of Time [F(2,38)=14.38, p < .01, ηp2=0.43], and pairwise comparisons showed that T2|T1 accuracy was significantly greater during posttest1 relative to the pre-test (Mpre=0.42, SD=0.25, Mpost1=0.55, SD=0.19, p=.001, see Fig. 2), as well as during post-test2 relative to the pre-test (Mpost2=0.48, SD=0.27, p < .01). The performance of the OpC group slightly decreased from post-test1 to post-test2, but the change was not statistically significant (p=.10). Finally, for the OvC group, the effect of Time was not significant [F(2,28)=2.71, p=.08, ηp2=0.16]. The OvC group showed a slight, but non-significant improvement in T2|T1 accuracy from the pre-test to post-test1 (Mpre=0.38, SD=0.21, Mpost1=0.42, SD=0.22, 35.6% vs. 41.8%, p=.07), and no significant changes from post-test 1 to post-test 2 (Mpost2=0.43, SD=−0.22, p=.66).

Thus, only the OpC group showed a significant improvement on the ABT task after playing the FPS videogame, while the participants in other groups demonstrated similar levels of ABT performance before and after the video game. Similar to the results of Experiment 1, performance of the OpC group on the ABT task did not drop significantly after 30 min of rest.

HRV analysis

First, for each group, we computed the changes in LF and HF, as percentage difference in the LF and HF values, for the last 5min of video-game playing in comparison to the first 5min. Due to the noise in EKG recording, LF data for one participant from the OvC group were discarded. The results plotted in Figure 4.

The OvC group showed no significant changes in HF ((M=5.60, SD=43.64), t(14)=0.49, p=.6 or in the ratio ΔLF/HF (M=2.95, SD=13.23), t(14)=0.87, p=.4. However, the increases in LF (M=49.54, SD=64.54) were significant, t(14)=2.97, p=.01), indicating unchanged parasympathetic activity and increased sympathetic activity (Toledo et al.,, 2003). The OpC group showed significant decreases in HF (M=−37.08, SD=16.49), t(19)=−10.06, p < 001, but no significant changes in LF (M=1.72, SD=75.81), t(18)=0.09, p=.9) or in the ratio ΔLF/ HF (M=−1.14, SD=5.19), t(18)=0.95, p=.35. The pattern of HF decreasing and LF increasing (or remaining unchanged) indicates a reduction in parasympathetic activity and increase in sympathetic activity with a shift in balance toward relative sympathetic enhancement (Toledo et al., 2003).

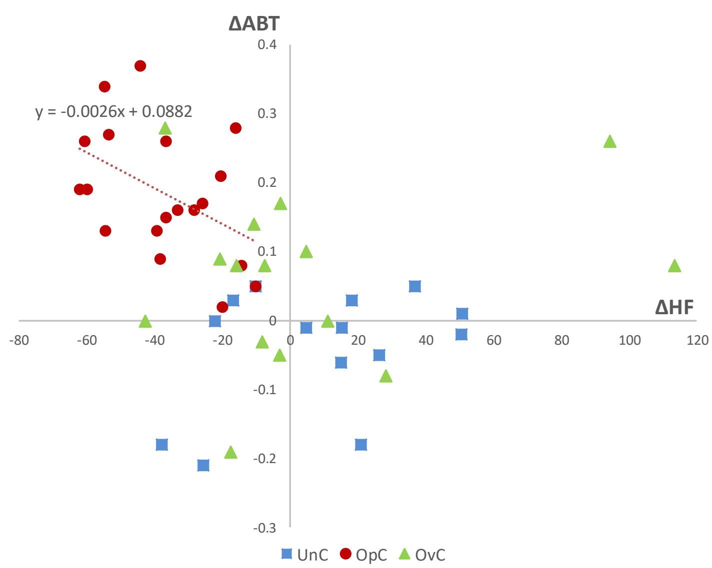

Figure 4. Changes in ABT versus changes in HF for UnC, OvC, and OpC groups

In summary, our results in Experiment 2 support the existence of the enhanced cognitive states, characterized by significant improvement in the temporal aspects of attention. The finding that only the OpC group exhibited a significant improvement on the ABT task from the pre-test to post-test 1, lending support to our hypothesis that the observed enhancements were not due specifically to the activity of video-gaming, but due to enhanced cognitive states requiring optimal challenge. Furthermore, the regression analyses showed the magnitude of attentional enhancements to be directly related to HF decreases, suggesting that the enhanced cognitive state is not uniform across individuals. Another interesting finding is that although the OvC group showed sympathetic activation, no improvement was observed in their performance on the ABT task. Thus, according to our results although sympathetic activation is a necessary condition for enhanced cognitive states, it is not sufficient by itself to induce the state. Our finding that the OpC group was the only group that had significant HF decreases suggests that not only the increase in sympathetic activity, but also the decrease in parasympathetic activity is critical for reaching enhanced cognitive states.

However, although we observed the trend, we did not observe a significant decrease in ABT performance back to baseline for the OpC group after 30 min of rest, suggesting either that an enhanced cognitive state might last longer than 30 min or that efficient learning takes place during the state.

EXPERIMENT 2

Method

Escape Room Game (ERG)

We selected the theme of "the Forgotten Temple" from one of the ERG operators in Singapore. In this plot, a group of treasure-hunters (recommended 3-5 players) are locked in a two-room structure with settings resembling an ancient temple. The goal of this adventure game is to find the key to the door of exit. There are 8 stages of problem solving (i.e. intermediate goals) each linked to the next in a certain sequence, and lead the players to the key. Teamwork is implied to complete the task. In order to avoid drastically different time taken for successful escape, players are given a portable phone and entitled to maximum five calls for hints.

Tetris

In this game (Tetris by Palmantics, http://www.palmantics.com/games/tetris/), 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.

Participants

Twenty-four participants (N = 14 males) participated in ERG condition and 15 participants (N = 7 males) participated in Tetris condition. The participants were recruited through online advertisement at the National University of Singapore. For the ERG condition, to ensure that the players in each group were comfortable working with each other, in the advertisement we encouraged them to form a group with his/her friends. To standardize the group performance, we also indicated that for condition participants should sign up in a team of four members. In the end, we have six groups of participants, among which 1) two groups are a mixture of NUS graduates from Engineering, Computing or Social Sciences; 2) one group involves graduate students from the NUS Communication and Media Department; 3) the other three groups are current undergraduate students from Psychology, Science and Computing respectively. For Tetris condition, participants were recruited from Psychology and Computing Departments; all the participants had a gaming experience in Tetris of minimum 1 hour per day, for 4 days a week for at least 6 months.

Procedure

Similar to the video-game condition, we used Attentional Blink Task (ABT) as an indicator of the enhanced cognitive state. We obtained computer access for ABT installation from the same ERG operator whose operation also involves a gaming café at the same premise. This setting ensured that the ERG players would be able to perform ABT immediately after their escaping to capture the effect of the enhanced state. Participants were pre- and post-tested on the ABT. The experiments with Tetris players were performed in the lab.

In the Tetris condition, the participants were asked to play a computerized Tetris game for one hour. The participants started the game at level 1 and the game automatically increased the falling speed of the blocks whenever 10 lines were cleared. Participants continued playing the game until the falling speed of the blocks was too fast for them to keep up, after which the game was reset back to level 1 for the subsequent round. Participants completed as many rounds as possible within approximately 1 hour. In the ERG condition, the participants first were briefed on the ERG instructions and the plot of the Forgotten Temple. They were also reminded that the time limit to escape the room was one hour and they could make a maximum of five calls for clues. Their personal smart phones were put aside into a private locker before they entered the room for escaping, such that they could only utilize the clues in the escape room itself. After the group successfully escaped, they were brought back to the café for the post-test ABT.

Results

Two participants form the ERG condition, who showed non-blinker performance (i.e. participants who did not show attentional blink effect but showed increasing trend for T2|T1 accuracy from Lag 2 to Lag 7) on the ABT from the same group, were excluded from the analysis.

Among the six groups of ERG participants, four groups escaped successfully within one hour, another group took 75 minutes to complete the escaping, and the last group did not manage to escape successfully. The time taken to escape were 40 minutes for the group with undergraduates from the School of Computing and around the 60th minute mark for all other groups except the one taking 75 minutes. For the ERG condition, a paired-sample t-test was significant, $t(21) = 3.93$, $p = 0.001$), $M_{pre} = 0.35$, $SD=0.22$ for the pre-test, and $M_{post} = 0.47$, $SD=0.26$ for the post-test, suggesting that ERG is able to induce the boost of temporal attentional capacities in a team of players, similar to FPS video-gaming in Experiment 1. However, for the Tetris condition, t-test was not significant $t(14) = 0.27$, $p = 0.73$), $M_{pre} = 0.41$, $SD=0.25$ for the pre-test and $M_{post} = 0.34$, $SD=0.24$ for the post-test.

Further analysis was conducted to compare the ABT improvements in Experiment 1 and 2 see Figure 5). The only groups that significantly improved on the ABT performance were OpC group that played FPS (Experiment 1) and ERG group (Experiment 2). Although overall ABT improvement from the ERG participants ($M_{ERG}=0.12$, $SD_{ERG}=0.14$) appears to be smaller than that of the OpC participants after FPS video-game ($M_{OpC}=0.18$, $SD_{OpC}= 0.09$), which could be explained by the difficulty to match skill-level balance during ERG, the difference is not statistically significant, $t(40)= -1.69$, $p=0.09$.

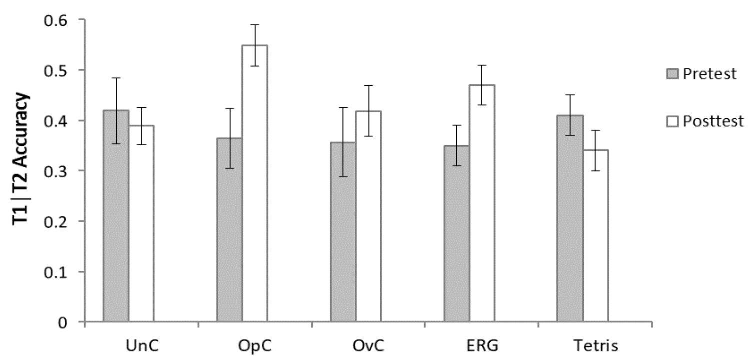

Figure 5. Comparative improvement of T1/T2 Accuracy on the ABT task in UnC, OpC, OvC groups (Experiment 1) and ERG group (Experiment 2)

While most participants (N=19) had improvements on the ABT after playing ERG, three participants from three different groups either showed no improvement (one participant) or encountered a slight drop in performance by 0.11 and 0.05 respectively. Thus, we may conclude that not everyone was experiencing the enhanced cognitive states even if the majority of the group did, possibly due to match-skill misbalance that was difficult to control during ERG. Also, not all ERG players were likely to have the same level of participation. Nevertheless, we did observe overall significant ABT enhancement as a results of ERG, in contrast to OvC and UnC conditions in Experiment 1, suggesting that ERG games can induce an enhanced cognitive states in most of the players.

Although we had only 6 groups playing ERG, we found significant correlation $r = -0.82$, $p <0.05$ between the time it took each group to complete the game (to escape) and Group Enhanced Cognitive State (i.e., enhanced cognitive state of each group, calculated as average of that group participants' ABT improvements). In summary, although it was impossible to control an optimal challenge during ERG, the results of Experiment 2 showed that overall improvement on the ABT in ERG group was comparable of OpC in Experiment 1, suggesting that it is possible to induce the state of flow in a team of players during adventure physical game. In contrast, we did not see any significant changes in ABT performance after one hour of playing Tetris, suggesting that high-arousal aspect of the ERG game is necessary for inducing the enhanced cognitive states.

DISCUSSION

The results of the two experiments suggest the existence of enhanced cognitive states in which temporal and spatial aspects of focused attention are dramatically enhanced for limited durations. These states are similar to flow experiences described in the phenomenological literature in the following aspects: First, the results of Experiment 1 showed that the observed attentional enhancements are not due to video-gaming per se, as only participants whose skills optimally matched the video-game level significantly improved their performance on the ABT. Second, the OpC group experienced the greatest decrease in HF in comparison with other groups, suggesting that heightened arousal is also a necessary condition for a flow state to occur. It is, however, not a sufficient condition, since there were participants in the OvC who were exhibiting increases in sympathetic activation without any attentional enhancements. Thus, not only sympathetic activation, but also a withdrawal of parasympathetic control, appears to be a critical physiological marker of enhanced cognitive states, and the magnitude of decreases in parasympathetic activity was directly related to the magnitude of attentional enhancements in the OpC group.

We were surprised to find, in Experiment 1, that there was no significant decline in game-players' performance on the ABT after 30 min of rest (although we did observe a trend in this direction). It is possible that the enhanced cognitive states experienced by the players in these experiments lasted more than 30 min following the gaming. Another possibility, however, is that learning during the enhanced state was especially efficient, enabling players to develop potent strategies for performing the ABT, which they later used when performing post-test2. Future research should investigate the duration of the enhanced state, the factors affecting it (e.g., the level of challenge experienced during the inducing activity, baseline attentional capacities, and experience with the activity) as well as the possibility to achieve accelerated learning in these states.

Furthermore, the results of Experiment 2 provided evidence that the enhanced cognitive states could be induced by ERG team playing but not Tetris. While ERG and Tetris have common features, such as 1) engagement in activity that requires full attention from players, 2) goal-directed actions of solving puzzles; and 3) appropriate level of challenge with immediate feedback, these features are not sufficient to induce the enhanced cognitive state. The difference between ERG and Tetris in high vs. low arousal. Similar to FPS, ERG is an adventure game, in which players are engaged in stressful activities (players are locked in an enclosed environment, where they need to solve related puzzles in order to survive and find the way out). Tetris is not an adventure game and it does not induce stress. Although the very term "flow" suggests a state of effortlessness, and the phenomenological literature connects the flow state with "euphoric feelings" (Csikszentmihalyi, 1990), it also describes flow in the context of coping with stress (Csikszentmihalyi, 1992). Wilson (1972) claims that life-threatening experiences such as fighting in a battlefield or engaging in an extremely dangerous task (e.g. defusing a bomb) inherently require intense focus, and LeFevre (1988) argues that flow cannot be induced by stress-free and low-challenge activities.

In conclusion, our study experimentally demonstrates that high-arousal games can elicit an enhanced cognitive state that resembles prior descriptions of flow or peak experiences, and is characterized by a significant temporary boost in focused attention. For this boost to occur, several conditions must be met, such as 1) heightened arousal, 2) active engagement in the activity, and 3) optimal skill-challenge match. These enhanced cognitive states appear to be universal, in the sense that the observed enhancements seem to be similar across different activities (listening to music, or doing certain types of meditation), not limited specifically to gaming. Overall, the current findings have not only theoretical but also practical implications. First, this study proposes a tool (video-gaming) to cognitive psychologists and neuroscientists to investigate enhanced states experimentally. Second, this study could make such experiences more accessible to the general population. Although it is transient, a temporary boost in focused attention can nevertheless be utilized in order to enhance performance during critical periods. In addition, the enhanced cognitive states might be directly related to creativity, and understanding how to attain such states may help us to boost creative performance (Csikszentmihalyi, 1996). Furthermore, even though these states are of limited duration, the learning experience obtained during this state could be long lasting. Psychologists should further investigate these states and the ways to induce them, since this will open up the possibility of consciously accessing the latent resources of our brain and boosting our cognitive capacities upon demand.

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REFERENCES

Akselrod, S., Gordon, D., Ubel, F. A., Shannon, D. C., Barger, A. C., & Cohen, R. J. (1981). Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat to beat cardiovascular control. *Science, 213,* 220-222.

Berntson, G. G., Bigger Jr., J. T., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., . . . Van Der Molen, M. W. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology, 34,* 623-648.

Bigger, J. T., Fleiss, J. L., Rolnitzky, L. M., & Steinman, R. C. (1992). Stability over time of heart period variability in patients with previous myocardial infraction and ventricular arrhythmias. *American Journal of Cardiology, 69,* 718-723.

Camm, A. J., Malik, M., Bigger, J. T., Breithardt, G., Cerutti, S., Cohen, R. J., . . . Singer, D. (1996). Heart rate variability - standards of measurement, physiological interpretation, and clinical use. *Circulation, 93,* 1043-1065.

Chabris, C. (1999). "Prelude or requiem for the Mozart effect'? *Nature, 400,* 826-827.

Cowley, B., Charles, D., Black, M., & Hickey, R. (2008). Toward an understanding of flow in video games. Comput. *Entertain., 6(2),* 1-27.

Csikszentmihalyi, M. (1975). Play and intrinsic rewards. *Journal of Humanistic Psychology, 15(3),* 41-63. doi: 10.1177/002216787501500306.

Csikszentmihalyi, M. (1990). *Flow : the psychology of optimal experience (1st ed.),* New York: Harper & Row.

Csikszentmihalyi, M. (1992). A response to the Kimiecik and Ajckson papers. *Journal of Applied Sport Psychology, 4,* 181-183.

Csikszentmihalyi, M. (1996). *Creativity : flow and the psychology of discovery and invention (1st ed.).* New York: HarperCollinsPublishers.

Csikszentmihalyi, M. (1997). *Finding flow : the psychology of engagement with everyday life (1st ed.).* New York: BasicBooks.

De Manzano , O., Theorell, T., Harmat, L., & Ulen, F. (2010). The psychophysiology of flow during piano palying. *Emotion, 10,* 301-311.

Dye, M. W. G., Green, C. S., & Bavelier, D. (2009). The development of attention skills in action video game players. *Neuropsychologia, 47(8-9),* 1780-1789. doi: DOI 10.1016/j.neuropsychologia.2009.02.002.

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

Getzels, J. W., & Csikszentmihalyi, M. (1976). *The creative vision A longitudinal study of problem finding in art*. New York: NY John Wiley & Sons.

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423(6939),* 534-537. doi: Doi 10.1038/Nature01647

Green, C. S., & Bavelier, D. (2006a). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology-Human Perception and Performance, 32(6),* 1465-1478. doi: Doi 10.1037/0096-1523.32.6.1465

Green, C. S., & Bavelier, D. (2006b). Enumeration versus multiple object tracking: the case of action video game players. *Cognition, 101(1),* 217-245. doi: 10.1016/j.cognition.2005.10.004

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science, 18(1),* 88-94.

Ho, C., Mason, O., & Spence, C. (2007). An investigation into the temporal dimension of the Mozart effect: Evidence from the attentional blink task. *Acta Psychologica, 125(1),* 117-128.

Keller, J., & Bless, H. (2008). Flow and regulatory compatibility: An experimental approach to the flow model of intrinsic motivation. *Personality and Social Psychology Bulletin, 34(2),* 196-209. doi: Doi 10.1177/0146167207310026

Klasen, M., Weber, R., Kircher, T. T. J., Mathiak, K. A., & Mathiak, K. (2011). Neural contributions to flow experience during video game playing. Social Cognitive and Affective Neuroscience, 7, 485–495. doi: 10.1093/scan/nsr021

Kotler, S. (2004) The Rise of Superman: Decoding the Science of Ultimate Human Performance. Boston: Houghton, Mifflin, Harcourt

Kozhevnikov, M., Louchakova, O., Josipovic, Z., & Motes, M. A. (2009). The enhancement of visuospatial processing efficiency through Buddhist Deity Meditation. Psychological Science, 20(5), 645-653.

Kozhevnikov, M., Li, Y., Wong, S., Obana, T., & Amihai, I. (2018). Do enhanced states exist? Boosting cognitive capacities through an action video-game. *Cognition, 173,* 93–105.

LeFevre, J. (1988). Flow and the quality of experience during work and leisure. In M. C. Csikszentmihalyi, I. (Ed.), *Optimal Experience (pp. 307-318)*. Cambridge, England: Cambridge University Press.

Li, R. J., Polat, U., Makous, W., & Bavelier, D. (2009). Enhancing the contrast sensitivity function through action video game training. *Nature Neuroscience, 12(5),* 549-551. doi: Doi 10.1038/Nn.2296

Malliani, A., Pagani, M., Lombardi, F., & Cerutti, S. (1991). Cardiovascular neural regulation explored in the frequency domain. *Circulation, 84,* 1482-1492.

Maslow, A. H. (1962). *Toward a psychology of being.* Princeton, NJ: Van Nostrand-Reinhold.

Maslow, A. H. (1965). Religions, Values, and Peak-Experiences. Journal for the Scientific Study of Religion, 5, 179. https://doi.org/10.2307/1384286

Maslow, A. H. (1999). *Toward a psychology of being (3rd ed.).* New York: J. Wiley & Sons.

Mayer, R. (2014). *Computer Games for Learning: An Evidence Based Approach.* Cambridge, MA: MIT Press.

Moller, A. C., Meier, B. P., & Wall, R. D. (2010). Developing an experimental induction of flow: effortless action in the lab. In B. Bruya (Ed.), *Effortless Attention: A New Perspective in the Cognitive Science of Attention and Action* (pp. 191-204). London, U.K.: MIT Press.

Nakamura, J., & Csikszentmihalyi, M. (2002). The concept of flow. In C. R. Snyder & S. J. Lopez (Eds.), *Handbook of positive psychology* (pp. 89-105). New York, NY, US: Oxford University Press.

Pagani, M., Lombardi, F., Guzzetti, S., Rimoldi, O., Furlan, R., Pizzinelli, P., . . . Malliani, A. (1986). Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympathovagal interactin in man and conscious dog. *Circulation Research, 59,* 178-193.

Pomeranz, M., Macaulay, R. J. B., Caudill, M. A., Kutz, I., Adam, D., Gordon, D., . . . Benson, M. (1985). Assessment of autonomic function in humans by heart rate spectral analysis. *American Journal of Physiology, 248,* H151-H153.

Procci, K., Singer, A. R., Levy, K. R., & Bowers, C. (2012). Measuring the flow experience of gamers: An evaluation of the DFS-2. *Computers in Human Behavior, 28(6),* 2306-2312. doi: DOI 10.1016/j.chb.2012.06.039

Rauscher, F. H., Shaw, G. L., & Ky, K. N. (1993). Music and spatial task performance. Nature, 365(6447), 611-611.

Shernoff, D., Csikszentmihalyi, M., Schneider, B., & Shernoff, E. (2003). Student engagement in high school classrooms from the perspective of flow theory. *School Psychology Quarterly. 18(2),* 158-176. https://doi.org/10.1521/scpq.18.2.158.21860

Sherry, J. L. (2004). Flow and media enjoyment. *Communication Theory, 14(4),* 328-347.

Spence, I., & Feng, J. (2010). Video Games and Spatial Cognition. *Review of General Psychology, 14(2),* 92-104. doi: DOI: 10.1037/a0019491

Stein, K. M., Borer, J. S., Hochreiter, C., Okin, P. M., Herrold, E. M., Devereux, R. B., & Kligfield, P. (1993). Prognostic value and physiological correlates of heart rate variability in chronic severe mitral regurgitation. *Circulation, 88,* 127-135.

Tang. M.F., Badcock, D.R., Visser, T.A.. (2014). Training and the attentional blink: limits overcome or expectations raised? P*sychonomic Bulettin & Review*. 21, pp.:406-11. doi: 10.3758/s13423-013-0491-3.

Toledo, O. Gurevitz, H. Hod, M. Eldar & Akselrod, S. (2003). Wavelet analysis of instantaneous heart rate: a study in autonomic control during thrombolysis. *American Journal of Physiology -- Regulatory, Integrative and Comparative Physiology, 284,* R1079-R1091.

van de Borne, P., Nguyen, H., Biston, P., Linkowski, P., & Degaute, J. P. (1994). Effects of wake and sleep stages on the 24-h automatic control of blood pressure and heart rate in recumbend men. *American Journal of Physiology, 266(2),* H548-H554.

van Dijk, A. E., van Lien, R., van Eijsden, M., Gemke, R. J., Vrijkotte, T. G., & de Geus, E. J. (2013). Measuring cardiac autonomic nervous system (ANS) activity in children. *Journal of Visualized Experiments, 74,* e50073.

Weber, R., Tamborini, R., Westcott-Baker, A., & Kantor, B. (2009). Theorizing Flow and Media Enjoyment as Cognitive Synchronization of Attentional and Reward Networks. *Communication Theory, 19(4),* 397-422. doi: DOI 10.1111/j.1468-2885.2009. 01352.x

Welch PD (1967) The use of fast fourier transform for the estimation of power spectra: a method based on time averaging over short, modified periodograms. *IEEE Trans on Audio and Electroacoustics* AU-15: 70–73. Wilson, C. (1972). *New pathways in psychology, Maslow & the post-Freudian revolution.* New York: Taplinger Publishing Company.