Chapter 14
EEG-Based Evaluation of the Effect of Emotion on Relaxation Management

Xin Ru Ng, Maekayla Yen-C Lee, Xinyue Wang, and Phyo Wai Aung Aung

Abstract Emotion is a vital part of our lives in our interactions with the environment. With more hectic lifestyles, relaxation is critical to re-energising our mind. Emotional adjustment and relaxation bring benefits such as reduced anxiety and improved task performance. Studies have shown the relationship between emotions and relaxation in applying relaxation techniques to reduce negative emotional states, such as stress. In contrast, our study investigated, using EEG features, how different emotional states, fear, anxiety and happiness, affect one's ability to relax using EEG features. We collected EEG from 15 participants according to the experiment protocol comprising baseline, emotion-arousing "non-relaxed" tasks (happiness, fear and anxiety), each followed by a "relaxed task". We used six band-power features extracted from EEG signals applying statistical analysis methods to test research hypotheses. We applied band-power with statistical analysis methods to test our research hypotheses. Using paired samples *t*-test, individual band-power features (alpha, theta, beta) of "non-relaxed" tasks compared with that of baseline tasks showed a highly significant difference ($p < 0.001$). We then used supervised machine learning to test binary classification accuracy of relaxation state among different task pairs. The results showed lower 9.61% mean accuracy of modified tasks compared with baseline task. Baseline task pair achieved 82.98% while only obtained 74.54%, 73.52% and 72.06% accuracy for anxiety, fear and happiness non-relaxed and relaxed task pairs, respectively. Our results showed that emotions affect one's ability to relax and to varying degrees. These findings could allow a better understanding of what it is required to neutralise emotion effects and enhance relaxation.

Keywords Component · EEG · Relaxation

X. R. Ng · M. Y.-C. Lee · X. Wang (✉)
Nanyang Girls' High School, Singapore, Singapore
e-mail: w.xinyue9@gmail.com

X. R. Ng
e-mail: clairey.beary333@gmail.com

P. W. Aung Aung
Nanyang Technological University, Singapore, Singapore

H. Guo et al. (eds.), *IRC-SET 2021*, https://doi.org/10.1007/978-981-16-9869-9_14

14.1 Introduction

Across many studies, relaxation has consistently been shown to be extremely useful in people's daily lives, bringing significant health benefits such as reduced general depression, anxiety and stress [1, 2] and management of physical pain [3]. It also improves task performance, such as academic performance in students [4]. However, in our fast-paced society, many find it hard to relax and get such benefits, with a Cigna 360 Well-Being Survey showing that 92% of working Singaporeans report feeling stressed. This is 8% higher than the global average at 84% [5].

A common method used to determine the effectiveness of relaxation techniques is by using the brain–computer interface (BCI). We measure electrical activities of the brain through scalp electrodes using electroencephalogram (EEG). Analysis of EEG signals enables us to provide objective and quantifiable mental states, such as concentration and relaxation [6]. Past studies have been done, showing that conventional relaxation techniques improve BCI performance, such as mindfulness meditation [7].

Past studies have also shown how conventional relaxation methods affect one's emotions, such as meditation reducing negative mood. There is also previous research that has tried to find how relaxation affects fear, such as using relaxation as a therapy to overcome the fear of snakes or dentists [8, 9]. We found out various relaxation methods applied for stress relief and reducing anxiety with mixed outcomes [10]. However, there has been limited research on how different emotions affect one's ability to relax. There is some research that seems to suggest that humour allows one to relax more easily, but is not completely conclusive [11]. Our study aims to find the effect of three emotions, anxiety, fear and happiness, on relaxation as opposed to when emotions are not stimulated, and also compare the effects of the three emotions with each other.

14.2 Objectives and Hypotheses

We aim to find out if selected emotions (fear, anxiety and happiness) affect one's ability to relax and how the different emotions, when stimulated, would affect one's ability to relax as compared to when no emotions stimulated (during the baseline). We hypothesise that emotion induced relaxation would all hinder one's ability to relax with varying degrees of impact. We predict that in descending order, anxiety, fear and happiness would affect emotions the most, with happiness having a positive effect and allowing users to relax better than the baseline.

For our experiment, we aimed to find out how three different selected emotions, fear, anxiety and happiness, would affect one's ability to relax. We chose emotions that are more relevant to people's daily lives and are also easy to stimulate desirable emotional states with visual and audio stimuli. Our experiment stimulates these three emotions, each followed by the same relaxation task for each participant, to analyse the individual effect of the three emotions on the relaxation task. We collected EEG data of the participants through wearable Muse headband throughout the duration of the experiment. Then we could analyse to determine the relaxation states of the participants using machine learning and statistical analysis throughout the experiment. We also compare the effects of each stimulated emotion on each subject's relaxation.

14.3 Research Methods

Data collection and experiments started after obtaining ethical approval, and participants had obtained parental consent prior to their participation. The experiment strictly follows the standard safe management measures put in place due to the COVID-19 pandemic.

The experiment relies on audio and visual stimuli to induce different emotions in the subjects. Studies have shown that using audio and visual stimuli together is effective to improve relaxation [12]. There are three main blocks in the experiment, each comprising different emotion-inducing stimuli for each of the three emotions, and the same relaxation task for all three blocks. All emotion-inducing stimuli and relaxation tasks are 4 min each, red and blue colour boxes, as shown in Fig. 14.1. Before the experiment, participants also fill in a pre-experiment survey, where they would indicate their preferred choice of stimuli for certain tasks for personalised emotion stimulation.

Before showing emotion-inducing tasks, baseline data from each participant is first collected for comparison with emotionally induced tasks. Data at a non-relaxed state is first collected for 4 min, where participants are made to count the number of red-coloured dots while ignoring green-coloured dots on a screen. This is followed by a 15 s break. Next, participants are made to inhale and exhale as according to instructions on a screen for baseline relaxation. Participants take part in the emotion-inducing tasks after the baseline.

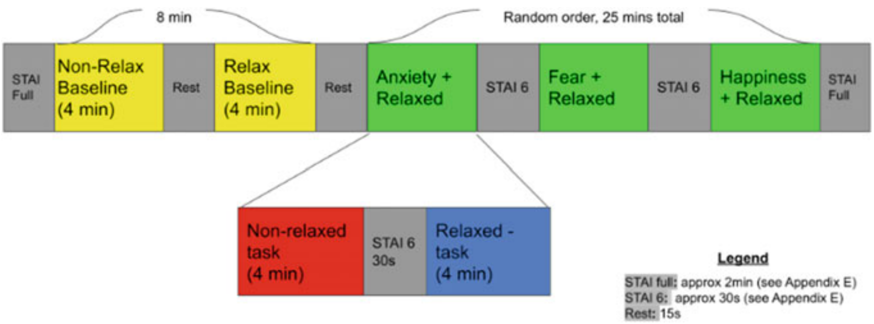


Fig. 14.1 Experiment protocol sequence and timing diagram

For the happiness- and fear-inducing tasks, all participants will watch videos with audio. Participants choose their choice of most emotion-inducing stimuli for these two emotions, happiness and fear, in the pre-experiment survey. Their personalised choice of stimuli will be used for the first 2 min of the task, while the last 2 min of stimuli is standardised and the same for all participants. For the anxiety task, the participants will be asked to answer multiple-choice math questions, while fast-paced, noisy music plays in the background. Math questions and multiple-choice questions mimic conditions in examinations, which is known to cause anxiety and stress, especially in students [13]. For the relaxation task, classical music is played, while participants choose their choice of most relaxing visual stimuli, either photographs of forests or oceans, through the pre-experiment survey. Classical music and photographs of nature scenes are used as both classical music [14, 15] and nature scenes [16, 17] have been proven to be effective relaxation methods.

After each stimulus, a short eight-question survey consisting of six questions of State-Trait Anxiety Inventory (STAI-6) (Appendix 3) and two questions regarding valence and arousal of the subject. This allows us to determine the emotional and relaxation states of the subject and is used in data analysis to help analysing EEG data. The full STAI survey and two valence–arousal questions are done at the start and end of the experiment.

We used OpenSesame software (Appendix 1) to design experiments that allow for graphical display, incorporating Python scripting, and allow us to run experiments with little to no coding experience. We explain full details of the experiment design in (Appendix 1).

14.4 Data Collection and Results

We collected EEG data from participants, as seen in Fig. 14.2, using a Muse 2016 headband. We also tracked eye gazes using a Tobii EyeX eye tracker and user key presses in response to particular visual stimuli presented (Appendix 2). We synchronised all data across different sensors and stimulus presentation events using world clock absolute timestamps.

We apply band-pass filters (0.5–45 Hz) to raw EEG signals and remove artefacts using a set of moving average filters. Then, we segmented the filtered data by synchronising timestamps of different unique tasks carried out during the experiment. With individual segmented data, we extracted six band-power features for relaxation states classification and statistical analysis as shown in Fig. 14.3.

We conducted analysis of variance (ANOVA) using band-power features on all tasks, non-relaxed and relaxed task pairs using band-power features. In our analysis, we only used four band-power features from Tp9, Tp10, Fp1 and Fp2 (theta, alpha, low beta, high beta) instead of all six bands as they can discriminate against the different relaxation states best. (Appendix 4). For all three comparisons, there was highly statistical significance ($p < 0.001$). Since there were generally significant differences for all the non-relaxed and relaxed tasks, we then moved on to paired

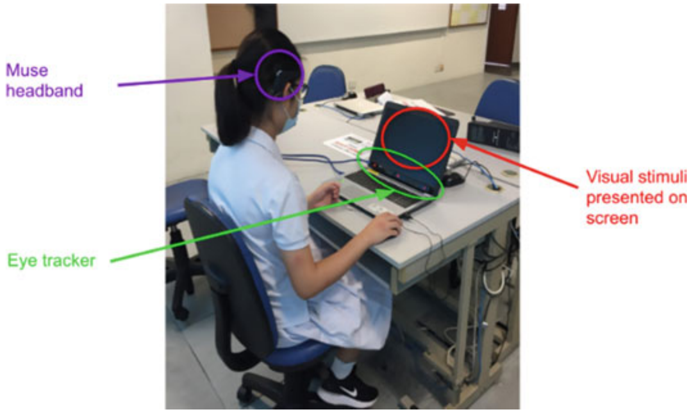


Fig. 14.2 Experiment set-up and subject performing the experiment task

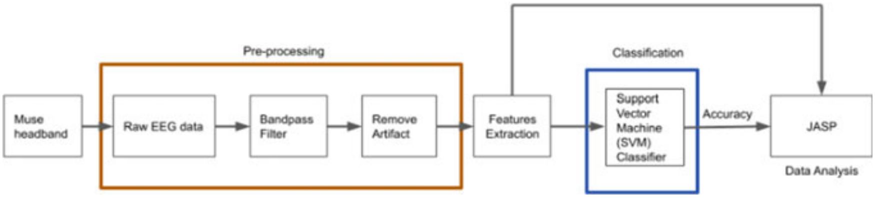


Fig. 14.3 Sequence diagram for data analysis

sample *t*-tests. We compared the individual non-relaxed tasks to the baseline and to each other to see if there is a significant difference between each pair as given in Table14.1.

Using ANOVA and *t*-tests, we had found that there is a significant difference between the different emotions. To see which non-relaxed task had a larger effect on relaxation, and whether it is a negative or positive effect, we then used supervised machine learning method to test binary classification accuracy of "relax" versus "non-relax" among different task pair (e.g. anxiety-relaxed versus anxiety-non-relaxed) using tenfold cross-validation as shown in Fig. 14.4.

We also used STAI questionnaire results in our analysis and compared it with the accuracy as seen in Fig. 14.5. Refer to (Appendix 3) for the calculation of the scores and more details.

From Fig. 14.5, participants' average STAI scores decreased the most in the relaxation task after the anxiety-inducing task, followed by after the fear-inducing task. The scores also increased slightly in the relaxation task after the happiness-inducing task.

Table 14.1 Results of paired sample *t*-tests

Non-relaxed tasks *p*-values*		
	Fear-nonrelaxed	Happiness-nonrelaxed
Anxiety-nonrelaxed	Tp9 highBeta: 0.981 Fp2 alpha: 0.055 Tp10 lowBeta: 0.658 Remaining: **<0.001**	Tp9 alpha: 0.264 Fp1 theta: 0.050 Tp10 lowBeta: **0.012** Remaining: **<0.001**
Fear-nonrelaxed		Fp1 lowBeta: 0.961 Fp2 alpha: **0.008 (<0.05)** Tp10 lowBeta: 0.003 Remaining: **<0.001**
Relaxed tasks *p*-values*		
	Fear-relaxed	Happiness-relaxed
Anxiety-relaxed	Tp9 theta: **0.009** Fp2 highBeta: 0.148 Remaining: **<0.001**	Tp9 alpha: **0.027** Fp1 theta: 0.230 Fp2 alpha: 0.288 Remaining:**<0.001**
Fear-relaxed		Tp10 theta: **0.004** Tp10 alpha: 0.834 Remaining: **<0.001**

* We use *p*-value thresholds for significant test as 0.05 and 0.001

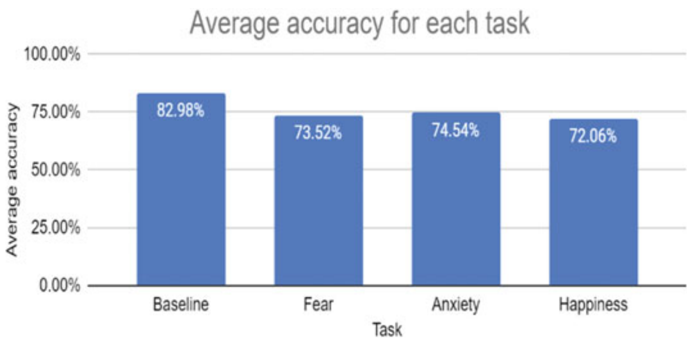


Fig. 14.4 Average classification accuracy of each task pair

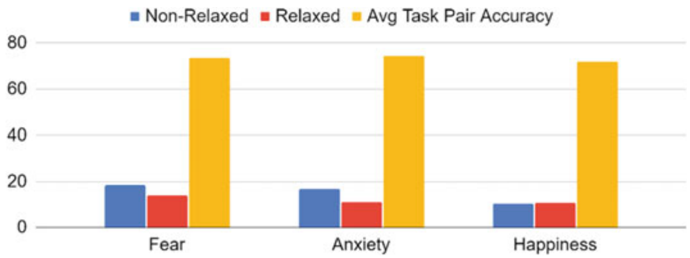


Fig. 14.5 Comparison of average STAI scores and average task pair accuracy

14.5 Discussion

We used statistical analysis using ANOVA and paired sample *t*-tests, and we found that there is generally high statistical significance ($p < 0.001$) for all non-relaxed tasks and between non-relaxed task pairs and relaxed task pairs. To find which emotion had the most impact on relaxation and to what extent, we used the accuracy from tenfold cross-validation to do so. Referring to Fig. 14.4, there is a large decrease in accuracy from the baseline pair to the non-relaxed pairs, with a 8.44%, 9.46% and 10.92% decrease in accuracy for anxiety, fear and happiness non-relaxed and relaxed task pairs, respectively, with an average of 9.61% decrease. This shows that all emotions do affect relaxation, and in order of ascending extent of effect, happiness, fear and anxiety affect relaxation the most. This was similar to what we have predicted.

STAI is used as a measure of anxiety, with higher scores indicating higher levels of anxiety. Referring to Fig. 14.5, our participants' average STAI scores showed the largest decrease in anxiety in the relaxation task after the anxiety-inducing task, followed by after the fear-inducing task. The scores also showed a slight increase in anxiety during the relaxation task after the happiness-inducing task. This supports our results from the accuracy. The average scores as seen in Fig. 14.5 also correctly predicted that anxiety and fear affected relaxation the most, while happiness affected relaxation the least. However, it did not correctly match whether relaxation was affected by fear or anxiety the most. This could be because STAI indicates a negative emotion or a positive emotion but not what kind of negative emotion it is.

Based on the results above, our main hypothesis has been proven correct; however, we have wrongly predicted the order of which emotions have the most impact on relaxation. Happiness affects relaxation the least, followed by fear and then by anxiety. We have wrongly predicted that happiness has a positive effect on relaxation. However, our hypothesis that STAI would largely correctly predict the effect on relaxation was correct. We could apply these findings to better consider one's emotional states when relaxing and a better understanding to neutralise emotional effects to enhance relaxation.

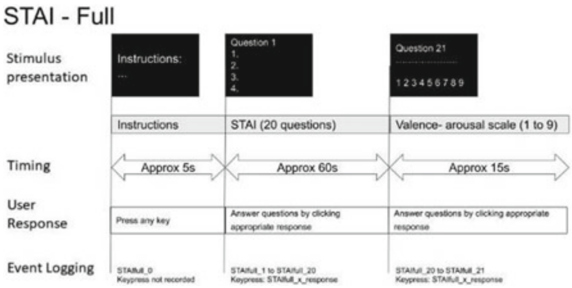
However, we did not take into consideration how the different emotion-inducing tasks, especially the happiness task, could have also caused participants to relax during the task itself, resulting in a lower-than-expected difference in relaxation state between the non-relaxed and relaxed tasks, which could have affected the accuracy found during the paired *t*-test. We also only had 15 participants, which was a small number, and larger sample size would have resulted in better representation. Future research could take a closer look at what causes the difference in the effect of relaxation states for the different emotions and what is the best way to mitigate the negative effects of these emotions on relaxation.

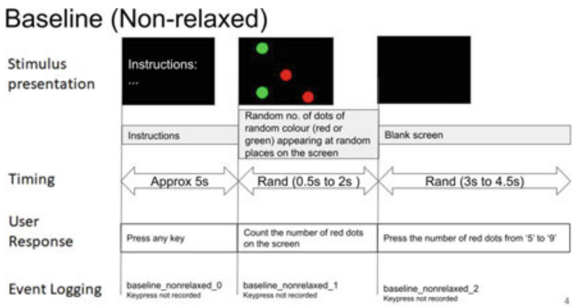
14.6 Conclusion

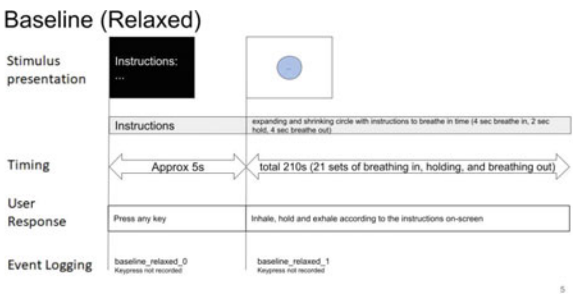
In our study, we aimed to find out the influences of three different emotions: fear, anxiety and happiness, on relaxation. After designing and implementing the experiment software, we collected EEG data from 15 participants according to the experiment protocol consisting of baseline, emotion-arousing (fear, anxiety and happiness) and relaxation tasks. We used signal processing and machine learning methods to compute and compare the mean accuracies of each non-relaxed and relaxed task pair. We also applied extracted band-power features with different statistical analysis methods to test our research hypotheses. Overall, our results showed that the different emotions affected relaxation to varying degrees. These findings could allow a better understanding of emotions' effects on relaxation, which could potentially be useful in areas such as stress management and psychological therapies. Our study is the first step in bringing notable interest and attention to applying different effects of individual emotions in relaxation and utilising particular emotions to improve the relaxation.

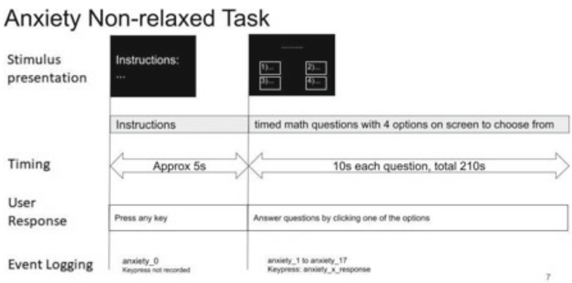
Appendix 1. Experiment Procedure

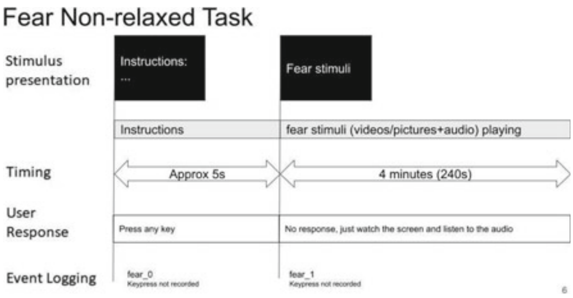
OpenSesame is a programme to create experiments for psychology, neuroscience and experimental economics and a graphical experiment builder for the social sciences. OpenSesame is free, open-source and cross-platform programme. It features a comprehensive and intuitive graphical user interface and supports Python scripting for complex tasks. Additional functionality, such as support for eye trackers, input devices and video playback, is available through plug-ins. OpenSesame can be used in combination with existing software for creating experiments. We used it to create our experiment. The below figures are the exact experiment design.

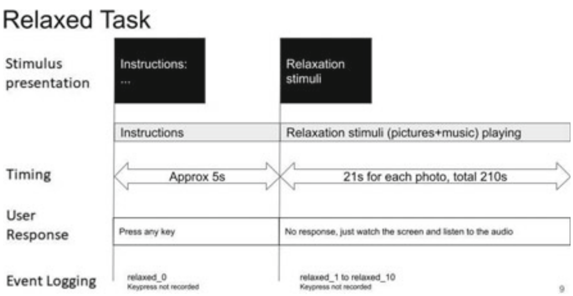

STAI - Full
Stimulus presentation
Instructions:
...
Question 1
1.
2.
3.
4.
Question 21
1 2 3 4 5 6 7 8 9
Instructions
STAI (20 questions)
Valence- arousal scale (1 to 9)
Timing
Approx 5s
Approx 60s
Approx 15s
User Response
Press any key
Answer questions by clicking appropriate response
Answer questions by clicking appropriate response
Event Logging
STAIfull_0
Keypress not recorded
STAIfull_1 to STAIfull_20
Keypress: STAIfull_x_response
STAIfull_20 to STAIfull_21
Keypress: STAIfull_x_response

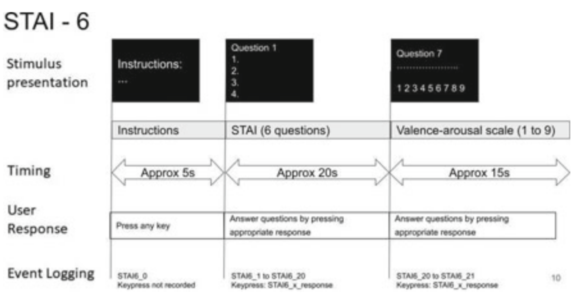

Baseline (Non-relaxed)
Stimulus presentation
Instructions:
...
Instructions
Random no. of dots of random colour (red or green) appearing at random places on the screen
Blank screen
Timing
Approx 5s
Rand (0.5s to 2s)
Rand (3s to 4.5s)
User Response
Press any key
Count the number of red dots on the screen
Press the number of red dots from '5' to '9'
Event Logging
baseline_nonrelaxed_0
Keypress not recorded
baseline_nonrelaxed_1
Keypress not recorded
baseline_nonrelaxed_2
Keypress not recorded
4

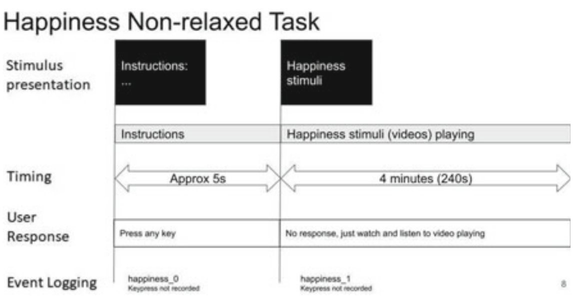

Baseline (Relaxed)
Stimulus presentation
Instructions:
...
Instructions
expanding and shrinking circle with instructions to breathe in time (4 sec breathe in, 2 sec hold, 4 sec breathe out)
Timing
Approx 5s
total 210s (21 sets of breathing in, holding, and breathing out)
User Response
Press any key
Inhale, hold and exhale according to the instructions on-screen
Event Logging
baseline_relaxed_0
Keypress not recorded
baseline_relaxed_1
Keypress not recorded
5


Anxiety Non-relaxed Task
Stimulus presentation
Instructions:
...
Instructions
timed math questions with 4 options on screen to choose from
Timing
Approx 5s
10s each question, total 210s
User Response
Press any key
Answer questions by clicking one of the options
Event Logging
anxiety_0
Keypress not recorded
anxiety_1 to anxiety_17
Keypress: anxiety_x_response
7


Fear Non-relaxed Task
Stimulus presentation
Instructions: ...
Fear stimuli
Instructions
fear stimuli (videos/pictures+audio) playing
Timing
Approx 5s
4 minutes (240s)
User Response
Press any key
No response, just watch the screen and listen to the audio
Event Logging
fear_0
Keypress not recorded
fear_1
Keypress not recorded
6


Relaxed Task
Stimulus presentation
Instructions: ...
Relaxation stimuli
Instructions
Relaxation stimuli (pictures+music) playing
Timing
Approx 5s
21s for each photo, total 210s
User Response
Press any key
No response, just watch the screen and listen to the audio
Event Logging
relaxed_0
Keypress not recorded
relaxed_1 to relaxed_10
Keypress not recorded
9


STAI - 6
Stimulus presentation
Instructions: ...
Question 1
1.
2.
3.
4.
Question 7
1 2 3 4 5 6 7 8 9
Instructions
STAI (6 questions)
Valence-arousal scale (1 to 9)
Timing
Approx 5s
Approx 20s
Approx 15s
User Response
Press any key
Answer questions by pressing appropriate response
Answer questions by pressing appropriate response
Event Logging
STAI6_0
Keypress not recorded
STAI6_1 to STAI6_20
Keypress: STAI6_x_response
STAI6_20 to STAI6_21
Keypress: STAI6_x_response
10


Happiness Non-relaxed Task
Stimulus presentation
Instructions: ...
Happiness stimuli
Instructions
Happiness stimuli (videos) playing
Timing
Approx 5s
4 minutes (240s)
User Response
Press any key
No response, just watch and listen to video playing
Event Logging
happiness_0
Keypress not recorded
happiness_1
Keypress not recorded
8

Appendix 2. Stimuli Used

Relaxation

Audio: “Venus, the Bringer of Peace”, Gustav Holst.

Photographs: scenes of forests and oceans. Samples:

Fear: All: Jumpscares and scenes from horror movies.

Personalised: Jumpscares and scenes from horror movies, movie clips featuring snakes and movie clips featuring spiders.

Happiness:

All: Comedy video “Fastest Newscast Ever”, Studio C.

Personalised: “Penguin chicks rescued by unlikely hero”, BBC and clips from cartoons “Spongebob” and “Tom and Jerry”.

Anxiety: Audio: “Threnody for the Victims of Hiroshima”, Krzysztof Penderecki.

Questions: 30 mental arithmetic questions [e.g. Q: $3(4 + 46/2)$ (a) 81, (b) 73, (c) 78 and (d) 96].

To be consistent, we used both audio and visual stimuli for the relaxed task and all non-relaxed stimuli.

The order of the three blocks (of the non-relaxed stimuli each followed by a relaxation task) are randomised for each participant so as to ensure that the order of emotions induced does not affect the results.

Appendix 3. STAI Questionnaire

STAI stands for State-Trait Anxiety Inventory. It is a commonly used measure of trait and state anxiety. All 20 questions are rated on a four-point scale (“not at all”, “somewhat”, “moderately so” and “very much so”). Ten of the 20 items are anxiety-present, and are scored with one point for “not at all” and four points for “very much so”, while the other ten items are anxiety-absent and are scored with one point for “very much so” and four points for “not at all”. The total score ranges from 20 to 80, with higher scores indicating higher levels of anxiety symptoms. A cut-off score of 40 is commonly used to define probable clinical levels of anxiety. For the STAI-6, the total score is scaled down to range from 6 to 24, with a cut-off score of 12. The STAI has shown to be a valid and reliable measure.

Results of average STAI-6 scores and accuracy:

Average	Non-relaxed STAI-6 score	Relaxed STAI-6 score	Average task pair accuracy
Anxiety	16.93	10.93	74.543
Fear	18.33	13.87	73.51
Happiness	10.27	10.87	72.06

The results of average STAI-20 scores for the start of the experiment and for the end of the experiment are 39.93 and 48.33, respectively.

We analysed the participants' scores for each STAI-6 questionnaire done after each task, which has a total score ranging from 6 to 24. Overall, participants showed the highest levels of anxiety after the fear-inducing task, followed by the anxiety-inducing task and then the happiness-inducing task. The happiness-inducing task also resulted in a score of 10.27 which is below the cut-off point of 12 to define probable clinical levels of anxiety.

Participants' average STAI scores decreased the most in the relaxation task after the anxiety-inducing task, followed by after the fear-inducing task. However, the average score increased slightly in the relaxation task after the happiness task. Thus, the relaxation task after each non-relaxed task was most effective after the anxiety-inducing task, followed by after the fear-inducing task. The relaxation task was the least effective after the happiness-inducing task, and it also resulted in marginally higher levels of anxiety.

We also analysed participants' scores for the full STAI questionnaire done at the start and the end of the experiment, which has a total score ranging from 20 to 80. Most participants' scores increased by the end of the experiment, with an exception of two out of the 15 participants whose scores decreased, and one participant whose score remained the same. The mean of participants' scores increased significantly by the end of the experiment which showed that overall participants' levels of anxiety generally increased.

Appendix 4. Experiment Data

ANOVA results for all tasks.

Band-power feature	All tasks *p*-value*	All non-relaxed tasks *p*-value*	All relaxed tasks *p*-value*
Tp9 theta	< 0.001	< 0.001	< 0.001
Tp9 alpha	< 0.001	< 0.001	< 0.001
Tp9 lowBeta	< 0.001	< 0.001	< 0.001
Tp9 highBeta	< 0.001	< 0.001	< 0.001
Fp1 theta	< 0.001	< 0.001	< 0.001

(continued)

(continued)

Band-power feature	All tasks *p*-value*	All non-relaxed tasks *p*-value*	All relaxed tasks *p*-value*
Fp1 alpha	< 0.001	< 0.001	< 0.001
Fp1 lowBeta	< 0.001	< 0.001	< 0.001
Fp1 highBeta	< 0.001	< 0.001	< 0.001
Fp2 theta	< 0.001	< 0.001	< 0.001
Fp2 alpha	< 0.001	< 0.001	< 0.001
Fp2 lowBeta	< 0.001	< 0.001	< 0.001
Fp2 highBeta	< 0.001	< 0.001	< 0.001
Tp10 theta	< 0.001	< 0.001	< 0.001
Tp10 alpha	< 0.001	< 0.001	< 0.001
Tp10 lowBeta	< 0.001	0.006	< 0.001
Tp10 highBeta	< 0.001	< 0.001	< 0.001

* We use *p*-value thresholds for significant test as 0.05 and 0.001

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