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Cognitive Fatigue in Habitual Video Gamers and Non-gamers among Military Pilots in Training

RESEARCH

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ABSTRACT

Background: Military pilots operate in stressful situations that require multitasking and high cognitive demand. Prolonged periods of intense and sustained activities cause cognitive fatigue that leads to impairments in cognitive and physical performance. Frequent action video gaming is associated with enhanced attention and accuracy and could attenuate cognitive fatigue in military pilots in training.

Aim: This study investigated the effect of time load dual-back task (TloadDback), an effective method in inducing cognitive fatigue, on cognitive function in habitual video gamers and non-gamers among military pilots in training.

Methods: Thirty male student pilots (25 ± 1 years) were divided into those who had habitually played action video gaming ($n = 15$, gamers) and those who had not ($n = 15$, non-gamers). All participants performed a psychomotor vigilance task (PVT) and 1-Back tasks before and immediately after cognitive fatigue induced by the TloadDback.

Results and Conclusion: After the cognitive fatigue task, subjective fatigue ratings increased significantly in both groups. The reciprocal reaction time and middle cerebral artery blood velocity (MCBV) decreased in both groups. The non-gamers' reaction time during 1-Back significantly reduced ($p < 0.05$) but increased in gamers. The changes in MCBV were negatively associated with corresponding changes in hemoglobin index ($r = –0.599$, $p = 0.001$). In conclusion, cognitive fatigue result in reductions in attention, and cerebral blood velocity in military pilots in training. Habitual gamers demonstrated reduced tolerance to cognitive fatigue than non-gamers presumably through reduced cerebral oxygenation.

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INTRODUCTION

Pilots operate in highly stressful situations that require multitasking and high cognitive demand. The workload of pilots increases during aircraft control, cognitive distraction, and gravity force (Ercan & Gunduz, 2020; Mohanavelu et al., 2020; Hebbar et al., 2021). Prolonged periods of intense and sustained activities in pilots can cause cognitive fatigue that leads to impairments in psychomotor performance, increases safety risk, and reduces aviation safety. The reduction in cognitive performance is more pronounced in younger and less experienced pilots. (McMahon & Newman, 2018; Kelly & Efthymiou, 2019). Psychomotor vigilance and/or sustained attention are the crucial cognitive domains to prevent fatigue-related errors and risks in aviation (Boudreau et al., 2018; Maki et al., 2022). Cognitive fatigue superimposed on the gravity force and hypoxic exposures reduces brain perfusion and cerebral oxygenation, both of which are associated with attenuated cognitive function (Konishi et al., 2019; Ercan & Gunduz, 2020).

Video gaming is a popular recreational activity among young adults worldwide. Frequent action video gaming is associated with enhanced cognitive function, increased attentional abilities, and greater accuracy (Dye et al., 2009; Bediou et al., 2018). In contrast, excessive video game hours are associated with reductions in working memory and prefrontal lobe activity (Kawaike et al., 2019; Jang et al., 2021). The prefrontal area activity correlates negatively with weekly gaming days among habitual gamers. After playing an action video game, cerebral blood velocity decreases in the prefrontal area (Chou et al., 2013). Currently, it is unknown if habitual video gaming is associated with a better ability to cope with cognitive fatigue in military pilots.

Studies focusing on cognitive fatigue and mental workload in aviation have been conducted in flight simulators or during actual flight duties (McMahon & Newman, 2018; Wang et al., 2020; Rosa et al., 2022). However, the equipment must be able to sustain a G-force and fit in a confined space, the procedure during actual flight duties is extremely difficult and cost-inhibitive. Accordingly, as flight simulation has become an important preparation for military pilots in training, laboratory-based test that can induce cognitive fatigue in military pilots is needed. Time load dual-back task (TloadDback) is a 16-minute dual-task test that is effective in inducing cognitive fatigue in healthy adults (O'Keeffe et al., 2020). The increasing fatigue sensation and psychomotor vigilance decrement have been demonstrated as the consequence of cognitive fatigue (Gui et al., 2015; Guo et al., 2016; Angius et al., 2022). TloadDback may be a promising procedure targeted to pilots although such a possibility has not been tested.

Hence, the present study aims to investigate the effect of TloadDback on cognitive function in habitual video gamers and non-gamers among military pilots in training. Cognitive function was assessed using two different tasks, which are necessary for encompassing a wide range of cognitive functions associated with the complex cognitive demands of the flight. The psychomotor vigilance task (PVT) is a sustained attention task while the 1-Back task (1-Back) is a working memory task. To gain physiological insight, reaction time, cerebral blood velocity, and cerebral oxygenation, were monitored during those tasks. We hypothesized that TloadDback would induce student pilots' cognitive fatigue and that habitual gamers would demonstrate more favorable cognitive performance and neurophysiological responses when compared with non-gamers.

METHODS

PARTICIPANTS

Thirty right-handed military pilots in training enrolled in advance training squadrons were recruited from the pilot training school in the Royal Thai Air Force. They had been in the training program for 9 months to a year. All participants completed a medical history questionnaires and physical activity readiness questionnaire (PAR-Q+) and Global Physical Activity Questionnaire (GPAQ) to determine eligibility. The participants had no chronic medical history including cardiovascular disease or any other diseases. No participants were taking prescribed medications. Participants with no window at the temporal bone of the skull for transcranial Doppler ultrasound assessment were excluded. The participants were divided into habitual gamers (n = 15) and non-gamers (n = 15) based on their experience in playing video games in their leisure time. All participants signed a written informed consent before starting the study. All procedures were approved by the ethics committee from Bhumibol Adulyadej Hospital, Royal Thai Air Force (IRB #45/65).

STUDY DESIGN

As shown in Figure 1, the study was conducted on three different days in two weeks. During the first visit, height, body weight, heart rate at rest, and blood pressure were measured prior to cardiorespiratory exercise tests. Familiarization and individualization for cognitive fatigue, attention, and working memory tasks were conducted on the second visit. The participants conducted PVT and the 1-Back tests 3 times each in a familiarization session (Ercan & Gunduz, 2020). The TloadDback individualization was conducted after finishing the PVT and the 1-Back familiarization after a 20-minute break. On the third visit, a cognitive fatigue session was conducted in a quiet laboratory room. Participants abstained from caffeinated drinks and foods for 2 hours prior to participating in the study. Participants filled out baseline assessment, Suanprung Stress test-20 (SPST-20), National Aeronautics and Space Administration task load index (NASA-TLX), Brunel mood scale (BRUMS), and cognitive fatigue scale (CFS) prior to practicing 15-trial PVT and 1-Back to familiarize the tests. Participants sat facing the wall in front of a mirrored monitor with a wired keyboard and a wired mouse, which controlled the programs during the cognitive tasks. Before and after the cognitive fatigue induced by the 16-minute dual-task test, TloadDback, the 36 trials of cognitive tests, PVT, and 1-back were conducted. The reaction time was recorded. The PVT outcome was assessed using reciprocal reaction time (1/RT) (Basner & Dinges, 2011). The 1-Back outcome was assessed using reaction time (Meule, 2017). Participants immediately filled out the post-cognitive fatigue questionnaire after finishing 1-Back. Psychomotor data, reaction time, and neurophysiological responses data, middle cerebral artery blood velocity (MCBV), and cerebral oxygenation as assessed by hemoglobin index (HBI) were assessed during PVT and 1-Back tasks.

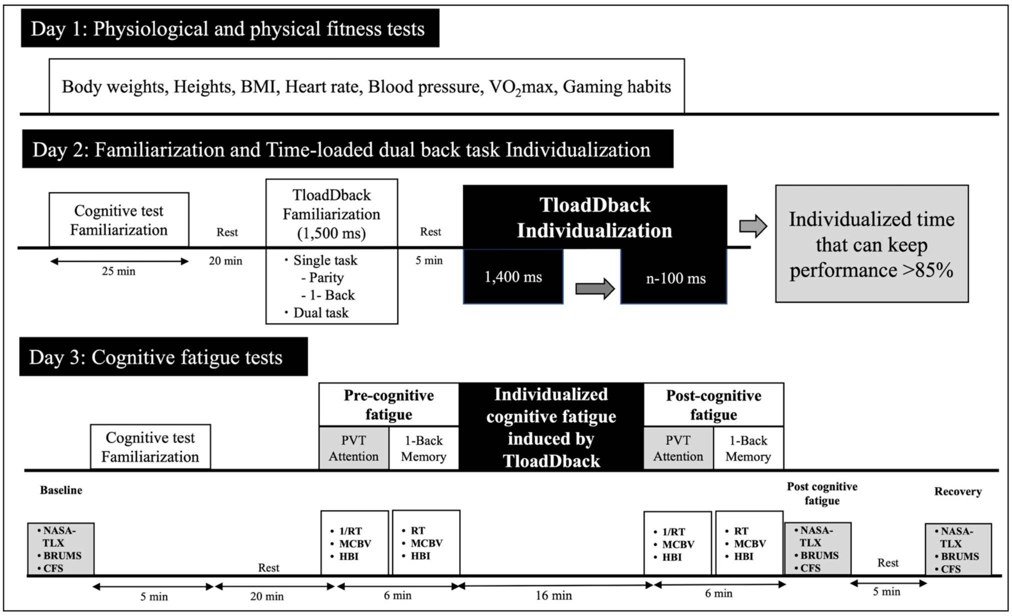

Figure 1 Study designs. Body mass index (BMI); Psychomotor vigilance task (PVT); 1-back task, (1-Back); Time-loaded dual back task (TloadDback); Cognitive fatigue scale (CFS); Brunel Mood Scale (BRUMS); Reaction time (RT); Middle cerebral artery blood velocity (MCBV); Hemoglobin index (HBI).

Cognitive tasks

The TloadDback task is a dual-task combining a classic N-back task updating working memory task and an equality judgment task. It is a 16-minute sequence of alternate numbers and letters. The n-back task is a 1-Back task, which is a series of continuous letters (Borragan et al., 2017). The TloadDback was the open-source program (Borragan et al., 2017), conducted on MATLAB 2021a/Psychtoolbox 3.0.18, and loaded on a notebook (1.33 GHz processor and 4 GB RAM, Microsoft® Windows10). Participants pressed the spacebar using their left hand when a seen letter was similar to a previous letter. Participants used their right hand for the equality judgment task by distinguishing even and odd numbers (1-9). When a number was presented, participants pressed "2", or pressed "3" when the presented number was even and odd number, respectively. TloadDback individualization was conducted in a block of 30 numbers and 30 letters with an initial changing letter duration at 1,400 ms and decreased by 100 ms per block with at least a 1-minute break and a bottle of water was provided during the break. Individual processing capacity was assessed as the minimal time stimulus duration that participants could maintain task accuracy at >85%.

The PVT and 1-Back were administered using the open-source psychometric test battery, the psychology experiment building language (PEBL) version 2.1 loaded on a notebook (2.3

GHz Quad-Core Intel Core i7 and memory 16GB, macOS Monterey version 12.4). The PVT is a sustained attention test. Participants pressed the space bar as fast as possible when they saw a red circle appear randomly between 2 to 12 seconds on a black screen. The reaction time was recorded. The PVT outcome was assessed using reciprocal reaction time (1/RT), which is attributed to high effect sizes and high operational validity of lapse to distinguish alert states in small sample sizes (Basner & Dinges, 2011). The 1-Back is a working memory test. The test is a series of square positions and letters that appeared alternately in a nine-block grid, which the letters are shown in the middle. Participants pressed the left shift when a present letter was similar to the previous letter and pressed the right shift when the present square appeared in the same position as the previous one. The response time of left and right hands were recorded, and the 1-Back reaction time was the averaged data of those responses time.

MEASUREMENTS

Heart rate at rest and blood pressure were assessed by the automated device (Carscape V100 monitor; GE Healthcare, Milwaukee, WI). Body weight and body mass index (BMI) were assessed by the bioelectrical impedance device (Omron HBF-375, Kyoto, Japan). Maximal oxygen consumption was determined using the Bruce protocol on a motorized treadmill (Landice, Randolph, NJ, USA) during which grades and intensity were increased every 3 minutes until exhaustion. During the test, heart rate and expired gas were continuously monitored using a heart rate monitor (Polar H10, Polar Electro Oy, Vantaa, Finland) and the breath-by-breath gas analyzer (Cortex Metamax 3B, Leipzig, Germany).

Suanprung Stress Tess-20 (SPST-20) was a 20-item questionnaire that assessed the stress events during the past 6 months (Mahatnirunkul et al., 1997). The scores were a 5-point rating scale (1 = "none", 2 = "slight", 3 = "moderate", 4 = "severe", and 5 = extremely severe). The total scores were interpreted as total stress into 4 levels: low stress (0–24), moderate stress (25–42), high stress (43–62), and severe stress (63 and above). SPST-20 was the questionnaire developed to assess stress for the Thai population. SPST-20 was widely used to determine stress in clinical work and a stress management clinic. SPST-20 had high reliability at 95% confidence interval with Cronbach's alpha >0.7 and concurrent validity >0.27 for stress measurement.

Global Physical Activity Questionnaire (GPAQ) was a 16-item questionnaire developed by WHO for physical activity surveillance in countries to evaluate three physical activity domains, activity at work, travel to and from places, and recreational activities. The physical activities were calculated into metabolic equivalents (MET) evaluating physical activity intensity. Met is the ratio of a person's working metabolic rate relative to the resting metabolic rate. The level of physical activity was defined into three levels, low, moderate, and high (World Health Organization, 2021).

Subjective rating of fatigue was assessed using a self-rating visual scale, during which participants marked the scales that matched their perception of fatigue. The mental workload was assessed by the National Aeronautics and Space Administration task load index (NASA-TLX), which was one of the most widely-used questionnaires to determine cognitive workload. NASA-TLX was a multi-dimensional rating scale of six related mental workload dimensions that include mental demand, physical demand, temporal demand, effort, performance, and frustration. These six scales were able to account for a highly significant percentage of the variance in overall workload ratings (r^2 values ranged from 0.78 to 0.90) and the correlation between the test-retest ratings was 0.83 (Hart & Staveland 1988). There were 2 steps in calculating the NASA-TLX. First, participants drew marks on the 0-100 scale of 6 subscales. Secondly, participants indicated the score on 15 pair-wise comparisons of 6 subscales, which contributed more load to the cognitive fatigue task (0 or 1). The weighted score of each dimension was valued 0–5. The NASA-TLX was calculated from the mean of total 6 subscales multiplied by the weighted score (Hart & Staveland, 1988).

The cognitive fatigue scale (CFS) and Brunel mood scale (BRUMS) were considered as subjective cognitive fatigue measurements in the present study. Participants rated the cognitive fatigue that they perceived on the CFS, which visual analog scales were the most practical method of assessing mental fatigue, was a 100 mm scale (0 = not at all and 100 = extremely) (Smith et al. 2019). The BRUMS was a validated mood measure, which had high internal consistency with Cronbach alpha coefficients (Terry et al. 1999). Test-retest reliability coefficients have ranged from 0.26 to 0.53 over a 1-week period (Terry et al. 2003), which is appropriate for a measure of transient feeling states (Parsons-Smith et al. 2017). The BRUMS contained 24 items of a five-point scale questionnaire (0 = not at all and 4 = extremely), which was divided into 6 subscales including anger, confusion, depression, fatigue, tension, and vigor. The fatigue subscale comprised 4 items, worn out, exhausted, sleepy, and tired. The sum of BRUMS fatigue subscale was scored between 0 to 16 (Smith et al., 2019).

Middle cerebral artery blood velocity (MCBV) was determined noninvasively using transcranial Doppler ultrasound (CX50, Philips Healthcare, Anodover, MA, USA) with a 1.8 MHz transcranial Doppler probe (S5-1 Transducer, Philips Healthcare, Anodover, MA, USA). Probe was placed at left temporal window during the cognitive fatigue session. Middle cerebral artery blood velocity was determined in time average mean velocity and recorded during the last 1.5 minutes of PVT and 1-Back (Matthews et al., 2010; Konishi et al., 2019).

Cerebral oxygenation was recorded continuously with near-infrared spectroscopy (SenSmart X-100, Nonin Medical, Plymouth, MN) with a regional oximetry sensor (SenSmart 8204CA). The sensors were placed on the participant's forehead at the middle of the eyebrows and hairline to assess frontal lobe oxygenation. The hemoglobin index (HBI) is an estimate of the amount of hemoglobin per unit volume of tissue. (Tanaka et al., 2021) and was collected during the last 1.5 minutes of PVT and 1-Back. HBI was derived by scaling the estimated concentration of oxygenated and deoxygenated hemoglobin to the measured total hemoglobin and normalizing that to the proportion of blood in the total brain volume.

STATISTICAL ANALYSES

Data were analyzed using IBM SPSS Statistics (Version 25, SPSS, Chicago, IL). Physiological variables are presented in means ± SD. Outlier detection was assessed by Grubb's outlier test using GraphPad statistical software (San Diego, CA). As a result, 1–2 outlier points were eliminated from variables before the statistical analyses. The eliminated data points did not change the main outcome. Tests of normality were conducted using the Shapiro-Wilk statistic test. The differences between habitual gamers and non-gamers were assessed using an independent T-test. All variables of self-reported score between habitual gamers and non-gamers in cognitive fatigue activation tasks were assessed by a 2 × 3 (Group × Time) repeated measure ANOVA followed by a post hoc test with LSD multiple comparisons.

RESULTS

Selected participant characteristics are presented in Table 1. Thirty participants were young healthy men. There are no significant differences in age, height, body weight, BMI, heart rate, blood pressure, and VO_2max between habitual gamers and non-gamers. Habitual gamers had video paying time of 12 ± 5 hr/wk while non-gamers had no playing time.

PARTICIPANT CHARACTERISTICS	GAMERS	NON-GAMERS
Number (n)	15	15
Age (yr)	25.1 ± 1.2	24.5±1.2
Height (cm)	174 ± 6	173 ± 7
Body weight (kg)	72.8 ± 13.6	72 ± 12.6
BMI (kg/m^2)	24.1 ± 4.2	23.8 ± 2.6
Heart rate at rest (bpm)	70 ± 10	70 ± 13
Systolic blood pressure (mmHg)	123 ± 10	121 ± 10
Diastolic blood pressure (mmHg)	69 ± 8	70 ± 9
VO_2max (ml·kg^{-1}·min^{-1})	51.3 ± 5.5	49.2 ± 5.3
Video playing time (hr/wk)	12 ± 5	0
Suan Prung Stress Test-20	42.2 ± 9.8	38.3 ± 13
PHYSICAL ACTIVITY LEVEL (GPAQ)	**N (%)**	
– Moderate	6 (40)	6 (40)
– High	9 (60)	9 (60)

Table 1 Selected characteristics of military pilots in training.

Values are n or means ± SD. Global Physical Activity Questionnaire (GPAQ).

As shown in Figure 2 and Table 2 after the cognitive fatigue induced by the TloadDback task, cognitive fatigue scale, NASA-TLX, and BRUMS showed significant increases in both groups ($p < 0.05$) without any significant group differences.

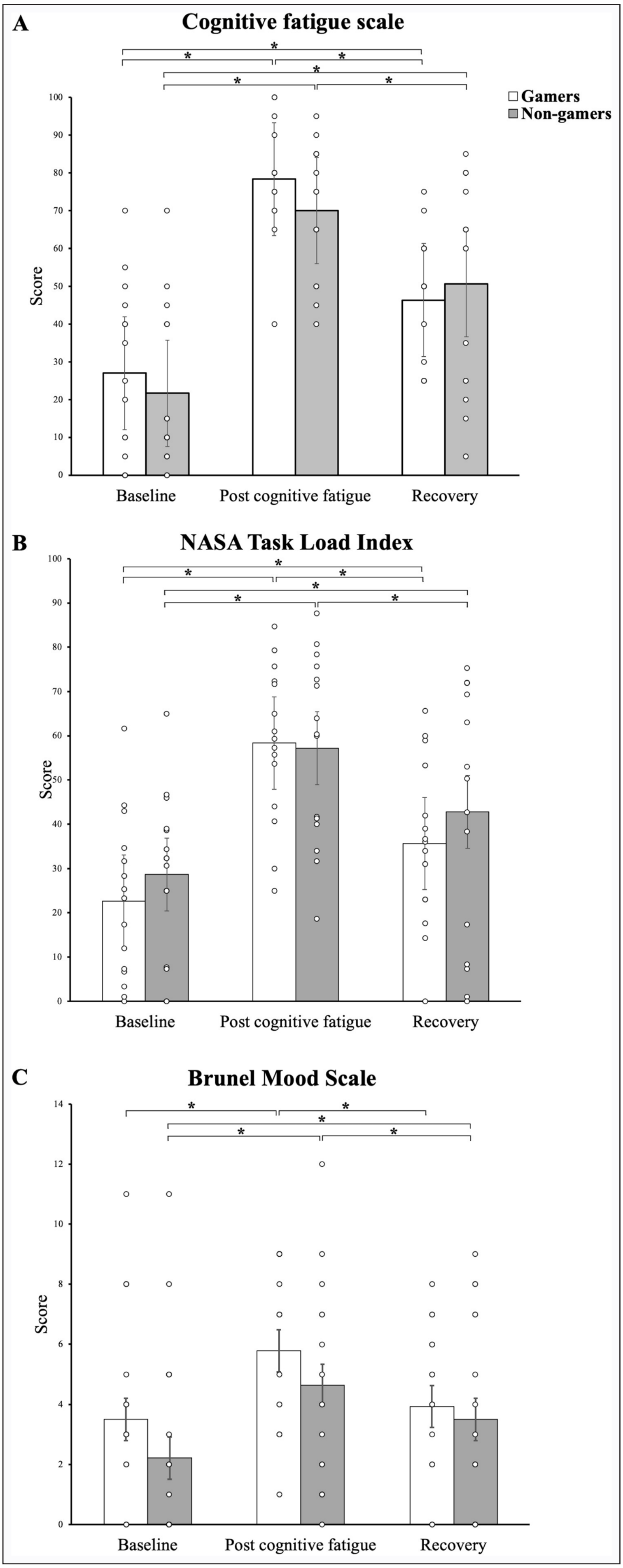

Figure 2 Subjective measures of cognitive workload including cognitive fatigue scale **(A)**, NASA task load index (NASA TLX) score **(B)**; Brunel Mood Scale (BRUMS) **(C)**.

*$p < 0.05$.

VARIABLES	GAMERS			NON-GAMERS			ANOVA STATISTICS			EFFECT SIZE
	BASELINE	POST-COGNITIVE FATIGUE	RECOVERY	BASELINE	POST-COGNITIVE FATIGUE	RECOVERY	TIME	GROUP	INTERACTION	
NASA-TLX	22.67 ± 18.24†, ‡	58.36 ± 17.57*, ‡	35.64 ± 18.51*, †	28.67 ± 18.50†, ‡	57.20 ± 21.10*, ‡	42.80 ± 28.76*, †	0.000	0.527	0.541	0.140
Cognitive fatigue scale	27 ± 22.66†, ‡	78.33 ± 15.07*, ‡	46.33 ± 16.56*, †	21.67 ± 21.52†, ‡	70 ± 17.42*, ‡	50.67 ± 26.92*, †	0.000	0.604	0.270	0.273
BRUMS- fatigue scale	3.5 ± 2.38†	5.78 ± 2.81*, ‡	3.93 ± 2.30†	2.21 ± 2.61†, ‡	4.64 ± 3.52*, ‡	3.5 ± 2.75*, †	0.000	0.334	0.177	0.350

Table 2 Subjective measures of cognitive workload including cognitive fatigue scale, NASA task load index (NASA TLX) score; Brunel Mood Scale (BRUMS)-fatigue scale after individualized cognitive fatigue induced by TloadDback.

Values are means ± SD. *P < 0.05 vs Baseline, †P < 0.05 vs Post-cognitive fatigue, ‡ P < 0.05 vs Recovery

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As illustrated in Figure 3 and Table 3, PVT and 1-Back measures were reported in percentage changes between before and after cognitive fatigue induced by the TloadDback task. The reciprocal reaction time during PVT of both groups decreased without significant differences between the group. MCBV decreased significantly in both groups with non-gamers decreasing more sharply compared with habitual gamers ($p < 0.05$). The hemoglobin index of habitual gamers decreased whereas non-gamers increased with a significant group difference between gamers and non-gamers ($p < 0.05$). The 1-Back measures were also reported in percentage changes before and after cognitive fatigue induced by the TloadDback task. The reaction time increased after TloadDback in habitual gamers but decreased in non-gamers ($p < 0.05$). MCBV assessed by TCD decreased in both groups.

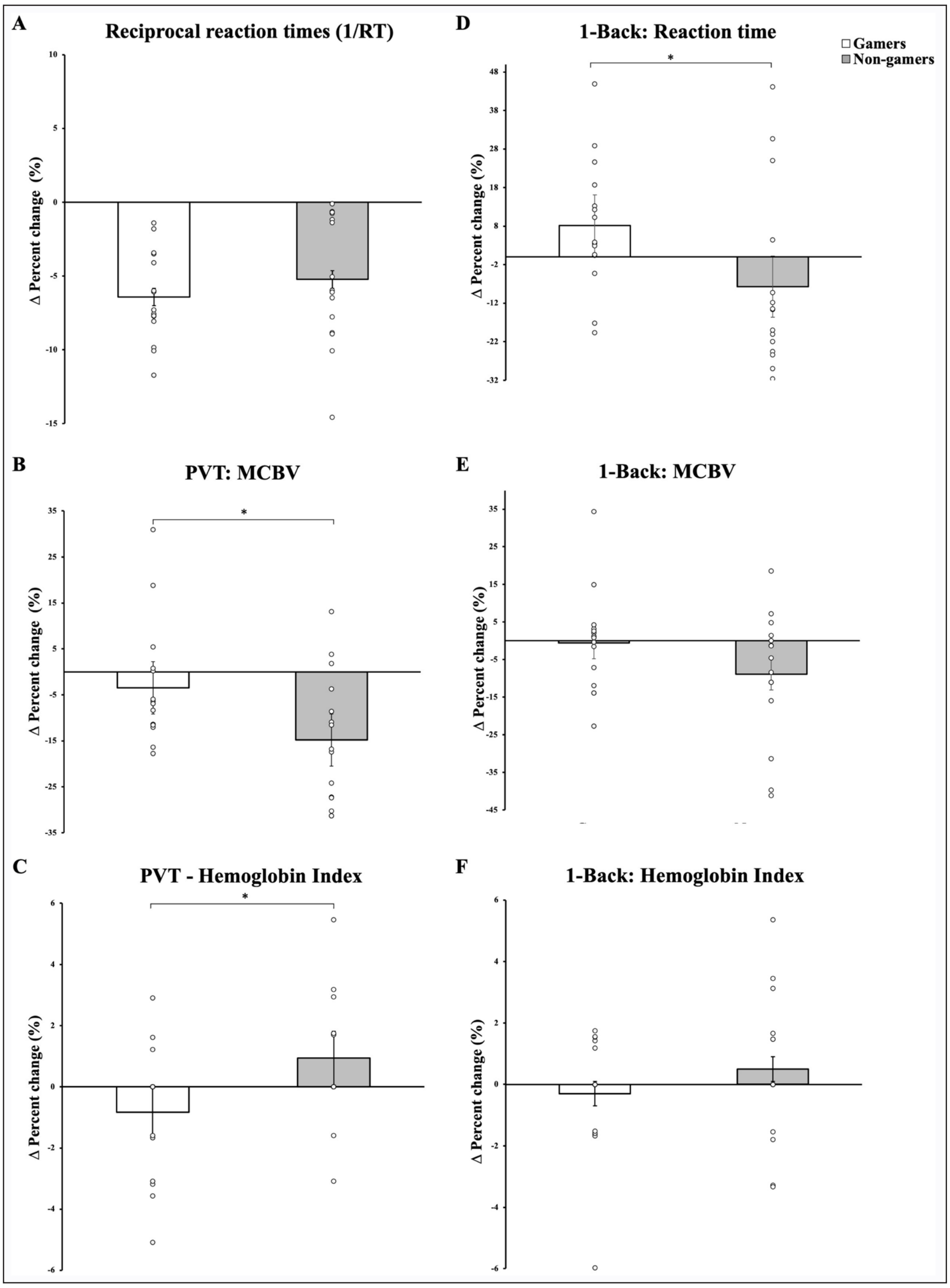

Figure 3 Changes in reaction time **(A & D)**, middle cerebral artery blood velocity (MCBV) **(B & E)**, and hemoglobin Index (HBI) **(C & F)** during psychomotor vigilance task (PVT) and 1-Back test before and after cognitive fatigue induced by TloadDback.

**p* < 0.05.

VARIABLES (% CHANGE)	GAMERS	NON-GAMERS
Psychomotor Vigilance test		
Reciprocal reaction time	–6.4 ± 3.1	–5.2 ± 4.4
Middle cerebral artery blood velocity	–3.5 ± 13.3	–14.8 ± 14.1*
Hemoglobin index	–0.8 ± 2.2	0.9 ± 2.2*
1-Nback		
Reaction time	8.2 ± 16.8	–7.7 ± 23.2*
Middle cerebral artery blood velocity	–0.5 ± 13.5	–8.9 ± 17.1
Hemoglobin index	–0.3 ± 2	0.5 ± 2.5

Table 3 Percent change of psychomotor variables after individualized cognitive fatigue induced by TloadDback.

Values are means ± SD.

*p < 0.05.

The association between cerebral blood velocity and PVT measures of cerebral oxygenation in student pilots is presented in Figure 4. The changes in MCBV were negatively associated with corresponding changes in hemoglobin index (r = –0.599, p = 0.001).

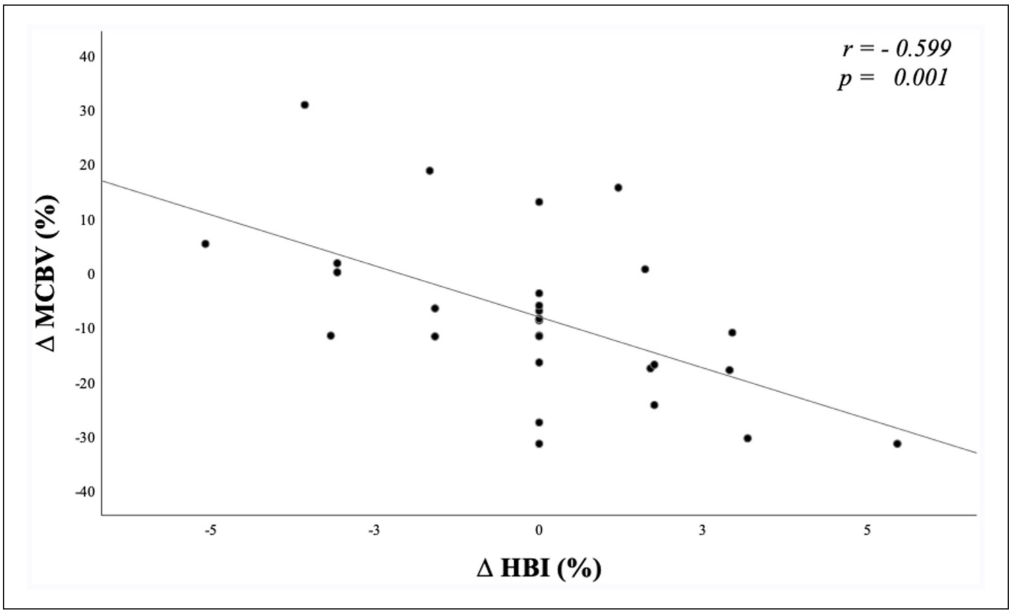

Figure 4 Associations of changes in middle cerebral artery blood velocity (MCBV), during psychomotor vigilance task with hemoglobin Index (HBI).

DISCUSSION

The major findings of this study are as follows. A 16-minute TloadDback task was able to induce cognitive fatigue in military pilots in training as evidenced by significantly increased cognitive fatigue scales, NASA-TLX scores, the fatigue subscale in BRUMS, and decreased sustained attention assessed by PVT reciprocal reaction time ($p < 0.05$). After TloadDback, significant decreases in MCBV were found during PVT and 1-Back in both gamers and non-gamers, with non-gamers experiencing significantly lower values compared with habitual gamers. Hemoglobin index as assessed by the near-infrared spectroscopy decreased during PVT and 1-Back in habitual gamers but increased in non-gamers. These results indicate that habitual gamers demonstrated reduced tolerance to cognitive fatigue than non-gamers and that this appears to be mediated by differences in cerebral oxygenation.

The present study demonstrated that TloadDback can induce cognitive fatigue in military pilots regularly trained in high-performance environments. The cognitive fatigue task decreased PVT reciprocal reaction time and increased cognitive fatigue rating in both habitual gaming and non-gaming student pilots. The increase in fatigue rating and the decrease in psychomotor vigilance are characteristic consequences of cognitive fatigue (Gui et al., 2015; Guo et al., 2016; Angius et al., 2022). In particular, psychomotor vigilance and/or sustained attention are crucial cognitive domains that are closely linked to aviation fatigue-related errors and risks (Williamson et al., 2011; Boudreau et al., 2018; Maki et al., 2022). Changes in PVT observed in the present study are consistent with a previous study conducted in a much longer (12-hour duration) simulated flight, in which reaction times were increased and accuracy decreased (Mcmahon & Newman, 2018). TloadDback that can be completed in 16 minutes may be a cost- and time-efficient tool that can be applied to simulate cognitive fatigue in pilots.

The reduction in PVT reciprocal reaction times indicates cognitive fatigue occurrence in gamers and non-gamers (Basner & Dinges, 2011). However, the increase in reaction time of habitual gamers during 1-Back denotes delayed responses in working memory tasks compared with non-gamers who experienced decreases in reaction time. These results indicate that cognitive fatigue task does not alter non-gamers' working memory but prolongs gamers' reaction time. In a study involving young adults, excessive gaming hours are related to reductions in verbal and working memory (Jang et al., 2021). The repeated excitement and fear that video games create can increase a form of stress called interactive stress that decrease cognitive preparedness (Aliyari et al., 2018). After playing an action video game compared with playing a football game, a number of consecutive wrong answers increased (Aliyari et al., 2020). In the current study, habitual gamers played both action video games and sports games while they studied in high complex operation demands, and eight gamers played games for about 2 hours per day similar to high-risk internet gaming disorder users reported by Jang et al. (2021). Habitual gamers may have exaggerated their stress from playing video games concurrent with their daily military training. This may have reduced their working memory readiness as revealed by increases in 1-Back reaction time.

The studies of prefrontal cortex activation during cognitive activity using functional magnetic resonance imaging demonstrated that the regional cerebral blood velocity is negatively correlated with sustained attention load to visual stimuli (Mazoyer et al., 2002; Matsuda & Hikari, 2006). The dorsal prefrontal cortex activation gets attenuated during playing video games, and this can lead to impair oxygenated hemoglobin, which occurs from increasing attention demand (Matsuda & Hiraki, 2005). The reduction in MCBV as assessed by transcranial Doppler ultrasound occurs during vigilance tasks in both hemispheres (Matthew et al., 2010). The decline in vigilance is associated with a reduction in MCBV (Warm et al., 2008; Funke et al., 2010). Additionally, MCBV was negatively associated with cognitive fatigue rating (Boissoneault et al., 2019). In the present study, MCBV during PVT and 1-Back decreased in both habitual gamers and non-gamers, with a greater decline during PVT in non-gamers. This indicates that both groups experienced cognitive fatigue as shown by increased reaction time in PVT. Particularly, non-gamers were able to increase their attention level compared with habitual gamers. Interestingly, changes in hemoglobin index during PVT and 1-Back are consistent with the idea that habitual gamers increasing their attention. The greater hemoglobin index in non-gamers may reflect the increasing effort since cerebral oxygenation is sensitive to task effort (Funke et al., 2010). The increasing oxygenated hemoglobin was related to the increasing brain activity observed in the fatigue-fighting drivers to maintain attention (Chuang et al., 2018). This can be a reason that non-gamers increased their accuracy and decreased their reaction time in 1-Back. Additionally, the 3-hour driving task significantly decreased drivers' vigilance and oxygenated hemoglobin while the fatigue perception such as tiredness, headache, and lack of energy were increased. Cognitive fatigue might be related to inadequate oxygen delivery to the brain (Li et al., 2009). In this study, the gamers and non-gamers significantly increased CFS, and the gamers' vigilance and hemoglobin index deteriorated. Moreover, prefrontal cortex activity during working memory negatively correlates with the number of days playing video games (Kawaike et al., 2019). The gamers in this study are habitual game playing, and the results show that they increased their reaction time during 1-Back.

There were several limitations of the present study that should be emphasized. The number of participants was relatively small. Additionally, only men were studied. However, all the student pilots in Royal Thai Air Force were currently men. MCBV was assessed only on the left middle cerebral artery and bilateral TCD was not conducted. More importantly, because this is not a randomized controlled intervention study the cause and effect relationship involving video games cannot be determined.

CONCLUSION

The results of the present study demonstrated that TloadDback is a cognitive fatigue task that can be applied to induce cognitive fatigue in military pilots in training. After cognitive fatigue task, the sustained attention of habitual gamers decreased significantly. The working memory of non-gamers was not impacted by cognitive fatigue, but its effect was visible in habitual gamers who prolonged reaction time. These cognitive changes were associated with the corresponding changes in cerebral oxygenation. These results indicate that the habit of playing action video games may be unfavorable for young pilots. Future interventional studies are warranted.

DATA ACCESSIBILITY STATEMENTS

The datasets generated and/or analyzed during the current study are not publicly available.

ETHICS AND CONSENT

All experiments were approved by the Bhumibol Adulyadej Hospital Ethics Committee, Royal Thai Air Force (IRB No. 45/65).

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COMPETING INTERESTS

The authors have no competing interests to declare.

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