Analyzing Fear Using a Single-Sensor EEG Device

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Abstract. Single-sensor EEG hardware provides possibilities for researchers to measure fear in human beings. Previous research show that consumer-grade EEG devices can be used to measure different states of mind. However, as is often the case with similar research, post-hoc questionnaires are used to measure the emotional state. This paper will focus on the physiological and psychological state of an individual in fear, comparing continuous subjective feedback with EEG measurements. Data has been collected using a Myndplay Brainband and a rotary meter, while 30 subjects viewed soothing and scary films. The rotary meter proved useful for obtaining continuous feedback and, although more research is needed, differences in brainwaves for fearful and calm states are found for multiple frequency bands.

Keywords: Fear analysis · EEG · Psychological response · Physiological response

1 Introduction

Emotions like fear are difficult to measure. On the psychological level, subjective ratings can be biased and difficult to compare. On the physiological level, multiple techniques can be used to measure the level of fear, like fMRI's, skin conductance or heart rate monitors. If you measure the physiological effects, it is still very hard to know if these effects are caused by fear, or by another factor. For example, sweating can be caused by experiencing fear, but on a hot summer day it is difficult to say if the sweating is caused by fear or by the heat. More often electroencephalography (EEG) is used to measure physiological changes of a human being. An EEG device measures the brainwaves of an individual.

In several studies, the physiological level of fear is measured using skin conductance and heart rate [1–3]. These studies show that skin conductance is a good method to measure the physiological effects of fear. Though, skin conductance is also a multifaceted phenomenon. It shows elevation in sweating in fear, but also in other emotions [4]. This makes it hard to recognize if the sweating is caused by fear or another emotion. Using an EEG headset, the researcher has a better indication of the emotion of an individual. However, professional EEG devices with over a hundred sensors are difficult to use and very expensive. These days, single-sensor EEG devices are

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becoming more readily available. These consumer-grade headsets only have a few sensors and are mostly used for gaming purposes [5].

Because these headsets have fewer sensors, it could be that data retrieved from these headsets are not as reliable or accurate as professional EEG devices. To use these single-sensor headsets in research, it is necessary to know if it is possible to measure emotions like fear with these headsets. If this would be possible, applications would be able to use these single-sensor headsets as an input device, resulting in a more user-friendly setup and possibly even more accurate results. This in turn could be beneficial for any such application, ranging from entertainment to serious gaming and training.

This research project will focus on the question if such psychological and physiological levels of fear are related to each other. In other words, do measurements from single-sensor EEG devices correspond with physiological measurements and subjective ratings with regard to fear. This will be done by first researching if single-sensor EEG devices, in this case the MyndPlay Brainband, can be used to measure fear responses of an individual. Second, using continuous subjective ratings of fear, the EEG measurements are explored to find indicators for different aspects of fear.

2 Background

The limbic system is a set of brain structures that lies directly under the cerebrum. The limbic system is considered to play a major role in emotion processing. Using functional magnetic resonance imaging (fMRI) researchers demonstrate that the amygdala (a part of the limbic system) shows a higher activity in response of fear stimuli [6]. Because the limbic system is a structure deep in the brain, the use of fMRI was the most common non-invasive technique to measure these fear responses.

It was long thought that emotions like fear were only processed in the limbic system. However, more recent research suggests that not only the limbic system is responsible for emotion processing and that there is some kind of emotion circuit in the brain that processes emotions [7]. This would mean that brainwaves are produced while processing emotions. Brainwaves are synchronized electrical pulses from neurons communicating with each other. Brainwaves can be detected by the use of an electroencephalography (EEG) recorder. EEG is a non-invasive measurement of electronic activity on the scalp. Studies used an EEG recorder to find more brain areas involved in emotion processing and one of these studies show that the right frontal region of the brain is activated for negative emotions such as fear [8]. In other research not only different brain regions activated during emotions like fear was looked at, they also investigated a certain ratio called the slow wave/fast wave ratio [9]. Putman et al. found that the slow wave/fast wave ratio (SW/FW) is increased in hyperactivity disorder and that this SW/FW correlates negatively with fearful modulation.

Nowadays, EEG devices are not only available for professionals and more and more consumer-grade devices using dry electrodes become available. This makes the EEG device cheap as well as easy to use for non-professionals. There is however the question to what extent these devices can be used for research and other purposes, including questions such as are the measurements accurate enough or can they be used reliably.

Studies show promising results about the use of these single-sensor EEG headsets for research to detect different mental states [10, 11]. In this paper a further analysis is made of measuring emotions with a single-sensor EEG device.

3 Method

The research conducted for this paper is explained in detail below. First, more information on the participants and measurements taken are given. Thereafter, the procedure for the experiment is explained as is the analysis that will be performed on the data gathered.

Participants. The sample consisted of 30 students and employees from the VU University Amsterdam. From these participants, 70% were male (N = 21) and 30% were female (N = 9). The youngest participant was 18 years old and the oldest participant was 38 years old (M = 22.20, SD = 3.69).

Measures. To measure the psychological level of fear of the subjects, the subject will make use of a rotary potentiometer. The rotary potentiometer will be connected to a Phidget board and gives continuous values from zero to 1000. Every second an average of all the values will be recorded, which will be scaled to a value between 0 and 10, rounded down and averaged over all participants to end up with a single rotary meter value for each second. Besides the rotary meter values, there is a seven-item questionnaire about the feelings of the subject. Individuals answer the items on a five point Likert scale. EEG signals are used to measure the physiological effects. It measures the brain waves of a human, expressed in Hertz. The MyndPlay Brainband, used in this study, is a single sensor EEG headset providing data at a sampling rate of 512 Hz. It can recognize eight different types of EEG frequency bands (brainwaves): delta (0.5–2.75 Hz), theta (3.5–6.75 Hz), low-alpha (7.5–9.25 Hz), high-alpha (10–11.75 Hz), low-beta (13–16.75 Hz), high-beta (18–29.75 Hz), low-gamma (31–39.75 Hz), and mid-gamma (41–49.75 Hz).

Procedure. All the participants from the sample are asked to watch a set of videos used in previous research [11, 12]. Before the subjects watch the video, they will practice using the rotary meter. In this research, four videos will be presented to the subjects. The first video is a relaxing video of a beach, the second video is a documentary, the third video is a stressful video with scary clips, and the last video is again the video of a beach. The EEG is measured during this whole trial. During the trial, the subject is asked to turn the rotary meter if he or she feels more scared in order to measure the subjective thoughts of the individual. After this, the participant is asked to fill in a few questions about how they felt during the trial. All the questionnaires and measurements are anonymous.

Data Analysis. The data analysis of this research consists of three parts. The MyndPlay BrainBand provides EEG measurement per second with brainwaves ranging from delta to mid-gamma, as well as eSense^{TM} values for attention and meditation. The eSense^{TM} values will not be used in this study. The brainwaves are categorized in delta, theta, low-alpha, high-alpha, low-beta, high-beta, low-gamma or mid-gamma waves.

Firstly, the average values of the rotary meter will be used as an approximation of an overall subjective rating of fear for that video. This will be done to see if the rotary values are more or less comparable to subjective ratings given in post-hoc questionnaires and results found in previous research.

To determine if there is a difference between the brainwaves in calm and fearful state, a paired t-test will be used. This will be done by comparing peaks of the calm state and fearful state. In this research, the fearful state is measured during the stressful video. The calm state is measured during the documentary and is used as a baseline. Peaks will be determined individually by finding values more than four standard deviations away from the mean value of the individual during the calm state. This will be referred to as the peak-value. Consecutively, all the peaks are summed up per person per brainwave.

Next, the brainwaves of the calm and fearful state will be compared. To compare these states, the brainwaves will be processed to get a peak-value ratio. This will be done by dividing the amplitude of the brainwave by the peak-value of the individual. This peak-value ratio will signify a possible discrepancy between a brainwave value and the peak-value. If this ratio is higher than one, it will mean that there is a peak at that moment. This peak-value ratio is calculated in order to dismiss noise of the different individuals. The peak-value ratio will be compared to the video content. This will be a subjective analysis.

Visualizations will be made in order to show the relation between the psychological and physiological levels of the individuals. This is done by making graphs displaying the relation between the rotary meter values and the peak-value ratio of the EEG in fearful state. These graphs will be analyzed manually to find which frequencies of brainwaves correspond with subjective ratings of fear.

4 Results

Below various results of the experiment are presented. At first, the subjective ratings alone are considered, after which these ratings are compared with the measurements taken with the single-sensor EEG device. Here, first the calm and fearful state are compared using various frequencies, after which those frequencies are compared with the continuous subjective ratings of fear gathered with the rotary meter.

4.1 Subjective Feelings

The first aim of this research was to see if the rotary meter is a reliable way to measure the subjective feelings of an individual. Figure 1 shows the average rotary meter values during the different videos. As can be seen, during the scary video the test group was most frightened. However, in the beach videos some people felt a little frightened as well. This pattern corresponds with subjective ratings found in similar experiments using the same videos [11, 12] and is supported by the answers of this questionnaire as well. Here, participants indicated that they did not feel completely calm during the first video of the beach and were even less calm during the second video of the beach.

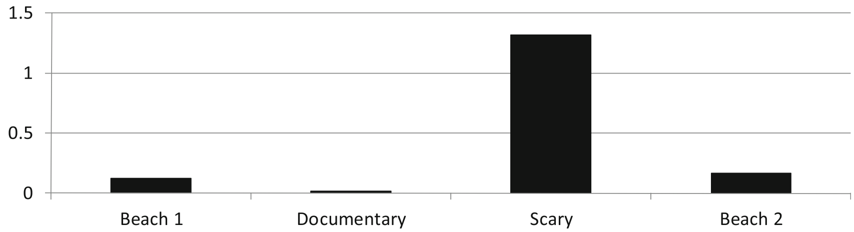

Fig. 1. Average rotary meter values for the different videos.

Moreover, participants did feel frightened during the third video and experienced various startle moments, but did continue to watch the video without closing their eyes.

4.2 Brainwaves in Calm and Fearful State

The first aim of this research was to test if there is a difference between the amount of brainwave peaks in a calm state and a fearful state. To test this, a paired t-test was conducted, comparing the amount of peaks in calm state and fearful state. This was done per brainwave. The paired t-test results show that there is a significant difference between the peak levels in calm state and fearful state for the delta ($p = 0.003$), theta ($p = 0.005$), low-alpha ($p = 0.048$), high-beta ($p = 0.030$), low-gamma ($p = 0.049$) and mid-gamma brainwaves ($p = 0.011$).

Figures 2, 3 and 4 show the peak-value ratio of the brainwaves during the documentary and the scary film of the delta, low-beta and low-gamma bands. The x-axis represents the time and the y-axis represents the average value of all the trials of the peak-value ratio. In these graphs, the grey line corresponds with the brainwave in the fearful state. The black line represents the brainwave in the documentary. The documentary was 180 s long and the scary film was 310 s long.

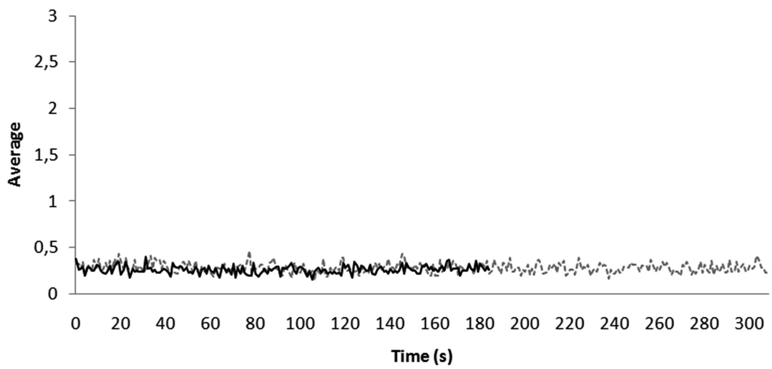

Fig. 2. Delta brainwaves from documentary (black) compared to scary film (grey).

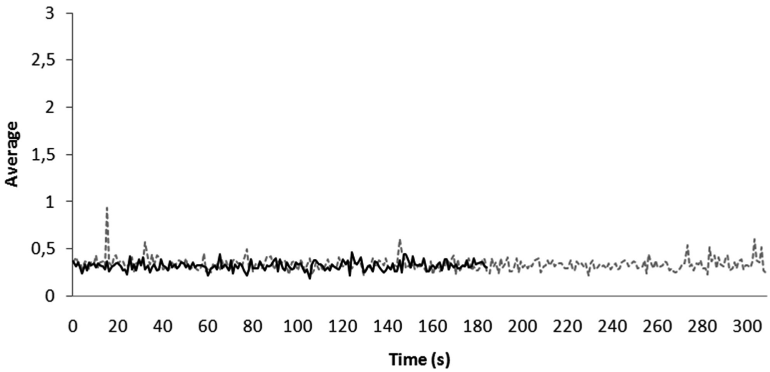

Fig. 3. High-beta brainwaves from documentary (black) compared to scary film (grey).

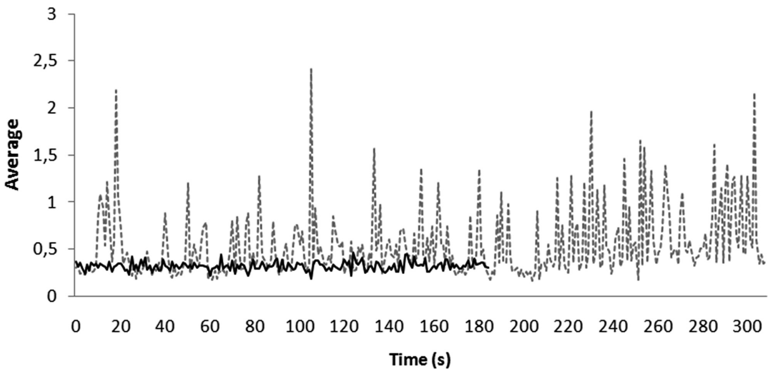

Fig. 4. Low-gamma brainwaves from documentary (black) compared to scary film (grey).

In this study there will be focused on two kinds of fearful states. First, there are the startle moments. In the video used, two of such moments occur at 14 and 30 s into the video. Secondly, there are the moments where the tension is rising for the viewer. These are the moments where the viewer thinks something is going to happen, but nothing did so far. In the video used, two of those scenes were shown from 15 to 30 and 177 to 227 s into the film.

As can be seen in Fig. 2, the delta brainwave does not specifically react to one of these fearful moments. The two lines overlap with each other. This means that the peak-value ratio in the documentary and the scary film are very alike. The delta band does not react on the fearful moments.

As can be seen in Fig. 3, the high-beta brainwaves react on the startle moments, but not to the moments of tension. The dashed grey line from the scary film is higher than the black line of the documentary during the startle moments, but not during the moments of tension. This means that the peak-value ratio of the low-beta band is higher in the scary film during these startle moments than the peak-value ratio during the documentary. The high-beta band reacts only on the startle moments.

As can be seen in Fig. 4, the low-gamma brainwaves react on the startle moments as well as some of the moments of tension. The grey line from the scary film is higher than the black line of the documentary during the startle moments. During the moments of tension, the low-gamma brainwave has more activity during most of this moment. It is seen that from seconds 15 to 20 and 182 to 190 into the film, the low-gamma has a higher peak-value ratio in fearful state. This is during the beginning of these tension moments. The low-gamma band reacts on the startle and tension moments.

Overall, the high-alpha, low-beta and low-gamma brainwaves differ most from each other in the calm and fearful state. These frequency bands react the most in fearful situations. The low-alpha, low-beta, high-beta and low-gamma brainwaves react on the startle moments. The high-alpha, low-beta and low-gamma react on some of the moments of tension. However, this is only a preliminary finding and more (targeted) experiments are required to identify exact causes for each activity in the various frequencies.

4.3 Rotary Meter Values and EEG Peak Levels

The second part of this research was to test if there is a relation between the psychological level, the rotary meter data, and the physiological level, the EEG levels, in fearful state. Figures 5 and 6 show the rotary meter values and the peak-value ratio of the brainwaves of the scary film over time. The dashed grey line represents the rotary meter values, while the black line represents the brainwave values over time.

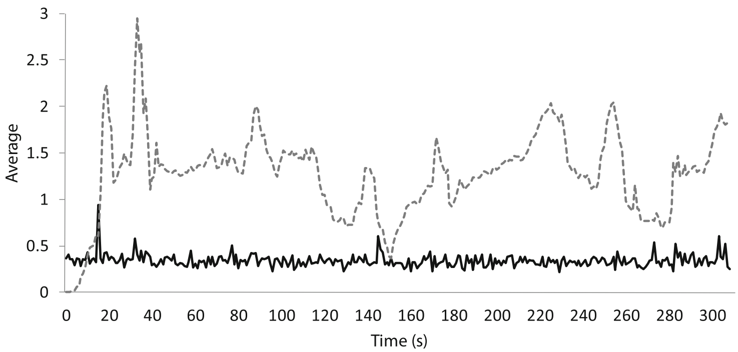

Fig. 5. High-beta brainwaves (solid black) compared to rotary meter values (dashed grey).

Figure 5 represents the high-beta band compared to the rotary meter values. In the previous subsection, it is shown that the high-beta band reacts on startle moments on seconds 14 and 30. It is expected that the rotary meter values will be higher on these moments as well. Looking at the rotary meter values, there are two peaks right after the peaks of the high-beta band, on seconds 20 and 35 into the video. These peaks of the rotary meter show that the subjects were more scared on the startle moments. The rotary meter values do show a delay.

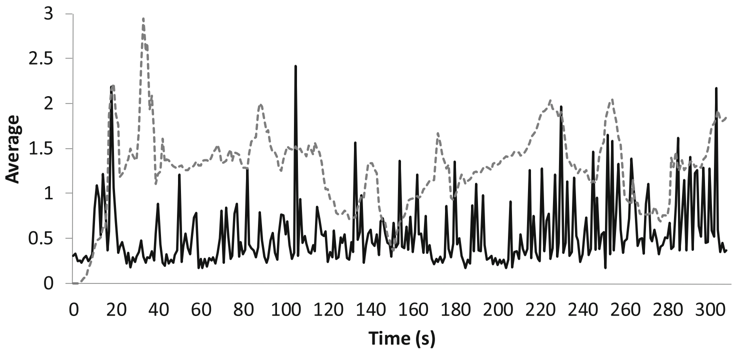

Fig. 6. Low-gamma brainwaves (solid black) compared to rotary meter values (dashed grey).

Figure 6 represents the low-gamma band compared to the rotary meter values. In the previous subsection, it is shown that the low-gamma band reacts on the beginning of tension moments. It is expected that the rotary meter values will get higher over the time on these tension moments. Looking at the rotary meter values, these get progressively higher from seconds 22 and 180 into the film. These progressively higher values of the rotary meter show that the subjects gradually got more frightened. The rotary meter values again show a delay with the tension moments of the videos.

5 Discussion

Different results are reported in the previous section. In this section, the results of the major findings will be discussed. First, the significance found in the peaks of the documentary compared to the scary film will be discussed. Secondly, the results of the peak-value ratios in the different films are of interest. Thirdly, the rotary meter values compared with the questionnaire will be discussed. Lastly, the rotary meter values compared with the brainwaves are of interest.c

5.1 Peaks in Calm and Fearful State

There is a significant difference found in most of the brainwaves of the subjects in calm and fearful state. These findings do not correspond to previous research [11]. This can be explained by the different method used to define peaks in the brainwaves. The method used in this research is based on the method used in the research of De Man, with the main difference being that they used the standard deviation of an individual while watching the first beach video. In this research, the standard deviation of an individual watching the documentary is used. The standard deviation of the documentary is used, because many subjects indicated they were stressed during the first beach video. They expected something scary to happen. In the documentary they were calmer. The documentary therefore is a better baseline. This could be an explanation for the different findings. The fact that significant differences were found, suggests that a low level EEG device like the MyndPlay Brainband can indeed be used to measure an emotion such as fear.

5.2 Brainwaves in Calm and Fearful State

The results of the peak-value ratios in the different films are very promising. Though research about EEG brainwaves in different settings is still very recent, these results show that different brainwaves react on different aspects of fear. The higher frequency bands, like the beta and gamma, seem to have more activity during the fearful film. This corresponds with the hypothesis that higher frequency bands are more active during moments of concentration [13]. If the low-alpha, low-beta, high-beta and low-gamma waves have a higher amplitude, it might suggest that the person has a startle moment. There are however numerous reactions visible in the peak-value ratios which are more difficult to relate to the video content in this manner. As such, it is important to continue this line of research and devise more focused experiments to figure out the exact nature of these reactions.

5.3 Subjective Feelings

Looking at the values of the questionnaire and the rotary meter, it can be seen that the rotary meter gives a good representation of the subjective feelings of the individuals. The rotary meter values reflect the answers in the questionnaire and are in line with results found in previous research. The subjects indicated that they did not feel calmer during the second beach video than during the first beach video. The rotary meter values show a slightly higher average in the second beach video. This can suggest that the rotary meter is a good indicator of the subjective feelings of an individual over time and could result in more fine grained results than Likert scales tend to provide. Using a rotary meter to show the subjective feelings instead of a questionnaire afterwards, can thus be very useful in research. This way, subjects are not distracted by other factors of the test that can change their feelings afterwards. The rotary meter is not difficult to use for either the researcher or the participant. It is necessary to show the participant how the rotary meter works beforehand, otherwise the subject seems to forget to use the rotary meter.

5.4 Rotary Meter Values and EEG Peak Levels

The results show that the rotary meter values have some correlation with the brainwaves. Though it is hard to test this correlation, as different brainwaves seem to react to different aspects of fear. To test the correlation between the brainwaves and the subjective feelings, there has to be a research testing for only one aspect of fear. For example, there could be a study where subjects watch a video with only startle moments. Then it can be statistically tested which brainwave reacts to these startle moments and a correlation test can be conducted. It can be seen in the graphs that there seems to be a delay between the brainwaves and the rotary meter data. This is likely caused by the reaction time of the participant. When testing for correlation between the physiological and psychological effects of fear, the reaction time of the individual has to be taken into account.

6 Conclusion

Using a single-sensor EEG device and a rotary meter, psychological and physiological reactions towards fearful stimuli were analyzed. On various levels, promising results were found. For one, a difference was found in the amount of peaks and in the peak-value ratio between the brainwaves in calm and fearful state. Moreover, it appears that different brainwave frequency bands react to different aspects of fear, like startle moments. On the other hand, using a rotary meter to retrieve continuous subjective ratings of fear worked very well. Although subjects needed to practice using the rotary meter beforehand, using the device did not interfere with the experiment and viewing.

Nevertheless, more research has to be done to determine exactly which brainwaves react to which aspect of fear as well as the response to other types of emotion or activity. Especially experiments focusing on very specific triggers should be considered to underpin the exact causes of the various reactions found in the EEG measurements. It is however clear that even with these low-cost consumer-grade EEG headsets, various emotional responses can be detected.

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