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Integrated Analysis of EEG and eye tracking to measure emotional responses in a simulated healthcare setting

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Abstract

Electroencephalography (EEG) and eye tracking devices are used in this study to assess the capability of such systems to measure emotional responses in a healthcare-related environment. Experiments are conducted in which positive, negative and neutral stimuli are presented to participants and data is captured from both systems simultaneously. Images from the International Affective Picture System (IAPS) are employed to trigger standardised emotion states and calibrate the experiment, whilst images from a medical drama are used to provide hospital-based stimuli. It is found that EEG and eye tracking can successfully indicate emotion features, with the EEG data providing better visualisation, whilst eye metrics are more meaningful with statistics. Both devices show that the emotional responses to hospital-based images differ to the responses from standardised images. Greater variation between participants in the hospital-based stimuli indicates that personal experiences from healthcare related events can influence emotional responses to related stimuli.

Keywords: Electroencephelohraphy; EEG; eye tracking; emotional responses; healthcare; hospital

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1. Introduction

Electroencephalography (EEG) is being used increasingly in research to better understand how humans respond to certain events or stimuli. Much of the research so far has been conducted in relation to marketing, however, there has been advances in EEG research in other fields, such as neuroscience and psychology. EEG involves the use of electrodes to measure the electrical signals produced by the brain. EEG is the most common method of signal acquisition due to the quality of signals obtained, ease of use, and safety for participants and researchers; however, EEG is vulnerable to artefacts from the eyes, internal body movements, and resistance from the cables [1].

High quality eye tracking systems with greater accuracy have been developed over recent years, so the research into emotions and eye tracking has increased accordingly [2]. Although, most of this research is related to psychology; additional areas include medicine and neuroscience. Eye tracking measures the movements of the eye and the direction of gaze. There is a physiological connection meaning the movements of the eyes have been linked to different processes in the brain. Video-based eye tracking devices, for example Tobii glasses, have accurately measured gaze using the reflection of infrared light off the cornea. The fovea controls gaze and naturally points towards the stimulus being processed at any given time, showing there is a link between the eye and the brain. Hence, eye tracking devices are beneficial as they follow the pattern of gaze to help understand visual attention. Some eye movements occur unconsciously, meaning eye tracking has helped to understand unconscious processing of behaviour in humans [3].

The study was heavily focused around simulated healthcare and hospital-based environments, as there was found to be a gap in research regarding the impact of hospital-based settings on emotional responses. There is limited research surrounding the impact of emotions within a hospital environment, but this is an important area to explore. Patients and loved ones experience heightened and often unprecedented emotions when in a hospital scenario, so typical emotional responses may differ in this setting. If medical professionals knew about differences in emotional responses when delivering news, it has the potential to improve the experience for both the professionals and the patients. An experiment was designed to capture the emotional responses produced by a series of images that portrayed positive, negative, and neutral emotions. The aim of the study was to assess the capabilities of an EEG and an eye tracking device to measure emotional responses and to demonstrate if there were any differences in the emotional responses of participants, in response to hospital-based stimuli, compared to standardised emotional stimuli.

The following sections of this paper detail related work, the methods and materials, the experimental procedure, results, a discussion, and lastly a conclusion with future work recommendations.

2. Previous work

EEG has proven over time to have a good ability to detect emotions in the brain, especially compared to facial expression recognition. Facial recognition is unreliable as people may display different expressions to what they feel. The brain is split into lobes and hemispheres: left frontal, right frontal, left parietal-temporal-occipital, right parietal-temporal-occipital. The different lobes and hemispheres should be considered independently when analysing emotions, due to their different functions. It has been found that positive emotions are more commonly detected in the left hemisphere and negative emotions in the right hemisphere [4]. Galvão summarised that activity in the left frontal hemisphere showed positive emotions, or high valence, whilst the right frontal hemisphere showed negative emotion - low valence [5]. Furthermore, they stated that electrodes within the frontal and parietal lobes are most regularly used as they have proven to generate the most accurate results.

Eye movements that occur throughout the collection of EEG data, such as blinks, can significantly impact the data and make analysis of such data very challenging. The brain produces smaller signals with lower amplitude compared to other sources, such as the eyes, so the signals tend to be much weaker. It has been found that blink artefacts were more easily identifiable, as they showed as large disturbances throughout the signals, however, other types of eye movement were harder to identify and correctly remove. Hence, using EEG and eye-tracking devices in combination meant that the eye movement disturbances within the EEG data could be corrected, therefore improving the overall quality of the data [6].

Research in EEG has found that the gamma frequency range (25-50Hz) produces better differentiation between emotional states and produces clearer data charts [7, 8]. For the processing of EEG data, it has been found that the left frontal electrodes portray positive emotions, whilst the right frontal electrodes portray negative emotions. Power spectrum was found to successfully show emotional states with these electrodes, but there has been no existing agreement on which metrics are definitively the most accurate [9].

The International Affective Picture System (IAPS) contains many images which portray positive, negative and neutral emotions – all have been previously verified by a large group of both men and women to validate the emotions shown, using a rating scale of valance and arousal [10]. Researchers can request access for use, therefore improving the reliability of data as all studies with IAPS have used similar data, increasing the comparability and application.

Recent research has found that users tend to focus more heavily in the centre on an image during research, which creates a 'centre bias' when measuring visual attention; better metrics for measuring visual attention were found to be fixations, with added benefits found from the use of saccades and pupil size [2]. A previous study utilised images of paintings and faces to find a strong positive correlation between the participants' rating of liking and total duration of fixation and number of fixations, but no correlation was found with average fixation duration [11]. It has been found that a combination of at least 3 different eye-tracking parameters provided the best accuracy of results (85% or more); emotional stimuli across all the studies analysed (11) included sounds, videos and images [12].

2.1. Open questions in research

There is a clear belief that EEG and eye tracking are suitable for measuring emotional responses, but despite the variation in previous work, it was noticed that none of the research was based on the effects of emotions within a hospital or healthcare environment. A hospital can be an extremely upsetting and stressful place for some individuals, so it should be important to understand how this can have an impact on the emotions experienced by individuals. Hence, it became the focus of this study to identify how a hospital setting can influence emotional responses.

3. Methods and Materials

3.1. Equipment

The EEG system used was the Brain Products actiCAP slim with 32 electrodes and LiveAmp wireless amplifier, connected to BrainVision Recorder software. The eye tracking device used was the Tobii Glasses 3, accompanied by software from Tobii; Glasses 3 for recording and Pro Lab for analysis.

3.2. Participants

Six participants volunteered to take part in this study; one experiment was conducted per participant. Ethical approval was obtained from the Cardiff University Ethics Committee before any volunteers were recruited. Participant consent forms were signed by each participant ahead of the experiments.

3.3. Practical experiments

A range of images were selected using the IAPS [10] to stimulate emotional responses and used as a guide when selecting hospital-based images from Grey's Anatomy - a popular television programme that follows the lives of doctors and patients [13]. Images of doctors interacting with each other and patients, surrounded by hospital-based equipment, machines, or vehicles, were taken from episodes of Grey's Anatomy to portray positive, negative and neutral emotions within a hospital setting. The negative hospital-based stimuli featured visibly upset patients, or graphic details, such as wounds and blood. The positive hospital-based stimuli featured visibly happy doctors, patients receiving happy news, and doctors caring for babies. Images were found using Google Images, with search terms such as "Grey's Anatomy happy". Negative images were selected as those with low valance, positive emotions were chosen to have high valance, and neutral images were chosen to have low arousal and a central valance. Where possible, the images from Grey's Anatomy were aligned with similar images in the IAPS.

The images were arranged to ensure there was a variation of transition types and an even spread of emotion types throughout the experiment (see Table 1). A series of IAPS images were placed at the beginning and end for comparison and validation.

Table 1 Order of emotional stimuli within experiment

Slide	Type	Emotion	Slide	Type	Emotion
1	IAPS	Positive	16	Hospital	Neutral
2	IAPS	Neutral	17	Hospital	Negative
3	IAPS	Negative	18	Hospital	Neutral
4	IAPS	Neutral	19	Hospital	Neutral
5	IAPS	Positive	20	Hospital	Positive
6	IAPS	Negative	21	Hospital	Negative
7	Hospital	Positive	22	Hospital	Neutral
8	Hospital	Positive	23	Hospital	Positive
9	Hospital	Negative	24	Hospital	Negative
10	Hospital	Neutral	25	Hospital	Neutral
11	Hospital	Negative	26	Hospital	Negative
12	Hospital	Positive	27	Hospital	Positive
13	Hospital	Neutral	28	IAPS	Negative
14	Hospital	Negative	29	IAPS	Positive
15	Hospital	Positive	30	IAPS	Neutral

The images were displayed through a PowerPoint presentation on an iPad, in the order shown above (Table 1), with a pre-set timer of 20 seconds for each image. A blank white slide was placed before all images, so the participant could not see any of the images ahead of the experiment.

The experiment location within the laboratory was chosen to make the participant feel private, have sufficient lighting and accessibility to required computer (see Figure 1). To conduct the calibration, the calibration card was held up against a blank background, so the seating position was purposefully selected to be near a blankly painted (white) wall with adequate lighting.

The experiment was designed so that both the EEG and eye tracking glasses would be used simultaneously, then the results analysed together and separately. The start of the presentation was aligned with the start of the EEG recording, meanwhile screen recordings were collected from each computer to allow identification of any issues with the data.

One experiment was run per day, due to the requirement to wash the cap and electrodes after each use.

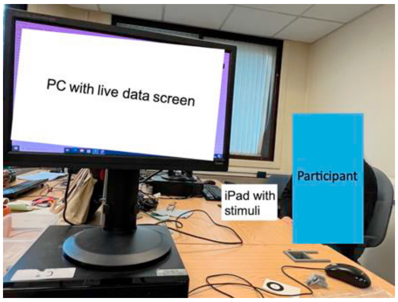

Figure 1 Laboratory set-up

3.4. Data analysis

Data collected from the EEG and eye tracking systems was analysed independently and in combination, to identify any trends and assess the capabilities of using both systems to measure emotional responses in simulated healthcare scenarios.

Each participant file from the EEG recording was imported into EEGLAB [14] where an array of pre-processing steps and analysis techniques were applied to them. Experiments 3, 5 and 6 were discarded due to missing data or interferences that occurred during the practical experiment. A table of events was imported into each participant file to separate all images (1-30), specifying the time point in seconds and the type of image. Epochs were extracted to assess the images individually. An additional set of 3 studies (participants 1, 2 and 4) were made within EEGLAB, splitting the images into positive, negative, and neutral for both IAPS and hospital images (6 conditions). The frequency range was set to 1-40 Hz during pre-processing.

The channel measures were precomputed for event-related potential (ERP) and power spectrum plots. The left and right hemispheres of the brain were split and compared to each other for the three types of emotions being portrayed, split for both IAPS and hospital. ERP topography maps were generated for the time frame [-0.5 4.5]. Power spectrum charts were produced for the gamma frequency range (30-40 Hz). The power charts were edited in MATLAB to differentiate each condition by colour and shape.

All Tobii recordings were imported into Pro Lab and events were manually added to mark the start of each image display, as well as the start and end of each experiment. A time of interest (TOI) was set between each event to create a TOI for each image. A rectangular area of interest (AOI) was established for each participant, which had to be relatively wide around the iPad screen due to the movement of the participants' heads. The metrics pupil diameter, total duration of fixation and number of fixations were exported into Excel and formed into tables split by participant, emotion type and image type. The data was imported into MATLAB where plots were created. For all eye tracking plots, the 10 images for each of the emotion type were superimposed for each participant. Experiments 5 and 6 were excluded due to interruptions during the practical experiments.

Excel was used to calculate the percentage increase between images for each of the eye tracking metric. The average percentage increase was calculated for each emotion state and used to perform statistical analysis; the mean, median, standard deviation (SD) and 95% confidence interval (CI) were calculated. Additionally, a Student's T-test was performed to calculate the p-values using the Excel function 'TTEST'. Only 2 sets of data could be included in each test, so it was conducted between the positive and negative results for each metric. A two-tailed test was used as it was considered best practice to allow for other circumstances in results. The test type was determined to be unequal, as the variance levels are unknown for each condition.

To analyse the EEG and eye tracker in combination, the existing data was interpreted together to identify any additional meanings or outcomes. Individual images were analysed in greater detail with the creation of specific plots of the power spectral density for an individual images, which was then compared against the other metrics.

4. Experimental Procedure

A series of six final experiments were conducted, testing one participant on each given day, each time following the protocol.

Before each participant arrived, the researcher gathered all necessary equipment and began to prepare for the experiment. Participants were instructed to take a seat on arrival. The EEG cap was placed on the participant's head and a tape measure was used to centralise the cap. Impedance gel was applied to each electrode until they were all below the 25 kΩ resistance limit (approximately 15-20 minutes) – see Figure 2. Next, the eye tracking glasses were placed on the participant's head and secured with a strap, ensuring that the pupils were central within the frame. Alternative nose pieces could be used, if required, to optimise the fit. To conduct the calibration of the glasses, the participant was turned around to ensure they were facing the blank white wall. After the calibration had been completed, it was essential that the participant was asked to follow the calibration card with their eyes while keeping their head still, to check that the calibration was accurate. It was obvious that the calibration had been completed to a sufficient level if, when the participant moved their eyes, the dot in the calibration card was followed by the coloured ring on the screen in Glasses 3. The recording was started within Glasses 3, then the Brain Products Recorder was opened on the display and a screen recording was started.

Figure 2 Researcher applying impedance gel during experiment (consent given to show faces)

The PowerPoint was put into presentation mode on the iPad, showing the blank white screen, and the screen recording was started. Once it was confirmed all required recordings had started, the participant was asked to begin the slideshow, at which point the recording on BrainVision Recorder was started. The participant was instructed to sit back and purely appreciate the images, meanwhile the researcher sat behind the computer to watch the live signal as it was outputted from the EEG.

After the slideshow had reached the end (after 10 minutes), all recordings were stopped and saved. The equipment was removed from the participant and a brief debrief was given to the participants, after which they were free to go. A full debrief was sent to the participants later in the project, after all experiments had been completed and the results had been fully analysed.

All files were saved in the same, secure, location after the experiments had finished and each participant was assigned a number. This ensured that all participants remained anonymous throughout the analysis and within the writing.

5. Results

5.1. EEG

The ERP output showed participant 4 had much lower ERP signals in general compared to participant 2, whilst participant 1 was in-between. The clearest differences between left and right sides of the brain were shown in participant 1 (female), as the ERP signals were denser in the left frontal electrodes for positive images and right frontal electrodes for negative images. Participants 2 and 4 (male) showed less obvious differentiation between states. The same phenomenon was harder to identify in the hospital-based images and across the other participants. Participant 4, however, did show a slightly greater response in the right frontal electrodes for negative images, in both the IAPS and hospital types. The ERP shows the change in EEG, and therefore the emotional response to stimuli [15], so it can be taken that participant 2 showed the greatest emotional response overall.

The average topography scalp maps created were very variable between all participates and image types, showing a range of voltage potential across the scalp and no identifiable differences between positive and negative emotions. It was shown that the hospital-based images tended to concentrate at a specific point, whereas the IAPS images were variable across the whole scalp.

The average power spectrum plots can be seen in Figure 3. For the IAPS images (Figure 3a) it was found that, overall, the power was higher during positive stimuli, however, when comparing each emotion type across hemispheres, the power was greatest in the right electrodes for negative stimuli and left electrodes for positive stimuli. Neutral sat in between both positive and negative.

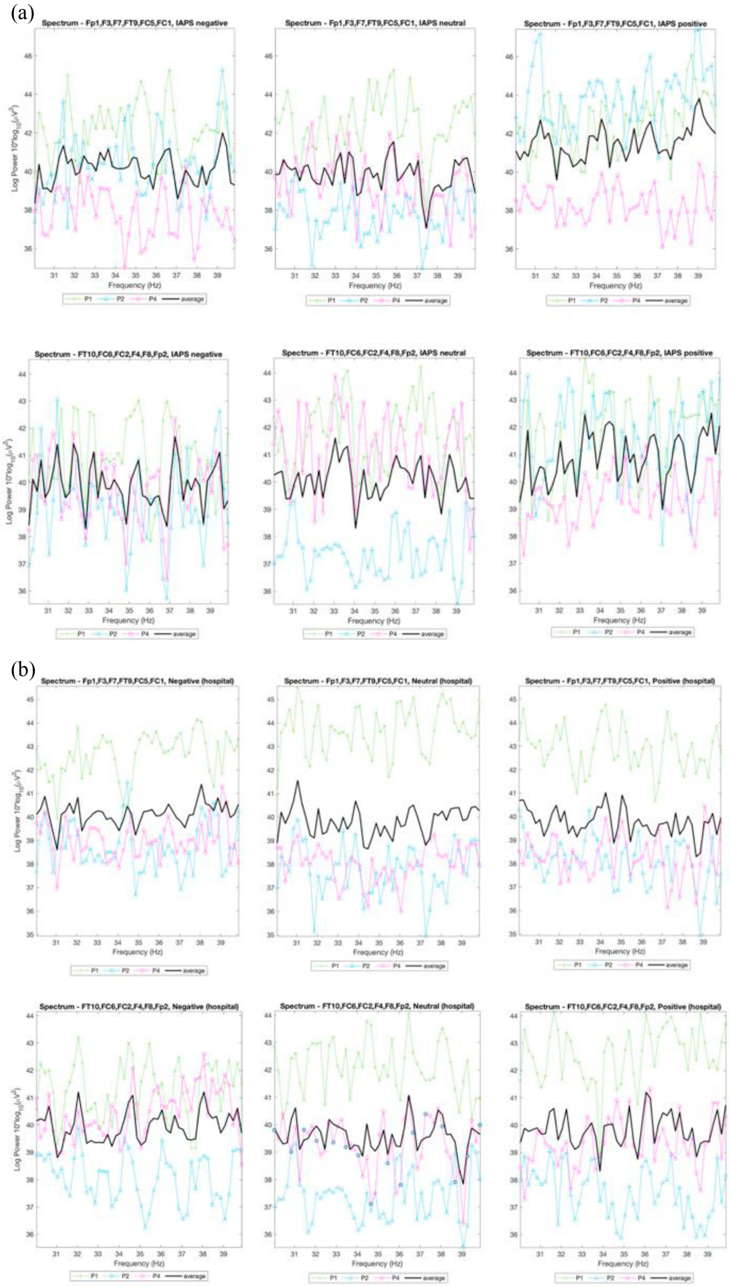

Figure 3 Average power spectrum plots of (a) IAPS images (b) hospital-based images

The emotional states were harder to distinguish in the hospital-based images (Figure 3b), but it was found that there was a greater consistency of power present in the right frontal electrodes during negative stimuli, compared to positive and neutral. Overall, it was found that the IAPS images showed greater consistency in the response of participants for each state, whilst there was more variation across the hospital-based images. Although there was variation between participants in the hospital-based images, there was consistency on an individual participant level.

5.2. Eye tracking

The total fixation duration responses (Figure 4a) varied between the different emotion stimuli within participants. Images 1-3 represent the IAPS stimuli in each section, which showed similar trends compared to the hospital-based stimuli, but with greater similarity between positive, negative, and neutral emotions. The hospital-based stimuli (images 4-10) showed greater differences between the emotion states, compared to IAPS, but there was no consistent emotion that performed higher/lower.

The number of fixations (Figure 4b) showed there was not a definitive emotional state that produced a greater number of fixations. Participant 4 showed a lower response overall for all emotion states, whilst the other participants were similar. The IAPS images showed greater differences in number of fixations, compared to total duration of fixations, and the hospital-based responses were equally as variable.

Similarly, there was not a particular emotion type which came out consistently higher/lower for average pupil diameter (Figure 4c). Although, looking at only the IAPS images (1-3) there was typically a lower pupil diameter for positive stimuli, compared to negative and neutral. This trend was lost in the hospital-based images as it became harder to differentiate image types.

Additionally, Table 2 shows the average percentage increase for each of the eye tracking metrics. For average pupil diameter, the negative stimuli tended to trigger a more negative response (reduction in pupil diameter). Total duration fixation was more variable between participants, but the total duration of fixations tended to increase for positive stimuli. For number of fixations, all except participant 1 showed a greater increase in fixations for negative stimuli.

5.3. EEG and eye tracking combined

When considered together, it can be said that the EEG results typically showed that the IAPS-based images gave a more consistent emotional response than the hospital-based images, whereas the emotional responses were variable across both IAPS and hospital stimuli with the eye tracking metrics.

Participant 4 had a much lower power output than the other participants during the IAPS positive stimuli in the left electrodes but was more consistent with the other participants in the right electrodes. When compared with the number of fixations (Figure 4b), participant 4 showed much lower than the others. Positive image 1 looked particularly low for number of fixations, so this

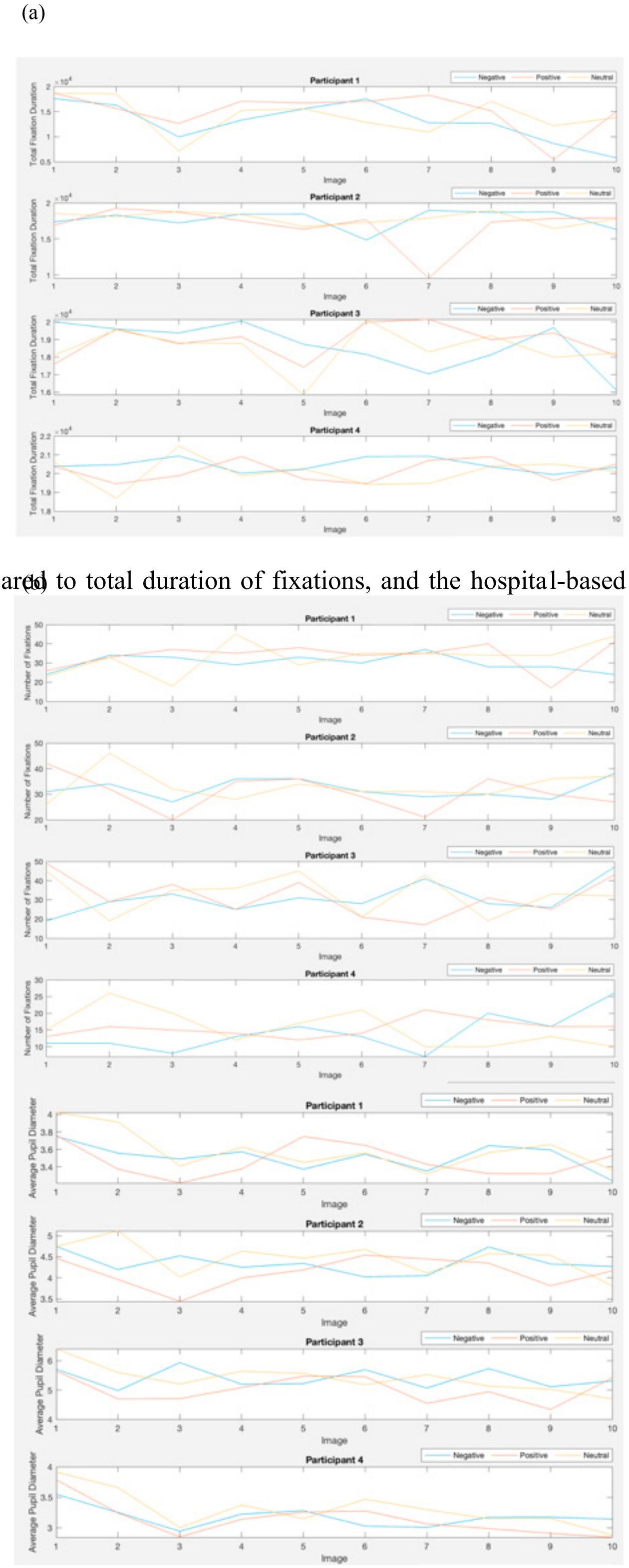

Figure 4 Eye tracking results for (a) total fixation duration (b) number of fixations (c) average pupil diameter

was looked at more closely in EEGLAB and compared to that of participant 2 who had a much higher response for power and number of fixations in the same image and set of electrodes. It was shown that participant 2 had a greater power spectral density, in the negative direction, compared to participant 4, confirming that the lower number of fixations indicated a smaller positive reaction.

Alternatively, participant 1 seemed to have a generally higher power response in all the hospital-based emotion types, but this did not translate into participant 1 generating the highest responses in all the eye metrics.

5.4. Statistics

Table 2 Average percentage increase for eye tracking metrics with statistics

All images	**Average pupil diameter**			**Total duration fixation**			**Number of fixations**		
Participant	**Negative**	**Positive**	**Neutral**	**Negative**	**Positive**	**Neutral**	**Negative**	**Positive**	**Neutral**
1	-1.45	-0.51	-1.74	-8.39	11.24	6.89	1.78	14.73	17.75
2	-0.82	-0.26	-1.65	0.09	5.00	-0.24	3.84	1.59	7.35
3	-0.16	0.38	-3.18	-2.07	0.59	0.71	16.09	9.09	13.40
4	-1.16	-2.86	-2.95	0.00	0.17	-0.05	24.62	4.13	3.33
Statistics									
Mean	-0.90	-0.81	-2.38	-2.59	4.25	1.83	11.59	7.38	10.46
Median	-0.99	-0.38	-2.35	-1.04	2.79	0.33	9.97	6.61	10.37
SD	0.55	1.41	0.80	3.99	5.15	3.40	10.75	5.81	6.38
95% CI	0.02	0.04	0.02	0.13	0.16	0.11	0.34	0.18	0.20

The calculated statistics for the eye tracking metrics can be seen above (Table 2), with the corresponding results from the Student's T-test as follows: average diameter, 0.92; total fixation duration, 0.08; number of fixations, 0.52.

6. Discussion

6.1. Experiments

The hospital-based images were chosen to align with the IAPS as much as possible, although, there was a lack of reliability as the hospital-based images had not been previously validated and tested.

One experiment was run per day due to the requirement to wash the EEG cap after each use, which may have introduced confounding factors. For example, the amount of light entering the room, which would have impacted the calibration of the eye trackers and therefore the accuracy and consistency across the results. The location and arrangement of the experiments remained the same to minimise the variability and confounding factors as much as possible, therefore improving reliability of the results. During the preparation for each of the final experiments, the amount of gel used was variable between participants due to the amount of hair that the participants had. Both these factors could have increased the amount of noise in certain experiments and therefore impacted the results.

The software for the eye tracker ran relatively smoothly; whereas there were issues with the EEG equipment that caused major disruptions to the experiments as the equipment failed to work and the data recordings were stopped automatically by the software. As a result, experiments 3, 5 and 6 had to be excluded from the EEG, whilst 5 and 6 were excluded from the eye tracking data, meaning the sample size was dramatically reduced, limiting the generalisability.

The EEG signals remained consistent across participants during the experiments, which showed repeatability. The appearance of the signals changed dramatically after all pre-processing steps had been applied in EEGLAB, some channels did not show up at all before this point. During the final few experiments, the electrode 'FC5' did not appear to be functioning as it stayed red after the application of impedance gel. Interestingly, signal data appeared for the given electrode after the data had been pre-processed in EEGLAB with re-referencing and filtering. As such, the missing electrode did not seem to influence the analysis process.

6.2. Results

Only the researcher could see live experimental results, meaning the participant was not distracted and could not attempt to purposefully change any of the results during the experiment based on what they saw – increasing validity.

There were no identifiable differences between positive and negative emotions in the average topography scalp maps, which showed that averages were not a reliable method for comparing emotions. Averages were better used within participant and emotional states, in a much more precise way. The power spectrum was the best metric for differentiating between positive and negative emotions, which showed that positive emotions were processed in the left frontal electrodes, whilst negative emotions in the right frontal. It was easy to compare the hospital-based images against the standardised images within the power plots as they gave clear visuals of the group results and individual results. It was found that hospital images showed greater variation in the way participants interpreted them, but there was consistency throughout the response of each participant individually. Meaning, participants may have personal experiences that cause them to react more/less strongly to hospital scenarios.

The ERP output highlighted again that there were differences in the way that participants respond to stimuli, across both IAPS and hospital images. Additionally, there was shown to be a difference between males and females as it was found the female participant showed greater differentiation between positive and negative stimuli. Although, this conclusion came from only 3 participants, so it was not reliable or generalisable.

Manual selection for all events within Pro Lab introduced repeatability issues, as it would be near impossible to align the TOIs to the same exact moment if repeated. Some metrics were out of scope as it was hard to define a specific AOI due to the movement of the participant's head and the size of the screen. Additionally, the results used were based on a wider region than desired and included unwanted data, therefore the use of AOI would have been more beneficial and definitive if using a larger screen.

It was harder to interpret the eye tracking charts compared to those from the EEG data, although there were still shown to be differences in the way that participants interpret hospital-based images. The numerical analysis and statistics of the eye tracking metrics were much more powerful, as comparisons could be drawn between the effects of changes in stimuli. The statistics showed that there was skew in the data, as the means and medians were inconsistent, but this could have been due to the small sample size. The total duration and number of fixations had higher SD than average pupil diameter, indicating that those conditions were more variable between participants. The same was true for the 95% CI, showing that average pupil diameter had the smallest CI range (+/- CI). None of the T-tests showed the results to be significant ($p<0.05$), indicating that no meaningful conclusion could be drawn from the eye tracking data, and further testing should be completed with a larger sample size. Despite the lack of significance, the experiments gave a valuable initial indication into the impact of a hospital environment on emotions and a much greater understanding of the equipment.

It was difficult to combine the metrics produced from EEG and eye tracking as they were so different, so the next step would be to analyse the devices in full synchronisation.

6.3. Limitations

The number of participants analysed was very small, so the conclusions were not applicable to real life, as the sample was not representative of the population. Additionally, the images used for the hospital-based scenarios had not been verified to trigger the associated emotions, so the validity and reliability of these results was reduced.

An alternative method to synchronise the EEG and Tobii data would have been to directly link them during recording and analyse them in BrainVision Analyzer software, however this software was not accessible for this project, meaning an alternative analysis software was used without this capability. The pieces of equipment were not completely synchronised during the data capture, meaning it was not possible to manually align the data types to conduct a full analysis.

7. Conclusion

The EEG data showed that positive emotions were identifiable in the left hemisphere, whilst negative emotions were identifiable in the right hemisphere, with the log power showing the most conclusive results. The percentage increase calculations and statistics were more powerful than visual charts for the eye tracking metrics, which showed that there were differences between emotional states. Both systems showed differences in how individual participants interpret emotions, as well as differences between the interpretation of hospital-based images compared to standardised stimuli, indicating that personal experiences contribute to the emotional responses to hospital-based scenarios. The project was fundamental in learning how to use the EEG and eye-tracking systems and therefore appreciating their capabilities in greater detail, especially for detecting emotional responses to hospital-based stimuli. More research should be conducted to elevate this concept further.

7.1. Future work

The study can be improved by repeating similar experiments with a greater number of participants, using EEG and eye tracking data in synchronisation. A larger screen would improve the value of AOI and gaze metrics. Additional areas to explore include gender and age differences, and the use of sounds to trigger emotions.

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