Development of Enhanced Stimulus Content to Improve the Treatment Efficacy of EEG–Based Frontal Alpha Asymmetry Neurofeedback for Stress Mitigation

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ABSTRACT The neurofeedback stimulus content has direct implications for the efficacy of the psychophysiological applications for neurofeedback modality. In particular, enhancements of neurofeedback stimulus content can facilitate improvements in the efficacy of neurofeedback applications in clinical practice. To further elaborate on this aspect, this study introduced systematic enhancements in neurofeedback stimulus content by developing enhanced neurofeedback stimulus content for stress mitigation. The enhancements included the automatic selection of colour of neurofeedback stimulus content environment and instruction messages, as well as, the adaptive selection of threshold of quantitative electroencephalogram (QEEG) features, such as frontal alpha power and frontal alpha asymmetry. The enhancements were based on the outcomes from previous research on the selection of neurofeedback stimulus content for stress mitigation. The improvement in the efficacy of neurofeedback stimulus content was measured statistically by comparing the QEEG and topographic maps. In this study, electroencephalogram data from 20 participants were acquired during multiple sessions of neurofeedback. Analysis of variance and a post hoc test were used to verify the improvement on the efficacy of the neurofeedback application for stress mitigation after the enhancements of the neurofeedback stimulus content; a t-test was used to verify the statistical significance of the stress mitigation by the neurofeedback. The results indicate that the enhancement of the developed neurofeedback stimulus content facilitated stress mitigation during the early sessions of neurofeedback. In conclusion, the efficacy of neurofeedback can be improved using the developed stimulus content with enhancements.

INDEX TERMS Neurofeedback, EEG, alpha asymmetry, stress, stimulus content, QEEG.

I. INTRODUCTION Neurofeedback is a modality that trains the human brain based on real–time information extracted from electroencephalogram (EEG) data for the treatment of neurological disorders in clinical and non–clinical setting [1]–[3]. EEG data are acquired and processed in real–time during a neurofeedback session. Subsequently, the data are converted into a decision variable to control the stimulus content and complete the sensory feedback loop [3] (Figure 1).
Thus, neurofeedback can train a person to intervene against dysfunctional neural signals and generate stable signals to facilitate improvement in health conditions without any external intervention [4]. Neurofeedback training can have several applications for the treatment of psychiatric illnesses including depression [5], and stress [6]–[8]. Neurofeedback may also help to improve the overall stability and communication of neural networks between and within the hemispheres [4]. Therefore, neurofeedback is being used focusing on alpha asymmetry [8] in the frontal regions of the brain to produce positive results for stress reduction [9], [10].

The efficacy of neurofeedback is subjective in its definition [11], [12]. The stimulus content, frequency band, and location of electrodes affect the success of the protocol design, which can help to improve the efficacy of neurofeedback therapy [13]. The selection of stimulus contents is based on the practitioner’s expertise for a particular therapeutic application of neurofeedback training. Several studies have used different stimulus contents in neurofeedback training for different applications related to cognitive therapeutic effects (e.g., audio stimulus content [14]–[16], audio–visual stimulus content [17], [18], and game stimulus content (GSC) [5], [7], [8], [19]).

In our previous study, the selection of the neurofeedback stimulus content for stress mitigation therapy was investigated [8]. The neurofeedback training efficacy was quantified using broad classification of the available neurofeedback stimulus contents which included audio, video, and GSC. The efficacy of neurofeedback stimulus contents was compared statistically for stress mitigation based on the frontal alpha asymmetry (FAAS). In addition, the topographic maps helped in the visual description of the neurofeedback efficacy for stress mitigation. The feedback from the participants after each neurofeedback session has also helped in determining the selection of the GSC. After the analysis of FAAS and feedback from practitioners in [8], GSC for neurofeedback training was proposed for stress mitigation after a systematic comparison of the neurofeedback stimulus contents.

The treatment withdrawal [20], [21] due to long duration of neurofeedback [4], non–responders to the stimulus content [22], [23], and lack of interest in stimulus content [16], [23], [24] during neurofeedback training may affect the efficacy. Therefore, the aim of this research is to improve the efficacy of neurofeedback for stress mitigation by developing the enhanced GSC based on the outcomes and observations in [8]. A detailed discussion on development and enhanced features, including the experimental procedure, is presented in the next section.

This paper is organized as follows: Section II discusses the development of the neurofeedback stimulus content with enhanced features for stress mitigation, the adaptive threshold selection, and the experimental procedure including the recruitment of the participants and the feature selection from EEG data. The results and analysis are presented in Section III, and, finally, the conclusion is presented in Section IV.

II. DEVELOPMENT OF ENHANCED GAME STIMULUS CONTENT FOR NEUROFEEDBACK TRAINING

The methodology for the development of enhanced GSC and experimental procedure adapted in this research is based on the findings and observations in our previous study [8], where the efficacy of several neurofeedback stimulus contents, including audio, video, and GSC, was compared. As a result, GSC was found to perform better for stress mitigation. During the study [8], a number of parameters were investigated for the performance enhancements. These parameters included the threshold selection, effect of environment colours [25], game platform [19] and instructions from the practitioners. The observations and the analysis in [8], are critical to identify the enhancements in development of the GSC. The GSC can be developed in different platforms such as 2D, 3D, and immersive 3D. The environment colours can be adaptively varied for better performance. The practitioner’s intervention can be replaced by automated messages displayed during the neurofeedback session based on participant’s performance for stress mitigation. Moreover, the GSC can be made adaptive for threshold selection of the alpha band power at the left frontal lobe (Fp1) and the right frontal lobe (Fp2) to modulate the FAAS. Therefore, the following parameters are included in developing the enhanced GSC.

- 2D or 3D or immersive 3D platforms for development of GSC is used.
- Colour selection of the environment of the GSC is based on the FAAS before neurofeedback session.
- Instruction messages should appear based on the FAAS during neurofeedback session.
- Adaptive threshold selection for Fp1 and Fp2 to modulate the FAAS for each session.

The consideration of these parameters resulted in the development of three different types of games having three variations. The overall methodology is elaborated in Figure 2. The GSC can be used in real–time with different EEG data acquisition and processing software. In this study, the EEG data were processed in MATLAB v2019b (Mathworks Inc. America).
A. GAME STIMULUS CONTENT BASED ON PLATFORM
Three types of GSC are developed for neurofeedback application based on development platform. The first GSC is a 2D (two-dimensional) shooting game in which asteroids and enemy spacecraft can be shot down by a spaceship (Figure 3(a)). The up, down, left, and right movements of the spaceship can be controlled by the participant using keyboard or joystick. The shooting power is dependent on the FAAS by achieving the threshold of alpha power. The second GSC is 3D (three-dimensional) with a still background (Figure 3(b)). In that GSC, a gem is generated once the alpha power threshold is achieved and the participant can collect the gem by controlling the movement of a rolling ball to touch the gem, and avoiding the hurdles. The third GSC is an immersive 3D, in which the participant can control the left–right movement of a racing kraft (Figure 3(c)). A rainbow, as a reward, is generated and the speed of the kraft is increased once the alpha power threshold is achieved.

B. ENHANCED COLOUR SELECTION
Colour plays a vital role for mental health [26]. Therefore, a selection of colours for the environment of the GSC are introduced by providing five colour selection schemes which include yellow, green, blue, pink, and teal (Figure 4). Each of the five colours are displayed for one minute during the eyes–open session. The performance is analyzed automatically and the colour is selected based on the number of times the participants achieve positive FAAS for each colour displayed during the eyes–open session before neurofeedback.

C. INSTRUCTIONS AND ENHANCED COLOUR SELECTION
The third enhancement has been included in the development of GSC by providing automatic instructions to the participant during neurofeedback training. With this enhancement, the GSC has been designated as version 3 (Figure 5). The instructions are displayed as messages to the participant as an enhanced feature in the GSC during neurofeedback training. The automatic instructions minimize the direct interference by the practitioners and help the participant to concentrate more during the neurofeedback session. The enhanced colour selection is based on the performance of the participant during the eyes–open session, as discussed in Section II-B, whereas the instructions are provided based on the real–time monitoring of the FAAS.
The instructions would appear on the display when the participant could not achieve the threshold of alpha power for 30 seconds. The duration of each instruction was five seconds. Different messages appeared on the display during the neurofeedback training based on the performance of the participant [27]–[29].

**D. ADAPTIVE THRESHOLD FOR ALPHA POWER**

Threshold selection for alpha power is based on manual inspection of the current performance of the participants and the experience of practitioners. Therefore, an adaptive selection of threshold of alpha power at Fp1 and Fp2 can be included in enhanced GSC. For this purpose, the eyes-open EEG data is acquired before each neurofeedback session and is used to select the threshold value. The alpha power of the EEG data is computed by taking average of the power spectral density (PSD in $\mu V^2/Hz$) over the alpha frequency range (8−12Hz). The estimate of PSD is calculated by using Welch’s method [8], [30]:

$$S_x(v) = \frac{1}{K} \sum_{k=1}^{K} P_k(v)$$

**FIGURE 4.** GSC with the enhanced colour selection of environment. Five colour environments for each GSC.

**FIGURE 5.** Instruction messages appear on the top left corner of the GSC.
where $K$ represents the number of segments, $P_k(v)$ is the periodogram of the $k^{th}$ segment, and the window size was kept 80 samples/sec with an overlapping frequency half of the window size for real-time process. The alpha power was used to calculate the FAAS by using the following equation \[31\]:

$$\text{FAAS} = \frac{F_{p2} \text{ alpha power} - F_{p1} \text{ alpha power}}{F_{p2} \text{ alpha power} + F_{p1} \text{ alpha power}} \quad (2)$$

The selection of a threshold for alpha power at Fp1 and Fp2 is based on the following criteria to achieve positive FAAS:

$$F_{p2} \text{ alpha power} > F_{p1} \text{ alpha power} \quad (3)$$

An iterative process is leveraged to meet these criteria and select the alpha power threshold for neurofeedback training. The $F_{p2} \text{ alpha power}$ is increased by 10% of its present value of alpha power and $F_{p1} \text{ alpha power}$ is decreased by 10% of its present alpha power value until the criteria in equation 3 is met (Figure 6). This enhanced parameter is included in all versions of GSC.

Based on parameters for enhancements identified in previous research [8], the three enhanced GSC can be classified into three different versions (Table 1). Each version incorporates the adaptive threshold approach as described in Section II-D.

### E. EXPERIMENTAL PROCEDURE

In this experimental study, the experiment design was similar to that adopted in previous research [8]. The participants were recruited according to the rules approved by the ethics committee of Universiti Pendidikan Sultan Idris, Malaysia (UPSI/PPPI/PKY/ETIKA(M)/014(207)), and in accordance with the Helsinki Declaration. Participants taking antidepressants or drugs and those with disabilities that limit the perception of stimulus content during the neurofeedback session were excluded. Ten participants (age: 26 ± 3.7 years) were recruited for neurofeedback training (neurofeedback group) based on scores of the stress test (> 300) [32]. EEG data for an equal number of participants having the stress test scores <150 (non–stressed) recorded in our previous study [8] is used to statistically compare the effect of neurofeedback training on the stressed participants (Table 2).

The participants were asked to sign a consent form before neurofeedback training and they were briefed about the purpose of the neurofeedback training and its procedure. A document containing the detailed procedures and best practices of neurofeedback was provided to each participant.

The data collection for this research follows the experiment design mentioned in [8]. Each participant was asked to sit in a comfortable chair in a quiet room. Subsequently, trier social stress test [33]–[35] which included three minutes...
of rest, a five minutes mental arithmetic test, and a five minutes speech task [34] (approximately 20 minutes) was administered to induce stress [8] in the participant. Each version of the three enhanced GSC, as presented in Table 1, was used in 2 consecutive neurofeedback sessions. Therefore, all 10 participants went through a total of 18 (9 × 2) neurofeedback sessions. There was one week break after every neurofeedback session. The neurofeedback session comprised of six neurofeedback training periods of three minutes each with a 20 second interval. In addition, five minutes of eyes–open data was also collected before and after the neurofeedback training periods. Therefore, the total EEG data recording duration for one session was 30 minutes. The participant has to achieve an alpha power threshold to earn the game scores as a reward. The neurofeedback training procedure remained same for all versions of GSC. The latency for GSC was less than 70 milliseconds. The GSC was randomly provided in different sessions of neurofeedback training.

1) EEG DATA ACQUISITION AND PROCESSING

The EEG data, including the eyes–open data, were recorded at 31 scalp locations placed according to international 10–20 system (Figure 7) using the MCScap Professional Cap (Mitsar Co. Ltd. Russia) with electrooculography (EOG) for all experimental sessions. All electrodes were referenced to a single vertex electrode, Cz, and EEG signals were amplified with a Mitsar–202 (Mitsar Co. Ltd. Russia) amplifier’s bandpass filter, 0.1–100 Hz. The impedance was kept below 5 KΩ by applying an electrolyte gel at the electrodes. The sampling rate was 500 Hz, with a 50 (±5) Hz notch filter to eliminate the electrical interference of the socket. It took approximately 25 minutes to complete the setup.

The EEG data were preprocessed by removing muscle artifacts, eye blinks and movements using independent component analysis [36]. After the removal of all artifacts, the EEG data were segmented into epochs (Table 3).

In general, it is challenging to visually inspect a considerable amount of EEG data acquired for the evaluation of neuronal activity in order to obtain a reliable and correct interpretation of the brain state and neurophysiological explanation from it [37]. Quantitative EEG (QEEG) feature extraction is a necessary step in EEG analysis. The relevant features are important and significant owing to their direct impact on feature selection. In this experimental study, the feature extracted from the EEG signal was the alpha power of the frontal lobe. Therefore, the EEG signal was analyzed using Welch’s method of spectral density estimation [30], [38] to extract the frontal alpha power (equation 1). The overlapping frequency for EEG data was 250 Hz, with a Hamming window size of 500 samples (overlapping frequency × 2) which provided a 50% overlap to minimize the loss of data. Feature selection was performed by selecting spectral densities occurring at a frequency range of 8–12 Hz and averaging them to estimate the alpha power of an epoch.

2) STATISTICAL ANALYSIS

The statistical analysis of QEEG features was performed to determine the efficacy of neurofeedback training with the enhanced GSC and compared with the results of [8] in which available stimulus content (audio, video, and game) were used. A one–way analysis of variance (ANOVA) was used to analyze the QEEG features of the enhanced GSC and the available neurofeedback stimulus contents to determine the difference in efficacy of neurofeedback training. The assumptions of normal distribution (by Shapiro–Wilk test, \( p > 0.01 \)) and the homogeneity of variance (by Levene’s test) were not violated.

The paired samples t–test was used to analyze the QEEG features of EEG data of the neurofeedback group for before and after the neurofeedback training, which was aimed to identify the effects of the enhanced GSC on FAAS. The assumption of normal distribution (by Shapiro–Wilk test, \( p > 0.01 \)) was not violated.

| Epoch                  | Duration (sec) | Sample Size (500 Sample/sec) |
|------------------------|----------------|------------------------------|
| Before NFB             | 300            | 150000                       |
| NFB Period             | 180            | 90000                        |
| Break between NFB Period | 20             | 10000                        |
| After NFB              | 300            | 150000                       |
The efficacies of enhanced GSC and the available neurofeedback stimulus contents were statistically compared using a post hoc test. The post hoc test was applied to the QEEG features with Bonferroni correction ($\alpha = 0.05$ or 95% confidence interval) to determine the difference between the efficacies of the enhanced GSC and the available neurofeedback stimulus content.

### III. RESULTS AND DISCUSSION

The primary finding of this research was the development of enhanced GSC to improve the efficacy of neurofeedback training for stress mitigation based on data analysis and observations from a previous study [8], in which a game was selected as neurofeedback stimulus content for stress mitigation. The results were analyzed by extracting the QEEG features. The extracted QEEG features of EEG signal were the frontal alpha power and FAAS from the EEG data of before, during, and after the neurofeedback sessions. The alpha power and topographic maps were used to assess the improvement in the training efficacy of neurofeedback using the enhanced GSC.

#### A. EFFICACY OF ENHANCED GAME STIMULUS CONTENT

The efficacy of the enhanced GSC for stress mitigation was analyzed by comparing the mean differences in FAAS [9], [39]. The QEEG feature (alpha power) of the EEG data before and after the neurofeedback session for all version of enhanced GSC were compared. The topographic maps of the brain were plotted for each version of the GSC (Figure 8). A comparison of the alpha powers showed a greater value at Fp1 than Fp2 for the induced stress before the neurofeedback session (Figure 8(a)). The alpha power after the neurofeedback with enhanced GSC was higher for the Fp2 than Fp1. This indicates the mitigation of stress after the neurofeedback session (Figure 8(b)).

The difference between the FAAS (before and after neurofeedback) for the enhanced GSC was analyzed to compare all the enhanced versions. The FAAS before and
after the neurofeedback session was compared for each participant (Figure 9). The bar chart shows that GSC v3 has higher differences than GSC v1 and GSC v2, whereas GSC v2 has higher differences than GSC v1.

The mean of differences between the FAAS before and after neurofeedback sessions for the enhanced GSC were compared with the available neurofeedback stimulus content (audio, video, game) [8] to determine the efficacy of neurofeedback for stress mitigation (Figure 10). The bar chart shows a greater mean differences in FAAS for the enhanced GSC (GSC v1, GSC v2, and GSC v3) than the available neurofeedback stimulus content [8].

The mean FAAS after neurofeedback indicates that the participants performed better with enhanced GSC as compared with the available stimulus content [8] (Figure 11).

**B. STATISTICAL COMPARISON**

The statistical comparison between FAAS of non-stressed data (0.125 ± 0.102) from previous study [8] and neurofeedback training with enhanced GSC data (0.169 ± 0.071) was performed to find the efficacy of neurofeedback training with enhanced GSC to mitigate stress.
The independent samples t–test was used to determine the statistically significant difference (Table 4).

The analysis of the results shows no statistically significant difference between both mean values of FAAS ($p > 0.05$, at 95% confidence interval) but it predicted the efficacy of neurofeedback training to mitigate stress.

The efficacy of the neurofeedback stimulus content was analyzed by comparing the FAAS of neurofeedback with available [8] and enhanced GSC ($F(3,36) = 12.54$, $p = 0.01$). One–way ANOVA was used to analyze the FAAS after neurofeedback (Table 5). A statistically significant difference is observed with a 95% confidence between FAAS ($p < 0.05$).

A post hoc test was also performed to compare FAAS after neurofeedback training with audio, video, game [8] and with enhanced GSC, to find the efficacy of different stimulus contents for stress mitigation (Table 6). The post hoc test shows that FAAS of the audio ($-0.046 \pm 0.133$) and video ($-0.018 \pm 0.117$) are significantly different ($p <0.05$) from the enhanced GSC ($0.219 \pm 0.058$). At the same time, there is no statistically significant difference between the game ($0.120 \pm 0.118$) [8] and enhanced GSC ($p <0.05$).

### TABLE 4. Independent samples t–test analysis between the non–stressed and neurofeedback training for enhanced GSC.

| Levene’s Test for Equality of Variances | t–test for Equality of Means | 95% Confidence Interval of the Difference |
|----------------------------------------|-----------------------------|----------------------------------------|
|                                        | F   | Sig. | t    | df  | Sig. (2–tailed) | Mean Difference | Std. Error Difference | Lower | Upper |
| Equal variances assumed                 | 3.03 | 0.099| -1.106 | 18.000 | 0.283 | -0.043 | 0.039 | -0.126 | 0.039 |
| Equal variances not assumed             |     |      | -1.106 | 16.058 | 0.285 | -0.043 | 0.039 | -0.127 | 0.040 |

### TABLE 5. One–way ANOVA to compare FAAS.

| Sum of Squares | df  | Mean Square | F    | Sig. |
|----------------|-----|-------------|------|------|
| Between Groups | 0.458 | 3 | 0.153 | 12.54 | 0.000 |
| Within Groups  | 0.438 | 36 | 0.012 | |
| Total          | 0.897 | 39 | | |

### TABLE 6. Post hoc test of Available (audio, video, game) and Enhanced GSC.

| FAAS (Audio, Video, Game) vs FAAS (GSC v1, v2, v3) | Mean Difference (I–J) | Std. Error | Sig. | 95% Confidence Interval |
|--------------------------------------------------|------------------------|------------|------|-------------------------|
| Tukey HSD                                        |                        |            |      |                         |
| Audio                                            |                        |            |      |                         |
| Video                                            |                        |            |      |                         |
| Game                                             |                        |            |      |                         |
| GSC v1, v2, v3                                   |                        |            |      |                         |
| Game                                             |                        |            |      |                         |
| Video                                            |                        |            |      |                         |
| GSC v1, v2, v3                                   |                        |            |      |                         |
| Game                                             |                        |            |      |                         |

*The mean difference is significant at the 0.05 level*

C. IMPROVEMENT IN EFFICACY OF NEUROFEEDBACK

The enhanced features aimed at improving the efficacy of the neurofeedback training session time for stress mitigation
were also evaluated by comparing the mean FAAS for before, during, and after the neurofeedback training for available [8] and enhanced GSC (Figure 12). The graph shows an increase in peak performance of FAAS of the participants after the fourth and fifth periods during the neurofeedback training [8]. The increase in the peak performance of FAAS with the enhanced GSC is achieved after the second and third periods during neurofeedback, which depicted the improvement in the efficacy of neurofeedback training with enhanced GSC compared to the available neurofeedback stimulus content [8]. The improvement in the efficacy of the neurofeedback session indicates that the time for a session can be minimized by reducing the number of periods during neurofeedback sessions to mitigate stress. It was also observed from the improvement in the efficacy of neurofeedback that the number of training sessions can be reduced by using the enhanced GSC.

The primary finding of this research was the development of enhanced GSC to improve the efficacy of neurofeedback training for stress mitigation based on data analysis and observations from a previous study [8], in which a game was selected as neurofeedback stimulus content for stress mitigation.

IV. CONCLUSION

The results of the enhanced GSC showed a significant improvement in the efficacy of neurofeedback for stress mitigation. The improvement in the efficacy of neurofeedback training was verified by comparing the mean FAAS for the neurofeedback sessions with available and enhanced GSC. The results showed that the participants’ performances were better with the enhanced GSC (GSC v1, GSC v2, GSC v3) than with the available neurofeedback stimulus content (audio, video, game). The early achievement of peak performance of FAAS with enhanced GSC can be helpful to reduce the time for neurofeedback session and ultimately, may also help to reduce the total number of training sessions. The reduction in neurofeedback session time and the total number of sessions may help to improve the treatment efficacy of neurofeedback training for stress mitigation.

REFERENCES

[1] V. K. Campos da Paz, A. Garcia, A. Campos da Paz Neto, and C. Tomaz, “SMR neurofeedback training facilitates working memory performance in healthy older adults: A behavioral and EEG study,” Frontiers Behav. Neurosci., vol. 12, p. 321, Dec. 2018.
[2] M. Nazer, H. Mirzaei, and M. Mokhtaree, “Effectiveness of neurofeedback training on verbal memory, visual memory and self-efficacy in students,” Electron. Physician, vol. 10, no. 9, pp. 7259–7265, Sep. 2018.
[3] S. J. Johnstone, S. J. Roodenrys, K. Johnson, R. Bonfield, and S. J. Bennett, “Game-based combined cognitive and neurofeedback training using focus pocus reduces symptom severity in children with diagnosed AD/HD and subclinical AD/HD,” Int. J. Psychophysiol., vol. 116, pp. 32–44, Jun. 2017.
[4] T. J. Chapin, Neurotherapy and Neurofeedback. Evanston, IL, USA: Routledge, Dec. 2013.
[5] A. Choobforoushdzadeh, H. Neshat-Doost, H. Molavi, and M. R. Abedi, “Effect of neurofeedback training on depression and fatigue in patients with multiple sclerosis,” Appl. Psychophysiol. Biofeedback, vol. 40, no. 1, pp. 1–8, 2015.
[6] K. Reiter, S. B. Andersen, and J. Carlsson, “Neurofeedback treatment and posttraumatic stress disorder: Effectiveness of neurofeedback on posttraumatic stress disorder and the optimal choice of protocol,” J. Nervous Mental Disease, vol. 204, no. 2, pp. 69–77, 2016.
[7] Y. Hafeez, S. S. A. Ali, W. Mumtaz, M. Moinuddin, S. H. Adil, U. M. Al-Saggaf, M. A. B. M. Yasin, and A. S. Malik, “Investigating neurofeedback protocols for stress mitigation: A comparative analysis of different stimulus contents,” IEEE Access, vol. 7, pp. 141021–141035, 2019.

FIGURE 12. Mean FAAS for each neurofeedback session (before, between period, and after) with available [8] and with enhanced GSC. Higher values of FAAS achieved sooner (in 2nd and 3rd periods) with enhanced GSC showing the reduction in training time as compared to available stimulus contents [8] where higher values of FAAS were achieved after 4th and 5th periods. NFB = neurofeedback.
[9] C. W. E. M. Quaedflieg, F. T. Y. Smulders, T. Meyer, F. Peeters, H. Merckelbach, and T. Smeets, “The validity of individual frontal alpha asymmetry EEG neurofeedback,” *Social Cogn. Affect. Neurosci.*, vol. 11, no. 1, pp. 33–43, Jan. 2016.

[10] X. Zhang, P. Bachmann, T. M. Schilling, E. Naumann, H. Schächinger, and M. F. Larra, “Emotional stress regulation: The role of relative frontal alpha asymmetry in shaping the stress response,” *Biol. Psychol.*, vol. 138, pp. 231–239, Oct. 2018.

[11] F. Ondorff-Plunkett, F. Singh, O. R. Aragón, and J. A. Pineda, “Assessing the effectiveness of neurofeedback training in the context of clinical and social neuroscience,” *Brain Sci.*, vol. 7, no. 8, p. 95, 2017.

[12] R. T. Thibault, M. Lifshitz, and A. Raz, “The self-regulating brain and neurofeedback: Experimental science and clinical promise,” *Cortex*, vol. 74, pp. 247–261, Jan. 2016.

[13] S. Enriquez-Geppert, R. J. Huster, T. Ros, and G. Wood, “Neurofeedback,” in *Theory-Driven Approaches to Cognitive Enhancement*, L. S. Colzato, Ed. Cham, Switzerland: Springer, 2017, pp. 147–164.

[14] J. H. Gruzelier, “EEG-neurofeedback for optimising performance. I: A review of cognitive and affective outcome in healthy participants,” *Neurosci. Biobehav. Rev.*, vol. 44, pp. 124–141, Jul. 2014.

[15] J. H. Gruzelier, L. Hirst, P. Holmes, and J. Leach, “Immediate effects of alpha/theta and sensory-motor rhythm feedback on music performance,” *Int. J. Psychophysiol.*, vol. 93, no. 1, pp. 96–104, Jul. 2014.

[16] J. H. Gruzelier, M. Foks, T. Steffert, M. J.-L. Chen, and T. Ros, “Beneficial outcome from EEG-neurofeedback on creative music performance, attention and well-being in school children,” *Biol. Psychol.*, vol. 95, pp. 86–95, Jan. 2014.

[17] R. Rostami, H. Sadeghi, K. A. Karami, M. N. Abadi, and P. Salamati, “The effects of neurofeedback on the improvement of rifle Shooters’ performance,” *J. Neurotherapy*, vol. 16, no. 4, pp. 264–269, Dec. 2012.

[18] S.-C. Kao, C.-J. Huang, and T.-M. Hung, “Neurofeedback training reduces frontal midline theta and improves putting performance in expert golfers,” *J. Appl. Sport Psychol.*, vol. 26, no. 3, pp. 271–286, May 2014.

[19] Y. Hafeez, S. S. A. Ali, S. Faraz, M. Moinuddin, and S. H. Adil, “Effect of neurofeedback 2D and 3D stimulus content on stress mitigation,” in *Proc. IEEE Student Conf. Res. Develop. (SCoReD)*, Perak, Malaysia, Oct. 2019, pp. 289–293.

[20] H. J. Engelbregt, D. Kesser, L. van Eijk, E. M. Suiker, D. Eichhorn, S. Karch, J. B. Deijen, and O. Pogarell, “Short and long-term effects of sham-controlled prefrontal EEG-neurofeedback training in healthy subjects,” *Clin. Neurophysiol.*, vol. 127, no. 4, pp. 1931–1937, Jan. 2016.

[21] S. E. Kober, D. Schweiger, M. Witte, J. L. Reichert, P. Grieshofer, C. Neuper, and G. Wood, “Specific effects of EEG based neurofeedback training on memory functions in post-stroke victims,” *J. Neuropsy. Rehabil.*, vol. 12, no. 1, pp. 1–13, Dec. 2015.

[22] C. Escolano, M. Aguilar, and J. Minguèz, “EEG-based upper alpha neurofeedback improves working memory performance,” in *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.*, Aug. 2011, pp. 2327–2330.

[23] C. B. F. Jensen, M. K. Petersen, J. E. Larsen, A. Stopczynski, C. Stahlhut, M. G. Ivanova, T. Andersen, and L. K. Hansen, “Spatio temporal media components for neurofeedback,” in *Proc. IEEE Int. Conf. Multimedia Expo Workshops (ICMEW)*, Jul. 2013, pp. 1–6.

[24] J. H. Gruzelier, P. Holmes, L. Hirst, K. Bulpin, S. Rahman, C. van Run, and J. Leach, “Replication of elite music performance enhancement following alpha/theta neurofeedback and application to novice performance and improvisation with SMR benefits,” *Biol. Psychol.*, vol. 95, pp. 96–107, Jan. 2014.

[25] A. Wright. (2020). *Psychological Properties Of Colours*. [Online]. Available: http://www.colour–affects.co.uk/psychological–prop

[26] A. J. Elliot, “Color and psychological functioning: A review of theoretical and empirical work,” *Frontiers Psychol.*, vol. 6, pp. 1–8, Apr. 2015.

[27] L. D. Pederson, *Dialectical Behavior Therapy: A Contemporary Guide for Practitioners*. Hoboken, NJ, USA: Wiley, Feb. 2015.

[28] S. Cormier, P. S. Nurius, and C. J. Osborn, Interviewing and Change Strategies for Helpers: Fundamental Skills and Cognitive Behavioral Interventions, 6th ed. Boston, MA, USA: Cengage Learning, 2008, p. 622.

[29] J. A. Cully and A. L. Teten, *A Therapist’s Guide to Brief Cognitive Behavioral Therapy*, 1st ed. Houston, TX, USA: Department of Veterans Affairs South Central MIRECC, 2008.

[30] O. M. Solomon, “PSD computations using Welch’s method,” [Power spectral density (PSD)], *Sandia Nat. Laboratories (SNL)*, Albuquerque, NM, USA, Tech. Rep. SAND-91-1533, ON: DE92007419, Dec. 1991.

[31] R. Abu Hasan, S. Sulaiman, N. N. Ashykin, M. N. Abdullah, Y. Hafeez, and S. S. A. Ali, “Workplace mental state monitoring during VR-based training for offshore environment,” *Sensors*, vol. 21, no. 14, p. 4885, Jul. 2021.

[32] T. H. Holmes and R. H. Rahe, “The social readjustment rating scale,” *J. Psychosom. Res.*, vol. 11, no. 2, pp. 213–218, Aug. 1967.

[33] B. M. Kudielka, H. Hellhammer, C. Kirschbaum, D. H. Hellhammer, and C. Kirschbaum, “Ten years of research with the trier social stress test–revisited,” in *Social Neuroscience: Integrating Biological and Psychological Explanations of Social Behavior New York, NY, USA: Guilford Press*, 2007, pp. 56–83.

[34] M. A. Birkett, “The trier social stress test protocol for inducing psychological stress,” *J. Visualized Exp.*, no. 56, pp. 1–6, Oct. 2011.

[35] A. P. Allen, P. J. Kennedy, S. Dockray, J. F. Cryan, T. G. Dinan, and G. Clarke, “The trier social stress test: Principles and practice,” *Neurobiol. Stress*, vol. 6, pp. 113–126, Feb. 2017.

[36] T. P. Jung, S. Makeig, M. Westerfield, J. Townsend, E. Courchesne, and T. G. Dinan, “Ten years of research with the trier social stress test–revisited,” in *Social Neuroscience: Integrating Biological and Psychological Explanations of Social Behavior New York, NY, USA: Guilford Press*, 2007, pp. 56–83.

[37] S. Haule, V. V. Nikulin, K.-R. Müller, and G. Nolte, “A critical assessment of connectivity measures for EEG data: A simulation study,” *Neuroimage*, vol. 64, pp. 120–133, Jan. 2013.

[38] M. H. Hayes, *Statistical Digital Signal Processing and Modeling*. Hoboken, NJ, USA: Wiley, 1996.

[39] C. W. E. M. Quaedflieg, T. Meyer, F. T. Y. Smulders, and T. Smeets, “The functional role of individual-alpha based frontal asymmetry in stress responding,” *Biol. Psychol.*, vol. 104, pp. 75–81, Jan. 2015.

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