# Impact of Music on Human Brain Activity during Mental Stress

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Abstract: Because music is an integral part of our lives, every step towards a better understanding of its impact on humans is beneficial. This paper deals with the impact of several types of music on the human brain activity during mental stress. An experiment was designed, and electroencephalography data, heart rate data and data from questionnaires were collected, processed and analyzed. All these steps are described and a subset of the large collection of results is presented.

## 1 INTRODUCTION

Music naturally accompanies our lives, evokes a plethora of emotions, both positive and negative, and affects our mood, physical and mental performance. A better understanding of what type of music and how it affects individuals can be very beneficial, for example, for the treatment of some diseases or just for improvement of concentration and cognitive performance. Some effects of music are nowadays commonly used in medicine, advertising, entertainment and other areas. However, how a particular type of music affects us is very individual and closely related to our experience, preferences and current situation.

The aim of this paper is to contribute to the understanding of how different types of music affect the activity of the human brain during mental stress. The presented research focuses on the acquisition and analysis of the electrical activity (that is considered to be influenced by listening to music) of the human brain by using the method and technique of electroencephalography. Heart rate is collected as a source of additional electrophysiological data.

The paper is organized as follows. The state of the art section presents experiments and findings that have been made in connection with the research of the impact of music on humans. The next section introduces the design of the experiment; the course of the experiment, hardware and software equipment used, participants, and acquired data are described. The data processing section comes with the basic processing methods and results applied to the collected data. The data analysis section provides selected results from the data evaluation and interpretation process. The last session concludes the obtained findings.

## 2 STATE OF THE ART

In this section we introduce some existing studies and findings concerning the impact of music on the physical and mental state of individuals in various situations. These studies have contributed in part to shaping the design and course of our experiment.

The impact of music, specifically tempo, rhythm, melodic structure, pause, individual preference, habituation, order effect of presentation, and previous musical training on changes in the cardiovascular and respiratory systems that could be potentially used for stress modulation is described in (Bernardi et al., 2006). The participants were initially allowed to rest for 20 minutes while their cardiovascular and respiratory indicators were measured. Furthermore, six different music styles were played in random order and two minutes without any music were randomly inserted into the music. At the end of the experiment, the participants rated each song according to their preferences. The results obtained on 12 practising musicians and 12 age matched non-musicians showed that music induced an arousal effect, predominantly related to the tempo. This effect was also independent of the preferences of individual participants. Other interesting results included, for example, that no habituation effect was seen and that musicians had greater respiratory sensitivity to the music tempo than

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non-musicians did.

The impact of listening to music on cognitive performance was investigated in (Dolegui, 2013). The study focuses on what is the impact of different genres of music, played at different volume levels, on the cognitive abilities of college students when completing academic tasks. The results showed that the participants performed best when they did not listen to any music during the tasks. On the other hand, high-intensity heavy-metal music dramatically worsened their performance. Despite expectations, listening to classical music did not confirm an increase in subjects' performance in the tasks.

The study (Lesiuk, 2005) examined the impact of listening to music on the state of positive affectivity, the quality of work, and time-on-task of computer information systems developers. The data was collected from fifty-six developers from four different Canadian software companies in their common work environment for five weeks. The results of this study suggested that listening to music in some work environments provoked a positive mood change and improved the quality of work done while reducing work time.

The experiment described in (Daly et al., 2014) deals with the emotional change induced by listening to music. One hundred and ten snippets of film music were selected for stimulation, including many different musical styles, offering a rich stimulus material for exploring emotional processing. During the whole experiment, the EEG signal was obtained from nineteen electrodes placed according to the international 10/20 system. The researchers found neural correlates of music-induced emotion in a number of frequencies over the pre-frontal cortex., e.g. between the emotional state of the participants and the frequency band changes in the 18 to 22 Hz range (beta activity). The study suggested that the observed changes in EEG recordings induced by a change in a person's emotional state did not depend on whether emotions were induced by listening to music or they were induced by other stimuli.

There are many brain imaging studies focusing on brain regions that are activated by familiar music. The issue how is the brain response influenced by the familiarity of music using electroencephalography was addressed in (Kumagai et al., 2017). The EEG signal was analyzed to investigate the relationship between cortical response and familiarity of music (melodies produced by piano sounds). The cross-correlation function averaged across trials, channels, and participants showed two pronounced peaks where the magnitude of the cross-correlation values were significantly larger when listening to unfamiliar and scrambled music. These findings suggested that the response to unfamiliar music was stronger than that to familiar music.

Two following articles deal with the issue of decoding music preference from EEG signals. A time-windowing feature extraction approach for investigation of the time-course of the discrimination between musical appraisal electroencephalogram (EEG) responses was presented in (Hadjidimitriou and Hadjileontiadis, 2013). The used EEG data set contained the responses of nine subjects during music listening; self-reported ratings of liking and familiarity were also collected. The features were extracted from the beta and gamma EEG bands and two classifiers were used to classify feature vectors into two categories (like, dislike) under three cases of familiarity (regardless of familiarity, familiar music, and unfamiliar music).

A single-sensor EEG biomarker for the assessment of spontaneous aesthetic brain responses during music listening was introduced in (Adamos et al., 2016). It reflects the listener's fondness for music regardless of the emotions induced by it. The participants were not engaged in any cognitive task and asked not to produce any kind of active response. The EEG recordings were performed in a common environment using a wireless EEG device. The resulting tool was considered to facilitate the personalization of modern music recommendation systems.

Many other studies have been carried out on how music affects humans, and although their conclusions do not always coincide, research has shown that music can affect humans both physically and mentally through emotions. Examples of such effects include e.g. changes in respiratory rate and heart rate, brain frequency and improved work performance. However, as these experiments have further shown, the effects of music on humans are very individual. It depends on the specific characteristics of the music being played, the person's experience of listening to it and its musical preferences.

In view of these findings, it was assumed that listening to different types of music while playing a memory game (which represents mental stress) will have an impact on a variety of electrophysiological signals which can be captured from humans. In our case the effect of music is considered to be translated into a change in the energy level of brain activity, heart rate, and in-game performance. At the same time, the behavior of experiment participants (and the nature of their data) will be influenced by their musical preferences and their overall experience with listening to music.

# 3 DESIGN AND COURSE OF EXPERIMENT

This section describes the design and course of the experiment dealing with the influence of music on human brain activity during mental stress. The electroencephalographic (EEG) signal and heart rate data were captured during the experimental sessions as well as data related to the mental stress of participants.

## 3.1 Experiment Scenario

The participants of the experiment (subjects) played a memory game (representing mental stress) of two different levels of difficulty either listening to three different types of music or in a quiet environment.

Prior to the start of the experiment, the subjects were allowed to rest while measuring their heart rate for five minutes. After this time period, the subject set the volume of the music played on the headphones to the level he/she was used to. He/she played one trail of the memory game to get acquainted with the game and to know how to switch to a new game.

The experiment was divided into two blocks (two difficulty levels). Each block consisted of four sessions that differed only in the type of music played:

- Playing the memory game in a quiet environment,
- Playing the memory game while listening to fast music,
- Playing the memory game while listening to slow (relaxing) music,
- Playing the memory game listening to music preferred by the participant.

Each session lasted four minutes and contained a four minute musical composition of one of the types of music described above. During each musical composition, the subject tried to reveal as many pairs of memory cards as possible with the highest accuracy. The subject could complete the memory game several times during one musical composition. There was a 15 second pause between the sessions for the subject to prepare for a new game. In the second block, the difficulty of the game increased - the playing cards were more similar. In the first block the pictures on playing cards were colored and more different (different musical instruments), while the second block they were black and white and contained only one type of picture (owl), which was slightly varied. Between two blocks there was a five minute pause, during which the subject could relax while switching the difficulty of the game. After completion of the experiment, the subject was rested for five minutes while his/her heart rate was still measured.

Throughout the experiment, the EEG signal from the Cz, Fz, and Pz electrodes was captured. At the same time, heart rate, and average accuracy together with the number of pairs successfully found in the memory game were recorded.

## 3.2 Hardware Equipment

The experiment was performed in (no info for the review process). It was equipped with all necessary hardware infrastructure for EEG and heart rate recordings. The *V-Amp* amplifier produced by the Brain Products company was used for EEG recordings. Intraaural earphones were used to isolate the subjects from the surrounding noise and to respect the constraints caused by wearing the EEG cap. Common ECI EEG caps (the 10-20 system defining locations of scalp electrodes) were used depending on the size of the subjects' heads. The reference electrode was placed approximately 1 cm above the nose and the ground electrode was placed on the ear. The *Xiaomi Miband* 2 smart wristband was used to measure heart rate. The wristband was connected to the mobile application *Tools & Mi Band* to allow continuous heart rate recording during each measurement. Two computers were used, the first one for visualizing, recording and storing EEG data, and the second one for playing a memory game.

## 3.3 Software Tools

The *BrainVision Recorder* was used to visualize and record the EEG signal. A simple and user friendly web application *Pairs One* (Gorin, 2016) was chosen for the experiment as a suitable representative of the memory game. It allows users to customize the game easily. The software *Matlab R2015b* with freely available extensions *EEGLAB v13.5.4b* and *ERPLAB 5.0* were used for processing and analysing the captured EEG data.

## 3.4 Music Compositions

The music played to the subjects during the experiment was divided into three categories: slow, fast and preferred one. The musical compositions labeled as slow and fast music were selected from the same artist and genre. They did not contain any lyrics, so that the text did not distract the subject from playing the game. The preferred musical compositions were selected directly by the subjects. They were instructed to select two of their favorite musical compositions.

Table 1: Detailed information about the music played during the experiment.

| Type | Author | Musical Composition (1st level) | Musical composition (2nd level) | Style |
|---|---|---|---|---|
| Fast | Metallica | Master of Puppets | Enter Sandman | metal |
| Slow | Kevin MacLeod | Sovereign | Fresh Air | classic |

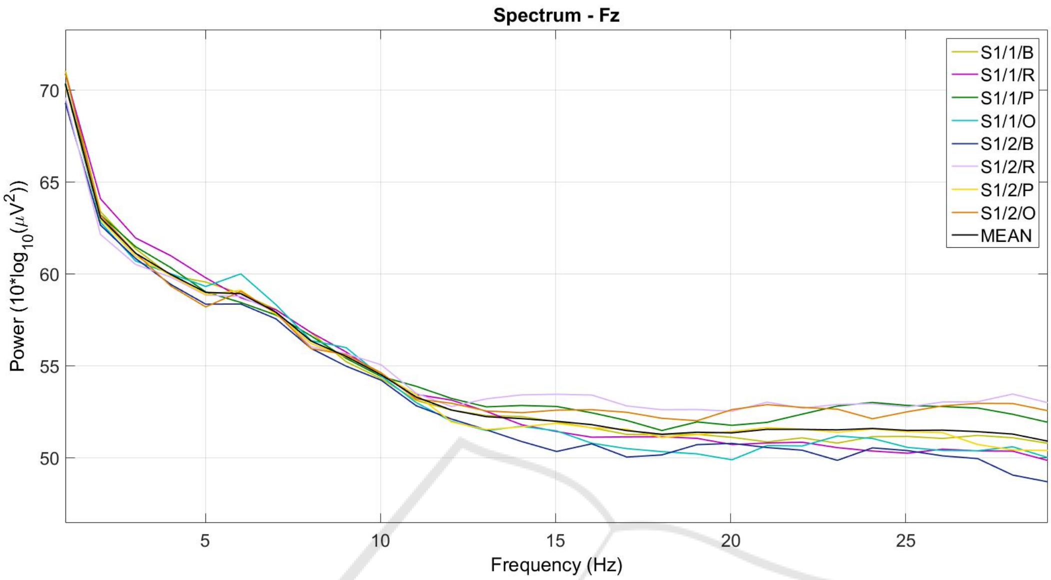


Figure 1: The frequency spectrum of subject 1 on the electrode Fz.

No restrictions were put on the subject in this selection.

Finally two sets of musical compositions were created, each containing one musical composition from each category. The first set of musical compositions was played during playing the first difficulty level of the memory game while the second set of musical compositions was played during playing the second difficulty level of the memory game. The detailed information on individual musical compositions (for the fast and slow music types, i.e. not for the music preferred by the participants) is given in Table 1.

### 3.5 Subjects

Twenty volunteers between the ages of 21 and 30 participated in the experiment, including ten men and ten women. Prior to the start of the measurement, all volunteers got necessary information about the experiment and were asked to give informed consent. Informed consent was obtained from all of them.

### 3.6 Data and Metadata

EEG data were recorded with the sampling frequency of 1 kHz; no filters were used during data recording. The resulting signal was stored into three files of the BrainVision format but two files were important in this case (.eeg file containing raw data, and .vhdr file containing metadata). All recorded data together with collected metadata were stored into the EEG/ERP portal, they are publicly available for registered users.

### 3.7 Questionnaire

At the end of the experiment, each subject was asked to fill in personal information and questionnaire. The questionnaire contained twelve questions relating to the experiment, e.g. how the participant was influenced by different music during the measurement, how boring the memory game was at the end of the experiment or how stressful the overall measurement for the subject was.

## 4 DATA PROCESSING

### 4.1 EEG Data Processing

The changes in energy levels on the alpha and beta frequency bands when playing the memory game under different conditions (listening to different types of music) were primarily investigated. The Fast Fourier

Table 2: Energy levels for all subjects in alpha and beta bands - the first block of the experiment.

| Subject | 1st session | | 2nd session | | 3rd session | | 4th session | |
|---|---|---|---|---|---|---|---|---|
| | α | β | α | β | α | β | α | β |
| 1 | 287,2 | 745,7 | 288,7 | 736,5 | 288,2 | 751,8 | 288,8 | 742,7 |
| 2 | 273,3 | 702,7 | 273,6 | 695,9 | 273,8 | 691,9 | 270,8 | 687,9 |
| 3 | 293,2 | 783,1 | 293,0 | 776,5 | 290,3 | 774,1 | 292,5 | 773,6 |
| 4 | 298,2 | 747,0 | 298,3 | 744,0 | 295,8 | 738,9 | 294,8 | 738,8 |
| 5 | 303,7 | 779,3 | 302,8 | 775,0 | 301,6 | 777,5 | 299,8 | 770,2 |
| 6 | 302,8 | 742,9 | 301,0 | 745,8 | 298,7 | 742,1 | 301,9 | 748,0 |
| 7 | 287,1 | 767,0 | 287,0 | 800,3 | 288,0 | 821,4 | 290,2 | 818,2 |
| 8 | 283,6 | 733,8 | 284,1 | 748,1 | 286,5 | 759,0 | 285,8 | 753,3 |
| 9 | 289,1 | 746,5 | 288,6 | 744,7 | 286,1 | 735,2 | 286,4 | 734,3 |
| 10 | 287,8 | 769,0 | 293,2 | 777,3 | 292,9 | 776,1 | 294,2 | 767,3 |
| 11 | 303,5 | 757,5 | 304,2 | 752,7 | 302,6 | 744,8 | 301,2 | 744,7 |
| 12 | 290,6 | 741,4 | 289,6 | 740,4 | 284,0 | 734,3 | 292,5 | 737,5 |
| 13 | 291,2 | 758,3 | 296,0 | 800,9 | 289,8 | 758,1 | 294,2 | 795,0 |
| 14 | 274,8 | 724,6 | 275,2 | 724,2 | 277,4 | 722,2 | 283,6 | 737,2 |
| 15 | 289,4 | 730,1 | 287,8 | 725,7 | 291,8 | 727,0 | 291,6 | 728,1 |
| 16 | 299,8 | 735,4 | 301,5 | 750,1 | 301,7 | 745,6 | 297,6 | 724,6 |
| 17 | 303,9 | 758,0 | 301,2 | 753,9 | 301,7 | 756,0 | 303,1 | 761,6 |
| 18 | 270,3 | 696,3 | 272,5 | 699,9 | 274,3 | 702,8 | 274,3 | 708,7 |
| 19 | 288,5 | 731,8 | 286,5 | 726,5 | 287,2 | 732,6 | 286,2 | 730,4 |
| 20 | 300,2 | 779,1 | 298,9 | 800,2 | 300,8 | 797,2 | 301,0 | 808,2 |

Transform was used to convert a discrete signal from the time domain to the frequency domain.

For each subject, eight EEG recordings corresponding to eight different measurement conditions (two blocks, each block containing four sessions) were obtained. An analysis of the frequency spectrum of the EEG signal was done for these individual recordings. To obtain the values of the energy level on the alpha and beta frequency bands several preprocessing methods had to be performed with the recorded EEG data: data filtering (the basic FIR filter was used) in the frequency range of 0,1 Hz – 30 Hz, automated (the moving window method was used) and manual detection and removal of artifacts, and calculation and visualization of the EEG signal spectrum.

Visualization of the frequency spectrum and calculation of energy levels in the alpha and beta bands were processed for all subjects and for the Cz, Fz, and Pz electrodes. As an example, the resulting graph for subject 1 on the electrode Fz is shown in Figure 1.

Tables 2 and 3 show energy levels for all subjects in the alpha and beta bands on the electrode Pz for the first and second block of the experiment. The alpha and beta bands were the most prominent on the Pz electrode, therefore these values were further used in data analysis.

## 4.2 Heart Rate Data Processing

Nine different heart rate values were obtained for each subject. The first value corresponds to the baseline heart rate, which was defined as the median of the values measured before and after the experiment. The other heart rate values correspond to the eight sessions of the experiment. The heart rate calculated for each session is the median of all the values captured during the session.

No heart values were obtained for subject 5 in the last two parts of the experiment, and no heart rate values at all were obtained for subject 15. In both cases it was due to technical troubles with the measuring device.

## 4.3 Memory Game Data Processing

The data related to the accuracy of subjects in the memory game were collected for each session and each subject. The accuracy was calculated directly by the application *Pairs One*. Two values were calculated for each subject. The total accuracy for each session of the experiment was calculated as the average of the accuracy of completed memory games in this session, and the total number of exposed cards for each session of the experiment was calculated as the sum of exposed cards for all (even incomplete) memory games in that session. Table 4 shows the total accuracy for all subjects in individual sessions.

Table 3: Energy levels for all subjects in alpha and beta bands - the second block of the experiment.

| Subject | 5th session | | 6th session | | 7th session | | 8th session | |
|---|---|---|---|---|---|---|---|---|
| | α | β | α | β | α | β | α | β |
| 1 | 284,7 | 737,4 | 286,6 | 755,0 | 286,5 | 742,3 | 286,8 | 752,0 |
| 2 | 270,6 | 682,9 | 269,1 | 685,2 | 270,8 | 685,3 | 267,8 | 683,7 |
| 3 | 294,1 | 778,4 | 291,9 | 782,7 | 292,1 | 779,7 | 294,4 | 787,8 |
| 4 | 296,3 | 738,5 | 289,8 | 731,9 | 292,0 | 729,4 | 291,5 | 732,1 |
| 5 | 302,9 | 775,0 | 299,7 | 768,0 | 300,6 | 767,7 | 300,7 | 763,2 |
| 6 | 297,7 | 736,0 | 303,5 | 741,2 | 301,3 | 742,1 | 303,5 | 743,1 |
| 7 | 283,1 | 761,4 | 284,8 | 786,9 | 284,6 | 811,2 | 284,1 | 811,5 |
| 8 | 280,3 | 725,1 | 281,2 | 726,8 | 280,9 | 730,2 | 282,1 | 727,7 |
| 9 | 286,0 | 731,7 | 287,0 | 734,4 | 285,7 | 733,2 | 290,9 | 740,0 |
| 10 | 285,4 | 771,6 | 295,1 | 762,1 | 298,6 | 757,2 | 289,6 | 767,6 |
| 11 | 303,9 | 750,1 | 302,4 | 758,0 | 301,7 | 758,5 | 301,3 | 761,1 |
| 12 | 286,6 | 749,0 | 284,4 | 737,6 | 288,1 | 741,5 | 291,1 | 734,3 |
| 13 | 294,5 | 802,9 | 292,8 | 823,0 | 300,1 | 869,4 | 296,2 | 862,6 |
| 14 | 276,8 | 724,2 | 275,4 | 724,8 | 279,1 | 740,4 | 282,5 | 734,4 |
| 15 | 292,0 | 725,4 | 291,7 | 724,1 | 287,6 | 723,0 | 291,2 | 724,9 |
| 16 | 300,6 | 744,1 | 297,8 | 733,8 | 298,6 | 728,4 | 300,3 | 739,3 |
| 17 | 301,4 | 748,7 | 299,9 | 754,7 | 300,7 | 751,8 | 304,4 | 755,3 |
| 18 | 272,4 | 709,4 | 274,2 | 698,9 | 274,0 | 699,7 | 274,6 | 704,0 |
| 19 | 284,6 | 724,4 | 285,2 | 726,6 | 287,8 | 741,0 | 287,8 | 727,4 |
| 20 | 301,4 | 803,8 | 303,3 | 803,4 | 303,1 | 803,3 | 302,3 | 821,5 |

# 5 DATA ANALYSIS

This section describes the control measurement which was performed to verify the effect of the order in which the music compositions were played and selection of results of applying statistical methods to the collected data.

## 5.1 Control Experiment

In the experiment, a control measurement was performed to verify that the order in which the musical compositions were played had/had not an impact on the measured values. One of the subjects was asked to undergo the experiment again; the order of the musical compositions was changed. In the beta band, an increase in energy level values was observed during the first three sessions and a subsequent decrease of energy level values was visible during the fourth and fifth sessions. In the rest of the experiment, there was no such a trend visible. No dependence on the order of sessions was observed in the alpha band and within the heart rate values.

## 5.2 Statistical Results

Finally the collected and preprocessed data were statistically evaluated. The Repeated Measures ANOVA was used for the evaluation of the heart rate and game performance in eight different conditions (eight sessions of playing the memory game) and the classic t-test was applied to the data to answer the interesting question given later in this paper.

Two following $H_0$ hypotheses were set for the evaluation of heart rate and memory game performance in the eight session of the experiment:

- The mean values of heart rate are the same under all conditions (i.e. without statistically significant differences)
- The mean values of the number of cards played are the same under all conditions (i.e. without statistically significant differences).

The results for both hypotheses (at the significance level $\alpha = 0.05$) showed that there was no statistically significant difference between the mean values of heart rate as well as there was no statistically significant difference between cards played under specified conditions.

For the next analysis of the data two variants of the classic t-test were used. The following research questions created the base for the subsequent determination of the hypotheses:

- What was the impact of the subjects' sex on the collected data?
- What was the impact of the game difficulty on the

Table 4: The overall accuracy of playing the memory game in individual sessions of the experiment.

| Subject | Memory Game Accuracy (%) in sessions | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | 37,0 | 44,0 | 34,0 | 36,0 | 44,0 | 34,0 | 36,0 | 39,5 |
| 2 | 56,5 | 49,0 | 47,0 | 39,0 | 42,0 | 36,0 | 65,0 | 38,0 |
| 3 | 53,0 | 54,0 | 52,0 | 57,0 | 54,0 | 59,5 | 47,0 | 68,0 |
| 4 | 59,0 | 59,0 | 56,0 | 66,0 | 69,0 | 46,0 | 60,0 | 55,0 |
| 5 | 40,0 | 37,0 | 52,0 | 49,5 | 52,0 | 35,0 | 37,0 | 55,0 |
| 6 | 59,0 | 72,5 | 72,0 | 68,5 | 64,5 | 72,0 | 69,0 | 53,0 |
| 7 | 65,0 | 65,0 | 68,0 | 61,5 | 63,0 | 59,0 | 57,5 | 57,5 |
| 8 | 58,0 | 36,0 | 49,0 | 49,5 | 50,0 | 61,0 | 60,5 | 59,5 |
| 9 | 67,0 | 68,5 | 72,5 | 60,5 | 72,5 | 72,5 | 72,5 | 62,5 |
| 10 | 54,0 | 45,0 | 52,0 | 40,0 | - | 50,0 | 50,0 | 52,0 |
| 11 | 77,5 | 66,0 | 68,0 | 70,5 | 74,0 | 79,0 | 81,5 | 68,0 |
| 12 | 68,0 | 56,0 | 73,0 | 71,0 | 61,0 | 59,0 | 72,0 | 71,0 |
| 13 | 44,0 | 44,5 | 31,0 | 48,0 | 35,0 | 33,0 | 33,0 | 58,0 |
| 14 | 63,0 | 72,5 | 53,0 | 60,5 | 43,0 | 44,0 | 78,0 | 65,5 |
| 15 | 61,0 | 50,0 | 58,0 | 45,0 | 64,0 | 45,0 | 61,0 | 56,0 |
| 16 | 62,5 | 54,0 | 54,5 | 64,0 | 61,5 | 51,0 | 59,0 | 68,0 |
| 17 | 44,0 | 59,0 | 40,0 | 38,0 | 50,0 | 47,5 | 42,0 | 47,0 |
| 18 | 56,5 | 48,0 | 41,0 | 44,5 | 53,0 | 29,0 | 42,0 | 26,0 |
| 19 | 63,5 | 52,5 | 55,0 | 45,5 | 52,0 | 37,0 | 45,0 | 44,0 |
| 20 | 41,0 | 50,5 | 38,0 | 36,5 | 49,0 | 50,0 | 37,0 | 46,0 |

collected data?

- What was the impact of the music played to the subjects and music preferences of the subjects on the collected data?
- What was the impact of music on the accuracy of subjects during playing the memory game?
- What was the impact of the subjects' interest in the memory game on the collected data?
- What was the impact of listening to music on the collected data?

Because the number of statistical results calculated over this data was very large, we focused only on some of them in this paper.

The effect of subjects' sex on the collected data was evaluated for the spectral values in the alpha and beta frequency bands as well as for the heart rate values. While the differences in heart rate values were not statistically significant for men and women, there was a statistically significant difference between the values in the beta frequency band on the Pz electrode ($t = 2,4925$; $p = 0,0227$) for men and women. It could indicate that women concentrated more on their game performance throughout the experiment.

No significant changes in the alpha and beta bands were observed when the difficulty of the game changed. While the subjects were playing the memory game in a quiet environment, with slow and preferred music, a slight drop in heart rate values was recorded (compared to a game with lower difficulty) for the game with a higher difficulty setting. This finding suggests that there might be a relationship between higher difficulty of the game and slowing of the heart rate. It was not confirmed that changing the difficulty of the memory game would bring different values of heart rate and in alpha and beta frequency bands for men and women.

The values in alpha and beta frequency bands differed minimally when it came to the effect of the type of music being played, only the values of heart rate were seen to slightly increase when playing fast music. For subjects who preferred fast music, the values observed in the beta band were significantly lower in all parts of the measurement than in the group which preferred slow music. Despite these differences, individual values were not found to be statistically significant within each part of the experiment.

Whether the subject perceived the type of music positively, neutrally or negatively did not affect his/her achieved accuracy in the memory game as it was expected.

Another question examined whether the alpha, beta, and heart rate values differ between the group of subjects who stated in the questionnaire that the game was boring at the end of the experiment and the group of the subjects who enjoyed the memory game. The collected data were compared for these two groups of subjects and for each session of the experiment.

In all eight sessions of the experiment, the alpha activity was significantly higher in the group of people who were bored at the end of the memory game. In contrast, the beta activity was significantly lower in this group. The heart rate values were higher in all sessions of the experiment for the group that enjoyed the memory game. These results could indicate that the subjects who enjoyed the memory game more were also more focused and excited throughout the experiment. Despite these significant differences, individual values were not found to be statistically significant within each session of the experiment.

It was observed that the subjects' experience of listening to music at work did not significantly affect brain activity or heart rate during the experiment.

## 6 CONCLUSIONS

The work investigated the impact of listening to different types of music on the activity of the human brain during mental stress (while the subjects were playing the memory game). Changes in the values of heart rate and brain activity in the alpha and beta bands were measured and analyzed, and the relationship of these changes to the music played and to the data obtained from questionnaires were examined. During the analysis the impact of music on the number of game cards exposed and the overall accuracy during playing the memory game was also evaluated.

Performing the control experiments, the dependence of the music on the order in which it was played was not confirmed.

The differences in heart rate values and the number of cards successfully played in the memory game were not found to be statistically significant in the individual sessions of the experiment. Even when we statistically evaluated other hypotheses, most of the results were statistically insignificant.

Since most of the results were found to be statistically not significant, the question of the construction of the experimental scenario itself arises. Given the results of the analysis of groups with different preferences in the selection of fast and slow music and groups with different levels of engagement, it might be beneficial to examine these differences in more detail in a separate experiment and to perform measurements on more subjects.

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