Capturing and using emotion-based BCI signals in experiments; how subject's effort can influence results

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This study uses minimally invasive technology to monitor the emotional response of a subject during stress inducing psychological tasks. The goal of these tasks is to investigate the possibility of measuring and subsequently categorising the subject's level of stress using biosignal devices. If a consistent metric of stress can be determined it may be used for many forms of human-machine interaction in areas such as assessment and training. Two separate psychological tests were conducted, The Stroop Colour Word Interference Test (20 subjects), and The Towers of Hanoi (17 subjects). These tests examine directed attention, and sustained, consistent attention respectively. NeuroSky's Mindset device was used to record the stress and attention level of each subject. We examined the subject's attention while undertaking these tasks, and assessed any correlation between this and their level of stress during the task.

This study shows that for most subjects, the less attent the subject is, the lower their stress level, and the higher the level of attention, the greater the level of stress (increased concentration etc.) As the difficulty of the task increased, some subjects appeared to 'lose interest' or reduce their level of attention, and consequently the level of stress measured decreased.

Keywords— Attention, Stress, BCI, Stroop, Emotional response, Meditation, Concentration

1. INTRODUCTION

1.1. Objectives

The aim of this study is to assess the use of biosignal analysis in measuring the emotional response of a subject, with an emphasis on stress. Detecting stress and the level of stress can be crucial in applications that are stress sensitive, such as devices controlled by speech, precision tactile control, and Brain Computer Interfaces (BCI). The detection of stress can also be beneficial in other areas such as computer assisted learning and assessment. Knowing if a student is stressed or not paying attention when learning about a subject can be beneficial information.

As the need for less invasive technology grows, it becomes increasingly important to understand how

devices such as BCIs can be used to monitor, categorise and assist subjects in their interactions with technology. The NeuroSky MindSet we use in this experiment captures the subject's levels of "Attention" and "Meditation". These terms are coined by NeuroSky. The attention scale indicates the subject's level of mental focus, and the meditation scale indicates the level of the subject's mental calmness (or stress). NeuroSky's MindSet records these human emotions in a minimally invasive manner (Crowley et al 2010). We use the MindSet unit to monitor the emotional response of a subject during stress inducing psychological tasks in order to return the subject's stress level. We subsequently categorise this stress level and investigate potential correlations of levels of stress and attention during a task; for example, can a low stress level be accounted for by a lack of attention?

1.2. Definitions

The following terms are frequently used in this paper: emotional response; stress; attention and effort. It is important that we clarify our definitions for these terms in the context of this study. We use the term emotional response to describe a subject's subconscious physiological response at a moment in time. Emotions (happy, sad) and feelings (stressed, anxious, attention and relaxed) fall under this category.

In the context of this study, the term stress is used to describe mental strain or tension; the emotional response of a subject to a stimulus (task or combination of tasks). Stress is a response produced by your body when you are subjected to various types of demand, whether physical or mental. When we use the term stress, unless stated, we are not referring to long term stress levels of a user sometimes termed as emotional stress.

For this experiment, our definition of attention refers to the capacity to maintain selective or sustained concentration, focusing the mind on a single task, object or thought. We use effort to define the exertion of physical or mental power required to complete a task.

1.3. Impact and Contribution

This study identifies a correlation between the level of stress and the level of attention of a subject. To gain a fuller understanding of user's emotional response, and the possibility of using this data to progress areas such as user learning and assessment, a multi-method approach is undertaken.

In the present study we use two separate psychological tests. The first test requires sustained and consistent attention (an implementation of the logic game The Towers of Hanoi). Each participant completes a computerised version of the Towers of Hanoi test three times. As the subject becomes familiar with the test their stress levels should drop. We hope to see this within the recorded biosignal data.

The second test is designed to increase in difficulty (The Stroop Colour Word Interference Test). The participants are required to complete a five minute Stroop test once. The speed of the test increases linearly with time. By the fourth minute the test becomes "too difficult" to complete. We hope to see the participants' stress levels continuously rising throughout the test. It is also noted that the participant may lose interest or decrease their level of effort when the test becomes "too difficult". We hope to be able to

capture these instances by recording the participants' attention levels.

This work shows that it is possible to record and categorise participant's levels of stress when undertaking a task. We also show that it is achievable to know when a participant is relaxed simply because they are not attentive. These are two valuable contributions to the fields of emotional response assessment, stress management, and biosignals research. Minimally invasive technology is paramount to the future of biosignal analysis and NeuroSky's MindSet device demonstrates the power and benefit of such technologies in laboratory studies.

2. MATERIALS AND RELATED WORK

2.1. NeuroSky

NeuroSky technologies have developed a minimally invasive, dry, biosensor to read electrical neuron-triggered activity in the brain to determine states of attention and relaxation. NeuroSky's MindSet device is a low-cost, easy to use Electro Encephalogram (EEG) developed for non-clinical human-computer interaction. Neural activity generates a faint electrical signal that constitutes the basis for EEG-based NeuroSky readings. MindSet captures these signals using electrodes and decodes them by applying algorithms to isolate individual signals and present them to the user as time-based signal information.

NeuroSky MindSet is used as a headset with three electrodes touching the skin at three different locations: beneath both ears and the forehead. It captures brainwave signals from 0 -100Hz and provides information on a user's Delta, Theta, Alpha, Beta, and Gamma brainwave band power levels. The signals captured are used as inputs to NeuroSky's algorithms to determine the level of attention and meditation (Robelledo-Mendez et al 2009). The algorithm returns one number per second on a scale from 0 to 100, representing the level of attention and meditation of the subject.

The meditation figure returned by the headset is used to record the users' state of arousal. If the user is relaxed and not under stress then the figure returned is low, whereas if they become stressed, as a result of performing a task for example, the figure returned is high. The attention figure captures the users' level of effort. If the user's effort level is high then the output can near 100 whereas if they make no effort at all it is nearer 0.

2.1.1. The Towers of Hanoi

The Towers of Hanoi is a mathematical game or puzzle. It consists of three rods, and a number of disks of different sizes which can slide onto any rod. The puzzle starts with the disks in a neat stack in ascending order of size on one rod, the smallest at the top, thus making a conical shape. The Tower of Hanoi is frequently used in psychological research on problem solving (Janssen & De Mey 2010).

The objective of the puzzle is to move the entire stack to another rod, obeying the following rules: Only one disk may be moved at a time; Each move consists of taking the upper disk from one of the rods and sliding it onto another rod, on top of the other disks that may already be present on that rod; No disk may be placed on top of a smaller disk.

2.1.2. The Stroop Colour-Word Interference Test

The Stroop Colour-Word Interference Test (Stroop, 1935) is a well-known psychological test of selective attention, cognitive flexibility and processing speed. The test exploits the fact that for experienced readers, the reading of a word has become an automatism. Individuals can read words much faster than they can identify colours.

In its original form, the test consists of words printed on a card, where a word stimulus and a colour stimulus are presented simultaneously to the subject (the name of a colour printed in the ink of another colour e.g. the word 'red' printed in blue ink). The assessment requires the subject to name the colour that is displayed and not the word i.e. to identify the colour stimulus and not the word stimulus. The automatic or most natural response is to determine the semantic meaning of the word.

The cognitive mechanism involved in this task is directed attention. The subject must manage their attention by inhibiting one response in order to say or do something else. The workload of the assessment and the demanding psychological task of directed attention have allowed the Stroop interference test to be utilised as a psychological or cognitive stressor as well as an important experimental paradigm to study attention [7]. The Stroop test has also been effectively used to identify changes in the attention level of a subject, including using the test as a diagnostic tool for Attention Deficit Hyperactive Disorder (ADHD) (Lufi et al 2006). Researchers have also adapted the original testing method as a means of inducing stress in test subjects. Rothkrantz et al. (2004) have used an adaptation of the Stroop test to induce stress in speech as part of their studies on Voice Stress Analysis.

The Rothkrantz variation is computer-based and incorporates a gradual increase in the level of difficulty in the test. Rothkrantz et al display the names of colours one by one on a computer screen at set time intervals over a five-minute period. The difficulty of the task is increased as the time between the appearances of the colours is shortened every minute by half a second, thus decreasing from two and a half second intervals during minute one, to intervals of half a second in minute five. Subjects are required to speak the name of the colour that is displayed to them, and this data is recorded for later analysis.

Rothkrantz et al (2004) analyse the speech data from each minute of the experiment. According to their study, the first minute is considered to represent normal conditions and is used as a control variable. When they compared the acoustic analysis of the data in minute one to the acoustic analysis of the data in minute five, an increase in fundamental frequency was observed (in minute five), as the subject becomes increasingly stressed. Rothkrantz et al suggest that the acoustic changes measured during minute five of this test demonstrate induced stress caused by the Stroop test.

3. PROCEDURE

3.1. Participants

Participants for this study were recruited using ad hoc sampling methods. The final sample consisted of 24 participants (19 male, 5 female). The ages ranged from 17-29.

3.2. Equipment

The tests were completed in a dedicated test environment. The test machine was a dual monitor, quad-core processor; dual graphics card capability Dell T3400. The BCI used to record the meditation and attention levels was NeuroSky's MindSet. A backup headset was used to check for consistent calibration. The participants used a computer version of The Towers of Hanoi written in JavaScript. This JavaScript version was run locally in a browser on the test machine. It was necessary to use a computer version of the puzzle to prevent a wrong move from taking place. If a user attempted to make a wrong move it would be undone and the user would be informed. A timer was set within the program. Once the user had completed the puzzle the timer would stop and the user would be informed they had completed the puzzle.

3.3. Design

3.3.1. NeuroSky

To get a base line set of figures returned by the MindSet we also recorded the user's completing a routine task. The routine task used was the user filling out a usability form for the headset. When a user completed this routine, relatively stress-free task the measurements returned by the MindSet never dropped below the figure of 40. We used this number to create a cut-off point of stress. The user was then categorised by how often their stress levels went below the line of stress. A simple example being if the user's level of stress stayed above the line of stress for 100% of the time recorded then they fell into the 'Very Calm' category.

Fig. 1. The red line shows the figures returned by the MindSet when a user completes a routine stress-less task

Figure 1 shows a subject's line of Stress. This was used as a baseline to create the four categories. For each subject using the figures returned from the headset while completing The Towers of Hanoi we are able to place each subject into a category. The participant's categorisation was dependant on the percentage of time the user's levels of meditation dropped below 40.

3.3.2. The Towers of Hanoi

The Towers of Hanoi seems impossible to many novices, yet is solvable with a simple algorithm. Once the user realises how to break it into smaller steps it becomes a simple matter of repetition. It is for these characteristics the Towers of Hanoi was chosen. The puzzle seeming impossible for the novice user puts him/her under stress at the onset of the task. Once they have understood the puzzle and are simply repeating the steps of the task their stress level should reduce.

3.3.3. The Stroop Test

Similar to Rothkrantz, our variation is computer-based and incorporates a gradual increase in the level of difficulty in the test. The names of colours are displayed one by one on a computer screen at set time intervals over a five-minute period. Subjects are required to speak the name of the colour that is

displayed to them, and this data is recorded for later analysis.

The meditation scale measured by the NeuroSky headset reflects the level of relaxation of the subject, and consequently we expected this data to change as the Stroop test induced stress for the subject. According to the design of the Stroop test, the subject should be most relaxed in minute one of the test and least during minute five of the test. The attention and meditation data for each subject was graphed so any changes in levels, or instances of minimum/maximum attention/meditation could be clearly identified.

3.4 Procedure

The experiment was completed by each subject individually. The subject were seated in front of the test computer and given instructions on how to correctly wear the NeuroSky MindSet. This was continued until the headset returned a strong signal. The experiment would not begin until the participant was correctly wearing the MindSet. The attention and meditation levels of the subject were recorded using the NeuroSky headset for the duration of the test. The test began by asking the participants to complete a few basic tasks within NeuroBoy. NeuroBoy is a test environment supplied with the MindSet by NeuroSky. The aim of the first these tasks was to get the participants familiar with the headset and to remove any levels of stress caused by the experiment surroundings.

The next section of the experiment was the Towers of Hanoi. Participants completed the Towers of Hanoi test three times. The attention levels and meditation levels were recorded by the MindSet for each of the three tests. Two observers also categorised the participants' level of attention and meditation for each test. Watching a participant it is clear to see and record if they are stressed when they are completing the puzzle. The time taken for each test was also recorded. Seventeen participants ($n=17$) completed The Towers of Hanoi 3 times. The number of times (runs) The Tower of Hanoi was conducted was 41 ($m = 41$). Ten runs were not completed as those users' were unable to finish the puzzle. These unfinished runs are recorded as "DNF" (did not finish) within table 1. The time taken for each test was also recorded.

The second section of the experiment was the Stroop Test. For this section each participant was subjected to our adaptation of the Stroop test. Our aim was to monitor the level of attention and stress of the subject during the Stroop test.

The experiment was conducted by showing the subject a movie containing the data for the Stroop test. The

movie was five minutes in duration and displayed colours at interval times based on the Rothkrantz variation. Subjects were asked to name the colour displayed as soon as they saw the stimuli.

During the five minutes of the Stroop test, subjects were required to wear the NeuroSky headset and speak into a microphone to capture the speech signal. The attention and meditation levels of the subject were recorded using the NeuroSky headset for the duration of the test. The tester noted the accuracy of each response (if the colour displayed matched the response given) from the subject for post-test analysis. Participants were then required to complete the CPQ and other questions about the headset and their experiences.

4. RESULTS

4.1. The Towers of Hanoi

Table 1. Meditation levels for Tower of Hanoi

#	First Hanoi	Second Hanoi	Third Hanoi
2	23 %	16 %	4 %
4	28 %	37 %	24 %
5	17 %	11 %	5 %
6	5 %	3 %	0 %
9	7 %	3 %	0 %
10	4 %	3 %	4 %
11	DNF	DNF	DNF
12	DNF	DNF	DNF
13	24 %	20 %	0 %

#	First Hanoi	Second Hanoi	Third Hanoi
15	7 %	0 %	0 %
16	33 %	24 %	0 %
17	5 %	12 %	6 %
19	DNF	DNF	DNF
20	20 %	8 %	16 %
21	DNF	4 %	3 %
22	6 %	0 %	0 %
24	0 %	4 %	0 %

All participants undertook the Towers of Hanoi puzzle as part of the experiment. Table 1 shows the results from the participants completing the Towers of Hanoi three times. The figures show what percentage of time the participants' meditation level dropped below 40. Of the 17 participants only 4 could not resolve the puzzle (#11, #12, #19, #21). All but two participants (#22, #24) had no previous knowledge or experience with this puzzle prior to the experiment. It is clear that these two participants benefited from their previous knowledge. The time the meditation levels spent lower than 40 never went below 6% and 4% respectively. It is also clear to see, for the majority of the participants, a decrease in stress levels from the users' first attempt to their third attempt.

4.2. The Stroop Test

In our study we could not consistently induce stress for each subject during minute five of the Stroop test. For some subjects, the results reflected those obtained by

Rothkrantz, i.e. an increase in stress was observed during minute five of the task. Other subjects maintained a consistent level of stress throughout the task, while a further group decreased their stress level during the task. In order to understand why there was such a variation in the stress reactions of the subjects we examined the level of attention in each subject during the task.

Figure 2 is a typical example of a plot from the headset data. The grey graph represents meditation (the lower the mark the more stress in the subject), and the black graph represents attention (the higher the mark the more attentive the subject). The three significant minimums in the grey graph (meditation) roughly correspond to the onset of a new minute in the Stroop test, i.e. an increase in the speed of the test and consequently an initial increase in the level of stress of the subject. The significant maximum in the grey plot of Figure 2 occurs in minute five of the test, and indicates that the subject has relaxed compared to the earlier minutes of the test. This seems to apply to individuals who were unable to keep up with the pace of the responses to the stimuli in minute five.

Fig. 2. Typical output from headset displaying attention and meditation plots. This figure demonstrates how the data returned from the headset is plotted over time.

In other examples, as the test became more demanding the attention level of some subjects began to decrease and their level of meditation began to decrease also, implying an increase in stress level. For other subjects, the opposite occurred – they relaxed and were less attentive in minute five.

5. DISCUSSION

5.1. NeuroSky

The data collected from the headset during the Stroop and Towers of Hanoi tests clearly demonstrate NeuroSky's suitability as a minimally invasive means of measuring the attention and meditation level of a subject. Both tests in this study show that the attention and meditation datasets outputted by the headset clearly indicate when a subject experiences a change in their level of attention or meditation. From our

results it is clear that other testing measures, like subject's attention, can influence stress levels, and that in certain test scenarios, stress should not be examined without another measure to confirm the reasons behind these stress levels.

5.2. The Towers of Hanoi

When a subject's levels of meditation fluctuate between 20 and 60 it indicates they are stressed. The subject's attention levels remain high throughout the task indicating he is making an effort to complete the task. Where attention levels consistently go below 40 the meditation figures returned become redundant. It is not the task that is affecting the subject's stress level it is their lack of effort. There are two circumstances where the meditation levels returned are low, it could be the subject is not under stress completing the task or it could simply mean the subject is not making an effort. For this reason, in order to return the stress levels of a subject induced by a task it is necessary to know the level of effort of the subject.

5.3. The Stroop Test

Based on our observation, and notably fewer responses to the stimuli, we believe that these subjects had resigned themselves to being unable to keep up with the speed of the test, i.e. reduced level of effort (Figure 3). Another grouping showed an increase in stress (low meditation) while maintaining a consistent attention level, demonstrating a good effort to complete the task and respond to the stimuli (Figure 4).

We hypothesize that these differences in how the subjects reacted to the workload of minute five may relate to personality type, and how individual's response varies when conducting a Stroop test to induce stress. The personality of the subject and how they react to stress appears to influence how they perform in the Stroop test. This is a matter that requires further investigation and study.

Fig. 3. A clear increase in meditation and decrease in attention, indicate this subject has reduced their level of applied effort during minute 5

Fig. 4. Minute 3 through to 5 of Stroop. This subject's attention level is maintained as they make a good effort to respond to the stimuli. Stress level increases as they attempt to complete the task.

6. CONCLUSIONS/FUTURE WORK

6.1. The Stroop Test

We were unable to consistently recreate Rothkrantz's (2004) induced stress results. We examined the relationship between the levels of attention and stress the subject was experiencing during the task. Close examination of the two signals highlighted a correlation between attention, stress and effort, which in turn offered an explanation for the inconsistent stress responses across the test subjects. These findings also suggest that the role of the Stroop test as a stressor is to vary the stress response of a subject rather than to linearly increase stress.

The results of our Stroop study in this experiment were greatly influenced by the subject's level of attention and determination to complete the test despite the increasing level of difficulty. Some subjects experienced an increase in stress level during the test, while others appeared to give up trying to respond with the correct stimuli. This brings in to question the role of personality type when assessing stress reactions, and subsequently, the suitability of the Stroop test as a means of inducing stress without taking personality type into consideration.

Psychologists have investigated associations between personality and stress related appraisals and responses. Penley & Tomaka (2002) examined how the Big Five personality dimensions (Neuroticism, Extraversion, Openness, Agreeableness and Conscientiousness) are associated with stress and coping processes, including subjective reactions and task performance. Scherer (1986), who has completed many studies on voice and stress, also highlights how personality can affect the stress response of a subject. He believes it is probably that some kind of coping mechanism related to personality

dimension influences how a subject behaves under stress. The relationship between personality type and the stress response of a subject may have an impact on psychological tests such as Stroop. The results of our study show that the stress response of a subject, and the level of applied effort of the subject, both impact on the end result of the task.

In future studies we will expand our recordings to cover other variables that affect subject's stress levels. It is our aim to design a new study using a psychological test that will linearly increase stress and keep effort constant. If the test design guarantees that the subject will keep trying throughout the duration of the test, the stress level can be more accurately assessed. We also intend to investigate how personality influences the subject's stress reaction by including a personality assessment in future work.

The Towers of Hanoi test results reaffirm the importance of capturing effort when looking at stress levels of a subject. If the subject gives up or makes no effort to complete the task then the subject's levels of stress will be affected by the task. In order to accurately assess stress level during an experiment it is important to keep the subject's level of attention/effort consistent.

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