Analyzing emotional video using consumer EEG hardware

Low-cost, easy to use EEG hardware produced for the consumer-market provide interesting possibilities for human-computer interaction in a wide variety of applications. Recent years have produced numerous papers discussing the use of these types of devices in various ways, but only some of this work looks into what these devices can actually measure. In this paper, data is used that has been collected using a Myndplay Brainband, while 30 participants viewed emotional videos eliciting different mental states. This data is analyzed by looking at average power in multiple frequency bands and eSense^{TM} values, as well as peaks in the measurements detected throughout the videos. Although average values do not differentiate well between the mental states, peak detection provides some promising results worthy of future research.

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3.1 Introduction

Electroencephalogram (EEG) is a measurement of electronic activity on the scalp. Recent developments made hardware measuring EEG signals available at low prices. Although most of these devices contain fewer sensors than professional EEG devices, data quality is comparable (NeuroSky, 2009a). More important though, these devices are very easy to use and can therefore be used in a variety of settings. Not surprisingly, more and more devices are appearing aiming at a particular consumer audience. Neurosky was one of the first companies developing a dry sensor EEG device 'to power the user-interface of games, education and research applications'.[1] Besides common EEG measurements, this device also outputs eSense™ values representing levels of attention and meditation (NeuroSky, 2009b). Based on the same chipset, Myndplay developed the Brainband, 'the world's first mind controlled media player'.[2] InteraXon is far along developing the Muse, an EEG device using six dry sensors to 'manage stress and settle your mind'.[3] This is not an exhaustive list and more examples can easily be found.

Just as Neurosky mentions research applications, many of these devices with access to the measurement data are appearing in scientific research. In the research project STRESS, a simulation-based training is envisioned to train professionals in high risk jobs to handle stressful incidents and improve their decision making in these situations. A software agent is being developed to analyze the trainee's mental state and provide support by either giving textual feedback or adapting the training scenario whilst running. However, such applications should not be limited to professional use and by using cheap and easy to use devices, in combination with the development of generic techniques, creating a virtual training to cope with everyday stress is envisioned as a feasible next step.

At this point in time, the virtual environment to be used for this research project is in its final stages of development. Therefore, the current work uses video to investigate whether such commercial EEG devices, in this case the Myndplay, can be used in such a training context to detect relevant mental states. The next section provides some background information on scientific research using these types of consumer EEG devices in various methods and applications. Afterwards, the process of data collection is described as well as the method for data analysis. The last two sections cover results and a discussion thereof.

[1] http://neurosky.com/products-markets/eeg-biosensors (accessed 4-2-2014).
[2] http://www.myndplay.com (accessed 4-2-2014).
[3] http://www.interaxon.ca/muse (accessed 4-2-2014).

3.2 Background

An extensive amount of research has been done using professional EEG hardware in a wide variety of contexts and applications. However, with the development of cheap, easy to use EEG hardware, using EEG as a human-computer interface for many types of applications has become plausible. Recent years have brought an increasing number of research papers, using these low-cost consumer EEG devices in a variety of applications. A selection of this work will be described below.

There are however differences between professional and consumer EEG hardware that need to be pointed out before continuing. First and foremost, the number of sensor is very limited on these low-cost devices with often just a single sensor, as is the case in this work as well. Therefore, measurements are made in only one location, which roughly corresponds to the FP1 position. Furthermore, while most professional devices require some sort of conductive gel or paste to be used, so-called dry sensors are used which eliminate this need without reducing data quality (NeuroSky, 2009a).

Consumer EEG devices are used in various scientific applications. Among them are applications using the outputted data in a way that is unrelated to the conceptual meaning of the measurement. For example, Vourvopoulos & Liarokapis (2011) uses the eSense™ attention value to drive forward a robot. In Diefenbach et al. (2004) a game is developed using a similar premise, where both the attention and mediation values are used to manipulate objects in the game. As a last example here, Yoh et al. (2010) also uses both these eSense™ values in an interactive story where the values are used to reach certain goals depending on the current chapter.

However, from a user-perspective it might be more natural when the action (increasing attention or meditation) matches the action required in the game (Nacke et al., 2011). For example, in Lee (2009) an archery game is used where the player needs to be focused and relaxed in order to make a good shot. Here, there is a more natural connection between the type of action required to make and the effect it has on the game. However, making such clear mappings from brain activity to particular actions is rather difficult. Other work is using measurements such as attention and meditation more indirectly. In Cho et al. (2013), attention is used to manipulate weather conditions during gameplay. A more sophisticated proposal has been made in Rebolledo-Mendez & De Freitas (2008), where attention levels result in particular in-game events aimed at increasing the attention of the player. Another option is to use biofeedback, where the measurements are simply displayed to the user. Training mindfulness is an area where such a technique is used and consumer EEG hardware makes it way in providing these measurements (Stinson & Arthur, 2013; Kido, 2012).

Another set of research papers focuses on discovering the potential of these devices through experimentation. In Crowley et al. (2010), a puzzle game is used to evaluate the eSense™ meditation values. They found that in trials where participants showed stressed behavior, meditation values often dropped below a certain threshold. However, during a routine stress-free task, these measurements never dropped below 40. In another study, a consumer EEG device is used to investigate the possibility of measuring interest during a first-person shooter game (Chan et al., 2010). Here, they found that attention levels of individual players spiked simultaneously during gameplay moments common to each player such as killing an enemy.

In this paper, we will add to this last set of research. Using emotional video, it is investigated whether consumer grade EEG devices can be used to detect various mental states. This work is in line with research such as Funk et al. (2012), where a more advanced EEG device is used to mark highlights in a video. Furthermore, most related work only focuses on the eSense™ values provided by the Neurosky chipset, but here all frequency bands will be considered as well. Various methods of analysis used in studies described above will be applied, such as looking at average values, lowered and heightened attention and meditation values as well as common peaks across participants in any of the measurements.

3.3 Method

For this research, the focus is on stressful stimuli, more specifically stressful movies. In the next section, the experimental setup used for data collection is explained. The second section covers the various approaches used for data analysis.

3.3.1 Data collection

Data collection was performed simultaneous with an experiment investigating the possibility of inducing anxiety using stressful video material (Section 2.3, p.34). Here, a group of 30 participants was shown five fragments of video in sequence. Between each video, the participants were asked about the emotion experienced (‘relaxed’, ‘bored’, ‘interested’, ‘excited’, ‘scared’) and its intensity on a scale from 0 (not at all) to 5 (very much). Of the participants, 17 were male and 13 female with an age between 20 and 64 years old (mean age of 33). EEG signals were recorded using the Myndplay Brainband, which is based on the Neurosky chipset. Furthermore, heart rate and skin conductance was measured using the PLUX wireless biosensors,[4] but are not used in this paper.

[4] http://www.biosignalsplux.com (accessed 4-2-2014).

Figure 2.1 (p.35) shows the sequence of videos viewed by the participants. On the same page in Section 2.3.2 it is shown that each type of video (beach/-documentary/stressful) induces different emotions; relaxed/boring, interesting and exciting/scary respectively. Furthermore, skin conductance shows a clear elevation during the stressful movie, which slowly decays in the subsequent clips. Based on this information, EEG measurements obtained during this experiment are expected to reflect those under different emotional states, thereby providing a relevant dataset for investigating the potential for consumer EEG devices to distinguish such different mental states.

3.3.2 Analysis

The hardware used provides raw EEG measurements, per second activity in frequency bands ranging from delta waves (1-3Hz) up to mid-gamma (41-50Hz) as well as eSense™ values for attention and meditation (NeuroSky, 2009b). For the current research, the frequency band values from the device itself were used which already have undergone noise-filtering and therefore raw EEG signals have not been used. Although little is known about the basis of the eSense™ values, they are used in related research and are thus also incorporated in this work.

Data analysis will be performed with a focus on two different aspects. First, average values of each variable (frequency bands and eSense™) for each movie will be calculated. These averages will be statistically compared to find any potential markers for particular mental states corresponding to the videos.

A different approach will also be taken, that is by calculating an average and standard deviation for each of the different frequency bands. Using these values, peaks in subsequent movies were identified by finding peaks more than four standard deviations away from the mean value. For the eSense™ values, a slightly different approach is used. These values range between 0 - 100 and are slightly lowered or elevated when the value decreases below 40 or increases above 60 according the documentation. As the current research focuses on negative stimuli, increased values for attention and decreased values for meditation are of our interest. Therefore, values above 60 in both the attention and the inverted meditation value will be considered as peaks and used as such in analyzing the results.

3.4 Results

The results of this research are discussed in two separate sections as described above. First, the average values over each video clip are compared. Afterwards, a more in-depth analysis of peaks in each signal is performed.

3.4.1 Mean activity

Figure 3.1 shows a collection of bar charts, including standard deviations, for each measurement that is provided by the Brainband. Starting from the top left, the first two graphs represent the average eSense^{TM} values. The remaining eight graphs show values for the different frequency bands that are outputted by the device itself. On visual inspection, it is clear that there is a large variation between the subjects, as could be expected. At this point, no individual tuning or normalization has been performed. Looking at the average values, both for the eSense^{TM} and frequency bands, no clear effect of the different movies can be distinguished, although some graphs show signs of possible effects.

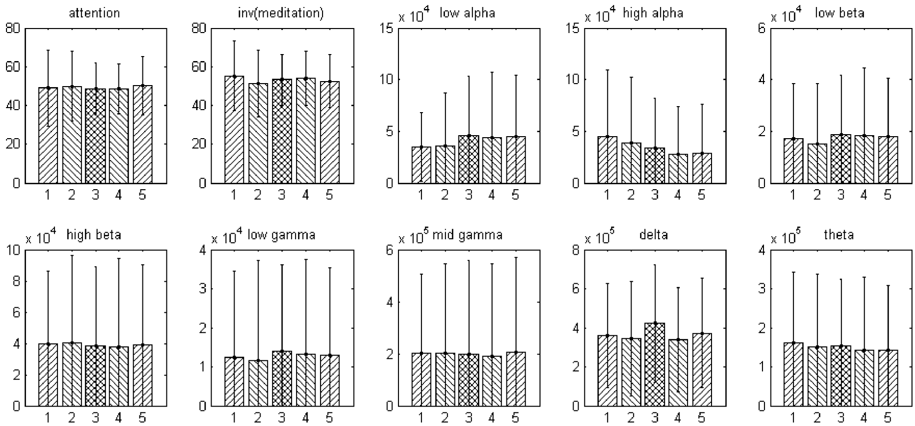

Figure 3.1: Average power (and standard deviation) of each variable per video

To check the results, a repeated measures ANOVA is performed for each outputted variable. With this measurement, it is calculated whether there is a statistical difference in the mean value of any of the five videos. Unfortunately, in none of the variables, a statistical difference was found with p values of 0.13 (meditation), 0.18 (high alpha) up to 0.90 (high beta). Similar test were performed after normalizing the measurements for each participant, resulting in slightly lower p values with a significant differences in the theta waves ($F(4, 27) = 3.05, p = 0.02$). Post-hoc analysis using a Bonferroni correction showed a significant difference between the second and third clip, that is the first documentary and the stressful movie ($t(27) = 3.40, p = 0.02$).

3.4.2 Peaks

A second method of analysis, peak detection, was used following the method described in Section 3.3.2. Figure 3.2 shows the peaks for each of the four videos that followed the first baseline movie. On the x-axis time is represented in seconds, with the stressful movie being 300 seconds long instead of the 180 seconds for the other three videos. The y-axis shows the various frequency bands as well as the attention and meditation. Each 'x' represents a peak for that aspect on that time point. In case of the meditation, the value has been inverted such that each peak represents the minimum of meditation as described above.

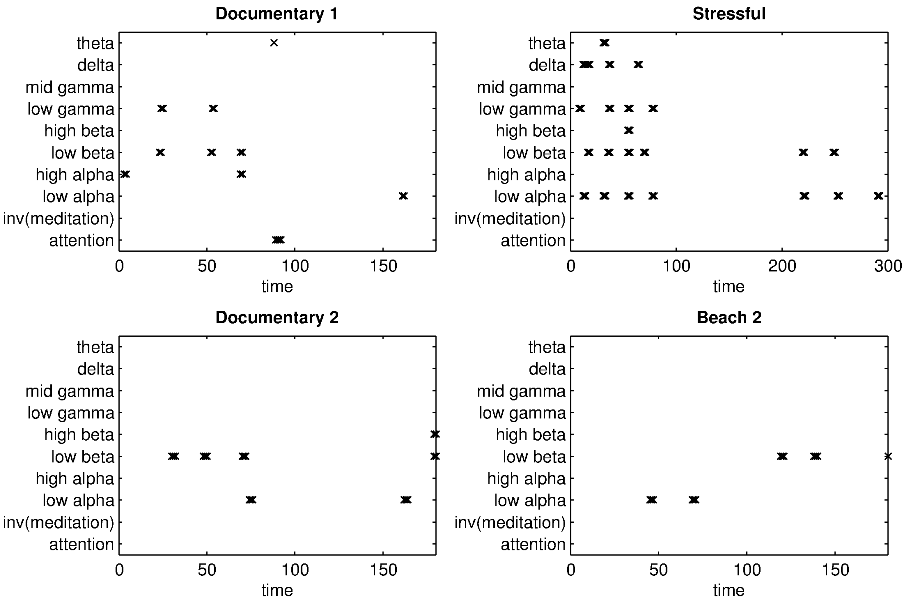

Figure 3.2: Measurement peaks in the last 4 clips compared to the first

As can be seen, there are some clear differences between the different videos, as well as a lack of peaks in the eSense™ values compared to these bands. In the following paragraphs, first the attention and meditation values will be discussed, thereafter the frequency bands. Before discussing all the results, the final paragraphs in this section relates these peaks to specific scenes in the video to get a feel for possible causes underlying the various peaks.

eSense™ values. The bottom two lines represent moments of slightly increased levels of attention and slightly lowered levels of meditation. Considering the attention level, there is only one point during the neutral video where it is increased. There is also only one point, during the same video, where attention is slightly decreased, but these results are not shown here. Overall, this would imply that during the experiment, participants paid an average amount of attention throughout.

Looking at the mediation values, there are no lowered values in any of the videos. For completeness, increased values of meditation were also checked. Here, each video showed a few moments spread out over the duration of the clip where meditation was increased. Even the stressful movie showed increased values for meditation, however all of these peaks were concentrated around the last minute of the video.

Frequency bands. Peaks in average power for each of the provided frequency bands are shown in the top rows of each graph in Figure 3.2. On first glance, it is clear that the stressful video produced many more peaks than the neutral videos and even less peaks are produced in the last clip of a beach. To better grasp the data underlying these peaks, take a look at Figure 3.3. Here, the average power (line) as well as the standard deviation (area) of the low-beta frequency during the stressful movie are shown. Peaks in the line, which are more than four standard deviations above the average during the first movie, are shown in the figure above.

Although during each video there are several peaks in various frequency bands, there are some clear differences between the stressful movie and the other ones. For one, peaks during the stressful movie appear in more bands simultaneously than in the other videos. Furthermore, there are multiple peaks in the delta band during the stressful movie, whereas none of the other videos contain peaks in this frequency range.

Peaks in relation to video content. In this paragraph, an in-depth examination will be made of the exact content of each video around the peaks. Although this analysis is rather subjective, it might offer some insights into possible reasons for peaks to occur, which in turn can be used for further research.

During the first documentary clip, the two peaks in various bands after 23 and 67 seconds coincide with strange sounds made by giant tortoises. The peaks after 52 and 160 seconds occur when one tortoise tries to climb another tortoise. The peak in attention after roughly 90 seconds occurs together with the introduction of some ‘exciting’ music. Peaks in the second documentary have less clear relations to the content, with the peak after 30 seconds co-

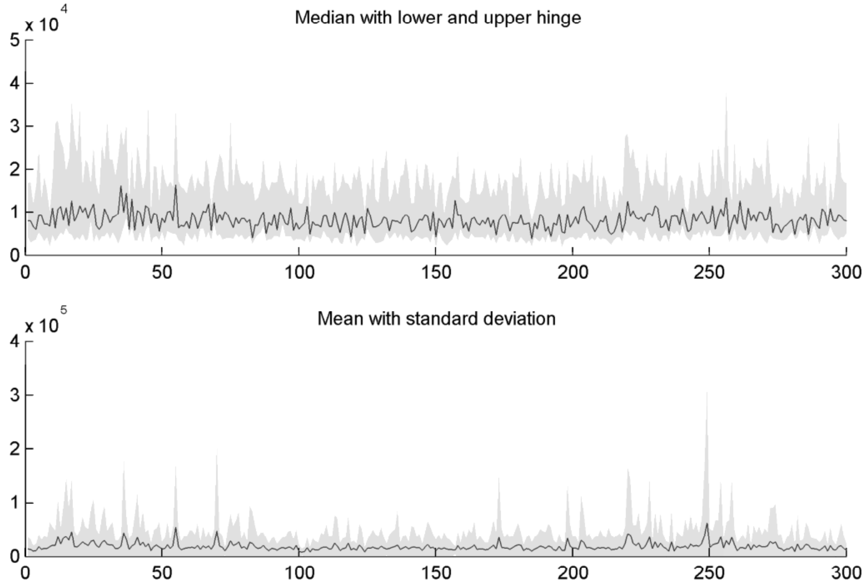

Figure 3.3: Average power (and standard deviation) over time in the low beta frequency band

occurring with a penguin walking into an ocean and the two peaks after 50 and 60 seconds marking the beginning and end of an computer generated animation. The clip of the beach was chosen to be as unexciting as possible, and these peaks subsequently cannot be related to any remarkable event in the movie.

The stressful video contains many peaks, among which many occur roughly simultaneously. We consider the contents of the video around 13, 32, 55, 78, 221, 252 and 291 seconds of interest. These moments are based on the peaks in the low alpha range as these always seem to occur at roughly the same time as peaks in any of the other bands. A multitude of these instances coincide with typical moments of fright in the video. There are however a few moments that are more interesting. At 55 seconds, the clip briefly shows a woman huddled up on the floor of a psychiatric hospital. The peak at 221 seconds is after a longer scene with ominous music playing while the camera slowly moves through a house. The peak occurs at the end, when a door is slowly opened, just to reveal another empty room. Each of the other peaks mentioned above occur at moments of fright such as a snake jumping towards the camera or during some explicit horror scene. It has to be said however, that this stressful video contains more of these types of moments, without a visible peak in the measurements.

3.5 Discussion

Many different results are reported in the previous section. Here, an attempt is made to discuss some of the major points brought forward by these results. First, the lack of any significant findings in the average values over each video is discussed. Secondly, the absence of peaks in the eSense^{TM} values are of our interest, as many related research did successfully use these measurements. Lastly, the promising results using peaks in the frequency bands are discussed further, explaining what future research is needed to better understand and be able to use such measurements.

Looking at the average value for each video resulted in non-significant differences in each of the measured variables. For attention and meditation, differences were very small and variation between and within participants was rather large. This could have obscured any potential differences, however in our opinion it is more likely that on average no differences exist. Possible changes within attention and meditation due to some visual scene seem to come and go rather fast. Therefore, it might be more plausible to expect the short moments where those values might significantly have changed to be averaged out by the longer period in which no change is present. A similar explanation can be given for the lack of significant differences in the frequency bands. No explanation can be given for the one significant effect that was found.

The reasoning above might be why many relevant research using the e-Sense^{TM} variables not look at the average, but at the periods in which it gets above or below a certain threshold, as was done here in Section 3.4.2. However, during none of the videos, attention or meditation was even slightly increased or decreased. Thus the question remains why other research was able to use these values to detect changes in attention and/or meditation and no effects were found here. One problem here is that due to the company trademark of these measurements, no information is available on how they are exactly calculated. However, another explanation could be based on the sensor location at FP1 measuring activity in the prefrontal cortex. The data used is obtained while participants viewed emotional video. Possibly this passive nature of the task might involve less activation from the prefrontal cortex, which is commonly associated with higher order cognitive processes that may be required in game-like setups as reported in related literature. However, based on the fact that there are findings made using the frequency bands, it cannot be ruled out that the underlying methods of calculating the eSense^{TM} values might play a role in explaining these findings.

Throughout each of the videos, peaks occurred in various frequency bands. First, it was clear that during the stressful movie, more peaks in more frequencies occurred. Furthermore, for the first documentary and the stressful movie, it was possible to manually find plausible explanations for these peaks.

Questions arise however, when it is considered that during the stressful movie similar scenes exist which do not coincide with a peak in the data or that peaks in the second documentary and in the last clip of an empty beach cannot be explained in a similar fashion. With regard to missing peaks for the stressful movie, it could be that these scenes were not stressful enough to cause such a peak. Alternatively, it might be the case that during the movie some form of emotion regulation was applied, thereby suppressing later peaks. On the other hand, peaks without a plausible cause in the videos could be that it is still not exactly known what causes these effects and the reason for the peak to occur is not obvious enough here to notice on visual inspection. This is however less plausible for the last video, which is the same video as participants saw the first time when no peaks were produced.

Thus, although these results are promising, more research is required before such measurements can be used in any application. A tailor made experiment in order to get more frequent subjective feedback on the mental state of participants can help in understanding the exact nature of the peaks. Furthermore, it is interesting to investigate the effects of active effort, instead of passive viewing of film, on data obtained with these consumer EEG devices. Combining these results, might give valuable insights into when and where these devices can be used for human-computer interaction.

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