Quantifying Mental Relaxation with EEG for use in Computer Games

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Abstract - *The aim of this study was to investigate the potential of implementing electroencephalographic (EEG) based measurement of mental relaxation as an interface for a simple computer game. In this game, a simulated ball is controlled to move left or right based on player's mental relaxation level. EEG data, blood pressure, heart rate and subjective perception of relaxation were recorded from 10 subjects, participating in 9 different activities. ANOVA with repeated measures was carried out on 9 different EEG indices to identify the indices that are most capable of distinguishing between the various relaxation levels. The results showed that EEG detected difference in relaxation levels that was undetected by blood pressure and heart rate measurement. The analysis of the EEG indices showed that the sum of indices such as alpha+theta, and alpha+beta+theta were good indices for measurement of relaxation.*

Keywords: EEG, mental relaxation, computer games.

1. Introduction

The idea of context-aware applications can be used in games that can adapt their behavior based on the information sensed from the environment. In order to produce games that are more interesting, gamers' level of relaxation or concentration can be detected during the game, and used to change the game behavior accordingly [1]. Previous research used heart rate, breathing rate, blood pressure, skin conductance level as a measurement to relaxation state [2]. However, since physical and mental relaxation states do not necessarily correlate, the measurement of mental relaxation states could provide information that are more useful.

Electroencephalography (EEG) is the recording of electrical activities of the brain. Previous studies have shown that mental relaxation state can be measured using scalp EEG [1, 3, 4]. Alpha band is predominant in a relaxed adult; theta band is the major component in light sleep stage, and beta band is predominant during concentration. Alpha and theta ratio are also used to assess relaxation as it is shown to be different for ADD or ADHD patients [5]. However, EEG results differ with different electrode placements. This research looks into the possibility of achieving relaxation measurement using a simple one channel (Fp1-Fp2) EEG device.

Existing EEG based games include: *Brainathlon* [6], which is an open source software game that provide players with a real time feedback of their current brain activities. The brain activity is used to control the game play. *Mindball*® [7], a game where players sit at each end of the table that is laid out with two goals and a little ball. The ball moves away from the player that is more calm and relaxed. The brainwaves used to move the ball forward are the alpha and theta waves; however, details of how these waves were used is unknown (e.g. weighting). *ElectricGuru* [8] is a free software which provides EEG feedback in the form of various graphics.

To our knowledge, *Mindball*® is the only EEG based relaxation game implemented with pre-frontal electrodes positions only. However, some users have expressed that *Mindball*® does not work.

The aim of this study was to investigate methods for the implementation of EEG based measurement of mental relaxation, and to demonstrate the potential of the interface with a simple game, where a simulated ball is controlled to move left or right based on player's mental relaxation level. Bulk of this research concerns investigating what frequency components of the EEG signals or the combinations of the frequency components best measures the user's mental relaxation level, as well as how viable it is to be measured in real-time, so that it could be implemented in a game.

The purpose of the game is to demonstrate how well the ball can be controlled with EEG signals via different relaxation level.

2. Methodology

EEG data was gathered from subjects participating in 9 different tests. An initial assumption was made that each test induces perceptible relaxation levels in the participants and those relaxation levels can be measured physiologically, subjectively and neurologically.

2.1. Participants

Ten right-handed males were recruited for the study, their mean age being 26.1 +/- 7.68 years. All participants signed consent forms, and were paid for their participation. According to the participants' self-report, they had normal vision and hearing, and had no history of neurological disorders. All recordings took place during the day time, within the same season of year.

2.2. List of Tests

Nine tests were set up for the experiment, as shown in table 1. All activities were done either at rest or with mouse clicking movement with right hand only. This is to ensure minimal artifact in the EEG data.

2.3. Equipments

The ModularEEG hardware design from the OpenEEG website [9] was used to build the EEG device for recording. BrainBay [10] was used to record the data into text files. Disposable stick-on ECG electrodes were used for EEG recording. A digital electro-sphygmomanometer was used to measure blood pressure and heart rate at the end of each test.

2.4. Trial Procedure

The subjects were fitted with the one-channel ModularEEG system. Nine tests were presented in random order. Five minutes of EEG data were recorded for each test, and a 6th minute was used to measure blood pressure and heart rate. The subjects were instructed to refrain from unnecessary movement, and to relax. All subjects were familiarized with the trial procedures and equipments before commencement of the trial. At the end of the experiment, the subjects were asked to rate the level of relaxation of each test in a Likert scale of 1 to 10, with 1 = most relaxed, and 10 = least relaxed.

2.5. EEG Preprocessing

EEG signals were sampled at 256 Hz. EEG voltage data was cleaned offline using the EEGLAB toolbox [11] in MATLAB to remove, by visual inspection, eye blinks and muscle movement artifacts. The cleaned data was then Fourier transformed into its frequency spectrum, using an epoch size of 1 second with 20% sliding Hamming window, resulting in at least 500 clean time-windows per test. EEG was then separated into bands (alpha, beta and theta) of absolute voltage for analysis. All indices used for analysis are shown in table 2.

Table 1: The 9 testing activities

Test	Activity	Implementation	Description
1	rest with eyes open	none	rest on a chair with eyes open
2	rest with eyes closed	none	rest on a chair with eyes closed
3	listen to relaxing music	Watermark	rest on a chair listening to relaxing music, eyes open
4	solve English word problems	Scrabble	play Scrabble on computer, use right hand for mouse clicking
5	solve math problems	simple multiplication	solve math problems on computer, use right hand for mouse clicking
6	card game, play as fast as possible	Solitaire	play Solitaire on computer, use right hand for mouse clicking
7	play a video action game	House of the dead	play House of the dead on computer, use right hand for mouse clicking
8	watching an action video	Face Off	watch the Face Off video
9	listen to Rock Music	The kids aren't right, Faint	rest on a chair listening to rock music, eyes open

Table 2: EEG indices used for analysis

Specific indices	Ratio of specific indices	Sum of specific indices
alpha (8~12Hz)	alpha/beta	alpha + theta
beta (13~30Hz)	alpha/theta	beta + theta
theta (4~7Hz)	beta/theta	alpha + beta + theta

2.6. Statistical Methods

One-way ANOVA (Analysis of Variance) was performed on the heart rate, blood pressure measurement and the subjective relaxation rating of the tests using STATISTICA. Means and standard error were plotted and compared. Tukey HSD [12] post-hoc tests were performed.

The EEG data gathered was large (+500 time-windows per test, per subject), thus parametric methods were used for analyzing the data. A three-way ANOVA with repeated measures on three factors (tests, indices, and time-windows) [13] was performed to analyze the data in MATLAB, in order to compare the difference between the three factors in the EEG data. Tukey HSD post-hoc tests were carried out on the selected significant factors. For all statistical analysis, a significance level of 0.05 was chosen.

2.7. The game implementation

The game was implemented in JAVA, using open source libraries from Brainathlon, and Sun's COMMAPI library [14] for the serial connection from EEG device to the PC. A simulated ball moves left or right along a horizontal axis controlled by the player's EEG signals relating to level of mental relaxation. Two players can compete simultaneously to determine who is more relaxed by comparing the relative position of the ball. The controllability of the ball was assessed by subject's perception of relaxation. See figure 1 for a screenshot of the game interface, and figure 2 for a diagram showing electrode placements at positions Fp1 and Fp2.

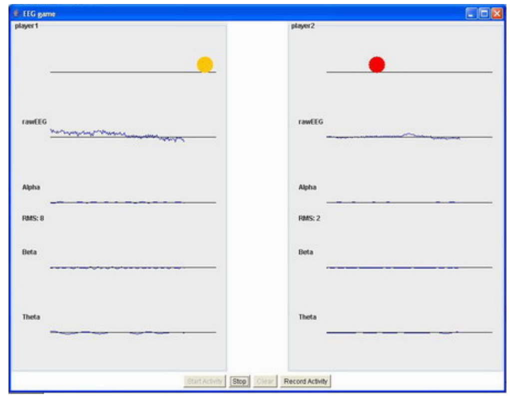

Figure 1: A screenshot of the game interface

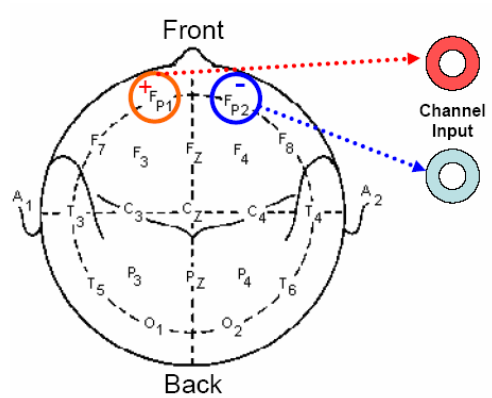

Figure 2: Electrode placements

3. Results

3.1 Measurement of Physical Relaxation

The ANOVA results showed that there is no significant difference between the means of systolic blood pressure and heart rate across the various tests (figure 3, 5). However there is a significant difference in diastolic blood pressure between test 7 (action game) and test 8 (action video) (figure 4).

3.2 Measurement of Subjective Relaxation

The ANOVA results showed a significant difference in the subjective relaxation ratings for the 9 tests. Post-hoc Tukey HSD comparisons indicated tests 1, 2 and 3 (resting activities) are significantly different from tests 4, 5, 6, 7and 8 (games and movie activities). Test 9 (rock music) is significantly different from test 2, 3 and 7 (eyes closed, relaxing music and action game). See figure 6.

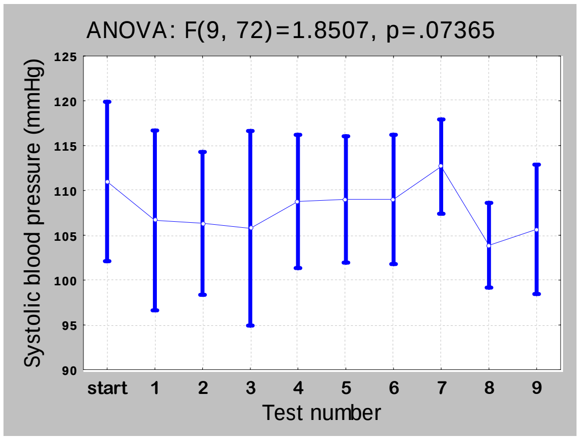

Figure 3: Systolic blood pressure after the 9 different tests

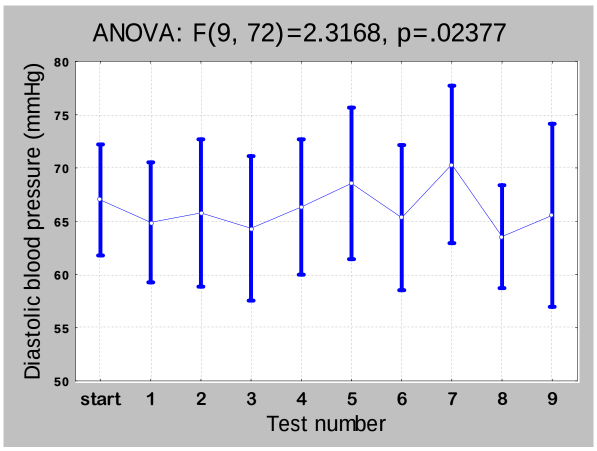

Figure 4: Diastolic blood pressure after the 9 different tests

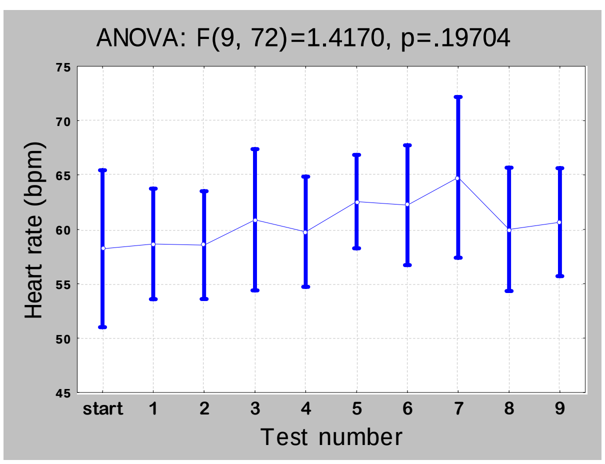

Figure 5: Heart rate after the 9 different tests

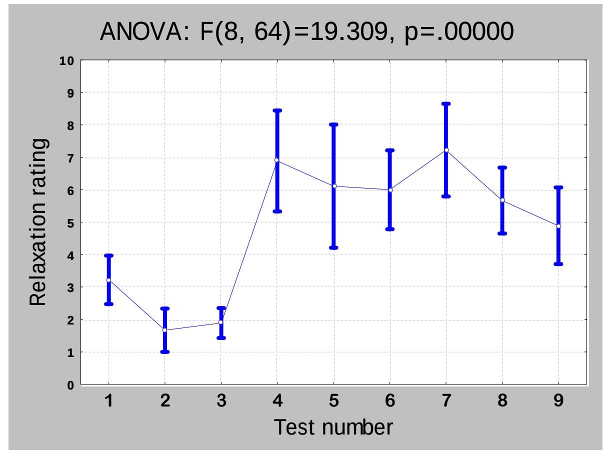

Figure 6: Subjective relaxation rating after the 9 different tests

3.3 Measurement of Neurological Relaxation

The ANOVA results for all 3 factors (test, index, and time-window) indicated a significant difference for tests, indices and time-windows. The interaction results showed that there is significant difference for index*time-window but no significant difference for test*time-window, and test*index*time-window. See table 2.

Tukey HSD post-hoc tests for the 9 tests in each index showed that (for summary see table 3):

Specific indices: there is no significant difference for alpha and beta, but for theta, there is a significant difference between test 6 (card games) with all other activities. See figure 7.

Ratio of specific indices: there is no significant difference for alpha/theta or beta/theta ratio, but in alpha/beta ratio, there is a significant difference for test 2(eyes closed) versus tests 4, 7 and 9. See figure 8.

Sum of specific indices: there is a significant difference for all sums tested. In the sum alpha+theta, there is a significant difference for test 6 (card games) versus all other activities, and test 2 (eyes closed) versus test 5 (math problems). The sum beta+theta showed more significant pairs, with the same significant pairs as the sum alpha+theta, as well as 3 more significant pairs: test 2 (eyes closed) versus test 4, 7 and 9 (word game, action game, rock music). The sum alpha+beta+theta showed the most number of significant pairs, with all the significant pairs in all other indices, as well as test 2 (eyes closed) versus test 1 (eyes open). See figure 9, 10.

Table 2: Three-way analysis of variance with repeated measures on three factors (within-subjects) table. Significance level = 0.05. The results are significant (S) or not significant (NS). SOV = source of variance, SS = sum of squares, df = degree of freedom, MS = mean square, F = f-test stats, P = p-value.

SOV	SS	df	MS	F	P	Conclusion
Between-Subjects	10549.107	9				
Within-Subjects	335092.280	449990				
Test	5779.194	8	722.399	9.023	**0.0000**	S
Error(Test)	5764.308	72	80.060			
index	165424.074	9	18380.453	118.725	**0.0000**	S
Error(Index)	12540.028	81	154.815			
Time-window	722.764	499	1.448	1.143	**0.0196**	S
Error(Time-window)	5689.136	4491	1.267			
Test*Index	5975.970	72	83.000	7.945	**0.0000**	S
Error(Test*Index)	6769.699	648	10.447			
Test*Time-window	5146.237	3992	1.289	0.991	0.6408	NS
Error(Test*Time-window)	46719.405	35928	1.300			
Index*Time-window	922.563	4491	0.205	1.214	**0.0000**	S
Error(Index*Time-window)	6841.044	40419	0.169			
Test*Index*Time-window	6119.856	35928	0.170	0.992	0.8505	NS
Error(Test*Index*Time-window)	55531.765	323352	0.172			
Total	340495.150	449999				

Table 3: Summary of significant pairs in each index. The results are labeled significant (S) or not significant (NS). The number of pairs shows the number of significantly different pairs.

Specific indices			Ratio of specific indices			Sum of specific indices		
alpha	beta	theta	Alpha/beta	alpha/theta	beta/theta	alpha + theta	beta + theta	alpha + beta + theta
NS	NS	S *8 pairs*	S *3 pairs*	NS	NS	S *9 pairs*	S *12 pairs*	S *14 pairs*

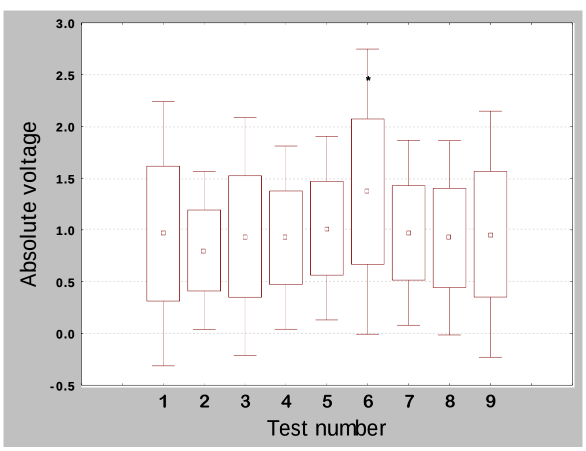

Figure 7: Absolute theta voltage

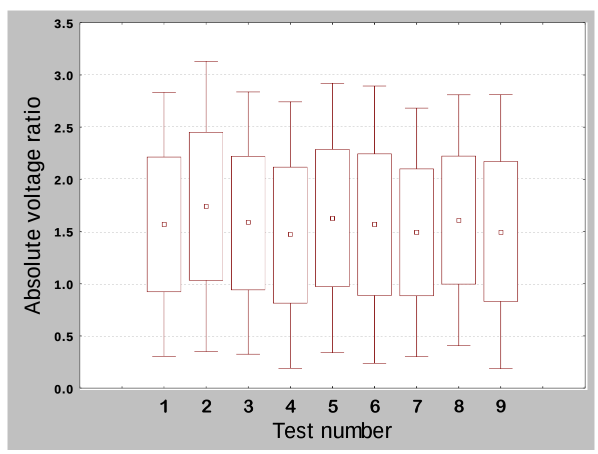

Figure 8: Alpha/Beta ratio

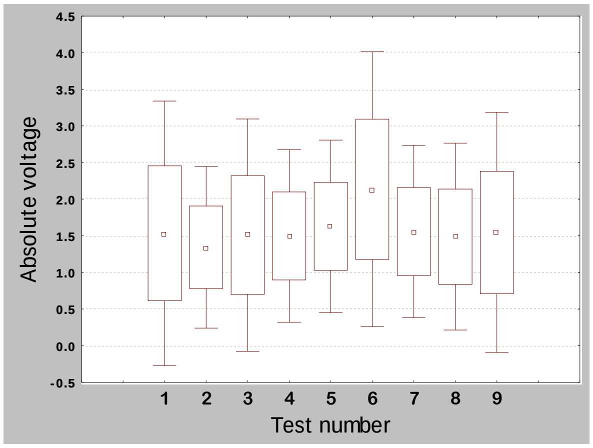

Figure 9: Absolute alpha + theta

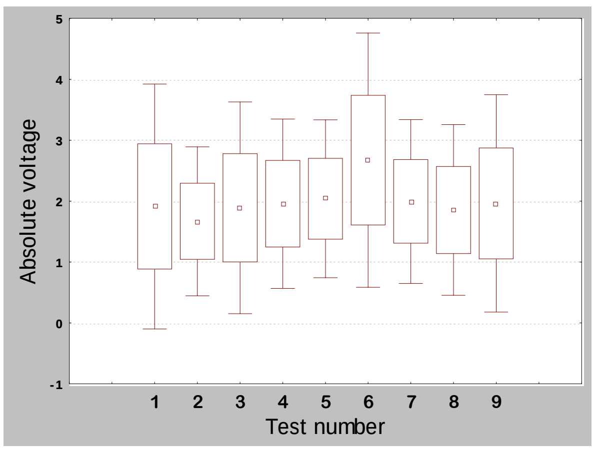

Figure 10: Absolute alpha + beta + theta

3.4 Qualitative Game testing

Two test-players ranked the indices according to the controllability. The test-players expressed their view that the sums of indices were much more controllable than the individual indices, and the ratios were not controllable at all. The sum of alpha and theta was then opened to a class of 20 students for testing. About half of the students indicated that they could perceive some control over the ball with their relaxation levels. The quantitative results are still being prepared.

4. Discussion

4.1 Result of Physical Relaxation

Diastolic blood pressure was the only measurement showing significant difference, but this was only between test 7 and test 8, hence blood pressure and heart rate measurement may not be a satisfactory indication of relaxation in this context. Perhaps only extreme physical relaxation changes such as during deep sleep, active sport or intense worrying would induce measurable changes in these parameters, beat-to-beat monitoring of these parameters could possibly provide more information.

4.2 Result of Subjective Relaxation

The subjective ratings of mental relaxation showed a significant difference between resting (test 1,2,3,9) and active (test 4,5,6,7,8) test scenarios. This shows that these testing activities do induce various levels of mental relaxation that are perceivable to subjects.

4.3 Result of Neurological Relaxation

The ANOVA results showed a significant difference in all individual factors, this shows that EEG signals (Fp1-Fp2) changes with test, indices, and time-window. The sums of indices have the most number of significant pairs indicating that the sums can distinguish between the tests better than individual indices or ratios, refer to table 3.

The greater difference in EEG as compared to heart rate and blood pressure measurement also shows that neurological measurement has more capability to distinguish the different mental states to these activities than the physical measurements.

5. Conclusion

This is the first study that attempts to measure mental relaxation state using one channel (Fp1-Fp2) EEG for game implementation. The EEG results indicate that the sum alpha+theta, and sum alpha+beta+theta are good indices for measurement of neurological relaxation. Game testing also reflects that these indices have the capability to measure basic level of relaxation in at least half of the players. However, further research should be done to investigate more combinations of indices. An EEG interface to measure mental relaxation could be used to create advanced computer games that are influenced by the state of relaxation of the player.

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