EEG based stress analysis using rhythm specific spectral feature for video game play

Shidhartho Roy 🔎 ^a, Monira Islam^{a,*}, Md. Salah Uddin Yusuf^a, Nushrat Jahan^a

^aDepartment of Electrical and Electronic Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh

Abstract

Background and Objective

For the emerging significance of mental stress, various research directives have been established over time to better understand the causes of stress and how to deal with it. In recent years, the rise of video gameplay is unprecedented, further triggered by the lockdown imposed due to the COVID-19 pandemic. Several researchers and organizations have contributed to the practical analysis of the impacts of such extended periods of gameplay, which lacks coordinated studies to underline the outcomes and reflect those in future game designing and public awareness about video gameplay. Investigations have mostly focused on the "gameplay stress" based on physical syndromes only. Some studies have analyzed the effects of video gameplay with EEG, MRI, etc., without concentrating on the relaxation procedure after video gameplay.

Methods

This paper presents an end-to-end stress analysis for video gaming stimuli using EEG. The PSD value of the Alpha and Beta bands is computed to calculate the Beta-to-Alpha ratio (BAR). In this article, BAR is used to denote mental stress. Subjects are chosen based on various factors such as gender, gameplay experience, age, and BMI. EEG is recorded using Scan SynAmps2 Express equipment. There are three types of video gameplay: strategic, puzzle, and combinational. Relaxation is accomplished in this study by the use of music of various pitches. Two types of regression analysis is done to mathematically model stress and relaxation curve. Brain topography is rendered to indicate the stressed and relaxed region of the brain.

Results

In the relaxed state, the subjects have BAR 0.701, which is considered the baseline value. Non-gamer subjects have an average BAR of 2.403 for 1 hour of strategic video gameplay, whereas gamers have 2.218 BAR concurrently. After 12 minutes of listening to low-pitch music, gamers achieved 0.709 BAR, which is nearly the baseline value. In comparison to Quartic regression, the 4PL symmetrical sigmoid function performs regression analysis with fewer parameters and computational power.

Conclusion

Non-gamers experience more stress than gamers, whereas strategic game creates more stress on human brain. During gameplay, the beta band in the frontal region is mostly activated. For relaxation, low pitch music is the most useful media. Residual stress is evident in the frontal lobe when the subjects experienced high pitch music. Quartic regression performs regression analysis follow the relaxation curve more accurately compared to 4PL symmetrical sigmoid function.

Keywords: Beta-Alpha ratio, EEG, Stress - relaxation modeling, Topography, Video gameplay.

1. Introduction

In the modern society, stress is a significant matter of concern. According to WHO, loss of productivity and mental health disorders have globally cost a significant capital [19]. When the human body is exposed to negative stimuli, it responds with stress. Acute stress is the result of short-term stressful events, which are typically indicated by transient

^{*}Corresponding author

Email addresses: swapno15roy@gmail.com (Shidhartho Roy), monira@eee.kuet.ac.bd (Monira Islam), suyusuf@eee.kuet.ac.bd (Md. Salah Uddin Yusuf), nushrat739@gmail.com (Nushrat Jahan) Preprint submitted to arXiv September 28, 2021

physiological changes. Acute stress lasting for a long time might turn into episodic stress. Chronic stress, anxiety, and clinical depression can result from prolonged exposure to stress factors or traumatic situations [21]. This paper mainly centers around acute stress. To study acute stress, video gameplay has been employed as the stimulus.

Video games (VG) are becoming increasingly popular among young people in current culture, and VG are growing in popularity not just as a research tool but also as an area of study. In addition, a plenty of research is focused on the neurological and behavioral consequences of VG because of the expanding popularity and universal applications, offering a comprehensive brain correlation in recent decades. Moreover, the rising diversity of digital technology, such as smartphones and tablets, has brought entertainment software or VG into the mainstream. Thus, a significant portion of society (more than 30% in tablets and 70% in smartphones) is exposed to these technologies and may now, in some way, be termed as casual gamers [8].

Because of its high temporal resolution, non-invasiveness, and low cost, electroencephalography (EEG) is frequently utilized in research, including neural engineering, neuroscience, and biomedical engineering (e.g., brain-computer interfaces, BCI [10], sleep analysis [18], stress analysis [32], and seizure detection [7]). EEG has provided insight into the brain's functioning in many cognitive processes and is regarded as the building block of functional signaling in the brain. Oscillations of various frequencies are linked to various cognitive functions. Alpha oscillations, for example, are linked to relaxation, whereas beta rhythms are linked to tension.

When it comes to relaxation, listening to music is unquestionably a top contender. Music has a powerful impact on both the mind and the body. Faster music can help us to concentrate and feel more alert. Upbeat music can boost one's mood and make one feel more optimistic about life. A slower tempo can relax the mind and muscles, making a person feel soothed while letting go of the day's stress. This study uses three different types of music (low, medium, and high pitch) to study relaxation.

In the mainstream media, both good and bad health claims associated with VG are common. These comments are primarily unconfirmed and sensational, based on 'expert' opinions, but without proof. Therefore, it is becoming increasingly important to know the actual impacts of long-term exposure to video gaming in a deeper technical context. The effect can be positive in the form of cognitive, motivational, emotional, and social benefits [33] or can be negative in the form of exposure to graphic violence, addiction, contribution to obesity, and cardiometabolism [13]. For a long time, video gaming has been on the increase. However, the growth in gaming was unprecedented during the COVID pandemic. According to a gamesindustry.biz study, VG sales have surged by 63 percent in 50 major areas since pre-pandemic time [34]. The home quarantine compelled everyone to explore the world of gaming, resulting in an 80% increase in the number of new games downloaded. Under the pandemic, the social infrastructure for individuals, particularly those in quarantine, has evolved into various platforms [15]. The rise of gameplay in recent years is evident from Fig. 1. In early 2020, when lockdown started, the duration of video gameplay in hours has almost doubled from before.

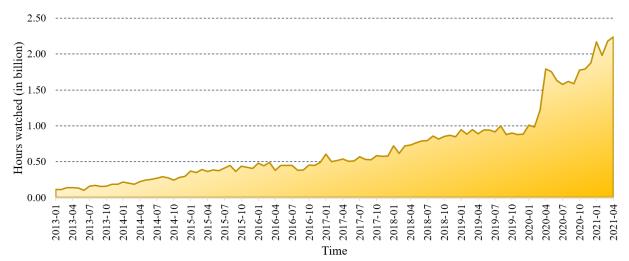


Figure 1: The surge of gameplay hours watched since 2013. At the beginning of the pandemic, the gameplay hours watched have almost doubled [29].

Some researchers have previously focused on the influence of VG, depending on participants' exposure to that particular game or studies, on the content features of VG [14]. Some research specializes in the genres of VG with prominent graphic violence (action, war, shooting, killing, etc.) On this basis, a reasonable quantity of scientific documentation on the research of violence in VG and violence acclimatization is used [16]. For decades, social, political, and scientific considerations have been given to the link between exposure to media violence and violent behavior. Extensive empirical data suggest that exposure to media violence impacts aggressive behavior, abuse, violent cognition, physiologic excitement, and teenage animosity [30]. Another study has shown that playing some VG, particularly "action" games, often improves the cognitive function [16]. It has also given thought on how the business may be better regulated to promote games for cognitive advancement. Considerable research has been conducted on the stressful effects of video gaming on the human brain [12]. Using EEG as a tool for study, Soysal et al. distinguished the function of the brain for different games and the stress level caused by them. It can differentiate between a relaxed and a stressed individual [26]. Saputra et al. researched a crucial aspect of video gaming and found that, in addition to the entertainment value of video gaming, players get stressed when they experience frustration as a result of virtual failure [24].

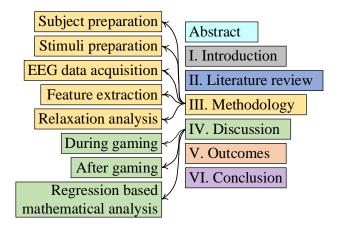


Figure 2: Paper organization structure.

Despite these researches, relatively few works are based on relaxing the stress caused by video gaming. The motivation behind this study was to resemble real-world scenarios as EEG stimuli and analyze video gameplay with EEG. For this purpose, we conducted an open survey on the nature of video gaming on various people. Among 214 participants, 41.35% indicated they do not do anything after gaming, while 38.67% stated they like some music after a prolonged gaming period. Because these two populations outnumber others,

Bio- medical signal type	Notable Methodol- ogy	Stimuli	Subject	Contribution	Ref
EEG	Stress-related hor- mone labeling, ML- based classification	construction work	Workers at Construc- tion Sites	Developed a procedure to recognize construction worker's stress by applying supervised learning algorithms	[11]
EEG	Multiclass SVM with error correcting out- put code (ECOC)	arithmetic task	20 to 24 years old male right-handed adults	The classification of stress with a precision of 94.79% shows the right prefrontal cortex domi- nance over mental stress.	[2]
EEG	Frequency analysis from average power	Multiplayer Online Battle Arena Video Game	18-25 years old 10 participants	First time experienced participant have signifi- cant difference for alpha/beta ratio than experi- enced gamer.	[24]
EEG	Unity3D game en- gine, EMOTIV kit	Video game	ADHD patients	EEG-based game that targets ADHD symp- tomatic individuals to augment their focus.	[4]
EEG and fNIRS	SVM classifier, deci- sion fusion of fNIRS and EEG signals	Montreal Imaging Stress Task (MIST)	22 male, right-handed adults (age 22 \pm 2 years)	suggesting fNIRS+EEG as an efficient tool of stress analysis	[3]
EEG, PPG and GSR	Keystroke Analysis	Video game	22 subjects (9 female) having mean age 29.3 years	Analysis of keystroke data gathered in the tests to suggest a new method of stress measurement	[9]
EEG	power spectral den- sity (PSD)	to prepare a talk on an unknown topic.	28 participants	Finding an appropriate EEG recording phase for classifying mental stress into many groups.	[6]
EEG	PSD, Wavelet trans- formation, topo- graphic analysis	Music of different genres.	48 individuals were selected from 11 to 50 years of age	Short length of music offers alleviation from ten- sion, however the stress is growing when indi- viduals have been exposed to music for a long period.	[23]
EEG	KNN, LDA, MLP	TempleRun video game	20 healthy subjects	A game player's competence level is classified on a consumer gaming device	[5]
EEG	CBA Ratio and the Statistical Analysis	Music	nine participants	In a stressful scenario, a drop of brain alpha wave frequencies and a concurrent increase in the par- ticipant blood pressure and pulse is shown	[20]
EEG	Genetic Algorithm- Based Feature Selec- tion	40 music videos	Thirty-two healthy participants	classification performance is best when the pro- posed GA-based method was used.	[25]
EEG, ECG	Analog amplification in the front-end	Colors and their names	Seven healthy young male subjects	Long-term daily monitoring is needed to evaluate chronic stress	[1]
EEG	PSD, beta/alpha ra- tio	Language based sus- tained mental task	52 subjects all aged from 20 to 23	Mother language creates the least stress.	[32]
EEG	Wavelet, PSD	Language based mu- sic	30 subjects all aged from 20 to 23	Bass frequency reveals more relaxation.	[22]

Table 1: EEG based stress analysis in the recent literature.

we pooled them in our study. To select the video gaming period, we asked our participants how long they play at a time. On average, they reported that they play 55.6 minutes of VG. Some gamers also documented that they play 3 to 4 hours at a stretch, and this has been considered as outlier in this study. The relaxation period of 12 minutes is also based on the survey. Subjects were asked to choose how long they want to spend time after video gameplay before starting another cognitive intensive work. The average response time was 11.08 minutes. Furthermore, a few studies have been discovered to develop a mathematical model based on stress development from gaming and the relaxation via music of various pitches. Our goal in this study is mental state analysis during gameplay of various game genres, brain mapping of these states, mental state analysis after playtime, relaxing via multiple forms of music, and corresponding regression analysis. This is, to the best of our knowledge, the first attempt to aggregate all of them ¹. The rest of the paper is organized as shown in Fig. 2.

2. Literature Review

From the very beginning of the research to examine the response of the brain due to video gameplay, the effects of video gameplay using EEG has been emphasized. Previously some of the studies have been focused on other techniques rather than EEG. But EEG had good accuracy in examining brain activity for video game playing. From 2017 to 2021, many developments took place in this era, such as using fMRI, MRI, PPG, GSR, fNIRS, ECG, etc. But accuracy was not good compared to EEG. Though ECG is the technique that is used the second-highest for this purpose, it is actually a low-quality method. Furthermore, it is difficult to eliminate noise with conventional filtering methods for fNIRS. From the table 1 below, it is clear that the EEG technique is best suited for examining the stress analysis in different time duration.

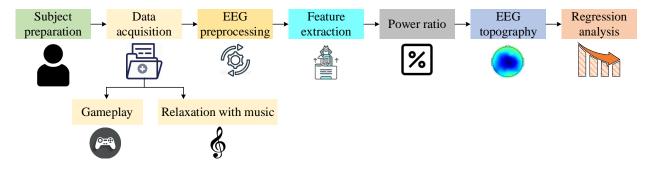


Figure 3: Block diagram of this experiment.

¹After acceptance, code and dataset will be made open access for further research in the link: https: //github.com/royShidhartho/Stress-analysis-video-gameplay

Another assessment observed from the literature review is that people aged 19 to 24 years are mostly impacted by video gaming. This circumstance has both positive and negative impacts on society. Though video gameplay can improve problem-solving skills, it is timeconsuming. We had also observed that old adults, as well as patients, are involved in playing gameplay. The peak age ranged from 19 to 24 years and with increasing age, the observation and the interest in video gaming becomes lower consequently.

3. Methodology

To achieve the objective of this experiment, several methods are used. Subjects were first prepared after settling on a data acquisition protocol using an EEG recording device EEG signal and pre-processing by both onboard and digital devices. The power ratio was computed after extracting features from the clean EEG signal. This experiment made use of a variety of games and music. Following the experiment, brain mapping was created using the EEG topography approach, and mathematical modeling was completed using regression analysis. Fig. 3 illustrates the block diagram of this experiment.

3.1. Subject Preparation

Four focus groups are organized for this study $(FG_1 - FG_4)$ and from four to 17 each (N = 45). Participants were selected using an open survey procedure based on their experience in gaming and their health condition. All subjects are between the ages of 20 and 24 years (22.29 on average) and university students. These are organized into four focus groups: two groups are called 'Gamers' who on average play games 10 hours a week or more. The other two groups play games for less than 2 hour per week or do not play at all. Both men and women participated in the gamer and non-gamer groups. The proportion of women in non-gamers is 45.83%, compared to 19.04% in gamers. There is also a lack of sleep disorders or other serious disorders in the selected subjects. Furthermore, the subjects were unaware of the study's goals. In figure 4, the subject distribution is depicted. Another criteria for selecting the subjects was to select them from a wide BMI spectrum. Eight of the subjects in this study are obese (BMI 30.0 and above), 18 of them are overweight (BMI 25.0-29.9),

12 of them are normal (BMI 18.5-24.9), and the rest of them, 7, are underweight (below BMI 18.5).

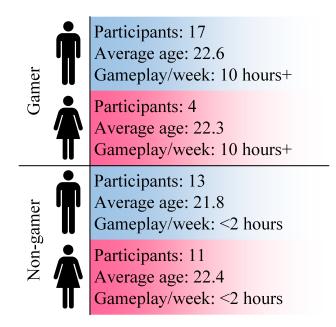


Figure 4: Subject distribution of this study. Blue shades denote the male subjects, and pink shade embodies the female subjects.

3.2. Stimuli preparation

VG is used as stimuli to create stress in this study. Based on game design, all VG were divided into three groups. On one end of the scale, puzzle games demand quick thinking, whereas strategy games need quick response and extended pondering.

1. **Puzzle:** Video puzzle games aim to solve riddles. Logic, pattern recognition, sequence resolution, and word completion are only a few of the problem-solving capabilities that these puzzles might test for. The player may have endless time or endeavors to solve a puzzle or a time restriction, or it may make it more challenging to do fundamental problems by having to do it in real-time.

Gameplay format: These games usually include rules in which players use a grid, network, or other interactive areas to control game pieces. In order to earn a triumph, the players must unravel clues so that they may then move to the next level. Usually, completing every riddle will lead to a more complicated task.

2. Strategy: A video strategy game promotes strategic thinking and preparation to win. It focuses on strategic, tactical, and sometimes logistical questions. In this area, there are additional action games. Many games also feature economic concerns and exploration. It is classified into four subtypes depending on whether the game is in turn or in real-time, whether strategic or tactical—for example, Rome: Total War, Dota 2, etc.

Gameplay format: In order to reduce opposing troops, a player must perform a sequence of operations against one or more opponents. Victory is achieved through a greater plan with less luck. The user receives a divine vision of the game world, with most strategy VG offering them indirect authority over the game units. Consequently, most strategy games involve a mixture of tactical and strategic considerations and contain various fighting components.

3. Combinational: It accumulates both the puzzle and strategy type games. Such as Grand Theft Auto, San andreas etc.

Gameplay format: A combination game implies a timed sequence of plays, each of which leaves the opponent incapable or near impossible to block or otherwise prevent the next succession.

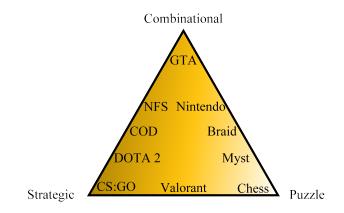


Figure 5: Game classification considered for this study.

3.3. EEG data Acquisition

The Scan SynAmps2 Express equipment (Computedics Ltd., VIC, Australia) was used to acquire EEG signals. A wired EEG cap containing 32 Ag/AgCl electrodes, comprising 30 EEG electrodes and two reference electrodes, was utilized to acquire EEG data (opposite lateral mastoids). An adapted international 10–20 system was used to put the EEG electrodes. All electrodes and the skin had a contact impedance of less than 5 $k\Omega$. The EEG recordings were amplified and digitized at 500 Hz using the Scan SynAmps2 Express device (resolution: 16 bits). Scan 4.5 from Neuroscan is the data collecting tool. On the computer, the raw data was stored as .cnt files. Figure 6 manifests the the experiment electrode positions.

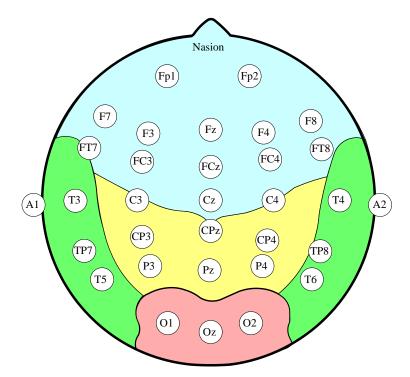


Figure 6: 10-20 system of electrode placement. Blue electrode denotes the electrode positions used in this experiment.

The acquisition of data is divided into two streams – one during video gameplay and one following gameplay. In the gameplay stage, the relaxed state value was captured initially after 10 minutes of relaxation in experimental set-up data. The data was collected during the games in an interval of 15 minutes. Data were recorded after the gameplay within a period of 3 minutes. The workflow of data gathering for the experiment is displayed in the Fig. 7 .



Figure 7: Data acquisition protocol. The orange color palette denotes the during gameplay phase, and the green color palette represents after gameplay phase.

3.4. Feature extraction

The FFT is a sophisticated reversible mapping technique used to transfer a signal from a time domain to a frequency domain. In the periodogram calculated by the FFT technique, the PSD properties of artifact-free EEG data may be evaluated. However, there is elevated volatility and low statistical precision in the periodogram. Welch developed a modified periodogram averaging approach, resulting in a reduction in PSD variance [31].

This process involves splitting time series data into segments, overlapping them, and then conducting FFT, calculating and averaging the amplitude of each segment. In this study, 72 minutes EEG signals were selected as samples, and the window length of each 10 seconds was divided into four equal segments. The time sequence was separated into 50% for each sample of 10 seconds, and four segments were overlapped. For each segment, FFT was used to calculate and average the capacity of the overlapping FFT coefficients in all segments. This calculation is done for all frequency ranges until, ultimately, the Alpha and Beta PSD ($\mu V^2/Hz$) values have been generated. The PSD is manifested according to Welch in the following equation:

$$P_d(f) = \frac{1}{MU} \sum_{n=0}^{M-1} \left| x_d(n) w(n) e^{-j2\pi f n} \right|^2, \tag{1}$$

for d = 1, 2, 3, ..., L signal intervals, $x_d(n)$ is the sequence, where M is the interval length. w(n) represents the window data, whereas U is the normalization factor for window power. U is defined as [27],

$$U = \frac{1}{M} \sum_{n=0}^{M-1} |w(n)|^2.$$
(2)

The Welch spectrum of power can be shown as the mean over these modified periodograms:

$$P_{Welch}(f) = \frac{1}{L} \sum_{i=0}^{L-1} P_d(f),$$
(3)

where P_{Welch} is each interval's periodogram of the EEG signal.

Rhythm power ratio The power ratio was calculated by dividing the absolute power of one frequency band by the absolute power of another frequency band, using the averaged PSD of each frequency band. Delta activity revealed the deep resting condition of a person. It was not presumed to display substantial activity in the face of stress, which is why this rhythm has not been studied. By dividing the PSD of beta by the PSD of alpha, the beta/alpha rhythm power ratio was determined. After that, it was evaluated with the ratio value of the difference between the baseline and the stress session. The processes can also be used to determine the Theta/Beta ratio and differentiate between relaxed and stressed states. The path of data collecting, signal pre-processing, feature extraction, and power ratio computation is depicted in Figure 3.

3.4.1. EEG topography

EEG topography is a sort of neuroimage including the geometrical design of uniformly spaced sites of multiple EEG electrodes on the head. A certain computer software maps the activity on the color screen or printer in many tones of colors by sorting the number of actions (for example, blue might represent low EEG amplitude, while yellow and red might represent larger amplitudes). From EEG topography, we are exploring the residual stress on the human brain. Residual stress is termed as the remaining stress after the designed relaxation period for this study.

In mathematical interpolation techniques (calculation of intermediate values on the values of their neighbors), the spatial locations between electrodes are established to provide a smooth color gradation. This technique delivers the position of rhythm, amplitude changes regarding the skull surface, and a considerably more precise and realistic image.

Comparing topographies for pattern similarity in various settings can demonstrate various thinking processes and so directly test cognitive theories. Topographic analysis of variance (TANOVA) is a statistical test that examines similarity topographies. In this topographic similarity measure, called "angle measure," the topographical pattern similarity is measured by a high dimensional angle between two topographies.

Multivariate topography patterns across all sensors are displayed as \vec{A} and \vec{B} vectors with a size equal to that of the two situations. The following equation (Eq. 4) calculates an angle cosine of θ to quantify the topographical similitude between the two scenarios.

$$\cos\theta = \frac{\vec{A}.\vec{B}}{\left|\vec{A}\right|.\left|\vec{B}\right|},\tag{4}$$

The cosine value is an index that shows the spatial correlation between two circumstances in which the +1 value indicates the same patterns as the -1 value. In addition, because the magnitude of the response in the two circumstances normalizes this index, it benefits that the magnitude of the responses does not impact it.

3.4.2. Regression analysis and metrics

Two types of regression analysis is employed in this paper.

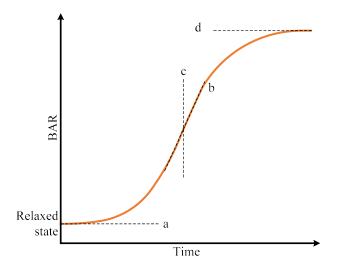


Figure 8: Symmetrical sigmoid function.

• **4PL Symmetrical sigmoid function** This results in a more advanced model that is better suited to many biological processes. The four-parameter logistic regression is known as this model (4PL). It is very beneficial for dose-response or receptor binding tests or comparative tests. It contains four parameters to be evaluated to 'fit the curve,' as the name suggests. The model is designed for data making an S-shaped curve. The model's equation is:

$$y = d + \frac{a-d}{1+\left(\frac{x}{c}\right)^b},\tag{5}$$

where , a =the least value that can be achieved (i.e. what happens at relaxed state.), d = the highest value that can be achieved (i.e. what happens after 1 hour of gameplay), c = inflection point (i.e. the point on the S shaped curve halfway between a and d), and b = Hill's slope of the curve (the steepness of the curve at point c).

Fig. 8 denotes the structure of the 4PL Symmetrical sigmoid function.

• Quartic Regression The quartic regression adapts to a data set with a quartic function (a polynomial function with a degree of 4). The form of quartic function is:

$$y = a + bx + cx^2 + dx^3 + ex^4 + fx^5$$
(6)

The quartic function takes a range of forms with various inflection points (when a function changes form) and zero to many roots (places where the graph crosses the axis). If the f value exceeds 0, three distinct fundamental forms can be present.

Metrics Two types of regression metrics are employed here to fit the stress and relaxation curve for this experiment.

• Coefficient of determination

A statistical measure of how close the data are to the correct regression line is R-squared. It is also known as the determination coefficient or the multiple regression coefficients. A linear model may explain a certain proportion of the variation in a response variable:

$$R^{2} = 1 - \frac{sum \ of \ the \ squares \ of \ residuals}{total \ sum \ of \ squares}$$
(7)

A high R^2 number, in general, suggests that the model is a good fit for the data, though fit interpretations vary depending on the context of study. For example, a R^2 of 0.44 shows that 44 percent of the variation in the outcome can be explained simply by predicting the outcome using the covariates in the model. In certain subjects, such as the social sciences, that proportion may be difficult to forecast; in others, such as the physical sciences, one would expect R^2 to be considerably closer to 100%.

• Akaike information criterion (AIC)

The AIC is a prediction error estimator and a comparable quality for a certain number of data models. AIC determines the quality of each model concerning each of the other models based on the collection of models for the data [17]. AIC offers a way to pick the model. The information theory is the basis of AIC. When used to describe the process that produced the data, a statistic model is virtually never accurate; hence, information is lost through the usage of the model to describe the process. The AIC calculates the amount of information lost by a particular model: the less information lost, the greater the model's quality [28].

$$AIC = 2k - 2ln(\hat{L}),\tag{8}$$

where \hat{L} is the maximum value of the likelihood function for the model and k is the number of estimated parameters in the model. AIC considers the trade-off between model goodness of fit and model simplicity when assessing the amount of information lost by a model. To put it another way, AIC considers both the risks of overfitting and underfitting.

3.5. Relaxation analysis

Music is used as a relaxation media in this study. Pitch has been used to categorize music in this research. Pitch is the characteristic that allows people to perceive sounds as "upper" or "lower" in the sense of musical melodies. It is a perceptual feature of sounds that allows them to be arranged on a frequency-related scale[1]. Only sounds with a precise and stable frequency that can be differentiated from noise can calculate pitch. Pitch is a significant auditory attribute of musical tones, along with duration, loudness, and timbre.

Pitch can be described as a frequency; however, it is a subjective psychoacoustical aspect of sound rather than a completely objective physical characteristic. Pitch has long been a critical topic in psychoacoustics, with theories of sound encoding, processing, and perception in the auditory system being created and tested. The frequency of vibration of the sound waves that create them determines the pitch of sounds. A high pitch is defined as a frequency of 880 hertz [Hz; cycles per second], while a low pitch is defined as a frequency of 55 hertz [Hz; cycles per second]. The music is divided into the following categories:

- Low pitch music: below 200 Hz,
- Medium pitch music: 200 to 600 Hz, and

• High pitch music: above 600 Hz

To bring down the beta band activity in previous levels, subjects are divided into 4 groups.

- Group 1: No music was introduced to bring down the brain activity to normal.
- Group 2: Low pitch music was introduced to bring down the brain activity to normal.
- Group 3: Medium pitch music was introduced to bring down the brain activity to normal
- Group 4: High pitch music was introduced to bring down the brain activity to normal.

4. Experimental result analysis

The full experimental study is divided into three phases; stress level observation during gaming, relaxation level determination after video gameplay and mathematical modeling of brain stress and relaxation. After discussing all the observations, the summary of the discussion's are pointed out in evaluation sub-section.

4.1. Stress analysis

Before going into the gameplay and data acquisition, the relaxed state alpha and beta value are measured. On average, the subjects exhibit BAR as 0.701 (Alpha = 4.329, Beta = 3.034). This value from now on is considered as the baseline value. When the gameplay starts, subjects have gone through 3 distinct set of VG; puzzle, combinational, and strategic. As the subjects are broadly divided into 2 groups, gamer and non-gamer, each group's data are calculated in average. For data acquisition, 15 minutes interval is considered.

Overall, in all categories of games, Strategic games are more stressful to subjects. By comparison of gamer and non-gamer, gamers are more likely to adopt strategic games. In the case of puzzle-type games, non-gamer people are more stressed than the gamer subject group. The difference is also more significant here. As gamer group are more used to solve the puzzle patterns it is less stressful to them. Same goes for strategic game also. But in the case of strategic game the action / shooting scenes of games are almost have same impact

Game	Gamer	After	Increase	After	Increase	After	Increase	After 1	Increase
Types	type	15 min	(%)	30 min	(%)	45 min	(%)	Hour	(%)
Durals	Gamer	0.729	0.0384	0.874	0.1979	1.297	0.4595	1.541	0.5451
Puzzle	Non- Gamer	0.862	0.1868	0.984	0.2876	1.542	0.5454	1.897	0.6305
Combi-	Gamer	0.814	0.1388	0.917	0.2356	1.341	0.4773	1.797	0.6099
national	Non- Gamer	1.084	0.3533	1.295	0.4587	1.742	0.5976	2.149	0.6738
G	Gamer	1.173	0.4024	1.376	0.4906	1.862	0.6235	2.218	0.6839
Strategic	Non- Gamer	1.337	0.4757	1.426	0.5084	1.856	0.6223	2.403	0.7083

Table 2: Change of mental states during gameplay, observed with BAR.

on both type of subjects. The difference is also been observed in the topographic plot of brain activity. In the topographic plot, the blue region indicates the dominance of alpha activity and the red region denotes the dominance of beta activity. After only 15 minutes of gameplay, the frontal lobe of non-gamers is indicating the dominance of beta band activity. This frontal lobe is directly connected with concentration, planning, and motor control. So, this topographic plot clearly indicates that non-gamers are more impacted with puzzle gameplay.

Over the gameplay time, this trend is continued to grow. Also in the same time, there is a medium hotspot of beta activity in the occipital lobe which is responsible for vision. This hotspot indicates the pressure increase in eyes for constant gameplay. And, also this region keeps growing over time. Another interesting phenomenon happens after 45 minutes of gameplay. The parietal lobe, responsible for body awareness, exhibits a mild hotspot connecting the frontal and occipital lobe. All of these brain activities clearly indicate that non-gamers show a greater beta activity over gamers. As strategic type games create the maximum stress on subjects, so in case of topographic representation only subject reaction on strategic game is depicted in Fig. 9.

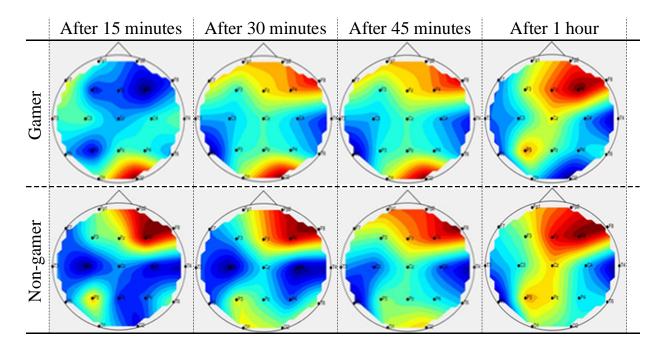


Figure 9: Topographic representation during gaming for strategic type gameplay. The blue color palette denotes the dominance of alpha activity in that region.

4.2. Music evoked relaxation analysis

4.2.1. Puzzle

In puzzle-type gameplay, the after-gameplay BAR was 1.541 for gamers and 1.897 for non-gamers. Among the four subject groups, the group exposed to low pitch music for relaxation was more evident to bring down the beta band activity faster than the other three groups. Within this group, the beta activity in the frontal lobe and motor cortex was downed significantly faster than the other three groups. Another interesting phenomenon happened in the group, which is not exposed to no music. Their response to the brain relaxation process was just below the medium pitch song-exposed group. It is evident from the brain response that low pitch music relaxes the stressed brain faster than high pitch music. Also, at the same time, high music relaxes the brain at a much slower rate, and the residual beta-band activity is highest among all three types of music. Another noticeable change in brain activity is the creation of a mild hotspot in the temporal lobe. The change of mental state for puzzle-type gameplay is shown in Table 3. The residual stress is evident in the frontal lobe when the subjects experienced high pitch music.

Music	Gamer	Immediately	After 3	After 6	After 9	After 12
Types	type	After	min	min	min	min
Low	Gamer	1.541	1.023	0.865	0.812	0.709
pitch	Non- Gamer	1.897	1.137	0.912	0.856	0.716
Medium	Gamer	1.541	1.148	0.892	0.841	0.714
Pitch	Non- Gamer	1.897	1.239	1.026	0.913	0.768
High	Gamer	1.541	1.267	0.914	0.862	0.736
pitch	Non- Gamer	1.897	1.342	1.103	0.924	0.784
No	Gamer	1.541	1.186	0.895	0.852	0.718
music	Non- Gamer	1.897	1.289	1.078	0.917	0.796

Table 3: Change of mental states after gameplay (puzzle), observed with BAR.

4.2.2. Combinational

For combinational game types, the residual stress after 12 minutes of rest was more than in puzzle-type gameplay. Table 4 documented the mental state change for relaxation after combinational type gameplay. The relaxation curve after combinational type gameplay is between the responses after puzzle and strategic type gameplay. The mild hotspots of the frontal lobe are smaller than strategic type gameplay (Fig. 10). Another notable observation is when subjects were not experienced with any music. In this case, the response is almost similar to the medium pitch music response.

Music	Gamer	Immediately	After 3	After 6	After 9	After 12
Types	type	After	min	min	min	min
Low	Gamer	1.797	1.434	0.968	0.873	0.713
pitch	Non- Gamer	2.149	1.614	1.172	0.866	0.72
Medium	Gamer	1.797	1.349	0.98	0.851	0.718
Pitch	Non- Gamer	2.149	1.614	1.172	0.924	0.829
High	Gamer	1.797	1.542	1.034	0.872	0.820
pitch	Non- Gamer	2.149	1.824	1.197	0.935	0.805
No	Gamer	1.797	1.479	0.971	0.807	0.724
music	Non- Gamer	2.149	1.672	1.094	0.894	0.815

Table 4: Change of mental states after gameplay (combinational), observed with BAR.

4.2.3. Strategic

For strategic type gameplay, low pitch music was helpful for both gamers and nongamers. Another interesting observation is that for non-gamers, high pitch music and no music yields an almost similar response in the relaxation curve. In Fig. 10 the phases of brain after 12 minutes for various cases are depicted in topographic representation. A mild hotspot of beta activity in the frontal lobe is present for non-gamers when they are experienced to medium pitch music for relaxation. Nevertheless, the overall percentage of beta activity is much higher in non-gamers who experienced high pitch music. When gamers have not experienced any music, some mild activity zones are visible frontal and occipital lobes. Overall, both for gamers and non-gamers, low pitch music brings more relaxation than any other relaxation procedure (Table 5).

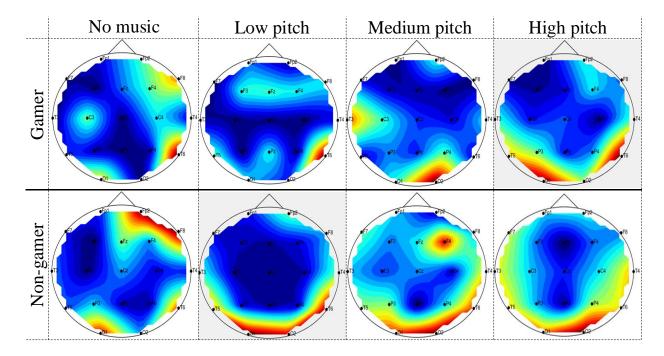


Figure 10: Topographic representation after gaming for strategic type gameplay. The red color palette denotes the dominance of beta activity in that region.

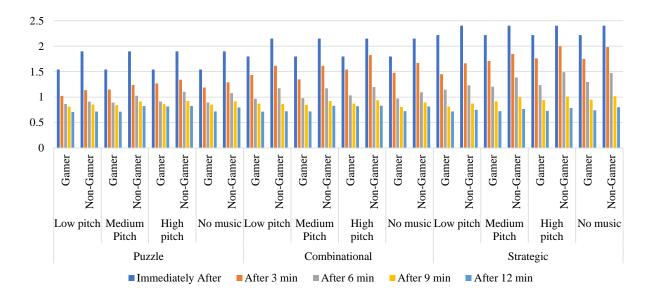


Figure 11: Brain relaxation after gameplay.

Music	Gamer	Immediately	After 3	After 6	After 9	After 12
Types	type	After	min	min	min	min
Low	Gamer	2.218	1.451	1.145	0.814	0.717
pitch	Non- Gamer	2.403	1.663	1.232	0.873	0.749
Medium	Gamer	2.218	1.71	1.205	0.917	0.723
Pitch	Non- Gamer	2.403	1.846	1.386	0.996	0.824
High	Gamer	2.218	1.76	1.235	0.94	0.816
pitch	Non- Gamer	2.403	1.999	1.49	1.008	0.827
No	Gamer	2.218	1.75	1.296	0.951	0.741
music	Non- Gamer	2.403	1.983	1.472	1.017	0.819

Table 5: Change of mental states after gameplay (strategic), observed with BAR.

4.3. Regression based mathematical analysis

For the mathematical modelling of the entire experiment, two different phases have been followed, such as:

- 1. During gameplay: Tables 6 and 7 denote the parameters for 4PL symmetrical sigmoid function and quartic regression, respectively. R^2 and AIC is used to measure the goodness of the mathematical modeling for the respective equations. In the later gameplay period, stress increase rate was much higher than the earlier time.
- 2. After gameplay: In Tables 8 and 9, the mathematical modeling for brain relaxation is documented. In the first three minutes the rate of relaxation is higher than the later segments.

In Fig. 12, the comparison between the two mathematical models is depicted. In almost all cases, the quartic regression dominates over the 4PL symmetrical sigmoid function. But this achievement has come with a price for quartic regression. On average, 20-30% more computational power was required to model quartic regression than the 4PL symmetrical sigmoid function.

Game	Gamer		Coeff	Metrics			
type	type	a	b	С	d	R^2	AIC
Duggle	Gamer	0.7113	5.0082	41.0507	1.6653	0.9996	-27.47
Puzzle Non Game	Non Gamer	0.7701	4.5143	42.8531	2.1471	0.9887	-8.195
Combi-	Gamer	0.7371	3.1548	62.6104	3.0142	0.9943	-12.68
national	Non Gamer	0.7223	1.1433	7008	8794	0.9919	-8.719
Ct	Gamer	0.7187	0.9913	2403	5339054	0.989	-6.724
Strategic	Non Gamer	0.7472	0.9616	290172	460270.4	0.9605	0.3441

Table 6: Parameters and metrics of mathematical modeling for during gameplay experiment (4PL symmetrical sigmoid function).

The strategic game creates more stress on the subjects of the three broad categories of games discussed here. However, gamer subject groups adapted more to strategic games because of their experience.

In the relaxation phase, the subject groups who experienced puzzle games achieved less BAR than other groups. Even for non-gamers, this observation stands out. We conclude that even when subjects were not experienced to puzzle games, puzzles are commonplace in our lives. So, the brain seems to adapt too quickly.

For mathematical modeling, during gameplay, the stress curve is very predictable, resulting in R^2 value 1 for every case. However, when 4PL symmetrical sigmoid functions were used to model relaxation curves, the R^2 value drops to even 0.9913. Only in two cases, the R^2 value attains 1. In quartic regression function, despite requiring much more

Game	Gamer			Coeffici	ient		Metrics
type	type	a	b	С	d	e	R^2
Deserte	Gamer	0.701	0.01184	-0.00136	5.373E-5	-5.086E-7	1
Puzzle	Non Gamer	0.701	0.04116	-0.00341	10.598E-5	-9.169E-7	1
Combi-	Gamer	0.701	0.02556	-0.00202	6.227E-5	-5.103E-7	1
national	Non Gamer	0.701	0.05173	-0.00268	7.081E-5	-5.629E-7	1
Ctantonia	Gamer	0.701	0.06878	-0.00379	9.874E-5	-7.942E-7	1
Strategic	Non Gamer	0.701	0.0989	-54541	0.000126	-9.152E-7	1

Table 7: Parameters and metrics of mathematical modeling for during gameplay experiment (quartic regression).

computational power, yields the R^2 value to 1.

5. Outcome of the Study

The key outcome of the study is delineated as follows:

- 1. Non-gamers experience more stress than gamers,
- 2. During gameplay, the beta band in the frontal region is mostly activated,
- 3. Strategic game creates more stress on human brain,
- 4. Low pitch music is the most useful media for relaxation,
- 5. Residual stress is evident in the frontal lobe when the subjects experienced high pitch music,
- 6. During relaxation, the alpha band in the frontal region is mostly activated,
- 7. 4PL symmetrical sigmoid function performs regression analysis with minimum parameters/ computational power,

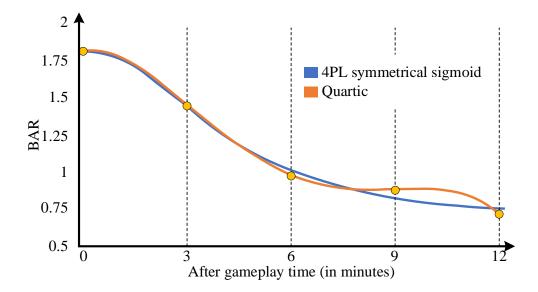


Figure 12: Residuals of cubic and original average data

Guntari	Maria	Gamer	Coefficient				Metrics	
Game type	Music type	type	a	b	с	d	R^2	AIC
		Gamer	1.5410	0.3937	360.9098	-2.4249	0.9979	-20.95
	Low Pitch	Non Gamer	1.8970	0.4967	14.7121	-0.5570	0.9973	-16.05
	Medium	Gamer	1.5414	1.2729	4.2799	0.5133	0.9937	-15.37
Puzzle	Pitch	Non Gamer	1.8970	0.79044	5.1763	0.2516	0.9999	-36.46
Puzzie	High Pitch	Gamer	1.5412	3.2904	3.4865	0.8151	0.9989	-24.73
	High Pitch	Non Gamer	1.8969	0.8284	8.9388	-0.0215	0.0009	-28.03
	NU	Gamer	1.5417	1.6380	3.9345	0.6141	0.9913	-13.77
	No music	Non Gamer	1.8969	0.4707	922.3299	-7.7168	1	-40.25
	Low Pitch	Gamer	1.7987	2.2673	4.1514	0.6491	0.994	-12.53
		Non Gamer	2.1484	1.4688	5.8055	0.2179	0.9996	-23.86
	Medium	Gamer	1.7975	1.6254	4.3045	0.5303	0.9984	-19.37
Combi-	Pitch	Non Gamer	2.1486	1.7268	4.3938	0.5875	0.9997	-25.68
national		Gamer	1.7970	2.3198	3.3399	0.7732	0.9999	-35.66
	High Pitch	Non Gamer	2.1487	1.7094	4.4000	0.5887	0.9999	-31
	No music	Gamer	1.7975	2.7664	4.1841	0.6739	0.9997	-27.28
	No music	Non Gamer	2.1490	2.5295	3.9101	0.7385	1	-42.42
	Low Pitch	Gamer	2.2175	0.8197	0.89861	-0.7128	0.9965	-12.21
	Low Pitch	Non Gamer	2.4024	1.1049	7.2473	-0.2689	0.9988	-16.5
	Medium	Gamer	2.2183	1.5853	5.8047	0.2552	0.9999	-30.82
GL	Pitch	Non Gamer	2.4022	1.2444	9.5813	-0.4817	0.9995	-21.38
Strategic	III d Dit d	Gamer	2.2188	1.6827	5.9997	0.2723595	0.9998	-25.39
	High Pitch	Non Gamer	2.399616	1.754762	7.592323	0.03812683	0.9985	-15.49
	No music	Gamer	2.217533	1.426625	7.804479	-0.06470811	0.9999	-28.79
	ino music	Non Gamer	2.400454	1.721276	7.344441	0.09479044	0.9989	-17.12

Table 8: After gameplay mathematical modeling with 4PL symmetrical sigmoid function.

8. Quartic regression performs regression analysis follow the relaxation curve more accurately compared to 4PL symmetrical sigmoid function.

<i>a</i> ,		Gamer			Metrics			
Game type	Music type	type	a	b	с	d	е	R^2
	I DUI	Gamer	1.541	-0.2693	0.0393	-0.0025	0.000051	1
	Low Pitch	Non Gamer	1897	-0.3926	0.0558	-0.00331	5.81276E-5	1
	Medium	Gamer	1.541	-0.1170	-0.01404	0.00367	-0.00018	1
Puzzle	Pitch	Non Gamer	1.897	-0.3543	0.0576	-0.0046	0.00014	1
Puzzle	High Pitch	Gamer	1.541	0.0203	-0.0599	0.0086	-0.00035	1
	High Pitch	Non Gamer	1.897	-0.2892	0.0459	-0.00415	0.00014	1
	No music	Gamer	1.541	-0.0649	-0.0333	0.00598	-0.00027	1
	No music	Non Gamer	1.897	-0.3355	0.0585	-0.0053	0.00017	1
	Low Pitch	Gamer	1.797	0.0247	-0.0784	0.0114	-0.00047	1
		Non Gamer	2.149	-0.1875	0.00181	0.00044	-9.774E-06	1
	Medium	Gamer	1.797	-0.1109	-0.02518	0.00474	-0.00021	1
Combi-	Pitch	Non Gamer	2.149	-0.1708	-0.0077	0.00194	-7.305E-5	1
national	High Pitch	Gamer	1.797	-0.11003	-0.0254	0.0047	-0.00019	1
		Non Gamer	2.149	-0.1661	-0.0104	0.0024	-9.465E-5	1
	No music	Gamer	1.797	0.0514	-0.0808	0.0107	-0.00041	1
	No music	Non Gamer	2.149	-0.0276	-0.069	0.0098	-0.00038	1
	Low Pitch	Gamer	2.218	-0.4486	0.0906	-0.00989	0.00038	1
	Low Pitch	Non Gamer	2.403	-0.3553	0.04918	0.00019	-0.00098	1
	Medium	Gamer	2.218	-0.1179	-0.0289	0.0044	-0.00017	1
Gu	Pitch	Non Gamer	2.403	-0.21475	0.0129	-0.00127	6.121E-5	1
Strategic	III I D'AI	Gamer	2.218	-0.0715	-0.0428	0.0059	-0.00023	1
	High Pitch	Non Gamer	2.403	-0.11075	-0.008	-0.0001019	5.0926E-5	1
	No music	Gamer	2.218	-0.1420278	-0.00801	0.00123	-3.549E-5	1
	INO MUSIC	Non Gamer	2.403	-0.1115	-0.01139	0.0006	1.852E-5	1

Table 9: After gameplay mathematical modeling with Quartic Regression function.

6. Conclusion

The study of stress analysis on the human brain for video gaming and music-evoked relaxation analysis is critical for understanding the human brain for everyday activities. This study is, to the best of our knowledge, the first of its kind. This paper presents a comprehensive stress analysis for video gameplay from a wide range of perspectives. Stress was analyzed from the rhythm-specific spectral feature, BAR, from EEG. Among all games, the strategic game proves to be the most stressful. Non-gamers exhibit more stress to video gameplay than gamers, demonstrating the adaptability of video gameplay with stress. Music of various pitches was used to compare no music after the gameplay for relaxation analysis. After video gameplay, low pitch music proved to be the most effective media for relaxation. Regression analysis was used to represent relaxation and stress mathematically better. The most effective function for this is quartic regression. EEG topography has been used to identify the activation hotspot within the brain for a specific game or relaxation procedure. During gameplay, the frontal region is particularly active. This work can be expanded to include other types of VG or even other stressful activities. In addition, any relaxation technique other than music can be used to normalize brain activity.

Acknowledgements

None. No funding to declare.

Declaration of Competing Interest

The authors have no conflict of interest to disclose.

References

- Ahn, J.W., Ku, Y., Kim, H.C., 2019. A novel wearable eeg and ecg recording system for stress assessment. Sensors 19, 1991.
- [2] Al-Shargie, F., Tang, T.B., Badruddin, N., Kiguchi, M., 2018. Towards multilevel mental stress assessment using svm with ecoc: an eeg approach. Medical & biological engineering & computing 56, 125–136.
- [3] Al-Shargie, F., Tang, T.B., Kiguchi, M., 2017. Stress assessment based on decision fusion of eeg and fnirs signals. IEEE Access 5, 19889–19896.
- [4] Alchalcabi, A.E., Eddin, A.N., Shirmohammadi, S., 2017. More attention, less deficit: Wearable eegbased serious game for focus improvement, in: 2017 IEEE 5th international conference on serious games and applications for health (SeGAH), IEEE. pp. 1–8.
- [5] Anwar, S.M., Saeed, S.M.U., Majid, M., Usman, S., Mehmood, C.A., Liu, W., 2018. A game player expertise level classification system using electroencephalography (eeg). Applied Sciences 8, 18.
- [6] Arsalan, A., Majid, M., Butt, A.R., Anwar, S.M., 2019. Classification of perceived mental stress using a commercially available eeg headband. IEEE journal of biomedical and health informatics 23, 2257–2264.
- [7] Chen, G., 2014. Automatic eeg seizure detection using dual-tree complex wavelet-fourier features. Expert Systems with Applications 41, 2391–2394.
- [8] Choi, E., Shin, S.H., Ryu, J.K., Jung, K.I., Kim, S.Y., Park, M.H., 2020. Commercial video games and cognitive functions: video game genres and modulating factors of cognitive enhancement. Behavioral and Brain Functions 16, 2.

- [9] Das, D., Bhattacharjee, T., Datta, S., Choudhury, A.D., Das, P., Pal, A., 2017. Classification and quantitative estimation of cognitive stress from in-game keystroke analysis using eeg and gsr, in: 2017 IEEE Life Sciences Conference (LSC), IEEE. pp. 286–291.
- [10] He, Y., Eguren, D., Azorín, J.M., Grossman, R.G., Luu, T.P., Contreras-Vidal, J.L., 2018. Brainmachine interfaces for controlling lower-limb powered robotic systems. Journal of neural engineering 15, 021004.
- [11] Jebelli, H., Hwang, S., Lee, S., 2018. Eeg-based workers' stress recognition at construction sites. Automation in Construction 93, 315–324.
- [12] Johnstone, S.J., Jiang, H., Sun, L., Rogers, J.M., Valderrama, J., Zhang, D., 2020. Development of frontal eeg differences between eyes-closed and eyes-open resting conditions in children: Data from a single-channel dry-sensor portable device. Clinical EEG and Neuroscience, 1550059420946648.
- [13] Kracht, C.L., Joseph, E.D., Staiano, A.E., 2020. Video games, obesity, and children. Current obesity reports 9, 1–14.
- [14] Kühn, S., Gleich, T., Lorenz, R.C., Lindenberger, U., Gallinat, J., 2014. Playing super mario induces structural brain plasticity: gray matter changes resulting from training with a commercial video game. Molecular psychiatry 19, 265–271.
- [15] Marston, H.R., Kowert, R., 2020. What role can videogames play in the covid-19 pandemic? Emerald Open Research 2.
- [16] Martínez-Tejada, L., Puertas-González, A., Yoshimura, N., Koike, Y., 2021. Exploring eeg characteristics to identify emotional reactions under videogame scenarios. brain sci. 2021, 11, 378.
- [17] McElreath, R., 2018. Statistical rethinking: A Bayesian course with examples in R and Stan. Chapman and Hall/CRC.
- [18] Motamedi-Fakhr, S., Moshrefi-Torbati, M., Hill, M., Hill, C.M., White, P.R., 2014. Signal processing techniques applied to human sleep eeg signals—a review. Biomedical Signal Processing and Control 10, 21–33.
- [19] Mozos, O.M., Sandulescu, V., Andrews, S., Ellis, D., Bellotto, N., Dobrescu, R., Ferrandez, J.M., 2017. Stress detection using wearable physiological and sociometric sensors. International journal of neural systems 27, 1650041.
- [20] Paszkiel, S., Dobrakowski, P., Lysiak, A., 2020. The impact of different sounds on stress level in the context of eeg, cardiac measures and subjective stress level: A pilot study. Brain Sciences 10, 728.
- [21] Rai, D., Kosidou, K., Lundberg, M., Araya, R., Lewis, G., Magnusson, C., 2012. Psychological distress and risk of long-term disability: population-based longitudinal study. J Epidemiol Community Health 66, 586–592.
- [22] Roy, S., Islam, M., Yusuf, M.S.U., Rohan, T.I., 2020. Frequency impact analysis with music evoked

stimulated potentials on human brain, in: Innovations in Electronics and Communication Engineering. Springer, Singapore, pp. 505–513.

- [23] Roy, S., Yusuf, M.S.U., Islam, M., Rohan, T.I., 2019. Age based mood swing analysis and brain mapping for music genre, in: 2019 5th International Conference on Advances in Electrical Engineering (ICAEE), IEEE. pp. 165–170.
- [24] Saputra, R., Iqbal, B.M., 2017. Stress emotion evaluation in multiplayer online battle arena (moba) video game related to gaming rules using electroencephalogram (eeg), in: Proceedings of the 2017 4th International Conference on Biomedical and Bioinformatics Engineering, pp. 74–77.
- [25] Shon, D., Im, K., Park, J.H., Lim, D.S., Jang, B., Kim, J.M., 2018. Emotional stress state detection using genetic algorithm-based feature selection on eeg signals. International Journal of environmental research and public health 15, 2461.
- [26] Soysal, Ö.M., Kiran, F., Chen, J., 2020. Quantifying brain activity state: Eeg analysis of background music in a serious game on attention of children, in: 2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), IEEE. pp. 1–7.
- [27] Subha, D.P., Joseph, P.K., Acharya, R., Lim, C.M., 2010. Eeg signal analysis: a survey. Journal of medical systems 34, 195–212.
- [28] Taddy, M., 2019. Business data science: Combining machine learning and economics to optimize, automate, and accelerate business decisions. McGraw Hill Professional.
- [29] TWITCH, 2021. Twitch statistics & charts.
- [30] Wang, L., Ding, X., Zhang, W., Yang, S., 2021. Differences in eeg microstate induced by gaming: A comparison between the gaming disorder individual, recreational game users and healthy controls. IEEE Access 9, 32549–32558.
- [31] Welch, P., 1967. The use of fast fourier transform for the estimation of power spectra: a method based on time averaging over short, modified periodograms. IEEE Transactions on audio and electroacoustics 15, 70–73.
- [32] Yusuf, M.S.U., Islam, M., Roy, S., 2019. Stress identification during sustained mental task and brain relaxation modeling with beta/alpha band power ratio, in: 2019 4th International Conference on Electrical Information and Communication Technology (EICT), IEEE. pp. 1–5.
- [33] Zayeni, D., Raynaud, J.P., Revet, A., 2020. Therapeutic and preventive use of video games in child and adolescent psychiatry: a systematic review. Frontiers in psychiatry 11, 36.
- [34] Zhu, L., 2021. The psychology behind video games during covid-19 pandemic: A case study of animal crossing: New horizons. Human Behavior and Emerging Technologies 3, 157–159.