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Enhancement of Cognitive Index with Computer Game Using Brain Signals and Hormonal Analysis: Randomized Controlled Trial

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Original Article

Abstract

Introduction: Nowadays, computer games play an important role on the cognitive and behavioral health of the community. The purpose of this study is to investigate the short-term effects of Flow Free ®on the neurologic characteristics of the players of these games.

Materials and Methods: A total of 40 healthy male students aged 20 years and above were randomly divided into the control and experimental groups. All tests were performed before and after the game in experimental group. The tests were performed only once in the control group without participating in the game following watching the game. Saliva samples were collected to measure cortisol and alpha amylase levels. Cognitive tests and electro-encephalography were performed. Data were analyzed using Wilcoxon signed-rank test.

Results: There was no significant difference between the groups in demographic characteristics and pre-intervention measures (the same as the experimental group participants without playing the game). The post-tests showed no significant change in the control group. In the experimental group, the Paced Auditory Serial Addition Test (PASAT) results indicated a significant increase in mental health ($P \leq 0.037$) and sustained attention ($P \leq 0.046$); the changes in the concentration of alpha amylase ($P \leq 0.009$) and salivary cortisol ($P \leq 0.01$) after the game showed a significant increase compared to the pre-test. Additionally, an increase in the mean surface of the pattern of stress index ($P \leq 0.039$) and attention index ($P \leq 0.048$) were recorded. The post-test measures in the experimental group were also significantly different from those of the control group.

Conclusion: Flow Free®, as a stimulant of the central nervous system (CNS), led to the increased activity of the stress path and changes in brain signals, hence strengthening the cognitive element of attention in the players after the game.

Keywords: Stress; Cortisol; Alpha amylase; Attention; Flow free®; Electroencephalography; Neurogame

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Introduction

Today, computer games play an important role in the quality of life (QOL) of children and adolescents. In addition, the time of playing computer games is increasing among the players (1). Research results indicate that computer games play an important role in behavioral health and cognition of individuals (2). So far, numerous studies have been carried out in the

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field of serious games (3) and the role of these games in the field of treatment, prevention of neurological disorders, and strengthening cognitive abilities has been specified (4). Investigation in this field seems necessary given the wide range of clients and the increasing production of computer games with different content. Games cause neurological, psychological, and physiological changes and generally affect individuals' health (2,5,6). Serious computer games can affect cognitive characteristics such as attention and concentration as well as emotional behaviors (7,8). Stress in computer games is an important cognitive indicator that plays an important role in strengthening or weakening other types of cognitive indicators of other individuals (9,10). The effects of stress in computer games on different abilities of the central nervous system (CNS) vary according to the style of the games and gender (10,11).

The Neurogame Group divides stress in computer games into four types based on the game style as follows (8,10,12).

Logic stress: In puzzle games, there is neither the stress of losing the game nor the stress of time limitation. In fact, the prefrontal cortex of the brain is involved in thinking and decision making. The brain frontal activity strengthens cognitive indicators such as problem solving, concentration, and correct decision making (8).

Limit stress: This stress is seen in runner games. In this style of games, due to the fear of losing, a limited stress is applied to the player. In this case, the hypothalamic-pituitary-adrenal (HPA) axis is activated and the cortisol hormone and the alpha-amylase enzyme are secreted (8). Increased cortisol secretion leads to limited stress, hence enhancing the cognitive parameters of attention and concentration, speed of action, and coordination between the fingers' and eyes' muscles (8,10,12).

Fear stress: This type of stress is present in scary and terrifying games.

Interactive stress: This type of stress is often seen in scary and violent games.

Both of the latter cases of stress (fear and interactive) are related to the scary games (4,10). The effect of computer games on individuals' CNS varies according to the content and style of games; So that it can be used to improve or weaken the cognitive characteristics of individuals (13). Computer games with different content can cause different changes in cortisol secretion level (10). In fact, computer games stimulate the adrenal sympathetic system (14). They also activate the stress system axis. The effect of computer games on the stress system leads to changes in the biological system. Chronic stimulation of the HPA pathway is directly related to neurological disorders. During the HPA axis activity, the hormone released from the hypothalamus reaches the anterior pituitary gland and causes the secretion of adrenocorticotropic hormone (ACTH). ACTH secretion regulates the cortisol hormone from the cortical part of the adrenal gland (9).

Stress responses can lead to behavioral, autonomic, and endocrinological changes in the brain (12). Moreover, investigations indicate that following the activity of the stress system, reactions that are generally referred to as fear may also occur in the stressed person (1,4,7,8,10,13). These reactions activate the sympathetic part of the stress system and, ultimately, lead to the emergence of sympathetic (or parasympathetic) responses in the individual (1,2). Based on the content and style of the game and the intensity of the stress-fear axis stimulation, neurologically, computer games can impose different effects on CNS (1).

Any environmental factor that causes abnormal changes in the cortisol hormone concentration can affect the brain signals and alter the cognitive parameters of individuals (15). The electroencephalography (EEG) signal is in fact the measurement of currents of nerve messages in the dendrites of neurons in the cerebral cortex (15). These signals have vital applications in various medical fields as well as brain-computer interface (BCI) systems (12,15). Decoding brain signals is one of the most important methods for examining cognitive indicators (13,16). If brain signals are considered as the brain language, by accurately recording the electrical signals, precise computer processing on them, and extracting information, one can identify the active points of the brain in a cognitive index (13,17).

Brain wave recording is a complex method that shows various electrical and biochemical activities of CNS online. These signals contain information that non-invasively reflects the functional characteristics of part of CNS (17). In previous studies, the mean level of the stress pattern and arousal index has been extracted from brain waves (12,15,18,19). If researchers can diagnose and classify computer games based on their style of play and content, an important step will be taken in preventing and helping to treat many neurological diseases and mental disorders and to enhance cognitive abilities in the field of health. With such an approach, games are purposefully produced and classified and serve the health sector (3). The Flow Free® game (Big Duck Games LLC, Sunny Miami, Florida, USA) is a single player game introduced for Windows, Android, and iOS operating systems. This game has been introduced as an index game by the elite of computer

games and is from the category of brain training games. In the present study, the neurological effects of the Flow Free game on individuals are investigated to determine whether this game affects certain neurological characteristics, what kind of stress does the HPA axis activity produce in this game, and is the stress effect positive or negative?

Materials and Methods

40 healthy male volunteer students aged 20 years and older were divided into control (n = 20) and experimental (n = 20) groups using a random number table. Before starting, all stages of the study were approved by the ethics committee of Baqiyatallah University of Medical Sciences, Tehran, Iran and the study design was registered in the Iranian Registry of Clinical Trials (IRCT) website. The study was performed at the Neurogame laboratory. Initially, the research method was explained to all volunteer participants and they were assured that their recorded information would remain confidential. After signing the informed consent, individuals entered the study based on the inclusion and screening criteria. The inclusion criteria included not playing the desired game in the past, not using any kind of addictive substance, and lack of a history of specific diseases and taking drugs, which were examined using self-expression and biological tests.

Game: The desired game, Flow Free, was in the style of the brain training games, which was played as 15 minutes per day for 3 days in the experimental group. The control group performed the same as the experimental group, except that instead of playing the game, the subjects watched it at specific times.

Evaluation: All tests were taken from the experimental group before and after playing the Flow Free game. Besides, in the control group, all tests were taken without playing and similar to the experimental group before and after watching the game. The selected individuals first answered questions including personal characteristics (age, drug and tobacco use, and mental health) and specialized game questions including favorite game and style of play as well as the number of hours spent playing the game. After that, the Paced Auditory Serial Addition Test (PASAT) was taken to measure mental health and sustained attention of individuals (12).

In the PASAT test, the subject heard 61 single-digit numbers with 3 seconds intervals consecutively through headphones and announced the results of adding each number in the microphone. At the end of the test, he was asked about the difficulty level of the test. The mental health level was measured with the sum of the highest number of correct answers and the sustained attention with the largest chain of consecutive correct answers. From all participants in the study (from the experimental group before and after the game and from the control group without playing the game only by seeing) saliva samples were collected in Falcon tubes with a volume of 10 ml and were stored in the freezer at -20 °C to compare the baseline with after the game (to examine the level of effect of the test game). To perform the analyses, the samples were first liquefied at room temperature, and after centrifugation at 3000 rpm for 5 minutes, 20 µl of each sample was isolated for testing. In order to measure salivary cortisol and alpha-amylase, human cortisol kit (Cortisol ELISA KIT, Diagnostics Biochem Canada Inc., dbc) and alpha-amylase specialized kit (Pars-Azmoon, Baharestan Industrial Center, Karaj, Iran) were used respectively using the Enzyme-linked immunosorbent assay (ELISA) techinque (10).

To record brain waves, the electrodes of the 14-channel EEG-Emotive device (EMOTIV Inc., San Francisco, CA, USA) were placed in special places on the volunteer's head. Then the brain waves were recorded as basal (closed eyes and open eyes). The brain signals and their analysis were processed in MATLAB software (MATLAB and Statistics Toolbox Release 2016b, The MathWorks, Inc., Natick, Massachusetts, USA). Based on numerous studies (8,10,12,15,18,19), data from brain signal processing were employed to assess the attention and stress indices. The signal energy in different bands and electrodes were calculated and compared. The amount of theta band energy in the FC region and the $\frac{\theta}{\beta}$ ratio were used to determine the attention level (10,15) where Pow (Ab) is the power of the electrode A signal in the b band (Equation 1).

$$attention = \frac{Pow(AF3_{beta})+Pow(AF4_{beta})}{Pow(AF3_{theta})+Pow(AF4_{theta})}$$ Relation 1

Given previous studies, the right frontal lobe is more active in individuals who have social anxiety and stress or are exposed to social threats (10,15). Based on the investigations performed in the field of analysis of frontal brain signals, the frontal lobe is more affected by the stress of computer games in comparison to other lobes of the brain (13,17). Therefore, the correct choice is to determine the amount of stress on the frontal lobe (Equation 2); as it explains the ratio of brain activity between the two hemispheres in the frontal area (10,15).

$$stress = \frac{pow(F_3(\alpha))}{pow(F_4(\alpha))}$$ Relation 2

Figure 1 shows a view of the location of the electrodes on the individual's head (12).

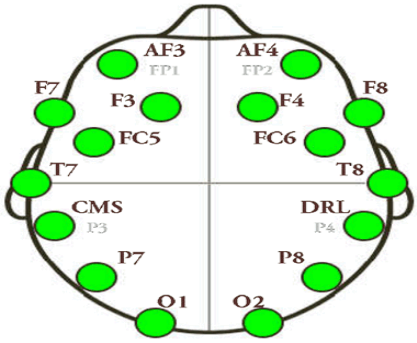

Figure 1. Location of electrodes on participant's head

The normal data distribution was examined using the Shapiro-Wilk test. In addition, Wilcoxon test was utilized to compare the means of the two groups at the significance level of 0.05 and the Mann-Whitney U test was used for the intra-group comparisons. Furthermore, the data were analyzed in SPPS software (version 20, IBM Corporation, Armonk, NY, USA).

Results

According to the inclusion and exclusion criteria, 17 subjects remained in the control group and 18 in the experimental group. Figure 2 demonstrates the different stages of the study and the drop of subjects during the study.

The intention-to-treat (ITT) analysis was not performed due to no drop in participants. The results of the Shapiro-Wilk test indicated that the data of the two groups did not follow the normal distribution. The mean age of the participants was 21 years and all of them were studying for a bachelor's degree. There was no significant difference between the experimental and control groups in terms of age and level of education ($P \leq 0.031$). A comparison of the indices studied in the two groups is presented in table 1.

The cognitive tests obtained from PASAT in the experimental group revealed that the mental health ($P \leq 0.037$) and sustained attention ($P \leq 0.046$) levels increased significantly after the game, but no change was observed in the control group. Additionally, there was a significant increase in the health level and sustained attention in the post-test compared to the control group ($P < 0.050$). The findings of the biological tests in the experimental group showed a significant increase in salivary cortisol hormone and alpha-amylase compared to before the game and also compared to the control group. Furthermore, the analysis of the players' brain signals in the experimental group after the game compared to before the game showed an increase in cognitive activities of the stress and attention indices. This increase was also significant compared to the control group, however no significant change was observed in the control group.

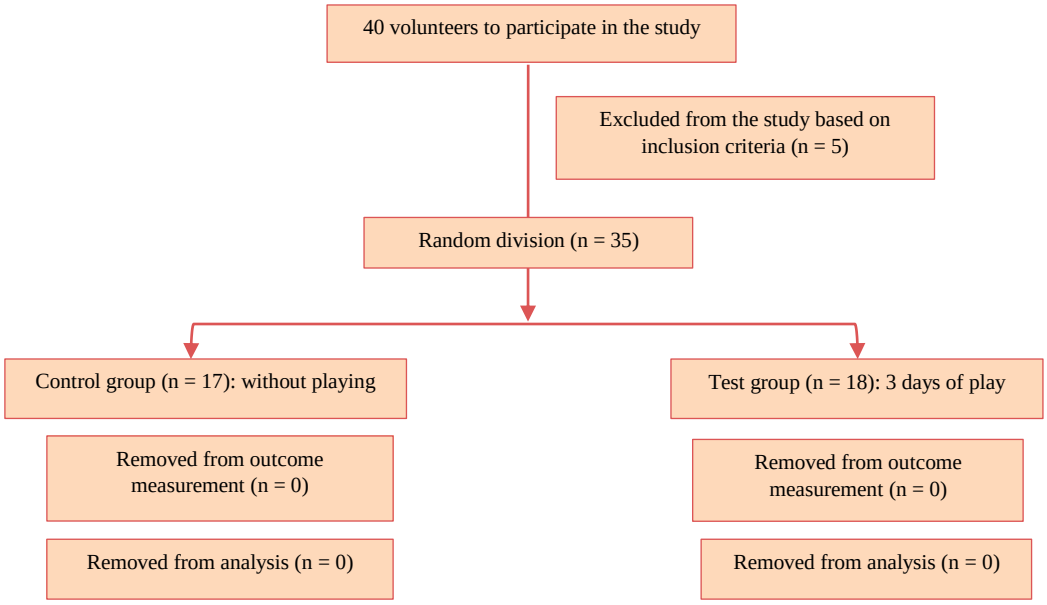

Figure 2. CONSORT flowchart and report of drops during the study stages

Table 1. Comparison of hormonal Indices and electroencephalography (EEG) in the study groups before and after the study

Variable	Group	Pre-test	Post-test	Percentage of changes	P value (Intra-group)
Mental health score in PASAT test	Experimental	45.97 ± 4.90	53.12 ± 4.88	15.55	0.037*
	Control	45.10 ± 5.10	46.03 ± 5.00	2.27	0.780
	P value (Intergroup)	0.065	0.049**	-	-
Sustained attention score in PASAT test	Experimental	14.00 ± 1.10	25.00 ± 1.10	78.57	0.046*
	Control	13.00 ± 0.90	15.00 ± 0.90	15.38	0.066
	P value (Intergroup)	0.051	0.037**	-	-
Alpha amylase level (ng/ml)	Experimental	1.83 ± 0.80	1.85 ± 0.60	1.26	0.009*
	Control	1.83 ± 0.75	1.83 ± 0.81	0.09	0.081
	P value (Intergroup)	0.058	0.011**	-	-
Cortisol level (g/dlµ)	Experimental	67477.10 ± 5.90	82426.70 ± 4.60	22.15	0.010*
	Control	67487.00 ± 8.20	67677.00 ± 8.40	0.28	0.062
	P value (Intergroup)	0.061	0.052	-	-
Stress index score	Experimental	3.71 ± 0.29	5.11 ± 0.32	37.70	0.039*
	Control	3.47 ± 0.32	3.51 ± 0.29	1.15	0.074
	P value (Intergroup)	0.076	0.023**	-	-
Attention index score	Experimental	4.19 ± 0.38	6.82 ± 0.42	62.76	0.049*
	Control	4.21 ± 0.41	4.39 ± 0.38	4.27	0.069
	P value (Intergroup)	0.071	0.049**	-	-

*Significant difference between pre-test and post-test stages, **Significant difference with control group
PASAT: Paced Auditory Serial Addition Test

Discussion

Today, researchers have found that serious computer games play an important role in QOL of individuals in society (1,3). Thus, numerous studies are being carried out in the field of computer games. The present study examined the effect of one of the serious computer games, which has been introduced as an index game by the computer game elite, on the stress-fear system and showed that the use of this game can play a stimulating role for brain activity and stress pathway.

Serious computer games are discussed as a therapy or adjunct therapy in Alzheimer's disease (AD), debilitating neurological disorders in autism and hyperactivity, and enhancing cognitive abilities such as attention, memory (13), and learning (1); So that the content and style of some serious computer games play an important role in cognitive, mental, and even physical health of individuals (1,4,15,16). Extensive investigations have been conducted on the effect of serious computer games on CNS of individuals (1,3,11). Computer games, as an environmental interfering factor, can cause genetic (20), hormonal (21), neurological (22), and behavioral (15) changes in the nervous system of their audience.

Environmental markers alter the nervous system and impair the normal secretion of hormones, even altering the expression of N-methyl-D-aspartate (NMDA) receptor genes (memory and learning index) in animals and humans (17,18). The NMDA receptor gene plays an important role in the development of cognitive parameters such as attention, concentration, memory, and learning in animals and humans, and environmental factors such as electromagnetic fields, electric fields, and even the virtual world play a stimulating role in the expression of this gene (17,19,20). Computer game addiction can alter the expression of the NMDA receptor gene. This change leads to impaired learning and memory of people addicted to computer games (17). In fact, the activity of CNS of individuals changes by computer games (5).

The results of the PASAT cognitive tests in Flow Free game showed improvement of mental health and sustained attention and also, increased secretion of salivary hormone cortisol and alpha-amylase in individuals after playing the Flow Free game. The findings of the present study were consistent with those of the study conducted on the mobile game Runner. No cognitive and hormonal changes were observed in the control group. The stress caused by

the Runner game was limited and mostly due to the fear of losing the game, which played a vital role in the indicators of attention, concentration, and speed of action of subjects (10). In Flow Free, the limited stress is not due to fear of losing the game, but more due to limited playing time. In this game, attractive colors and time limitation in the test game improved the subjects' concentration and attention after the game. In fact, the test game, similar to puzzle games, led to the functional activity in the brain, especially the frontal lobe. In Flow Free, in addition to limited stress, there was another type of stress, namely logical stress (21,22). Cortisol is a sign of stress and alpha amylase is a sign of fear, but the important point is the level of activity and effect of these two hormones on the stress-fear system. As if the effect was positive, the system activity would lead to the improvement in the neurological indicators and if the effect was negative, it would weaken positive cognitive indicators and strengthen negative cognitive indicators (20, 19).

Analyzing and processing brain signals can provide important cognitive information about a person. The amplitude of EEG signals depends on the synchronous function of cortical neurons (22). Simultaneous stimulation of a group of neurons produces a high-amplitude signal on the scalp skin; Because the signals produced by individual neurons are aggregated in the time domain (22,23). The frequency of simultaneous excitations also leads to the occurrence of intermittent EEG signal with a certain frequency (17,19,24). Besides, identifying specific brain bands can help strengthen or weaken the desired band. The signals contain useful information about the function of different parts of the brain. By processing brain signals, different positions of brain waves based on the intensity and weakness of the position are analyzed and identified by experts. This information has many applications in the diagnosis of various pathological conditions (epilepsy, brain tumors, neurological disorders) and brain engineering based on the cognitive indicators extracted (19,25-32).

Changes in the average energy power of the base state of brainwaves in the stress index increased after playing Flow Free compared to the baseline. Moreover, the changes in the mean energy power of the basal state of the brainwaves in the attention index increased after playing Flow Free, but no changes in the brain waves were observed in the control group. Considering the agreement of the biological results of increasing cortisol and alpha-amylase (increasing the activity of the stress-fear system) with the results of increasing the average stress energy power (in processing brain signals), it can be concluded that both methods confirm the increase in stress and the stress due to Flow Free is a limited and logical stress (10); both types of stress have a positive role in the functioning of the frontal lobe of the brain and therefore the subjects' attention and concentration improved after playing. On the other hand, there was an increase in the attention index of the PASAT test after playing Flow Free in individuals and at the same time, the average energy power of the attention index in processing brain signals after the game increased, both confirming the improvement of attention cognition index after the game.

Limitations

Among the limitations of the present study were financial constraints and the lack of a database of brain signals and lack of access to a suitable community of screened players.

Recommendations

It is suggested that similar studies be conducted by examining different and broader age groups.

Conclusion

The Flow Free game as a positive stimulus of CNS, led to the activity of the stress path and changes in brain signals, and as a result, strengthened the cognitive element of attention in players after the game. It can be claimed that the stress resulting from Flow Free game is of limited and logical stress and the positive stress group, both of which improving cognitive indicators of attention. By activating the frontal part of the brain, the two types of stress strengthen brain function and cognitive indicators such as attention, concentration, and correct decision making.

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Authors' Contribution

Hamed Aliyari: Study design and ideation, attracting financial resources for the study, supportive, executive, and scientific study services, providing study equipment and samples, data collection, analysis and interpretation of results, specialized statistical services, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication; Masoomeh Kazemi: Study design and ideation, attracting financial resources for the study, supportive, executive, and scientific study services, providing study equipment and samples, data collection, analysis and interpretation of results, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication; Hedayat Sahraei: Study design and ideation, attracting financial resources for the study, supportive, executive, and scientific study services, analysis and interpretation of results, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication; Mohammad Reza Daliri: attracting financial resources for the study, specialized statistical services, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication; Behrouz Minaei-Bidgoli: analysis and interpretation of results, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication; Sahar Golabi: providing study equipment and samples, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, and the responsibility of maintaining the integrity of the study process from the beginning to the publication.

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Conflict of Interest

The authors declare no conflict of interest.

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