Assessing a Brain-Computer Interface by evoking the auditory cortex through binaural beats

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DECLARATION

I hereby declare that the work which is submitted here is the result of my own independent investigation and that all the sources I have used or quoted have been indicated and acknowledged by means of complete references. I further declare that the work is submitted for the first time at this university/faculty towards the ***Magister Scientiae degree in Computer Information Systems*** and that it has never been submitted to any other university/faculty for the purpose of obtaining a degree.

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1. INTRODUCTION

1.1. INTRODUCTION

The physiological activities inside a human body and nervous system are processes that are constantly changing. They respond to what is happening in the outer world, and also to in the inner world of thought, perception and emotion. Indicators like heart rate, respiration, blood circulation, body temperature and others adjust themselves constantly based on the feedback they get from the body's built-in senses to find the optimum balance and state. These vital rhythms define a person's life, health, wellness and performance (MedicineZine, 2010).

Physiological activity can be measured using physiological metrics. These metrics include video-based metrics, electromyography (EMG), electrocardiography (ECG), eye-tracking and pupil dilation, galvanic skin response (GSR) and electroencephalography (EEG).

Video-based metrics can be used to analyse a user's facial expressions and gestures, where body language forms part of gestures. EMG is a graphical record of electric currents associated with muscle contractions (Princeton University, 2012(a)) where sensors are inserted into the user's muscles or attached to the user's face. ECG is a recording of the electrical activity of the heart (Proteus family network, 1998) and can be translated into line tracings on paper. Eye trackers calculate the approximate point upon which one fixates one's eyes on with extreme accuracy using *image sensor technology*. Such trackers use the user's eyes in combination with mathematical algorithms to calculate the point of gaze (Tobii – Eye-tracking research, 2011). GSR is a change in the electrical properties of the skin in response to stress or anxiety which can be measured either by recording the electrical resistance of the skin or by recording weak currents generated by the body (Princeton University, 2012(b)). EEG is a technique for studying the electrical current within the brain (MedicineNet.com, 2001). EEG is the metric the researcher will use in this study. To obtain usable data from the electrical current inside the user's brain a brain-computer interface (BCI) will be used.

A BCI is a collaboration in which a brain accepts and controls a mechanical device as a natural part of its representation of the body (Scribd, 2001). The interface enables a direct communications pathway between the brain and the object to be controlled. The goal of a BCI is not to determine intent by eavesdropping on brain activity, but rather to provide a new channel of output for the brain that requires voluntary adaptive control by the user (Wolpaw, Schalk, McFarland & Pfurtscheller, 2000). BCI systems depend on system design factors which are heavily influenced by participant motivation (Molina, 2003). The electrical activity in one's brain is also called brainwaves. For this study the Emotiv EPOC neuroheadset will be used as the BCI and will now be discussed in more detail.

1.2. BRAINWAVES AND BINAURAL BEATS

Brainwaves have been categorised into four basic groups: Alpha, Beta, Theta, and Delta waves. Although none of these waves is ever emitted alone, the state of consciousness of the individual may make one frequency more pronounced than the others (Bio-medical.com, 2002a). This means that when a person is in a different mental state, a different brainwave will be dominant.

The four major brainwave states are (Renewal Technologies Inc, 2008):

- Beta waves (13 to 30 Hz)
- Alpha waves (8 to13 Hz)
- Theta waves (4 to 8 Hz)
- Delta waves (0.5 to 4 Hz)

We can use these waves to change the user's mental state by changing the resonate frequency of the brain, and thus changing the dominant brainwave. This is called the *frequency following* response or *brainwave entrainment*.

Frequency following is when the brain begins to resonant with an external frequency, or *follow* along with the frequency (Keeley, 2006). The external frequency is created using binaural beats. *Entrainment* is a term taken from Physics which means the tendency for two vibrating bodies to lock into phase so that they vibrate in harmony (The Morry Method, 2011). This phenomenon was first observed by Dutch scientist, Christian Huygens, in 1665 while he was working on the design of the pendulum clock. He found that when he placed two of the clocks on a wall near each other and swung the pendulums at different rates, they would eventually end up swinging at the same rate (GAP, 2011). The most well-known form of brainwave entrainment is called the binaural beat, where a slightly different tone is presented into each ear (Mystic Mindpower, 2010).

A binaural beat is the phenomenon that was discovered by the German researcher H. W. Dove in 1839 (web-us.com, n.d.). What he found was that binaural beating took place when separate frequencies were introduced into each ear, for example, a tone of 100 Hz in the right ear and a tone of 108 Hz in the left. The brain strives to bridge the gap by creating a third tone that is the actual difference between the two: in this example, 8 Hz.

1.3. PREVIOUS STUDIES

1.3.1. BINAURAL BEATS

Many studies have been done on binaural tones and the influence thereof on people (see Table 1 – Table 5). Aspects investigated in these studies were:

- Table 1 – Cognition (verbal skills, nonverbal skills, attention, memory and overall intelligence and achievement)
- Table 2 – Stress (long-term and short-term stress)
- Table 3 – Pain
- Table 4 – Headaches/Migraines
- Table 5 – Mood

In 33 studies, 70% yielded positive feedback stating that binaural tones do have the ability to change the dominant wave frequencies of the brain and thus have an effect on cognition, stress, pain, etc. Most of the studies were done on attention deficit hyperactivity disorder (ADHD) children. ADHD is a problem with inattentiveness, over-activity, impulsivity, or a combination of these (PubMed Health, 2012). Everyday tasks were given to participants to test whether binaural beats could influence the time it takes to complete the tasks. The only metric used when testing *cognition attention* and *cognition overall intelligence and achievement* was time.

Table 1: Studies using binaural tones on Cognition

Aspect	Focus	Researcher/s	Year	N (sample size)	Hz	Result
Cognition	Verbal skills	Joyce & Siever	2000	• 8 healthy children • 12 ADHD children	7 – 9	Negative
		Wahbeh, Calabrese, Zwickey & Zajdel	2007(a)	• 4 healthy adults	7	Negative
	Nonverbal skills	Patric	1996	• 21 healthy children • 10 ADHD children	12 – 14	Positive
		Olmstead	2005	• 30 ADHD children ages 6-16	14 – 40	Positive
	Attention	Patric	1996	• 21 healthy children • 10 ADHD children	12 – 14	Positive
		Joyce & Siever	2000	• 34 ADHD children	7 – 9	Positive
		Olmstead	2005	• 30 ADHD children ages 6-16	14 – 40	Positive
		Lane, Kasian, Owens & Marsh	1998	• 29 healthy adults	16 – 24 1.5 – 4	Negative
		Wahbeh et al.	2007(a)	• 4 healthy adults	7	Positive
	Memory	Williams	2001	• 51 healthy adults	8.7, 10, 11.7	Positive
		Williams, Ramaswamy & Oulhaj	2006	• 30 cognitively healthy elderly	9 – 11.5	Positive
		Wahbeh et al.	2007(a)	• 4 healthy adults	7	Negative
	Overall intelligence and Achievement	Budzynski, Jordy, Budzynski, Tang & Claypoole	1999	• 8 students without academic difficulties • 8 students with academic difficulties	14, 22	Positive
		Patric	1996	• 21 healthy students • 10 ADHD children	12 – 14	Positive

Table 2: Studies using binaural tones on Stress

Aspect	Focus	Researcher/s	Year	N (sample size)	Hz	Result
Stress	Short-term stress	Morse & Chow	1993	• 10 Photic • 10 AVE • 10 adults having root canal	10	Negative
		Ossebaard	2000	• 13 Alpha • 12 Beta • Employees of addiction care facility	10, 25, 30, 35	Positive
		Le Scouarnec, Poirier, Owens, Gauthier, Taylor & Foresman	2001	• 14 mildly anxious adults	0.1 – 3.9 4 – 7.9	Positive
		Padnmanabhan, Hildreth & Laws	2005	• 36(music) • 36(nothing) • All undergoing surgery	0.1 – 3.9	Positive
		Wahbeh et al.	2007(a)	• 4 healthy adults	7	Negative
	Long-term stress	Ossebaard	2000	• 13 Alpha • 12 Beta • Employees of addiction care facility	10, 25, 30, 35	Positive
		Howard, Graham & Wycoff	1986	• 12 • 11 • All dental students	30, 8 – 14	Positive
		Le Scouarnec et al.	2001	• 14 mildly anxious adults	0.1 – 3.9 4 – 7.9	Negative
		Wahbeh et al.	2007	• 8 healthy adults	2.5 – 10	Positive

Table 3: Studies using binaural tones on Pain

Aspect	Researcher/s	Year	N (sample size)	Hz	Result
Pain	Nomura, Higuchi & Yu	2006	40 adult patients having a 2nd esophagogastro-duodenoscopy	9	Positive
	Manns, Miralles & Adrián	1981	14 adult patients with < 1year of bruxism and myo-facial pain-dysfunction syndrome	Selected by patient	Positive
	Manns et al.	1981	19 adult patients with < 1year of bruxism and myo-facial pain-dysfunction syndrome	Selected by patient	Positive

Table 4: Studies using binaural tones on Headaches and Migraines

Aspect	Researcher/s	Year	N (sample size)	Hz	Result
Headaches / Migraines	Noton	2000	55 adults with migraine	30	Positive
	Solomon	1985	28 adults, 15 with acute migraine, 6 with chronic muscle contraction headaches, 3 with sinusitis, 4 with migraine	1 – 3	Positive
	Solomon	1985	4 adults with chronic muscle contraction headaches	1 – 3	Positive
	Anderson	1997	7 adults, 50 migraines total	0.5 – 50	Positive

Table 5: Studies using binaural tones on Mood

Aspect	Researcher/s	Year	N (sample size)	Hz	Result
Mood	Lane et al.	1998	• 29 healthy adults	16 – 24, 1.5 – 4	Negative
	Wahbeh et al.	2007(b)	• 8 healthy adults	2.5 – 10	Negative
	Wahbeh et al.	2007(b)	• 4 healthy adults	7	Negative

1.3.2. EMOTIV EPOC NEUROHEADSET

The EPOC neuroheadset by Emotiv is based on the latest developments in neuro-technology. Emotiv has developed a revolutionary new personal interface for human-computer interaction: It is a high resolution, neuro-signal acquisition and processing wireless neuroheadset, which uses a set of sensors to tune into electric signals produced by the brain in order to detect user thoughts, feelings and expressions (Emotiv, 2010). The EPOC Emotiv uses spontaneous signals and generates a control signal based on a particular mental activity (Molina, 2003).

Lillian Zhou (Zhou, 2010) worked with the Emotiv headset for a one-semester independent work project. She ran several experiments with Emotiv, one manually (running the Emotiv in the background to collect data while instructing the participant to perform a task) and one with a simple integrated presentation and recording loop using Emotiv's native C++ application programming interface (API). This investigation showed that building and running experiments was too difficult to do in this manner, demonstrating the necessity of a full-featured application devoted to supporting Emotiv's use as a research tool, particularly for the purpose of allowing non-programmers to experiment with the device (Adelson, 2011).

In the research project for this dissertation, the researcher wanted to test whether binaural beats could influence the quality of and time to complete a task. The task was performed using the participant's brainwaves as an input stream to control a Lego mindstorm robot. The participant was exposed to different binaural beats that would change his/her dominant brainwave while completing the task. The Emotiv EPOC neuroheadset was used as BCI to capture data for analysis.

1.4. PROBLEM STATEMENT

Why can some people study, read books, and work while listening to music while other people simply cannot? Why do younger people seem to be more productive than older people while there is thunderous noise around them? People and some companies claim that if certain music is played specific outcomes can be expected depending on the type of music, for example, Baroque music is supposed to stimulate a person's mind to enhance the learning experience. Some companies create different sounds or songs with hidden frequencies to stimulate and create a specific outcome on the listeners' physiology.

This study will assess the impact of binaural beats on participants' performance using a BCI to control a robot.

1.5. RESEARCH QUESTION

Based on the problem statement the overarching research question for this study is:

- What is the effect (in terms of excitement, engagement, meditation, frustration and performance) of binaural tones on participants' task performance while manipulating a Lego mindstorm robot?

A secondary research question is:

- What dominant wave frequency (Alpha, Beta, Theta, or Delta) improves performance of participants while manipulating a Lego mindstorm robot?

1.6. AIMS AND OBJECTIVES OF THIS STUDY

The aim of this study is to establish, through a brain-computer interface, whether binaural beats can affect the performance of participants performing tasks. To achieve this aim, the following objectives will be pursued:

1. Undertake a comprehensive literature review in which the following aspects will be studied:
    - different types of physiological interfaces and behavioural interfaces;
    - physiological metrics and behavioural metrics;
    - available technologies for each physiological and behavioural metric; and
    - binaural beats.

2. Create and test different binaural beats.

3. Develop a system that the participants will interact with for the study. The system will include the use of:
    - a Lego mindstorm robot;
    - Microsoft Robotics Developer Studio 2008; and
    - an Emotiv EPOC Headset and SDK.

4. Perform the experiment and use the results to draw conclusions.

A secondary aim of this research study is to assess the impact of different sound frequencies on specific age groups. The researcher will assess the differences between the directions in which the participants have to move the robot.

1.7. HYPOTHESIS

The primary aim mentioned above led to the following four hypotheses:

H_0: A dominant Alpha brainwave does not affect participants' excitement, engagement meditation, frustration and performance when using the Emotiv EPOC neuroheadset to control a robot.

H_1: A dominant Beta brainwave does not affect participants' excitement, engagement meditation, frustration and performance when using the Emotiv EPOC neuroheadset to control a robot.

H_2: A dominant Delta brainwave does not affect participants' excitement, engagement meditation, frustration and performance when using the Emotiv EPOC neuroheadset to control a robot.

H_3: A dominant Theta brainwave does not affect participants' excitement, engagement meditation, frustration and performance when using the Emotiv EPOC neuroheadset to control a robot.

1.8. STUDY DESIGN

The data will be collected using a balanced cross-over design whereby each participant will be exposed to each of the 4 waves (and also without any wave) while using the Emotiv neuroheadset to control a robot. The sequences in which the participants will be exposed to each of the waves will be controlled. A control will also be incorporated where the participants will be exposed to no waves.

1.9. ANALYSIS

The primary objective of the statistical analysis for the usability performance is to compare the four waves with respect to the following outcome variables:

- Time to complete a task
- Number of errors
- Task success

The primary objective of the statistical analysis for the participant experience is to compare the different waves with respect to the following physiological outcome variables:

- Long-term excitement
- Short-term excitement
- Engagement
- Meditation
- Frustration

1.10. CHALLENGES

The major challenge that the researcher was faced with in terms of the proposed research was that the Emotiv SDK (Software Development Kit) did not capture the data as required for this study, thus a C# application had to be developed to capture the data in a specific time frame required for this study.

1.11. OUTLINE OF DISSERTATION

The final dissertation is organised in the following way:

Chapter 1 – Introduction

This chapter will provide the background on which the entire study is based. It also includes the problem statement, research question, aims and objectives, as well as the hypotheses.

Chapter 2 – Literature study

This chapter will provide the summary of the contemporary literature that will elucidate prior research and some relevant theories in the area of this study. Objective 1 (see 1.6) will be fully covered in this chapter.

Chapter 3 – Research design and methodology

This chapter will provide the details of the research design and methodology that have been used in this study. Objectives 2 and 3 (see 1.6) will be fully covered in this chapter.

Chapter 4 – Research tools

This chapter will name and discuss all the tools needed to complete the study.

Chapter 5 – Research data and findings

This chapter will report on the empirical research data and findings.

Chapter 6 – Conclusions and recommendations

This chapter will contain the conclusions and the recommendations. Objective 4 (see 1.6) will be fully covered in this chapter.

1.12. CONCLUSION

This chapter introduced the concepts of physiological metrics, brain-computer interfaces in the form of the Emotiv's EPOC neuroheadset, binaural beats and some of the major impacts they might possibly have on peoples' lives in the future. A problem statement was determined and the research question that was used to uncover the problem statement was introduced. The aim and objectives followed, after which four hypotheses were stated. The study design and analyses on participants' performance and user experience were briefly discussed. Finally, some potential challenges were discussed, followed by the outline of the dissertation. Introductions to various important aspects that must be considered will be given in Chapter 2 in the form of a literature review.

2. LITERATURE REVIEW

2.1. INTRODUCTION

This chapter introduces the reader to different definitions and interpretations of physiological and behavioural computing, binaural beats and robotics. The major existing physiological metrics, namely video-based, EMG, ECG, eye-tracking, GSR, and EEG are summarised and a short history of each is included. To begin with, three key terms in computer systems, namely interaction, human-computer interaction, and interfaces are discussed.

2.2. INTERACTION

Interaction in term of computer science may be defined as the operation of performing tasks on a computer. An interaction task is the entry of a unit of information by the user. Interaction tasks are defined by what the user wants to accomplish. They are user-centred, meaning that satisfying the user's needs is the most important goal (Kumar & Kumar, 2005). The main purpose of interaction design is to develop interactive products that are usable (Sharp, Rodgers & Preece, 2007). To be more specific, human-computer interaction will now be discussed.

2.3. HUMAN-COMPUTER INTERACTION (HCI)

HCI is the study, planning and design of how people and computers work together so that a person's needs are satisfied in the most effective way (Galitz, 2002). It has also been defined as the set of processes, dialogues and actions through which a human user employs and interacts with a computer (Baecker & Buxton, 1987). Essentially, HCI studies the communication between human and machine.

HCI draws supporting knowledge from both machine and human aspects (Kumar & Kumar, 2005). It deals with the design, evaluation and implementation of interactive computing systems for human use in a social context (Ghaoui, 2006). It includes more than just the design of screens and menus, having a deeper focus in that it builds functionality into systems (Jacko, 2009). HCI is a wide discipline which is related to computer science, psychology, cognitive science, human factors (ergonomics), design, sociology, library and information science, artificial intelligence and other fields (Kumar & Kumar, 2005).

Lew, Sebe and Huang (2007) mention that HCI is one of the leading challenges currently being faced in society. Therefore, it is necessary to design and implement an effective interface by including mental models, metaphors, visibility, affordability and feedback (Jacko, 2009). It is necessary to accommodate the machine by taking techniques in computer graphics, operating systems (OSs) and programming languages into consideration. It is also necessary to accommodate the human aspect with communication theory, graphic and industrial design principles, social sciences, cognitive psychology and human performance (Kumar & Kumar, 2005). For a person to have interaction with a computer system an interface is needed.

2.4. INTERFACES

An interface is defined as a common boundary or interconnection between systems, equipment, concepts, or human beings (Dictionary.com, 2012.a). For instance, a remote control is an interface between a person and a television set, and the English language is an interface between two people (ABC Institute of Applied Mathematics, 2012). A user interface is everything designed into an information device with which a human being may interact – including display screen, keyboard, mouse, light pen, the appearance of a desktop, illuminated characters, help messages, and how an application program or a website invites interaction and responds to it (SearchSOA, 2000).

Research regarding HCI has mostly been focused on graphical user interfaces which consist of a keyboard, a mouse and the monitor. Currently, HCI research has shifted to *multimodal* interaction, where natural human behaviour and characteristics are more important than looking at keyboard and mouse interaction. This allows the environment to not only be reactive, but also proactive, anticipating the user's activities, needs and preferences (Tan & Nijholt, 2010).

Interfaces may be regarded as consisting of two types, namely physiological and behavioural interfaces.

2.4.1. PHYSIOLOGICAL INTERFACES

The National Institute of General Medical Sciences (2006) defines physiology as the study of how living organisms function. Princeton University (2012(c)) defines physiology as the branch of the biological sciences dealing with the functioning of organisms.

Physiological interaction goes beyond the physical interfaces that a computer has (i.e. the input and output devices). Physiological interfaces secure and use real body characteristics, including breathing, talking, height, weight, heart-rate and eye-tracking. Some of the top innovations include automatic speech recognition (ASR), virtual reality, cave automatic virtual environments (CAVE) and biometrics (Haag, 2006).

2.4.2. BEHAVIOURAL INTERFACES

According to Princeton University's lexical database (Princeton University, 2012(d)) behaviour can be defined as a manner of acting or controlling oneself. It is also defined as the actions or reactions of a person in response to external or internal stimuli (Answers.com, n.d.). Farlex describes behaviour as the actions displayed by an organism in response to its environment (The free dictionary, 2009(a)).

Two types of behaviour can be distinguished, namely verbal and non-verbal behaviour. A discussion of both verbal and non-verbal behaviour will be given later in this document. Verbal behaviour gives insight into users' emotional and mental state while they are using the product. Non-verbal behaviour can be very revealing about one's experience with the product. Both the physiological and behavioural interfaces need a way to be measured. This is called metrics.

2.5. METRICS

A metric is a standard measure to assess performance in a particular area (BPR OnLine Learning Center Series, n.d.). The two types of metrics used while working with physiological and behavioural interfaces are physiological and behavioural metrics. Each will now be explained.

2.5.1. PHYSIOLOGICAL METRICS

If we can agree that physiology is how living organisms function, it is clear that physiology by definition will be measured in different ways when compared to behaviour. The following metrics are viewed as physiological and need special equipment to capture the data: video-based analysis, electromyography, electrocardiography, eye-tracking, galvanic skin response and electroencephalogram. Each will now be discussed in turn.

VIDEO-BASED ANALYSIS

Motion capture technologies are becoming increasingly popular in various types of interactive systems. Digital video is an excellent tool for conveniently gathering rich information about our surroundings as well as about human emotions. There are two main aspects to video-based analysis, namely facial and gestural analysis.

FACIAL EXPRESSION-BASED ANALYSIS

Facial expression analysis has a wide area of application domains, including HCI, lie detection, paralinguistic communication and psychiatry. Facial expression can be a behavioural and physiological metric. When special equipment is used to analyse facial expressions, this is known as a physiological metric. When a person is interpreting facial expression, it is known as a behavioural metric.

A video camera is aimed at a user's face to capture the user's facial expressions. The video is later used to assess the user's expressions at certain moments in the study. This method is computationally challenging due to the varying appearances of people and their facial expressions (i.e. there are personalisation problems). A system called

FaceReader, tested by Den Uyl and Van Kuilenburg (2005), classified eighty-nine percent (89%) of the expressions it was shown into one of six emotions (Tullis & Albert, 2008):

- Happiness
- Anger
- Fear
- Disgust
- Sadness
- Surprise

This shows that the video-based analysis can only be used effectively for these six emotions (see Figure 1).

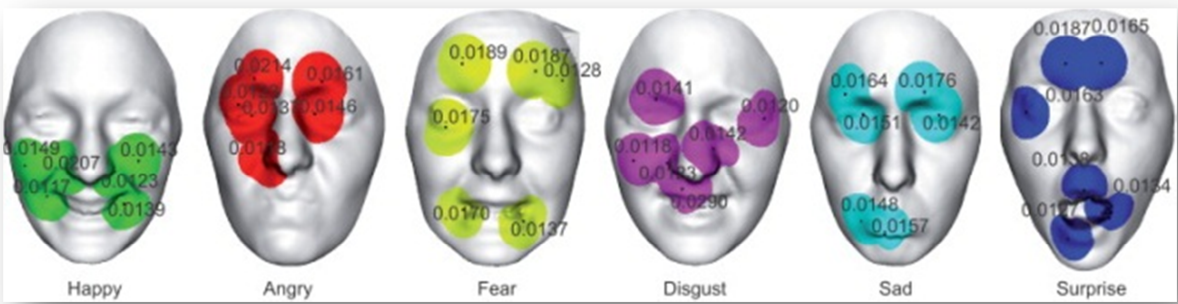


Figure 1: Six different facial expressions (Sciencedirect, 2011)

GESTURE-BASED ANALYSIS

Gesture recognition can be seen as a way for computers to begin to understand human body language (see Figure 2).

Hand gestures can be captured by a variety of sensors. Examples of these sensors are depth-aware cameras (Yang Liu & Yunde Jia, 2004), stereo cameras (Kue-Bum Lee, Jung-Hyun Kim & Kwang-Seok Hong, 2007), controller-based gestures (Tricom solutions, 2007) and single camera (Wei Du & Hua Li, 2000). In computer interfaces, two types of gestures are distinguished: offline gestures are gestures that are processed after the user's interaction with the object, for example the gesture to activate a menu, while online gestures are direct manipulation gestures, for example to scale or rotate a tangible object (Baldauf & Fröhlich, 2009).

Figure 2: Using gestures to interact with a computer (ScienceDaily, 2010)

Gestures can originate from any bodily motion or state but commonly originate from the face or hand. Gesture recognition is useful for processing information from humans which is not expressed through speech or type. These uses include sign language recognition (Starner & Pentland, 1995), socially assistive robotics, directional indication through pointing (Nickel & Stiefelhangen, 2006), control through facial gestures, alternative computer interfaces/input devices (Bretzner & Lindeberg, 1998), immersive game technology, virtual controllers (Freeman & Weismann, 1994), affective computing and remote control (Jun-Hyeong, Jin-Woo, Jung, Hyoyoung & Zeungnam, 2006).

ELECTROMYOGRAPHY/ELECTROMYOGRAM (EMG)

Electromyography (EMG) is a graphical record of electric currents associated with muscle contractions (Princeton University, 2012(a)).

There are two electrode categories, namely inserted electrode (see Figure 3) (which consists of fine wire or needles) and surface/floating electrode (see Figure 4) (Groh, 2008).

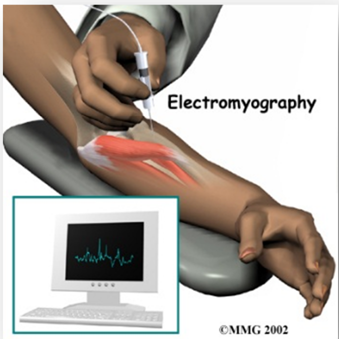


Figure 3: Inserted electrode into a person's arm (Nursingcrib, 2011)

Figure 4: Surface electrodes measure electric currents in muscles (Search Directories.com, n.d.)

Sensors are inserted into the user's muscles or attached to the user's face. These sensors can measure electrical activity in any muscle but in HCI we only use certain muscles of the face. They are most commonly used to measure activity of two muscle groups (Hazlett & Benedek, 2005):

- corrugator muscle (forehead) which is associated with frowning, and
- zygomatic muscle (cheeks) which is associated with smiling.

A study done by Hazlett (2003) on the frustration that users experience when using different websites has shown that elevated tension based on facial expression can add value to HCI studies.

HISTORY OF EMG

Jan Swammerdam (1637-1680), a Dutch anatomist and biologist, discovered that stroking the innervating nerve of the frog's gastrocnemius muscle generated a contraction. Francesco Redi (1626-1698) was the first to recognise the connection between muscles and generation of electricity (Medved, 2001). Alessandro Volta (1745-1827) developed a device which produced electricity and which could be used to stimulate muscles (Cram & Durie, n.d.). Luigi Galvani was credited as the father of neurophysiology for his similar work with frogs' legs in 1791. He showed that electrical stimulation of muscular tissue produces contraction and force (Medved, 2001). Because of limited instrumentation, his work was not fully accepted until almost 40 years later.

The first practical galvanometer was developed in early 1800s by Carlo Matteucci (Cram & Durie, n.d.). In 1838, Matteucci used this galvanometer to show that bioelectricity is connected with muscular contraction (Medved, 2001). In 1842 Matteucci demonstrated the existence of the action potential accompanying a frog's muscle.

Emil du Bois-Reymond was the first to detect electrical activity in voluntary muscle contractions of man in 1848 (Cram & Durie, n.d.). The participants placed their fingers in saline solution. Du Bois-Reymond then removed skin to reduce transfer resistance (Medved, 2001), and detected a signal through electrodes connected to a galvanometer when participants contracted muscles.

In 1850 Guillaume Duchenne applied electric stimulation to intact skeletal muscles (Basmajian, 1978), and also systematically mapped out the functions of nearly every facial muscle.

Knowledge of EMG developed as fast as technology could keep up. Willem Einthoven made a string galvanometer in 1903 and won the Nobel Prize for this invention, which used a thin conductor wire placed between two magnets (Medved, 2001). Forbes and Tacher were probably the first to use floating electrodes (see Figure 4) on a moving body (Schult & Wand, 2010). They used them to record EMG signals in elephants (Medved, 2001).

Adrian and Bronk developed the concentric needle electrode in 1929. They used this primarily for researching motor control and muscle schemes (Medved, 2001). This enabled detection in individual and small groups of muscle fibres.

Herbert Jasper constructed the first electromyograph between 1942 and 1944 at McGill University (Montreal Neurological Institute) (Medved, 2001). He also created a uni-polar needle electrode (Basmajian, 1978).

He used his instruments to perform groundbreaking work with epilepsy and neurology and is a member of the Canadian Medical Hall of Fame (The Canadian Medical Hall of Fame, 2011).

In 1962 John Basmajian compiled all of the known information about EMG (Basmajian, 1978). He also created fine-wire electrodes (Basmajian & Stecko, 1962) that were more comfortable than needles and could be used for longer periods (Whittle, 1999). The book *Muscles Alive* became an invaluable tool in the field. John Basmajian then founded the International Society of Electrophysiological Kinesiology (ISEK) in 1965 (The history of ISEK, n.d.). ISEK worked to create standards for EMG usage and reporting.

Carlo J. De Luca is however the most influential person in recent EMG history. He wrote the oft-cited paper *The Use of Surface Electromyography in Biomechanics* which cautions against failing to understand EMG's limitations (De Luca, 1997).

EXISTING TECHNOLOGY

In this section, the researcher will give examples of existing systems and/or devices that are used as EMGs. These examples include the KinetiSense and the Nexus.

KINETISENSE

The KinetiSense system consists of two small lightweight components, the command module and the motion sensor, connected with a thin, flexible cable (see Figure 5). Up to five motion sensors can be attached to one command module and the cable length can be customised at the time of purchase, making the KinetiSense system suitable for numerous applications (CleveMed, 2011).

Figure 5: KinetiSense system (CleveMed Blogs, 2010)

NEXUS

Nexus by MindMedia is a multi-channel physiological monitoring and feedback platform that utilises Bluetooth wireless communication, USB and flash memory (SD) technologies (see Figure 6). It supports a wide range of physiological sensors including (Mind Media B.V., 2006):

- EEG,
- EMG,
- ECG,
- EOG,
- SCP,
- GSR,
- respiration,
- blood volume pulse,
- high resolution skin temperature,
- oximetry, and
- force.

Figure 6: Nexus (Mind Media, n.d)

ELECTROCARDIOGRAPH (EKG / ECG)

According to the Proteus glossary (Proteus family network, 1998) an electrocardiogram is a recording of the electrical activity of the heart. WebMD (2011(a)) agrees that an electrocardiogram (EKG, ECG) translates the heart's electrical activity into line tracings on paper.

The sino atrial (SA) node is the heart's dominant pacemaker. It initiates a wave of depolarisation that spreads outward, stimulating the atria to contract as the circular wave advances (Hyperphysics, n.d.). The spikes and dips in the line tracings are called waves (see Figure 7).

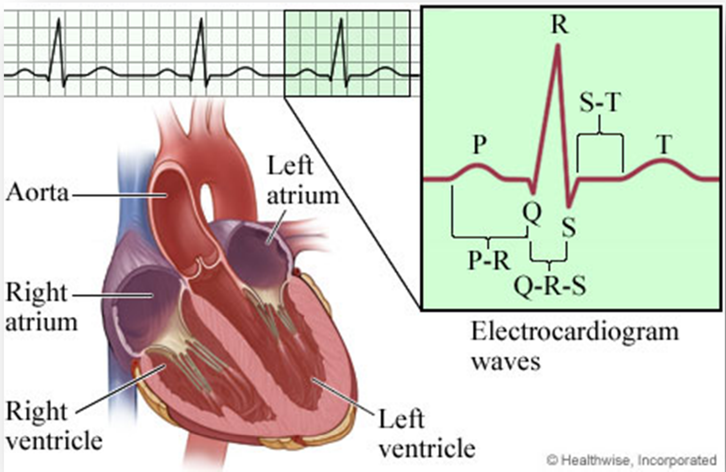


Figure 7: The heart and the heart-waves (WebMD, 2011(b))

These waves are:

- P-Wave: The SA-node fires, sends an electrical impulse outward to stimulate both atria and manifests as a P-Wave.
- QRS complex: A record of the movement of electrical impulses through the lower heart chambers (ventricles).
- ST segment: Shows when the ventricle is contracting but no electricity is flowing through it. The ST segment usually appears as a straight, level line between the QRS complex and the T wave.
- T wave: Ventricular repolarisation, meaning no associative activity of the ventricular muscle.

HISTORY OF ECG / EKG

Kollicker and Mueller discovered the electrical activity of the heart in 1856 when a frog sciatic nerve/gastrocnemius preparation fell onto an isolated frog heart and both muscles contracted synchronously (Oxford Journals, 2006).

In 1872, Alexander Muirhead attached wires to a feverish patient's wrist to obtain a record of the patient's heartbeat. He was studying for his D.Sc in electricity at St Bartholomew's Hospital. This activity was directly recorded and visualised, using a Lippmann capillary electrometer by the British physiologist John Burdon Sanderson. Augustus Waller was the first to approach the heart systematically from an electrical point of view while working in St Mary's Hospital in Paddington, London (Mechanical eBook.com, 2009).

Waller’s ECG/EKG machine consisted of a Lippmann capillary electrometer fixed to a projector. The heartbeat’s trace was projected onto a photographic plate which was fixed to a toy train which allowed heartbeats to be recorded in real time. He nevertheless saw little clinical application for his work. Willem Einthoven, working in Leiden, the Netherlands, used the string galvanometer that he invented in 1901 (see Figure 8). This was the breakthrough to the discovery of the modern EKG/ECG (AskDefine.com, 2012).

This invention was much more sensitive than the capillary electrometer that Waller used. Einthoven assigned the letters P, Q, R, S and T to the various deflections, and described the electrocardiographic features of a number of cardiovascular disorders. He was awarded the Nobel Prize in Medicine in 1924 for his great medical equipment discovery (Medical Machines Online, 2008).

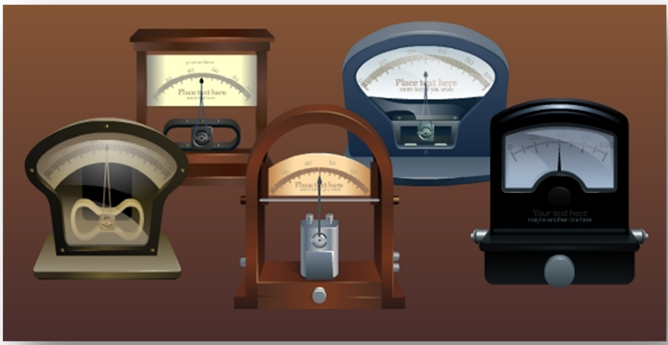


Figure 8: Galvanometers (Activeden, 2012)

During the 21st century, a new generation of monitors was designed. These monitors were flexible enough to remain with the patient during transportation. They later became thinner and lighter, incorporating flat-screen technology. Transport monitors even offered connectivity to the Internet. This allowed the clinician to use the Internet or the hospitals' intranet to view remotely a particular bedside monitors' real-time waveforms, vital signs and trends. The trend towards the development of non-invasive techniques will continue. In the near future, there may be some overlap between physiological monitoring and medical imaging because of the inherent non-invasive nature of medical imaging (Akshay, Lokesh & Shashidhara, n.d.).

EXISTING TECHNOLOGY

In this section, the researcher will give examples of existing systems/devices used as an EKC/ECG. These examples include the Burdic 8500, the Quinton Eclipse Premier and the Vitaljacket.

BURDICK 8500 ECG

The Burdick 8500 ECG/EKG was built for comfort. Burdick 8500 ECG equipment has a friendly user interface, multi-angle 7-inch widescreen, and colour display that makes reading waveform data easy, which streamlines workflow (see Figure 9).

Some of the features include the export of ECG records to network drives, USB or EMRs. The system can also store up to 300 ECG records. Ethernet connectivity is a standard feature. It is easy to use with features like an easy-to-clean keyboard, dedicated function keys, intuitive menu, and on-screen quick tips. It uses an interpretation package that enables one to calculate interpretations down to a one-day-old infant (Cardiac Science, 2011(a)).

Figure 9: Burdick 8500 ECG (eMED Healthcare, 2012)

QUINTON ECLIPSE PREMIER ECG

The Eclipse Premier ECG produces timely, high-quality and accurate ECG results (see Figure 10). The ECG machine is very easy to operate. The system consists of a full-size wireless ECG cart for good mobility. This ECG machine produces clean tracings and stable baselines. Eclipse Premier ECG machines are compatible with wireless 802.11 networks (Cardiac Science, 2011(b)).

Figure 10: Quinton Eclipse Premier ECG (Medline, 2012)

VITALJACKET

The VitalJacket is an extremely comfortable t-shirt that allows one to monitor the heart wave continuously for up to 5 days, using miniaturised components through a non-invasive device (see Figure 11). The signals can be interpreted offline as well as in real time. The product is composed of a t-shirt and a small electronic device box placed in a pocket. The product provider, Biodevices, has developed products in the biomedical field that strive towards the well-being and comfort of its users (Biodevices, 2010).

Figure 11: VitalJacket (Medicallabtech.com, 2012)

EYE-TRACKING AND PUPIL DILATION

An eye-tracker accurately calculates the approximate point upon which one fixes one's eyes by using *image sensor technology* that employs the user's eyes in combination with mathematical algorithms to calculate the point of gaze (Tobii – Looking forward, 2011).

The pupil is the hole in the centre of the iris that changes size in response to changes in lighting. It gets larger in dim lighting conditions and gets smaller in brighter lighting conditions (QualSight-Lasik, 2010). Dilation is the process of enlargement or expansion of the pupil (MediceneNet.com, 2010).

There are three main groups of eye-trackers (Duchowski, 2007):

1. Scleral contact lens/search coil

   One of the most precise eye movement measurement methods involves attaching a mechanical or optical reference object mounted on a contact lens which is then worn directly on the eye (see Figure 12).

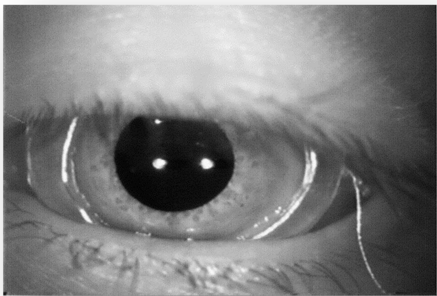


Figure 12: Scleral contact lens/search coil (Sciencedirect, 2005)

2. Video-based combined pupil/corneal reflection

   Video-based trackers use relatively inexpensive cameras and image processing hardware to calculate where the user is looking in real-time (see Figure 13 and

Figure 14). The optics of both table-mounted and head-mounted systems are essentially identical, with the exception of size. These devices, which are becoming increasingly available, are most suitable for use in interactive systems.

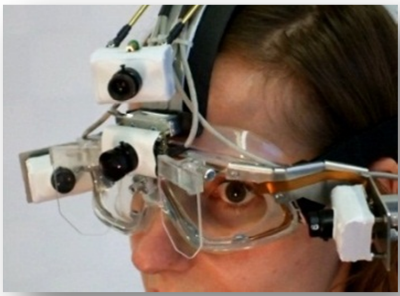


Figure 13: Head-mounted eye-tracker (Hack a day, 2010)

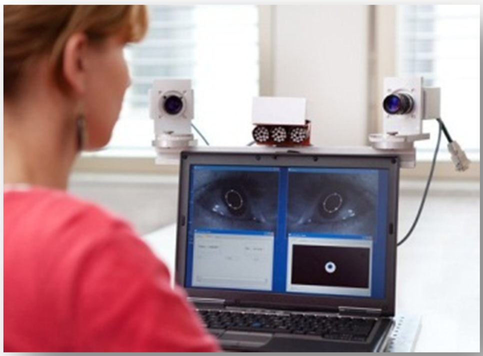


Figure 14: Table-mounted eye-tracker (POPCSI, 2010)

3. Electro-oculography (EOG)

   Electro-oculography, the most widely applied eye movement recording method approximately 40 years ago (and still used today), relies on measurement of the skin's electric potential differences of electrodes placed around the eye (see Figure 15). This technique measures eye movements relative to head position, and is, therefore, generally not suitable for point of regard measurements unless head position is also measured.

Figure 15: Electro-oculography (Picasa, 2011)

HISTORY OF EYE-TRACKING

Eye movement studies had been conducted for almost 100 years before computers were used in general, such as those done by Javal (1878) in the period 1878 to 1879. Early methods for eye movement studies were rather invasive, and involved direct mechanical contact with the cornea. In 1901 the first accurate, non-invasive eye-tracking technique, using light reflected from the cornea, was developed by Dodge and Cline (Dodge & Cline, 1901). Recordings of the temporal eye movements in two dimensions were done by Judd, McAllister and Steel (1905) by applying motion picture photography. A small white speck of material was inserted into the participant’s eye and its movement then recorded. Miles Tinker and his colleagues began to use photographic techniques to study eye movements in the 1930s.

In 1947 Fitts, Jones and Milto (1950) began to study the movements of pilots' eyes as they used the cockpit controls and instruments for a plane to land. This was done using motion pictures. The study by Fitts, Jones and Milton represents the earliest use of eye-tracking. Their study is now known as usability engineering.

In 1948, Hartridge and Thompson (1948) invented the first head-mounted eye-tracker. By 1958 Mackworth and Mackworth (1958) had devised a system to record eye movements superimposed on the changing visual scene viewed by the participant. In the 1960s, Shackel, Mackworth and Thomas advanced the concept of head-mounted eye-tracking systems, making them somewhat less obtrusive and further reducing restrictions on participant head movement (Castellina, 2009).

Eye movement research and eye-tracking flourished in the 1970s, with great advances in both eye-tracking technology and psychological theory to link eye-tracking data to cognitive processes. Researchers in these laboratories recorded much of their work in US military technical reports (Jacob & Karn, 2003).

Work in the 1970s focused on technical improvements to increase accuracy and precision and reduce obtrusiveness of participants. In 1973 the discovery was made that multiple reflections from the eye could be used to dissociate eye rotations from head movement. The advent of the minicomputer provided the necessary resources for high-speed data processing. This innovation was an essential precursor to the use of eye-tracking data in real-time as a means of HCI (Jacob et al., 2003).

Psychologists who studied eye movements and fixations prior to the 1970s focused on relationships between eye movements and simple visual stimulus properties such as target movement, contrast and location, but during the 1970s this attitude began to change gradually. While engineers improved eye-tracking technology, psychologists began to study the relationships between fixations and cognitive activity. This work resulted in some basic, theoretical models for relating fixations to specific cognitive processes (Hyönä, Radach & Deubel, 2003).

Scientific, educational, and engineering laboratories provided the only home for computers during most of this period. At this point, eye-tracking had not yet been applied to the study of HCI. Teletypes for command line entry, punched paper cards and tapes, and printed lines of alphanumeric output served as the primary form of HCI (Jacob et al., 2003).

As personal computers flourished in the 1980s, researchers began to investigate how the field of eye-tracking could be applied to issues of HCI. The technology seemed particularly handy for answering questions about how users search for commands in computer menus. The 1980s also ushered in the start of eye-tracking in real time as a means of HCI. Early work in this area initially focused primarily on disabled users. The combination of real-time eye movement data with other, more conventional modes of user-computer communication was also pioneered during the 1980s (Castellina, 2009).

As technological advances such as the Internet, e-mail, and videoconferencing evolved into viable means of information sharing during the 1990s and beyond, researchers again turned to eye-tracking to serve as a computer input device (Jacob et al., 2003).

EXISTING TECHNOLOGY

In this section, the researcher will give examples of existing systems and devices used as eye-trackers. These examples include the Eyegaze Edge communication system and the Tobii Glasses Eye Tracker.

EYEGAZE EDGE COMMUNICATION SYSTEM

The Eyegaze Edge communication system is designed for people with complex physical disabilities and is operated entirely with the eyes (see Figure 16). By looking at various control keys displayed on the screen, a user can synthesise speech to control his environment, type documents, run computer software, operate a computer and access the Internet. In order to operate the system, a user sits in front of the monitor and a specialised video camera mounted below the monitor observes one of the user's eyes (LC Technologies, 2009).

Figure 16: Eyegaze Edge communication system (Eyegaze, 2012)

TOBII GLASSES EYE TRACKER

The Tobii Glasses Eye Tracker is the new generation of mobile eye-trackers designed for the highest possible research efficiency. The Tobii glasses system includes a pair of eye-tracking glasses, a recording assistant, Infra-red (IR) markers and Tobii studio analysis software (see Figure 17).

The time it takes to get the user ready is only a fraction of the research session, allowing efficient research. The calibration that takes place after the study only takes 15 seconds to complete. The efficiency of Tobii glasses allows for running large numbers of studies in a short time period. One can even use multiple eye-trackers simultaneously within the same project. To prevent unnatural behaviour and to secure research validity, Tobii glasses are unobtrusive throughout the research process. There are no distracting mirrors or devices in front of the participant's eyes (Tobii – Eye-tracking research, 2011).

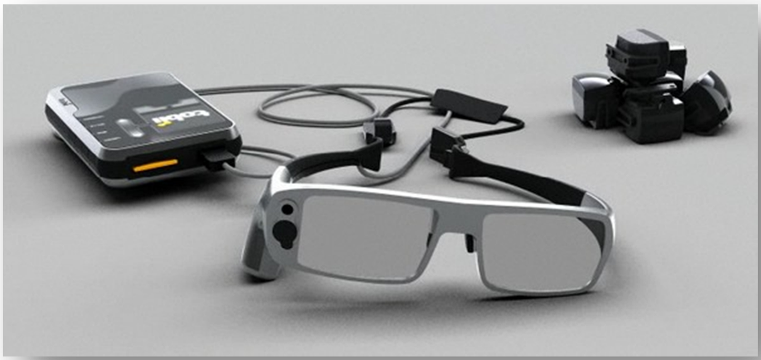


Figure 17: Tobii glasses eye-tracker (Engadget, 2010)

SKIN CONDUCTANCE/ GALVANIC SKIN RESPONSE (GSR)

According to Princeton University (2012(b)) galvanic skin response (GSR) is a change in the electrical properties of the skin in response to stress or anxiety. It can be measured either by recording the electrical resistance of the skin or by recording weak currents generated by the body. According to Alloy, Riskind and Manos (2005), GSR is a polygraphic recording of the changes in the electrical resistance of the skin – an indication of sweat gland activity. They further explain that there is an intimate relationship between emotion and physiological functioning: when a person's anxiety level raises, so may the activity of the sweat glands (see Figure 18).

HISTORY OF GALVANIC SKIN RESPONSE

GSR has gone through many phases of interest and rejection since the early 1900s. It has been used in important research on anxiety and stress levels (Fenz & Epstein, 1967), and it has been a part of lie detection (Barland & Raskin, 1973). Controversy has centred on the technique, underlying mechanisms, and the meaning of the responses obtained from the skin (Bio-medical.com, 2002(b)).

Figure 18: Representation of the electrical properties of the skin (SkyBlueCross, 2012)

Research into GSR began in the early 1900s. It was used for multiple types of research in the 1960s through the late 1970s, with a decline in use as more sophisticated techniques (such as EEG and MRI) replaced it in many areas of psychological research. GSR still sees limited use today, as it is possible to use with low-cost hardware (galvanometer) (Book Rags, 2006).

EXISTING TECHNOLOGY

In this section, the researcher will give an example of existing systems and devices used as a GSR, namely the GSR 2.

GSR 2

The GSR 2 is a single channel GSR-monitor (see Figure 19). The GSR 2 measures minute changes in skin pore size and sweat gland activity as it relates to tension. The GSR2 sits in the palm of the hand. Feedback includes variable pitch tone. As tension increases, tone increases; as tension decreases, tone decreases. It can measure the skin resistance range between 1,000 ohms and 3,000,000 ohms (Bio-medical.com, n.d.).

Figure 19: GSR 2 (ITstressControl.com, 2011)

GSR electrodes have been built into a standard Dell mouse (see Figure 20 and Figure 21). The electrodes measure GSR which could be used to gauge the human response to computing. While most rigs that measure GSR are large and invasive, thus altering test results, this non-obtrusive method seems harmless enough. Putting a hand on top of a mouse is second nature to most computer users (Van Nimwegen & Uyttendaele, 2009).

Figure 20: Standard GSR measurement (WhyWeProtest, 2008)

Figure 21: The GSR mouse (Engadget, 2008)

ELECTROENCEPHALOGRAM (EEG)

MedicineNet.com (2001) defines the EEG as a technique for studying the electrical current within the brain. WebMD (2011(c)) describes an EEG as a test that measures and records the electrical activity of one's brain.

Brain-computer interaction is a relationship between the brain and a device that enables signals from the brain to direct some external activity, such as control of a cursor or a prosthetic limb. The interface enables a direct communications pathway between the brain and the object to be controlled (Whatis.com, 2011).

HISTORY OF EEG

In 1875 Richard Caton, an English physician, discovered the presence of electrical current in the brain (Bio-medical.com, 2002(a)). Scientists first captured and recorded brainwaves in dogs in 1912. Hans Berger, a German neurologist, used his ordinary radio equipment to amplify the brain's electrical activity so that he could record it on graph paper in 1924. Berger observed that rhythmic changes varied with the individual's state of consciousness. For the most part, the scientific community of Berger's time did not believe his conclusions. Five years later his conclusions were verified through an experiment by Edgar Douglas Adrian and B.C.H. Matthews. In 1936, W. Gray Walter demonstrated that this technology could be used to pinpoint a brain tumour. By the 1950s the EEG (Figure 22) was used commonly throughout the United States (Emedicinehealth, 2011). Walter created a machine called a toposcope in the 1950s. The toposcope could create a map of the brain's surface by using EEG activity.

Figure 22: EEG system (A-N-T, 2012)

Brainwave frequency varies in specific regions of the brain. An EEG electrode placed on the scalp would pick up many waves with different characteristics. This makes it very difficult for researchers trying to interpret the data they receive from even one EEG recording. As mentioned before, brainwaves have been categorised into four basic groups: Alpha, Beta, Theta, and Delta waves. Although none of these waves is ever emitted alone, the state of consciousness of the individual may make one frequency more pronounced than the others (Bio-medical.com, 2002(a)).

EXISTING TECHNOLOGY

In this section, the researcher will give examples of existing systems and devices used as an EEG. These examples include the Actiwave, the Ambulatory EEG and the EPOC neuroheadset.

ACTIWAVE

The Actiwave range of miniature biomedical waveform recorders by camNtech are designed to capture EMG, EEG and ECG signals in daily living. Using ultra-miniature recorders which are available with either 1, 2 or 4 channels of recording capability, EMG, EEG and ECG waveforms can be recorded discreetly without the need for a large belt-mounted recorder or lengthy wires. Each recorder can simply be taped or glued to the skin near to the position of the electrodes (see Figure 23). The very small size and weight of these units make them ideal for paediatric and pre-clinical use (CamNtech, 2012).

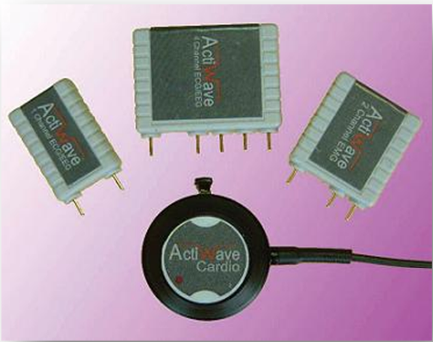


Figure 23: Actiwave system (BMedival, 2012)

AEEG SYSTEM

Ambulatory EEG (AEEG System) by CONTEC Medical Systems Co. is a relatively recent technology that allows prolonged electroencephalographic (EEG) recording in the home setting (see Figure 24). Its ability to record continuously for up to 72 hours increases the chance of recording an *ictal* event or *interictal* epileptic-form discharges. AEEG is a less expensive alternative to in-patient monitoring, with costs that are 51-65% lower than a 24-hour in-patient admission for video/EEG monitoring (Medscape Reference, 2011).

Figure 24: Ambulatory EEG (AEEG system) (Tjsk.org.cn, n.d.)

EPOC NEUROHEADSET

The EPOC neuroheadset by Emotiv (see Figure 25) is based on the latest developments in neuro-technology; Emotiv has developed a revolutionary new personal interface for HCI. The Emotiv EPOC is a high resolution, neuro-signal acquisition and processing wireless neuroheadset. It uses a set of sensors to tune into electric signals produced by the brain to detect user thoughts, feelings and expressions and connects wirelessly to most PCs (Emotiv, 2010).

Figure 25: EPOC neuroheadset by Emotiv (ABC News, 2011)

EMOTIV WORKING PRINCIPLES

The Emotiv system, like most EEG systems, measures the electrical activity associated with the brain and facial muscles. The BCI then takes these electrical activities in the form of signals and converts them into machine-understandable control signals. The Emotiv uses two common artificial and neural learning techniques, namely the McCulloch-Pitts and the Back Propagation Models (see Figure 26).

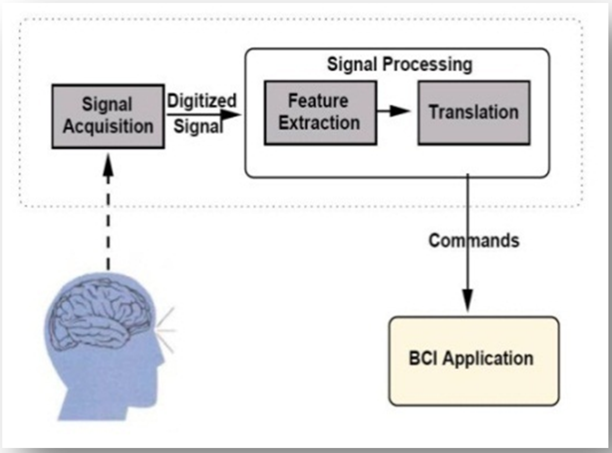


Figure 26: Block diagram of typical BCI (Fidis. (n.d.)

McCulloch-Pitts Model

The McCulloch-Pitts Model is the simplest kind of neural modelling available (McCulloch & Pitts, 1943). McCulloch and Pitts tried to understand how the brain could create highly complex patterns by using many basic cells that are connected together. They provided a very simplified model of brain cells (neurons) in their paper. These units are known as MCP neurons and a group of MCP neurons grouped together is known as an artificial neuron network. McCulloch and Pitts showed how to encode any logical proposition by an appropriate network of MCP neurons. The theory was that anything that can be done with a computer can also be done with a network of MCP neurons. The McCulloch-Pitts Model as it was implemented in the Emotiv was classified as supervised learning (see Figure 26).

Back Propagation algorithm

The Back Propagation algorithm used by the Emotiv is a supervised learning method and is a generalisation of the Delta rule (Hirose, Yamashita, & Hijiya, 1991; Horikawa, Furuhashi, & Uchikawa, 1992; Van Ooyen & Nienhuis, 1992). The Delta rule is a gradient descent learning rule for updating the weights of the artificial neurons in a single-layer perceptron. It is a well-established supervised training method that has been used over a wide range of diverse applications (Chakraborty, 2010). The Back Propagation algorithm consists of two phases, namely the propagation phase and the weight update phase, using the Delta rule. The two phases produce a ratio that influences the speed and quality of learning. This is known as the learning rate. This rate is used by the Emotiv to produce a representation of the effectiveness of a training session (in percentage). The two phases of the algorithm are repeated until the researcher is satisfied with the results.

The EPOC neuroheadset is mostly used in four fields:

- **Artistic and creative expression**
  - Use of thoughts, feeling and emotion to dynamically create colour, music, and art.
- **Life changing applications for disabled patients**
  - Controlling an electric wheelchair, mind-keyboard, or playing a hands-free game.
- **Games and virtual worlds**
  - Experience the fantasy of controlling and influencing the virtual environment with the mind. Play games developed specifically for the EPOC, or use the EmoKey to connect to current PC games and experience them in a completely new way.
- **Market research and advertising**
  - Get true insight about how people respond and feel about material presented to them. Get real-time feedback on user enjoyment and engagement.

This concludes the types of physiological metrics, a short history of each and examples of the existing technology for each metric. The researcher will now discuss the behavioural metrics.

2.5.2. BEHAVIOURAL METRICS

Investigation into verbal behaviour gives insight into one's emotional and mental state while using the product. As mentioned before, there are two types of behaviour used in HCI, namely verbal and non-verbal behaviour.

VERBAL BEHAVIOUR

Verbal behaviour includes forms and narrations of events as they are experienced, where one will make negative, neutral or positive comments on the product. These comments can then be used as data from which to draw conclusions by taking the positive to negative ratio into account.

NON-VERBAL BEHAVIOUR

Non-verbal behaviour can be very revealing about one's experience with the product. This includes facial expressions and body language (see Figure 27). Physical behaviour can be measured in a variety of ways. Some behaviours are easily observed (e.g. a smile usually indicates happiness), whereas other behaviours are more subtle and harder to observe (e.g. how to measure frustration). There is therefore a challenge to capture the data.

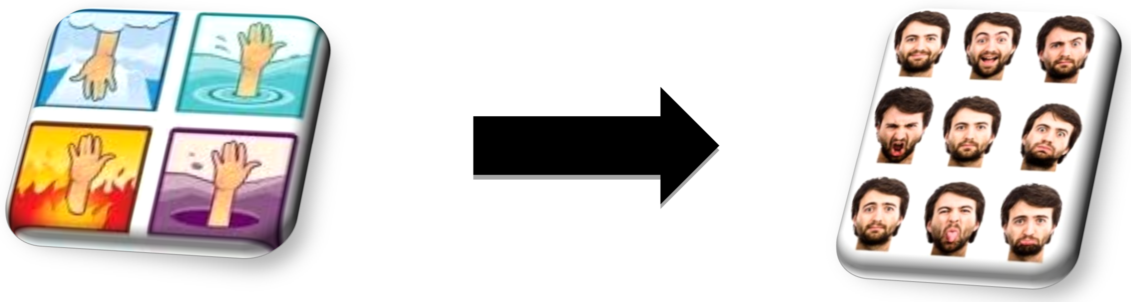


Figure 27: Represents the changes in environment that change non-verbal behaviour (No sweat public speaking, 2012)

This concludes behavioural metrics. The researcher will now discuss the binaural beats, the different types of waves used to create these binaural beats, and their uses.

2.6. BINAURAL BEATS

Binaural beats are the phenomenon that was discovered by the German researcher H. W. Dove in 1839. What he found was that binaural beating took place when separate frequencies were introduced into each ear, for example, a tone of 100 Hz in the right ear and a tone of 108 Hz in the left. The brain strives to bridge the gap by creating a third tone that is the actual difference between the two: in this example, 8 Hz (SoundRevedies.com, 2001). This creates a *frequency following* response.

Frequency following is when the brain begins to resonate with an external frequency, or follow along with the frequency. The external frequency is created using binaural beats. *Entrainment* is a term taken from physics which means *the tendency for two vibrating bodies to lock into phase so that they vibrate in harmony*. This was first observed by Dutch scientist, Christian Huygens, in 1665, while he was working on the design of the pendulum clock. He found that when he placed two of the clocks on a wall near each other and swung the pendulums at different rates, they would eventually end up swinging at the same rate. The most well-known form of brainwave entrainment is binaural beats, where a slightly different tone is presented into each ear (Mystic Mindpower, 2010).

Brainwaves have been categorised into four basic groups: Alpha, Beta, Theta, and Delta waves. Although none of these waves is ever emitted alone, the state of consciousness of the individual may make one frequency more pronounced than the others (Bio-medical.com, 2002(a)). This means that when a person is in a different mental state, a different brainwave will be dominant.

The four major brainwave states are (SoundRevedies.com, 2008):

1. Beta waves (14 to 35 Hz). These are found in the normal, waking state of consciousness. The person is alert, with a focus on the everyday activities of the

world. Beta waves are also present during states of anxiety, tension, fear, and alarm.

2. Alpha waves (8 to14 Hz). These accompany states of relaxed wakefulness, such as daydreaming and meditation. They are blocked by sensory awareness, conceptual thinking and strong emotions. Alpha waves generally appear in the occipital region of the brain (the visual cortex) when the eyes are closed.

3. Theta waves (4 to 8 Hz). These are found in near-unconscious states, very deep meditation, and as one drifts into or out of sleep. This rhythm has been connected to states of reverie and hypnogogic states that produce dreamlike imagery. It is difficult to maintain this state without training in the disciplines of meditation.

4. Delta waves (0.5 to 4 Hz). Found in the deepest part of the sleep cycle and in unconsciousness, these are the longest and slowest waves.

We can use these waves to change the participant's mental state by changing the resonate frequency of the brain, and thus changing the dominant brainwave. This concludes binaural beats. The researcher will now discuss the term *robotics*, the history of robots, the different types of robots that exist and their uses.

2.7. ROBOTICS

Robotics is the technology developed to combine software, mechanical manipulators, sensors, controllers and computers to provide programmable automation (Metro Technology Centres, 2012).

A robot is a mechanical device (mechanism) that moves around in the environment, and in so doing, physically interacts with this environment. This interaction involves the exchange of physical energy in some form or another. Figure 28 depicts the components that are part of all robotic systems (ElectronicsTeacher.com, n.d.(a)).

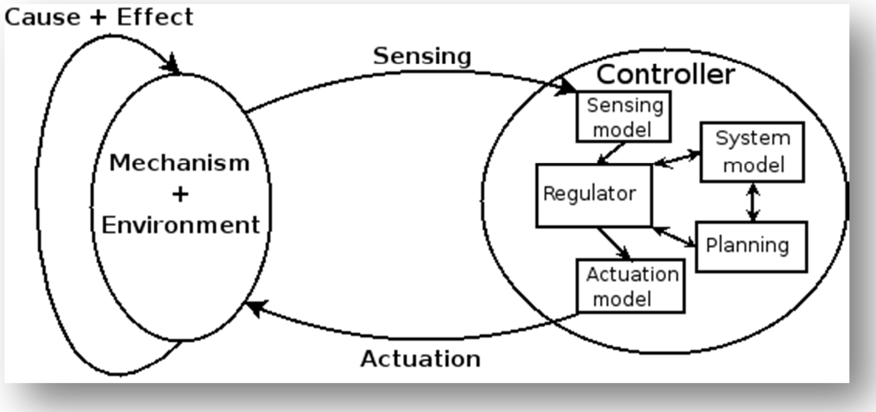


Figure 28: Components that are part of all robotic systems (ElectronicsTeacher.com, n.d.(a)).

2.7.1. HISTORY OF ROBOTS

The word *robot* was coined by the Czech playwright Karel Capek from the Czech word for *forced labour*. The use of the word robot was introduced into his play R.U.R. (Rossum's Universal Robots) which opened in Prague in January 1921 (University of Texas at Auston, n.d.).

The term *robotics* refers to the study and use of robots. The term was first used by the Russian-born American scientist and writer Isaac Asimov, who is best known for his many works of science fiction. Asimov proposed his three Laws of Robotics, and he later added a *zeroth law* (Hossain, 2011):

- Law Zero: A robot may not injure humanity, or, through inaction, allow humanity to come to harm.
- Law One: A robot may not injure a human being, or, through inaction, allow a human being to come to harm, unless this would violate a higher order law.
- Law Two: A robot must obey orders given to it by human beings, except where such orders would conflict with a higher order law.

- Law Three: A robot must protect its own existence as long as such protection does not conflict with a higher order law.

The first industrial modern robots were the Unimates developed by George Devol and Joe Engelberger in the late 50s and early 60s. Because Engelberger formed Unimation and was the first to market robots, he has been called the *father of robotics*. In the early to mid-80s the robot industry grew very rapidly, primarily due to large investments by the automotive industry (F.A.B.R.I.CATORS, 2005).

In the research community the first automata were probably Grey Walter's machine (1940s) and the Johns Hopkins beast. Tele-operated or remote controlled devices had been built even earlier with at least the first radio controlled vehicles built by Nikola Tesla in the 1890s. Tesla is better known as the inventor of the induction motor, alternating current (AC) power transmission, and numerous other electrical devices. Tesla had also envisioned smart mechanisms that were as capable as humans (Carnegie Mellon – School of Computer Science, 1996).

2.7.2. TYPES OF ROBOTS

According to Electronics Teacher (ElectronicsTeacher.com, n.d.(b)), there are six types of robots, and these will be discussed in the following section. These types of robots are mobile robots, stationary robots, autonomous robots, remote-controlled robots, virtual robots and BEAM robots.

MOBILE ROBOTS

Mobile robots are able to move and are used for tasks that are impossible for humans to perform, either because they are too dangerous or because people cannot reach the area that needs, for instance, to be searched. An example is the Mars Explorer, specifically designed to roam the surface of Mars. There are two types of mobile robots.

ROLLING ROBOTS

Rolling robots have wheels to move around. They are usually the fastest moving robots and are used for flat terrains.

WALKING ROBOTS

Robots on legs are usually used when the terrain is rocky and difficult to enter with rolling robots.

STATIONARY ROBOTS

Most of these robots work in an industry setting where they perform repetitive tasks without ever moving an inch.

AUTONOMOUS ROBOTS

These robots are self-supporting or in other words, self-contained. They run a program that gives them the opportunity to decide on the action to perform depending on their surroundings. At times these robots even learn new behaviour.

REMOTE-CONTROLLED ROBOTS

Complicated tasks are still best performed by human beings with real brainpower. A person can guide a robot by remote control, and in this way can perform difficult and usually dangerous tasks without being at the spot where the tasks are performed. To detonate a bomb, for example, it is safer to send a robot to the danger area.

VIRTUAL ROBOTS

Virtual robots are just programs – building blocks of software inside a computer. A virtual robot can simulate a real robot or just perform a repetitive task. The Internet has countless robots crawling from site to site. These *Web Crawlers* collect information on websites and send this information to the search engines.

BEAM ROBOTS

BEAM is an acronym for **B**iology, **E**lectronics, **A**esthetics and **M**echanics. These robots are made by hobbyists and can be simple and very suitable for novices.

BIOLOGY

Robots are often modelled after nature. A lot of BEAM robots look remarkably like insects. Insects are easy to build in mechanical form, and the mechanics may be motivation, while the limited behaviour can also easily be programmed in a limited amount of memory and processing power.

ELECTRONICS

Like all robots, BEAM robots also contain electronics. Without electronic circuits the engines cannot be controlled. Many BEAM robots also use solar power as their main source of energy.

AESTHETICS

A BEAM robot should look good and attractive. BEAM robots have an appealing and original appearance.

MECHANICS

In contrast to expensive big robots, BEAM robots are cheap, simple, built out of recycled material and often run on solar energy.

2.7.3. CONCLUSION

In this chapter the researcher discussed a few terms that need to be understood by the reader to follow the research described in this dissertation. This included interaction, human-computer interaction, interfaces, metrics, binaural beats and robotics. The research conducted is explained in Chapter 3.

3. RESEARCH DESIGN AND METHODOLOGY

3.1. INTRODUCTION

The previous chapter considered existing research regarding binaural beats and the Emotiv neuroheadset and also physiological and behavioural computing, binaural beats and robotics. This chapter will discuss the methodology used in the current study as well as the setup and environment in which the participants were tested. The software and hardware used for the study as well as the binaural beats, with the pre-test and post-test questionnaires, will also be discussed. Furthermore, the statistical analysis of the data is discussed.

3.2. PROCEDURE

A study was performed in order to determine if any one of the four dominant brainwaves increases participants' excitement, engagement meditation, frustration or performance when using the Emotiv EPOC neuroheadset to control a robot. The participant had to concentrate on a thought that he/she associated with forward to move the robot forward and concentrate on a thought that he/she associated with backward to move the robot backward. The researcher built a course on which the participant could move the robot. On this course were markers that displayed in percentages how much of the track was left to complete. As mentioned above, a laptop computer, binaural tones, an Emotiv headset and a Lego mindstorm robot were used.

Several terms that were used in the study are defined to avoid possible confusion:

- *Task success* means the accomplishment of the task by the participant. The extent to which it was accomplished was not taken into consideration (Tullis & Albert, 2008).

- *Time-on-task* is simply the time elapsed between the start of a task and the end of a task (Tullis & Albert, 2008).

- *Number of errors* was calculated based on the number of times the user tracked an incorrect sequence of actions (Tullis & Albert, 2008). The researcher monitored the participant while performing a task, in order to record the number of errors.

- *Efficiency* is the amount of effort and time required to complete a task. This is calculated by measuring the number of actions or steps that participants took to perform each task, along with the time that elapsed while doing it (Tullis & Albert, 2008).

- The *Emotiv Control Panel*™ is an application that configures and demonstrates the Emotiv detection suites (Emotiv Software Development Kit, 2011).

- The *Affectiv*™ is the detection suite that deciphers a user's emotional state (Emotiv Software Development Kit, 2011).

- The *Cognitiv*™ is the detection suite that evaluates a user's real time brainwave activity to discern the user's conscious intent to perform distinct physical actions on a real or virtual object (Emotiv Software Development Kit, 2011).

The initial steps followed in the study are schematically presented in Figure 29.

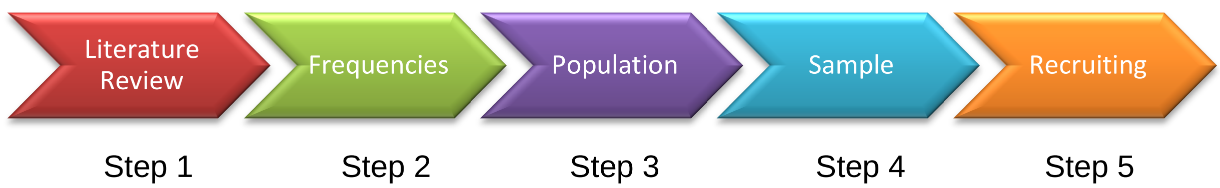


Figure 29: Schematic representation of the research design process

A more comprehensive description of the research design and methodology, based on Figure 29, will now follow.

3.2.1. LITERATURE REVIEW

In the literature review (see Figure 29, step 1) the researcher looked at interaction, human-computer interaction, interfaces, metrics, binaural beats and robotics (see Chapter 2). By doing research on these topics the researcher gained a better understanding of the terms/fields and also gained insight into previous and existing relevant technology.

3.2.2. FREQUENCIES

To create the binaural beats (see Figure 29, step 2), the researcher used the program called *Gnaural* version 1.0.20110215A (see 4.2.1). *Gnaural* is a programmable audio generator intended as an aural aid to meditation and relaxation, implementing the binaural beat principle.

The researcher created four different audio files to ensure that all frequency ranges were covered (see Figure 30):

- Audio file 1: Alpha sine wave – 12Hz
- Audio file 2: Beta sine wave – 24Hz
- Audio file 3: Delta sine wave – 2Hz
- Audio file 4: Theta sine wave – 6Hz

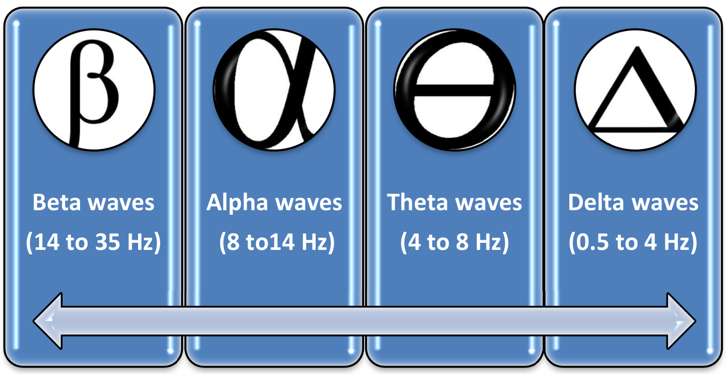


Figure 30: Different frequency ranges

The researcher used a within subjects design (see Figure 31). Within subjects design gives as many data sets as there are conditions for each participant. The fact that subjects act as their own control provides a way of reducing the amount of error arising from natural variance between individuals (Experiment-Resources.com, 2012(a)).

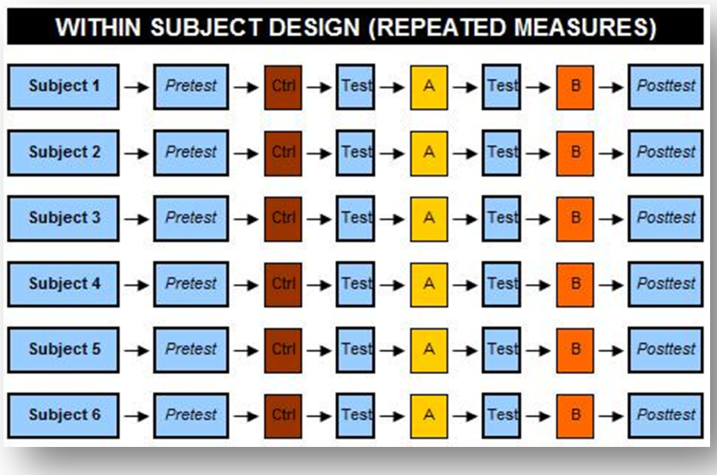


Figure 31: Within subjects design (Experiment-Resources.com, 2012(a))

Each participant was exposed to each wave and also to the control. Each participant was also exposed to all of the waves at the end of the session. The order of waves was changed in order to avoid learnability (see Table 6). This is called counter-balancing. Each participant had a unique reference number assigned to him/her. Participant P01S05G03 is taken as an example (see Figure 32):

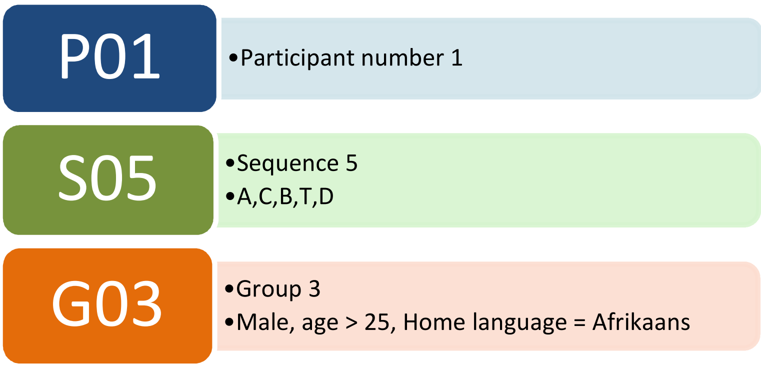


Figure 32: Unique participant number

This was the first participant (P01). Each participant was given a random sequence number between 1 and 10. If, for example, the first participant was given the number S05, the number 5 would not be available until the first 10 participants had completed the test. The participant with the sequence number S05 was exposed to the treatments in the following sequence (see Figure 33):

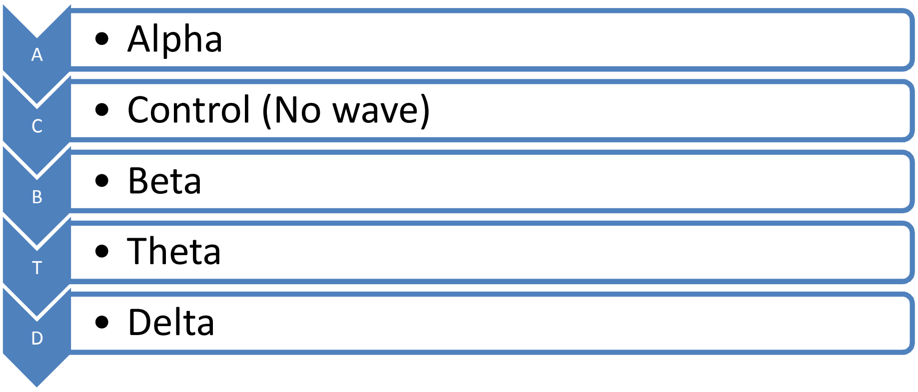


Figure 33: Sequence of treatments for participant

Table 6 shows which participant with a random sequence number received which sequence of treatments.

Table 6: Sequence of wave testing

Treatments					
Sequence NR	Treatment Sequence				
1	C	T	A	D	B
2	T	D	C	B	A
3	D	B	T	A	C
4	B	A	D	C	T
5	A	C	B	T	D
6	B	D	A	T	C
7	A	B	C	D	T
8	C	A	T	B	D
9	T	C	D	A	B
10	D	T	B	C	A

3.2.3. POPULATION

A research population (see Figure 29, step 3) is generally a large collection of individuals or objects that is the main focus of a scientific query. It is for the benefit of the population that research studies are done. However, due to the large size of populations, researchers often cannot test every individual in the population. This is the reason why researchers rely on sampling techniques (Experiment-Resources.com, 2012(b)), which will be discussed in the following sub-section.

The researcher tested any 50 people willing to participate. The participants had to fit the description of one of the following groups that are graphically represented in Figure 34.

3.2.4. SAMPLE

As mentioned above, sampling (see Figure 29, step 4) is usually done because it is impossible to test every single individual in the population. It is also done to save time, money and effort while conducting the research. The sample strategy for this study was a combination of stratified sampling and samples of convenience. Stratified sampling is when subsamples of the entire population are created to ensure that certain sample sizes are achieved for each subgroup (Tullis & Albert, 2008). The *sample of convenience* approach includes anyone willing to participate in a study (Tullis & Albert, 2008). Because of the sample of convenience approach, the researcher aimed to test at least 48 participants.

In this study the researcher had 50% male and 50% female participants (see Figure 35). All of the participants had the same amount of experience with the BCI before testing. Most of the participants were students and working at the university, thus their ages ranged between 13 and 50 years. The study was conducted on the University of the Free State's (UFS) Bloemfontein campus where most of the participants resided.

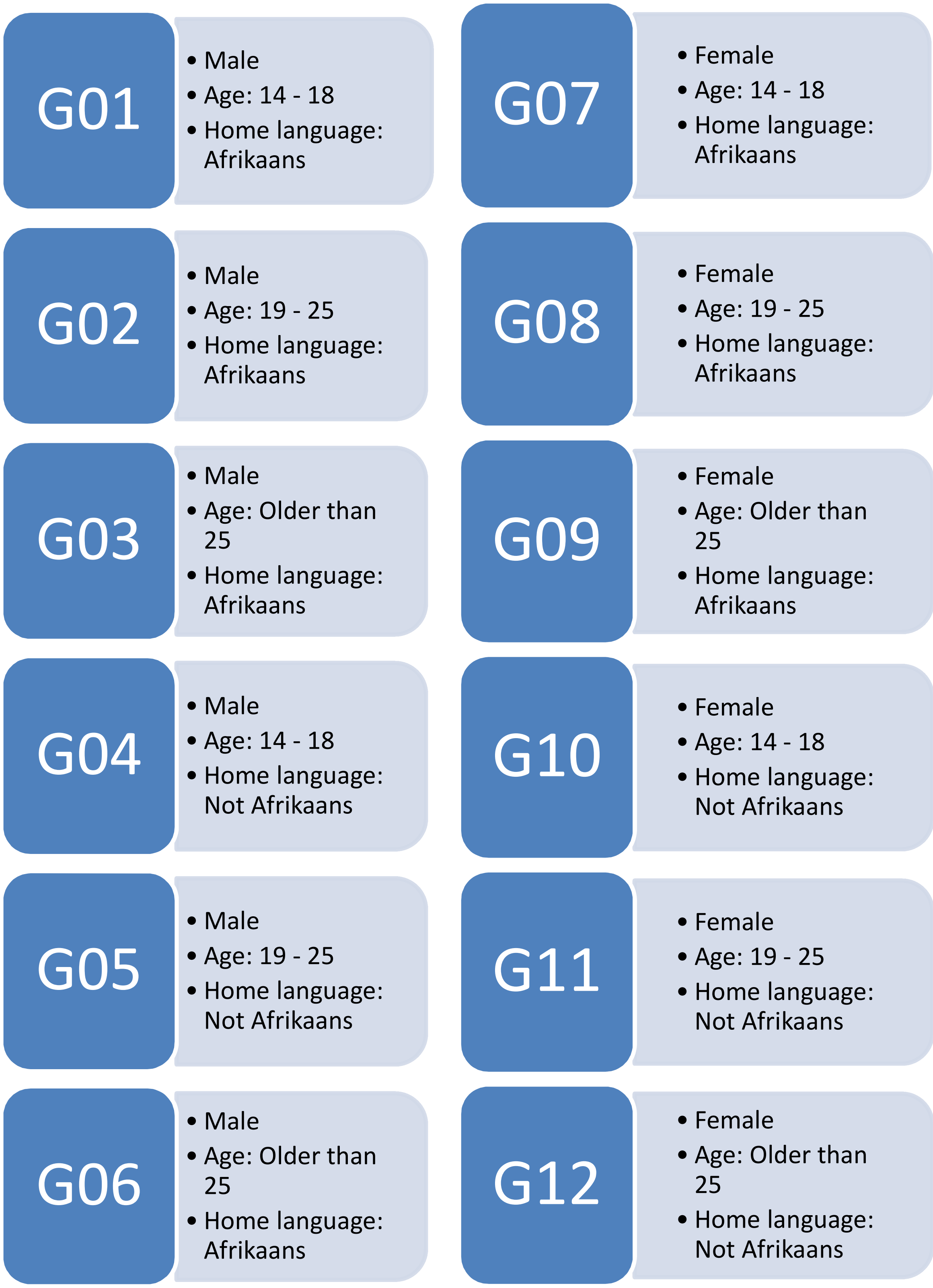


Figure 34: Population groups

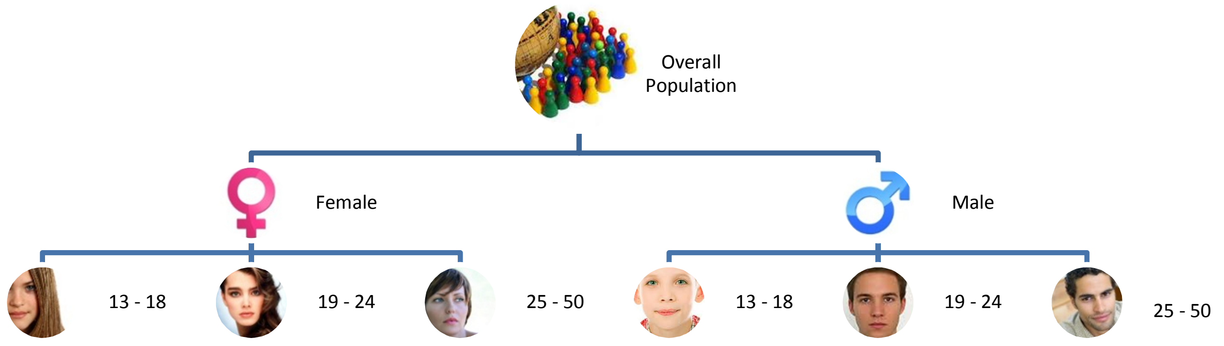


Figure 35: The population of the study

3.2.5. RECRUITING

The recruiting (see Figure 29, step 5) started with the researcher contacting participants in previous studies done by the Department of Computer Science & Informatics, University of the Free State. If the participant was interested in assisting in this study, the following steps were taken:

Participants were asked the following questions:

- Would you be interested in participating in this study?
- Would you be able to attend two sessions for this study?
- What day and time will suit you for this study?

The answers to the first two questions should have been 'Yes' for the person to be accepted as a participant. The last question was asked to set up the first session, which was also a training session.

3.3. RESEARCH DESIGN

A research design is concerned with a world view and belief system that guides an approach to the investigations made in a research study (Guba & Lincoln, 1994). It concerns the activities of a research study and describes the technique and logic of such an investigation. There was a set of shared assumptions that were made at this stage that helped to shape the study based on the environment in which it was conducted.

The practical concerns that were considered when designing this research project included (Ohioline, n.d.):

- What information was already available?
- How much money did the researcher have to spend on data collection?
- What procedures were feasible?
- Did the researcher have the staff and time to implement the data collection?

Various designs were considered in this research, all with specific advantages and disadvantages. The one chosen depended on the aims and the nature of the specific study and would affect the results and conclusion.

In the next session the researcher names and describes the possible types of research designs, namely descriptive designs, correlational studies, semi-experimental designs, experimental designs and test study before a full-scale study (Experiment-Resources.com, 2012(c)).

3.3.1. DESCRIPTIVE DESIGNS

The aim of the descriptive design is to observe and describe, and it includes descriptive research, case study, naturalistic observation and survey.

DESCRIPTIVE RESEARCH

Descriptive research design is a scientific method which involves observing and describing the behaviour of a participant without influencing it in any way. It does not fit neatly into the definition of either quantitative or qualitative research methodologies, but instead it can utilise elements of both, often within the same study. The term descriptive research refers to the type of research question, design, and data analysis that will be applied to a given topic (Educational Communications and Technology, 2001).

CASE STUDY

The case study research design has evolved over the past few years as a useful tool for investigating trends and specific situations in many scientific disciplines. It refers to the collection and presentation of detailed information about a particular participant or small group, frequently including the accounts of participants themselves. A form of qualitative descriptive research, the case study looks intensely at an individual or a small participant pool, drawing conclusions only about that participant or group and only in that specific context (Writing@csu, 2012).

NATURALISTIC OBSERVATION

In many scientific disciplines, naturalistic observation is a useful tool for expanding knowledge about a specific phenomenon or species. This technique involves observing participants in their natural environment. This type of research is often utilised in situations where conducting lab research is unrealistic, cost prohibitive or would unduly affect the participant’s behaviour (About.com Psychology, 2012(a)).

SURVEY

The survey research design is often used because of its low cost and easily accessible information. A survey may focus on factual information about individuals, or it may aim to collect the opinions of the survey takers (About.com Psychology, 2012(b)).

3.3.2. CORRELATIONAL STUDIES

The aim of correlational studies is to predict. They include case control studies, observational studies, cohort studies, longitudinal studies, cross-sectional studies and correlational studies.

CASE-CONTROL STUDY

In a case-control study the study group is defined by the outcome, not by exposure to a risk factor. The study starts with the identification of a group of cases in a given population and a group of controls under investigation (HealthKnowledge, 2009).

OBSERVATIONAL STUDY

Observational studies differ from experimental studies in that the researcher does not control the assignment of people to groups. Instead the groups are *observed*. Unlike experimental studies, observational studies do not look at the effectiveness of an intervention (Schultz & Grimes, 2002).

COHORT STUDY

A cohort study is a research program investigating a particular group with a certain trait, and observation takes place over a period of time. As the study is conducted, the outcome from participants in each cohort is measured and relationships with specific characteristics determined (The George Washington University, 2011).

LONGITUDINAL STUDY

A longitudinal study is observational research performed over a period of years or even decades. The longitudinal study design is good for looking at the effects or changes over a long period of time, usually as people age (Alleydog.com, 2012(a)).

CROSS-SECTIONAL STUDY

The cross-sectional study looks at an aspect different from the standard longitudinal study. This type of study utilises different groups of people who differ in the variable of interest, but share other characteristics such as socioeconomic status, educational background and ethnicity (About.com Psychology, 2012(c)).

CORRELATIONAL STUDY

A correlational study determines whether or not two variables are correlated. This means to study whether an increase or decrease in one variable corresponds to an increase or decrease in the other variable (Psychologyandsociety.com, 2012).

3.3.3. SEMI-EXPERIMENTAL DESIGNS

The aim of semi-experimental designs is to determine causes. They include field experiments and quasi-experimental designs.

FIELD EXPERIMENT

A field experiment is an experiment, research, or trial conducted under actual use conditions, instead of under controlled conditions in a laboratory. It is also known as a field test (BusinessDictionary.com, 2012).

QUASI-EXPERIMENTAL DESIGN

This is a type of experimental design that is very similar to the true experimental design with one key difference, namely that there is no random assignment of participants to groups (Alleydog.com, 2012(b)).

3.3.4. EXPERIMENTAL DESIGNS

The aim of experimental design is to determine causes and includes two designs, namely true experimental design and double-blind experiment.

TRUE EXPERIMENTAL DESIGN

True experimental design is regarded as the most accurate form of experimental research, in that it tries to prove or disprove a hypothesis mathematically, with statistical analysis. This design is one in which the researcher manipulates the independent variable(s) to observe its effect on some behaviour or cognitive process while using random assignment of participants to groups in order to control external factors from influencing the results (Alleydog.com, 2012(c)).

DOUBLE-BLIND EXPERIMENT

A double-blind experiment is an experimental method used to ensure impartiality and avoid errors arising from bias. In the experimental procedure neither the participants of the experiment nor the persons administering the experiment know the critical aspects of the experiment (The free dictionary, 2009(b)).

3.3.5. REVIEWING OTHER RESEARCH

The aim of the reviewing of other research is to explain. Designs include literature review, meta-analysis and systematic reviews.

LITERATURE REVIEW

A literature review is an evaluation, integrating previous research, and also explaining how it integrates into the proposed research program. This includes the process of reading, analysing, evaluating, and summarising scholarly materials about a specific topic (About.com Grammar & Composition, n.d.).

META-ANALYSIS

Meta-analysis is the use of statistical methods to combine results of different individual studies. This allows the researcher to make the best use of all the data that has been gathered by increasing the power of the analysis (Cochrane Collaboration, 2002).

SYSTEMATIC REVIEWS

A systematic review is a critical assessment and evaluation of all research studies that address a particular issue. The researchers use an organised method of locating, assembling and evaluating a body of literature on a particular topic, using a set of specific criteria (U.S. Department of Health and Human services, n.d.).

3.3.6. TEST STUDY BEFORE A FULL-SCALE STUDY

The aim of the test before a full-scale study is to determine whether the design will work. This entails a pilot study.

PILOT STUDY

A pilot study is a standard scientific tool for research, allowing scientists to conduct a preliminary analysis before committing to a full-blown study. Although not unknown in qualitative research, these are more common in large quantitative studies, since adjustment after the beginning of fieldwork is less possible than in qualitative work (AQR, 2012).

3.3.7. MIXED METHOD DESIGN

A mixed method approach is one in which the researcher collects, analyses, and integrates both quantitative and qualitative data in a single study or in multiple studies in a sustained program of inquiry (Traynor, 2006).

There are four major types of mixed methods designs (SAGE, n.d.):

- Embedded design
- Explanatory design
- Exploratory design
- Triangulation design.

EMBEDDED DESIGN

The embedded design is a mixed methods design in which one data set provides a supportive, secondary role in a study based primarily on the other data type. Here the researcher believes a single data set is not sufficient, that different questions need to be answered, and that each type of question requires different types of data. Researchers often use this design when qualitative or quantitative data needs to be included to answer the research question within a largely quantitative or qualitative study.

EXPLANATORY DESIGN

The explanatory design consists of two phases. Qualitative data helps explain or build upon initial quantitative results. This design can also be used when a researcher wants to form groups based on quantitative results and then follow up with the groups through successive qualitative research.

EXPLORATORY DESIGN

As with the explanatory design, the intent of the two-phase exploratory design is that the results of the first method (qualitative) can help develop or inform the second method (quantitative). This design is based on the premise that an exploration is needed for one of several reasons:

- measures or instruments are not available,
- variables are unknown, or
- there is no guiding framework or theory.

This design is particularly useful when a researcher needs to identify important variables to study quantitatively when the variables are unknown (SAGE, 2006).

TRIANGULATION

The purpose of this design is to obtain different but complementary data on the same topic to best understand the research problem. Researchers use this method to bring together the differing strengths and non-overlapping weaknesses of quantitative methods with those of qualitative methods. This design is used when a researcher wants to directly compare and contrast quantitative statistical results with qualitative findings or to validate or expand quantitative results with qualitative data.

A triangulation mixed methods design was used for this study. This design relied on the presentation of facts through words (qualitative) and statistical results represented by numbers (quantitative). It overcame the weaknesses of both methods and enabled multi-level analysis.

According to above-mentioned information it is clear that there are qualitative and quantitative elements in all the methods discussed. Research design is therefore often divided into two sections, namely quantitative and qualitative research.

QUALITATIVE RESEARCH

Qualitative research is directed at attaining a deep understanding of a specific organisation or event, rather than a surface description of a large sample of a population. It also aims to get a better understanding through first-hand experience, truthful reporting, and quotations of actual conversations (California State University – Long Beach, n.d.). The type of information desired can be obtained using participant observation, mail, online or telephone questionnaires and in-person interviews.

QUANTITATIVE RESEARCH

Quantitative research is all about quantifying relationships between variables. Examples of variables include weight, performance, time and treatment. Studies aimed at quantifying relationships are of two types: descriptive and experimental. In a descriptive study, no attempt is made to change behaviour or conditions – one measures things as they are. In an experimental study measurements are taken, some sort of intervention takes place, and then measurements are taken again to see what happened (Hopkins, 2000). In this study experimental data was collected using the Emotiv EPOC neuroheadset. The data was saved to a database for analysis. To acquire results from the quantitative data, measures of central tendency and measures of dispersion were used.

Central tendency refers to the *middle* value or perhaps a typical value of the data and can be calculated using the mean, median or mode of a dataset (Tullis & Albert, 2008). Measures of dispersion can be range, average deviation or variance and standard deviation (Tullis & Albert, 2008).

This study and the data are, therefore, both qualitative and quantitative (experimental) in nature. There was a need to understand and also to explain the argument by using evidence from the data and from the existing literature in order to answer the relevant research question for this study (Henning, Van Rensburg & Smit, 2004). A parallel approach by using quantitative and qualitative methods at the same time was followed, which included observation, questionnaires and user testing (The free dictionary, 2009(c)).

3.4. DATA GATHERING METHODS

The selection of a method for collecting information must balance several concerns, including resources available, credibility, analysis and reporting resources, as well as the skill of the evaluator. When choosing data collection methods there are some issues to keep in mind (Ohioline, n.d.):

Availability: The researcher may have information already available that can help answer some questions or guide the development of new guidelines.

Need for training or expert assistance: Some information collection methods will require special skill on the part of the evaluator, or perhaps staff will need to be trained to assist with the evaluation.

Pilot testing: The researcher will need to test the information collection instrument or process he designed, regardless of the form or structure. The researcher will need to plan time for this step and for any revisions that may result from this testing.

Interruption potential: The more disruptive an evaluation is to the routine of the project, the more likely it is that it will be unreliable or possibly sabotaged by those who feel they have more important things to do.

Protocol needs: In many situations, the researcher needs to obtain appropriate permission or clearance to collect information from people or other sources. The researcher will have to allow time to work through the proper channels.

Reactivity: The researcher does not want the manner in which something is asked to alter the response received. Reactivity may also be a concern if the researcher's presence during data collection may possibly alter the results.

Bias: Bias means to be prejudiced in opinion or judgment. Bias can enter the evaluation process in a variety of ways. *Reliability*: Will the researcher's evaluation process consistently measure what the researcher wants it to measure? If the researcher uses multiple interviews, settings, or observers, will they consistently measure the same thing each time?

Validity: Will the information collection methods produce information that measures what the researcher says he is measuring?
Different data collection methods that the researcher used for this study are given below:

- Performance tests: testing the ability to perform or master a particular skill (this includes the physiological testing).
- Self-ratings: a method used by participants to rank their own performance, knowledge or attitudes.
- Questionnaires: a group of questions that participants respond to verbally or in writing.
- Individual: individual's responses, opinions, and views.

As a way to gather views from participants on the use of the system, an open-ended questionnaire was used. The questionnaire also helped the researcher in getting reflections from the participants about their experiences with the integration of binaural beats and the BCI to perform tasks. The questionnaire data was captured using the Emotiv_NXT program. The analysed results of such data helped to consolidate the qualitative results that had been obtained.

Content analysis principles were used in analysing the data. These principles helped the researcher to look for patterns of understanding and problems that emerged from that data (Krippendorff, 1980).

3.5. METHODOLOGY

The study (see Figure 36) was performed in the Department of Computer Science & informatics at the UFS. A pilot study was carried out before the experiment to spot potential problems (Appendix F).

After participants had entered the room, the tasks before training or testing had to be completed (see 3.5.2). The experiment was divided into two sessions:

- Session 1: Training (see 3.5.3)
- Session 2: Testing (see 3.5.4)

All participants were treated equally to keep the data as accurate and consistent as possible.

3.5.1. PILOT STUDY

A pilot study was conducted before testing. This ensured that the experiment measured what it should, and that everything was set up correctly. Minor errors, which could potentially harm the experiment, are often found during this process. With a pilot study, one can gather information about errors and problems, and improve the design before putting a lot of effort into the real experiment.

It was deemed to be a good strategy to first have a pilot study with someone involved in the research although not too closely, and then to arrange a second pilot with a person who resembled the participant(s). These two different pilot studies gave the researcher valuable information about any potential problems in the experiment (Experiment-Resources.com, 2012(d)).

After the pilot study (see Figure 37) the researcher used the acquired information to go back and make improvements to the system. When satisfied with the system and its outputs, the training commenced.

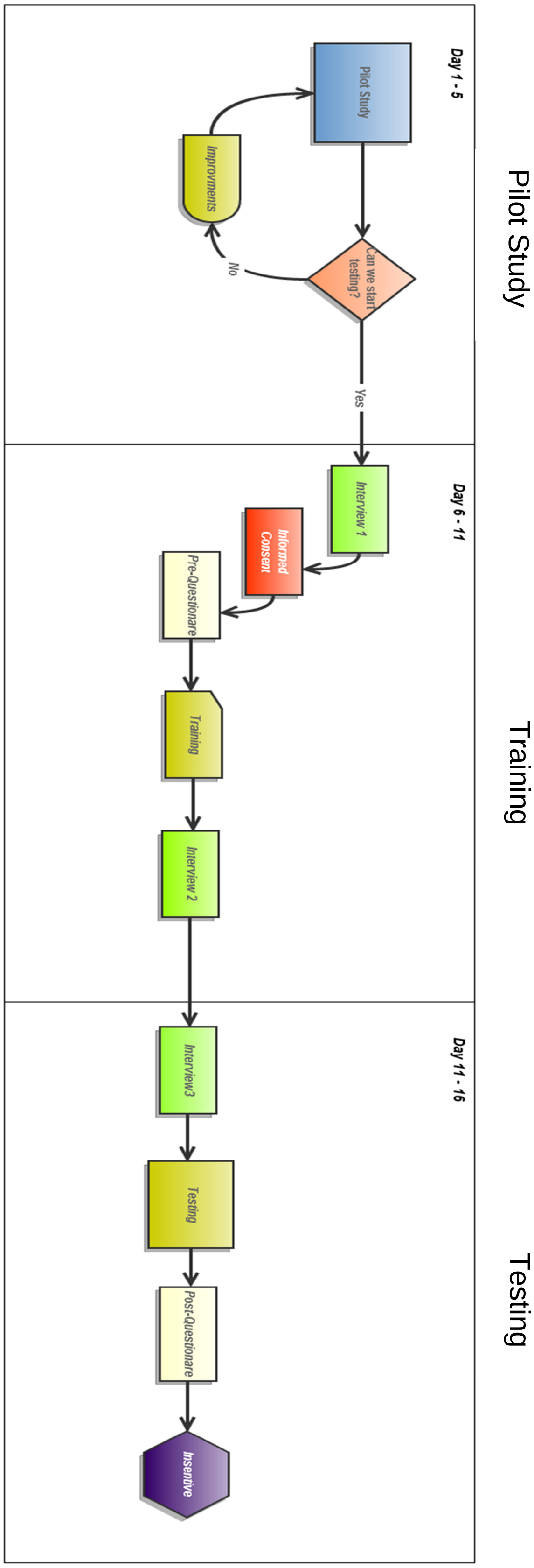


Figure 36: Schematic representation of the course of the study

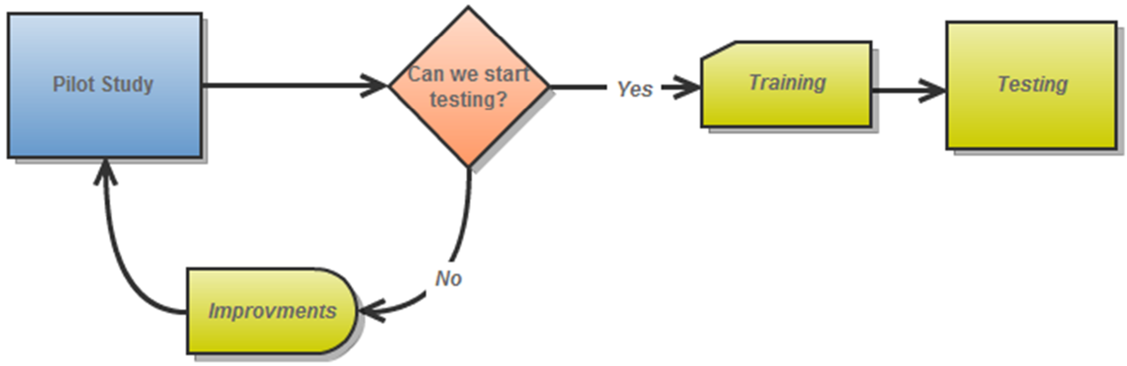


Figure 37: The pilot study

3.5.2. TASKS BEFORE TRAINING OR TESTING

At the start of all training and testing sessions the following steps were followed:

1. The mouse and chairs were positioned appropriately; a pen was provided for the participant to write with. The consent form was placed on the table where the participant was seated.
2. The computer had to be switched on.
3. The screen for the observer had to be switched on – only visible to the observer.
4. Once the computer was booted up, the Emotiv control panel 1.0.0.4 – Premium icon could be double-clicked to start the program.
5. The C# application (Emotiv_Nxt.sln), used to store the participants' details and capture the physiological data, was then started.
6. The Emotiv USB transceiver dongle was plugged into one of the computer's USB slots. A USB extension cable was used to position the transceiver in a prominent location away from the monitor and PC to improve reception.
7. The researcher ensured that the Bluetooth connection was correctly set up.
8. The Lego Mindstorm robot's battery was checked to ensure that it was charged and working properly.
9. The Saline Hydration Sensor Pack was opened with the black felt pads inside.
10. Before being mounted in the headset arms, the felt pads had to be wet with saline solution. The felt pads should be wet to the touch, but not soaking wet.

11. After the wetting process, the sensor units with their felt pads were removed from the hydrator pack and each one was inserted into the black plastic headset arms, turning each one clockwise one-quarter turn until a definite "click" was heard. The "click" indicated that each sensor was correctly installed in a headset arm.
12. The headset was then turned on, using the switch at the bottom end of the headset.
13. The Emotiv EPOC headset was then ready to mount on a participant's head. Using two hands, the headset could be slid down from the top of the participant's head and each arm adjusted accordingly to the right position. The EPOC Control Panel Headset Setup screen was used to ensure that the lights corresponded to the sensors, turning from red to green.

The researcher could then begin with the training or testing session.

3.5.3. TRAINING

The training session (see Figure 38) then followed. A short interview (see Figure 39) was held at the beginning of the training phase. The consent form was given to the participants to read and sign. The pre-questionnaire (Appendix C) was completed before the training of the participants with the Emotiv-neuroheadset commenced. After the participants received training with the Emotiv neuroheadset, a short interview (see Figure 40) was conducted.

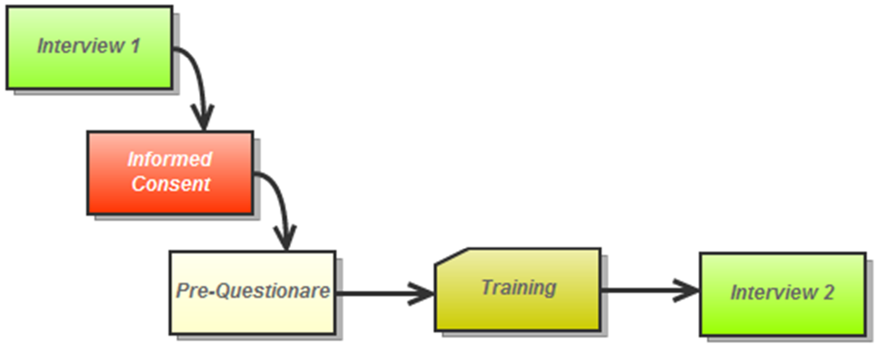


Figure 38: Training

In this interview the experiment, the consent form and the incentive were discussed.

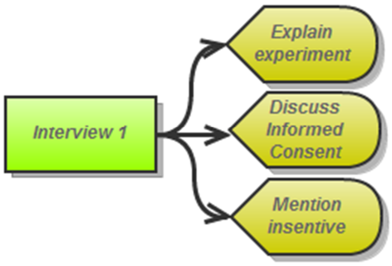


Figure 39: Interview 1

In this interview the training and the testing sessions were discussed.

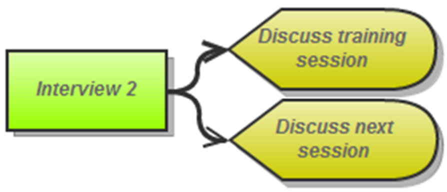


Figure 40: Interview 2

For each training session with a participant the following protocol was followed:

1. The participant was welcomed to the usability laboratory. He/she was seated and the consent form was thoroughly explained. (The usability laboratory was in a quiet environment.)
2. The consent form (see Appendix B) was handed to the participant and he/she was asked to read and sign it. He/she could ask for assistance while completing the form. Modern belief is that except in extreme circumstances, participants should be informed about any dangers before an experiment. At the very least, they should be given an informed consent policy and have the opportunity to have any data about them destroyed. Such a form was given to all participants before they were trained and tested (Dictionary.com, 2012(b)).
3. After the participant completed the consent form, his/her details (name, surname, student number and contact number) were entered into the Emotiv_Nxt.sln application and stored in the database.
4. After clicking on the Save button and closing the form the researcher now had the Physiological Data form activated. The researcher clicked the “Refresh” button and selected the participant and the session type from the drop-down list.
5. The researcher requested the participant to sit comfortably and attached the Emotiv headset. The Emotiv control panel was used to ensure that the headset sensors were all green and connected. The Affectiv Suite (which captured the participant’s physiological aspects) was explained to them.
6. The researcher switched to the Cognitiv Suite on the Emotiv Control panel and created a profile for the current participant.
7. The researcher then added the Push and Pull action to the participant’s profile.
8. The researcher switched to the training tab and trained the participant in the Neutral, Push and Pull actions.
9. After training, the Emotiv headset was switched off to save battery power and was lifted from the participant’s head.
10. The researcher then discussed the next session with the participant and set up a meeting.

The researcher could now continue to the testing phase.

3.5.4. TESTING

The testing session (see Figure 41) then followed. A short interview (see Figure 42) was held at the beginning of the testing phase. The actual testing of the participants – to acquire the research data – now took place. After testing the participants, a post-testing questionnaire had to be completed by each participant. The user then received the incentive.

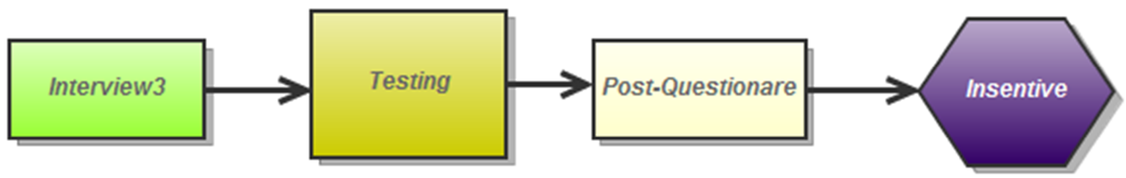


Figure 41: Testing

In this interview the testing process was explained.

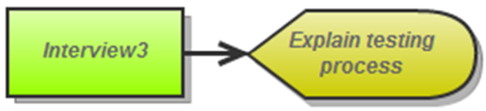


Figure 42: Interview 3

For each test session with a participant the following protocol was followed:

Step 1 to step 4 of the training session were repeated here in the testing phase, therefore the steps following step 4 will be presented. Instead of the consent form in the training session, the pre-test questionnaire was completed instead at this point in the testing phase.

5. The Lego Mindstorm robot was turned on and placed in the desired location for testing.
6. The rules (see Appendix A) and tasks (see Appendix D) were handed over and explained to the participant.
7. The stereo earphones were inserted into the participant's ears.
8. Before the test commenced, the researcher reassured the participant that any information that was captured would solely be used for research purposes and that participation was anonymous. The researcher also assured the participant that there was no wrong way to complete the tasks.
9. The binaural beat now started playing for two minutes and then continued for the duration of the task. The two minutes was needed to establish a baseline.
10. When the participants had listened to the binaural beat for two minutes, the researcher started data capturing.
11. The "Start Session" button was pressed on the Emotiv_Nxt.sln program to start capturing the participant's physiological aspects every 500 milliseconds.
12. While the participant was using the BCI to control the robot, the researcher ensured that all 14 sensors of the headset were in contact, using the Emotiv Control panel. If it occurred that the sensors were not attached properly (black-colour indicator), the sensors of the headset were reposition accordingly.
13. When the tasks were completed, the researcher clicked on the "End Session" button and saved the data.
14. When the participant had completed all the tasks, steps 3 to 5 and 9 to 13 were repeated with a different binaural beat.
15. After completing the task for all 5 sessions, the Emotiv headset was switched off to save battery power and lifted from the participant's head.
16. The post-test questionnaire was handed to the participant and he/she was asked to complete it.

The post-test questionnaire was handed back to the researcher after completion. The participant then received a R50 shopping voucher as incentive and was accompanied out of the room.

3.6. CONCLUSION

In this chapter the researcher discussed the research design chosen for this study, explained the nature of the population and sample of the study, outlined the procedures followed to complete the study and stated the data gathering methods. In the next chapter the researcher explains the tools used to be able to perform the experiment.

4. RESEARCH TOOLS

4.1. INTRODUCTION

The previous chapter considered the research design and methodology for this study. This chapter will discuss the tools the researcher used to be able to perform the experiment. This include software tools (Gnaural, Emotiv software development kit (SDK), Microsoft Robotics Developer Studio and Microsoft Visual Studio 2010) and hardware tools (Emotiv neuroheadset, Lego mindstorm robot and Acer laptop).

4.2. SOFTWARE

In this section the researcher discusses the different software programs used to create the binaural beats, a user profile, and a data capturing tool. The software includes Gnaural, Emotiv research edition SDK, Microsoft Robotics Developer Studio 2008 R3 and Microsoft Visual Studio 2010 Ultimate.

4.2.1. GNAURAL

The researcher used the program called *Gnaural* version 1.0.20110215A (see Figure 43). Gnaural is a programmable audio generator intended as an aural aid to meditation and relaxation, implementing the binaural beat principle as described in Gerald Oster's 1973 Scientific American article *Auditory Beats in the Brain* (Oster, 1973). This program is free software and can be redistributed and/or modified under the terms of the GNU General Public License as published by the Free Software Foundation.

As previously mentioned, the researcher created four different audio files to ensure that all frequency ranges were covered:

- Audio file 1: Alpha wave – 12Hz
- Audio file 2: Beta wave – 24Hz
- Audio file 3: Delta wave – 2Hz
- Audio file 4: Theta wave – 6Hz

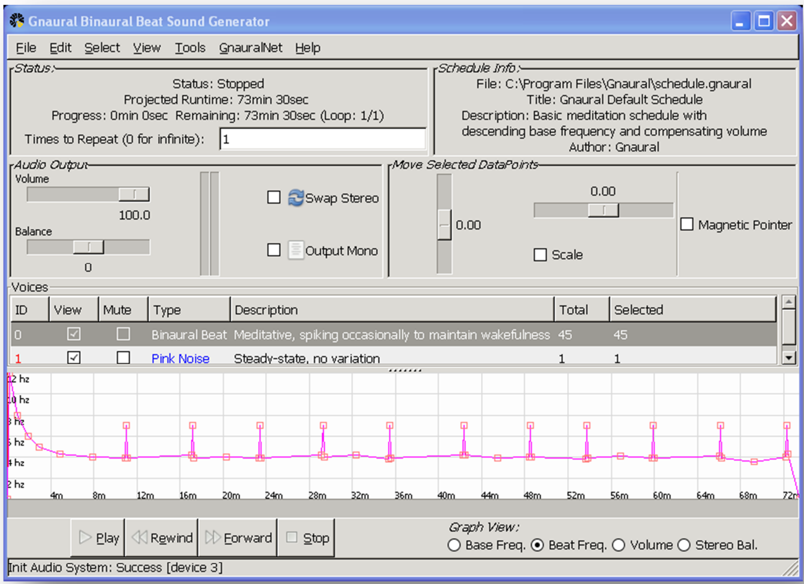


Figure 43: Gnaural user interface (Sourceforge, 2012)

4.2.2. EMOTIV RESEARCH EDITION SDK

The researcher used the Emotiv Control Panel release version 1.0.0.4 – premium and the Emotiv Research Edition SDK v1.0.0.4-PREMIUM for this study (see Figure 44). The Emotiv SDK includes a high resolution, neuro-signal acquisition and processing wireless neuroheadset, TestBench, and the proprietary software toolkit that exposes the APIs and detection libraries. This research edition consists of two *Suites,* namely the *Cognitiv* and *Affectiv* Suites.

COGNITIV SUITE

The Cognitiv Suite reads and interprets a user's conscious thoughts and intentions. Users can manipulate virtual objects using only their thoughts. The Cognitiv Suite was vital in moving the robot forward and backward in the testing phase of this research study.

AFFECTIV SUITE

The Affectiv Suite monitors user emotional states in real-time. It provides an extra dimension in game interaction by allowing the game to respond to a user's emotions. Characters can transform in response to the player's feelings. Music, scene lighting and effects can be tailored to heighten the experience for the player in real-time. The Affectiv suite can be used to monitor a user's state of mind. This Suite was used to record the participants' physiological data (long-term excitement, short-term excitement, engagement, meditation and frustration).

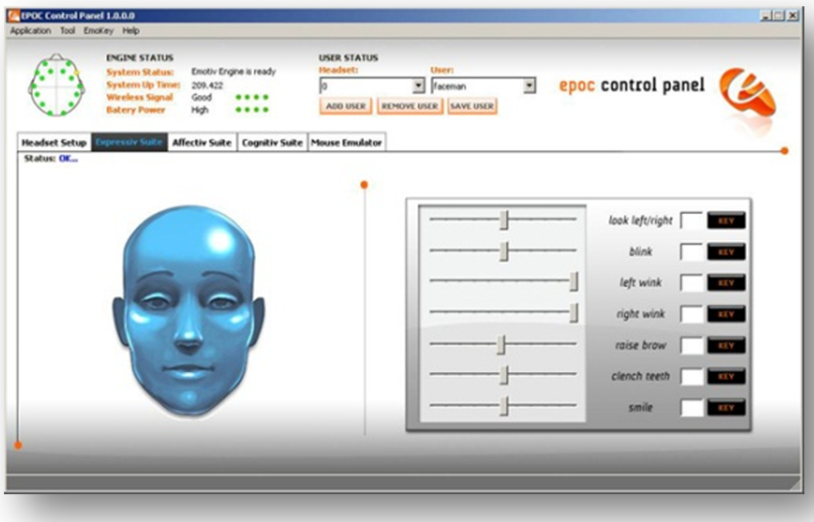


Figure 44: Emotiv control panel (Smart Device Central, n.d.)

4.2.3. MICROSOFT ROBOTICS DEVELOPER STUDIO 2008 R3

Microsoft Robotics Developer Studio (MRDS) is a Windows-based environment for robot control and simulation (see Figure 45). MRDS is based on Concurrency and Coordination Runtime (CCR): a .NET-based concurrent library implementation for managing asynchronous parallel tasks (MSDN Library, 2012(a)). This technique involves using message-passing and a services-oriented runtime, Decentralized

Software Services (DSS), which allows the organisation of multiple services to achieve complex behaviours (MSDN Library, 2012(b)).

Figure 45: Microsoft Robotics Developer Studio (Little Dreams, 2010)

4.2.4. MICROSOFT VISUAL STUDIO 2010 ULTIMATE

Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. It is used to develop console and graphical user interface applications along with Windows Forms applications, websites, web applications, and web services (see Figure 46). This software package was used to develop the software side of this study in C#.

Figure 46: Microsoft Visual Studio 2010 Ultimate (Redmond Pie, 2012)

4.3. HARDWARE

In this section the researcher discusses the different hardware used to establish an environment for testing and data collection. The hardware includes the Emotiv EPOC neuroheadset, a Lego Mindstorm NXT 2.0 robot and an Acer Travel Mate 5742G.

4.3.1. EMOTIV EPOC NEUROHEADSET

The EPOC is the first commercial BCI not to use dry sensor technology, requiring users to apply a saline solution to the head sensors (see Figure 47). The specifications of the neuroheadset are given in Table 7.

Figure 47: Emotiv EPOC model 1.0 headset (Student's Gumkhana IIT Kanpur, 2012)

Table 7: Emotiv EPOC model 1.0 headset

Number of channels	14 (plus CMS/DRL references, P3/P4 locations)
Channel names (International 10-20 locations)	AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4
Sampling method	Sequential sampling Single ADC
Sampling rate	128 SPS (2048 Hz internal)
Resolution	16 bits (14 bits effective) 1 LSB = 1.95μV

Bandwidth	0.2 - 45Hz, digital notch filters at 50Hz and 60Hz
Filtering	Built in digital 5th order Sinc filter
Dynamic range (input referred)	256mVpp
Coupling mode	AC coupled
Connectivity	Proprietary wireless, 2.4GHz band
Power	LiPoly
Battery life (typical)	12 hours
Impedance Measurement	Contact quality using patented system

4.3.2. LEGO MINDSTORM NXT 2.0 ROBOT

The intelligent NXT Lego brick features a 32-bit microprocessor, a large matrix display, 4 input and 3 output ports, and Bluetooth and USB communication links. The robot can include three interactive motors and four sensors (ultrasonic sensor, 2 touch sensors and a colour sensor). In this study none of these sensors were needed. The robot for this study used the NXT Lego brick and two drive motors (see Figure 48).

Figure 48: LEGO Mindstorm NXT 2.0 robot (Tel Aviv University, 2006)

4.3.3. ACER TRAVEL MATE 5742G

The system specifications for the Acer travel mate (see Figure 49) are given below:

- Acer Travel Mate 5742G
- Intel Core i5 CPU @ 2.67GHz
- 4GB RAM
- Windows 7 Professional 32-bit Operating System with Service Pack 1
- Bluetooth

Figure 49: Acer Travel Mate 5742G (Nefeg.com, n.d.)

All the software needed to complete this research study was loaded onto the Acer travel mate. The Bluetooth of this computer was essential for communication between the hardware and the software with the computer as the centre point of communication.

4.4. CONCLUSION

In this chapter the researcher discussed the necessary tools critical to the success of the study. In the next chapter the researcher explains the data captured and analysed and reveals the findings.

5. RESEARCH DATA AND FINDINGS

5.1. INTRODUCTION

The previous chapter discussed the research tools. The results and feedback from the participants will be analysed and discussed in this chapter. A comparison between participants' subjective indication of usability was completed.

5.2. DEMOGRAPHICAL INFORMATION

General information regarding the participants and their experience with the research tools will be discussed. Note that the data of the 5 participants used for the pilot study was not taken into consideration in the results to follow.

5.2.1. PARTICIPANTS

There were 50 participants, ranging from 13 to 50 years of age, of which 24 (48%) were females and 26 (52%) were males. The oldest participant was 50 and the youngest was 13. The participants were divided into 3 age groups: 13 to 18 years, 19 to 24 years and 25 to 50 years. Group 13 to 18 years had 16 participants (32%), group 19 to 24 had 17 participants (34%) and group 25 to 50 had 17 participants (34%). The average age of all participants was 23.84 years (see Table 8).

Table 8: Participant demographics

Information	Selective information	Total	Percentage
Gender	Male	26	52%
	Female	24	48%
Age	Average	23.84	
Home language	Afrikaans	30	60%
	English	8	16%
	Sesotho	10	20%
	Xhosa	1	2%
	Zulu	1	2%

Occupation	Student	40	80%
	Secretary	2	4%
	Accountant	1	2%
	Messenger	4	8%
	Farmer	1	2%
	IT Professional	1	2%
	Masseuse	1	2%

Most of the participants were students (80%), with the majority (66%) speaking Afrikaans as their home language. Some of the participants (16%) had English as their home language, while others spoke Sesotho (20%), Xhosa (2%) and Zulu (2%).

The participants had to indicate their familiarity with the use of technology and this discussion will follow below.

5.2.2. PARTICIPANTS' TECHNOLOGY USE

Participants had to indicate which technologies they had used before (see Table 9) and for what purpose (see Tables 10 – 14). A total of 48 (96%) participants stated that they had used a computer before and 8 (16%) participants had used a robot before. A Brain-Computer Interface (BCI) had been used by 9 (18%) participants before the study and 2 (4%) participants had used binaural tones before.

Table 9: Participants' technology use

Used before?	Total	Percentage
Computer	48	96%
Robot	8	16%
Brain-Computer interface	9	18%
Binaural tones	2	4%

COMPUTER

A total of 43 (90%) of the participants who had used a computer before, had used it for web browsing, 45 (94%) participants had used it for work or study, 27 (56%) for watching movies, 27 (56%) for games and 11 (23%) had used a computer for online shopping (see Table 10).

Table 10: Computer use

Use	Total	Percentage
Web browsing	43	90%
Work / Study	45	94%
Movies	27	56%
Games	27	56%
Shopping	11	23%

Participants were asked to indicate when last they had used a computer. Forty-four (92%) of the participants had used a computer less than 6 months ago, 1 (2%) had used it between 6 and 12 months ago and 3 (6%) had used a computer more than 12 months ago (see Table 11).

Table 11: Computer last used

When last used a computer	Total	Percentage
Less than 6 months ago	44	92%
6 to 12 months ago	1	2%
More than 12 months ago	3	6%

ROBOT

Participants were asked to state for what purpose they had used a robot before. Eight (100%) of the participants that had used a robot before had used the robot as part of a study.

BRAIN-COMPUTER INTERFACE (BCI)

Participants had to state for what purpose they had used a BCI before. Nine (100%) of the participants who had used a BCI before had used it as part of a study.

BINAURAL TONES (BTS)

Participants had to state for what purpose they had used BTs before. Two (100%) participants that have used a BT's before used it as a stimulant to improve studying.

MUSIC

The researcher also found it interesting to ask participants if they listened to music while performing a task that required concentration. Forty-two (84%) participants listened to music while working/studying.

5.3. DATA ANALYSIS

5.3.1. STUDY DESIGN

The data was collected using a balanced 5-treatment (session type), 5-period cross-over design whereby each subject was exposed to each of the 5 session types (Gaus and Högel, 1992 Arzneim-Forsch/Drug Res). Five subjects were allocated to each of the 10 different treatment sequences required by the design, so that 50 subjects participated in the trial.

5.3.2. ANALYSIS

The primary objective of the statistical analysis was to compare the five session types with respect to the following outcome variables:

1. Excitement (long)
2. Excitement (short)
3. Engagement
4. Meditation
5. Frustration

6. Duration
7. Number of errors

All statistical analyses were carried out using SAS 9.2.

5.3.3. COMPARISON OF SESSION TYPES

FIRST SIX VARIABLES

The first 6 variables above were analysed using an analysis of variance model (ANOVA model) fitted using SAS PROC MIXED. The model included the factors session type, period and participant as fixed effects.

Each of the 6 variables was analysed separately; data was available for both forward (F) and backward (B) modes and the session types were compared separately for the two types of mode.

From the ANOVA, point estimates and 95% confidence intervals were obtained for the mean measurement for session type as well as point estimates, with 95% confidence intervals and P-values for each pairwise comparison between session types.

Overall F-tests and associated P-values for session type and period were also obtained.

5.3.4. NUMBER OF ERRORS

The number of errors is a count and was therefore modelled using the Poisson distribution. The number of errors was analysed using a generalised linear model fitted using SAS PROC GENMOD. The model specified a Poisson distribution for the data, with a logarithmic link function. The factors session type, period and participant were fitted.

Each of the 5 tasks was analysed separately.

From the generalised linear model, point estimates and 95% confidence intervals were obtained for the natural logarithm of the mean number of errors for each session type, as well as point estimates and 95% confidence intervals (and associated P-values) for each pairwise comparison between session types (that is, for pairwise differences between the logarithm of mean number of errors).

These results on the logarithmic scale can be expressed on the original scale by taking the anti-log of point estimates and 95% confidence intervals. If this is done, we obtain point estimates and 95% confidence intervals for the mean number of errors for each session type, as well as point estimates and 95% confidence intervals (and associated P-values) for the pairwise **ratios** of mean number of errors between session types.

Overall F-tests and associated P-values for platform (and period) were also obtained.

5.3.5. COMPARISON OF DIRECTIONS

The *directions* refer to the backward and forward motion of the robot. The participants had to move the robot backward and forward while data was being captured.

FIRST SIX VARIABLES

The first 6 variables above were analysed using an analysis of variance model (ANOVA model) fitted using SAS PROC MIXED. The model included the factors direction and participant as fixed effects.

Data for each of the 6 variables and session types was analysed separately.

From the ANOVA, point estimates and 95% confidence intervals were obtained for the mean measurement for each direction, as well as point estimates, 95% confidence intervals and P-values for each pairwise comparison between directions.

NUMBER OF ERRORS

The number of errors was analysed using a generalised linear mixed model with random effects, fitted using SAS PROC GLIMMIX. The model specified a Poisson distribution for the data, with a logarithmic link function. The factor direction was fitted as fixed effect, and participant as random effect.

Data for each of the 6 variables and session types was analysed separately.

From the generalised linear mixed model, point estimates and 95% confidence intervals were obtained for the natural logarithm of the mean number of errors for each direction, as well as point estimates and 95% confidence intervals (and associated P-values) for each pairwise comparison between directions (that is, for pairwise differences between the logarithm of mean number of errors).

These results on the logarithmic scale can be expressed on the original scale by taking the anti-log of point estimates and 95% confidence intervals. If this is done, we obtain point estimates and 95% confidence intervals for the mean number of errors for each direction, as well as point estimates and 95% confidence intervals (and associated P-values) for the pairwise **ratios** of mean number of errors between directions.

The format of the following section will consist of the means in a table and in graphical form, a table containing the difference between means, the standard error, the P-values and the lower and upper values of the confidence interval and the differences between means in a graphical form. A discussion of the P-values and confidence intervals will then follow.

5.4. BETWEEN TREATMENTS

Here the researcher compared the different treatments (session types) to each other. The data on long-term excitement, short-term excitement, engagement, meditation and frustration can be judged on a scale from 0 to 1 (theoretical minimum and maximum values of the measurement).

5.4.1. LONG-TERM EXCITEMENT

MEAN VALUES

Considering the mean values of long-term excitement for the different session types, we find that for forward, Control had a mean value of 0.3632, Alpha 0.3334, Beta 0.3468, Delta 0.3314 and Theta 0.3500, and for backward Control 0.3698, Alpha 0.3395, Beta 0.3511, Delta 0.3482 and Theta 0.3515 (see Table 12).

Table 12: Means for long-term excitement

Treatment	Estimate	
	Forward	Backward
Control	0.3632	0.3698
Alpha	0.3334	0.3395
Beta	0.3468	0.3511
Delta	0.3314	0.3482
Theta	0.3500	0.3515

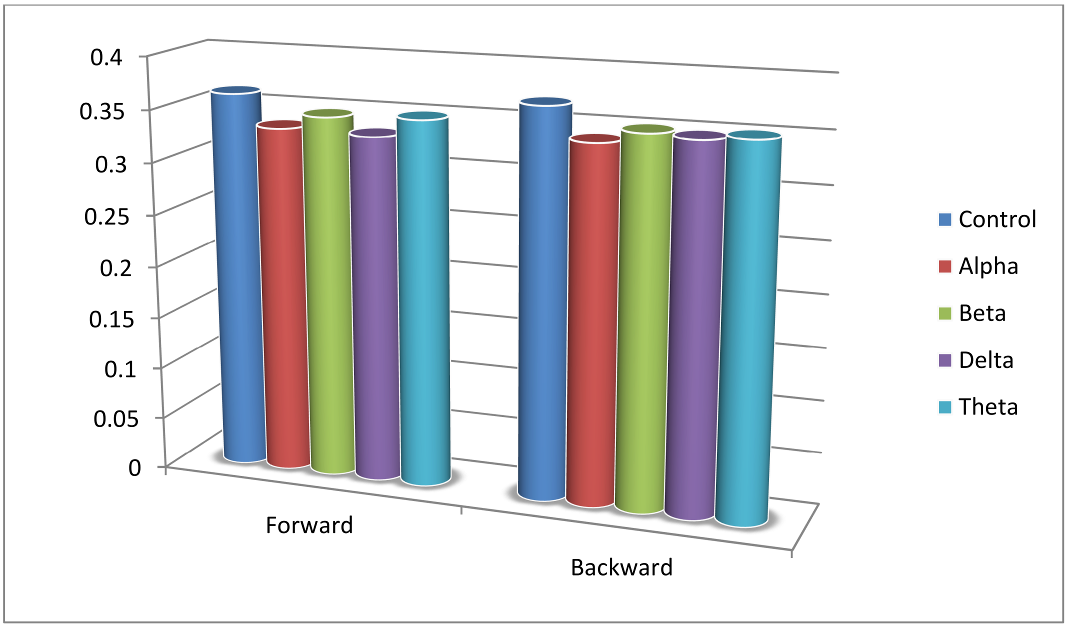
FORWARD

Long-term excitement during the Control session was the highest, followed by the Theta session, then the Beta session, the Alpha session and finally the Delta session (Graph 1). The difference between the highest value (0.3632) and the lowest value (0.3314) was 0.0318.

BACKWARD

Control session was the highest, followed by the Theta session, then the Beta session, the Delta session and finally the Alpha session (see Graph 1). The difference between the highest value (0.3698) and the lowest value (0.3395) was 0.0303.

These observed mean differences between treatments seem relatively small. However, a formal statistical comparison of the mean differences is presented below.



Graph 1: Mean values of treatments (long-term excitement)

DIFFERENCES OF MEAN VALUES

Table 13 presents the differences between the mean values for long-term excitement of the different session types, together with the associated P-values and 95% confidence intervals. The standard error of the mean differences for forward was 0.01972 and for backward was 0.02028.

Table 13: Differences of least squares means (long-term excitement)

Treatments	Estimate		P-value		Confidence interval			
					F		B	
	F	B	F	B	Lower	Upper	Lower	Upper
Control – Alpha	0.02982	0.03026	0.1322	0.1373	-0.00908	0.06872	-0.00974	0.07026
Control – Beta	0.01638	0.01867	0.4074	0.3584	-0.02252	0.05527	-0.02133	0.05867
Control – Delta	0.03176	0.02164	0.1089	0.2872	-0.00713	0.07065	-0.01835	0.06163
Control – Theta	0.01316	0.01826	0.5052	0.3690	-0.02573	0.05205	-0.02173	0.05825
Alpha – Beta	-0.01344	-0.01159	0.4962	0.5682	-0.05233	0.02545	-0.05158	0.02840
Alpha – Delta	0.001939	0.00862	0.9218	0.6713	-0.03696	0.04084	-0.04862	0.03138
Alpha – Theta	-0.01666	-0.01200	0.3993	0.5546	-0.05555	0.02223	-0.05199	0.02799
Beta – Delta	0.01538	0.002972	0.4363	0.8836	-0.02351	0.05427	-0.03702	0.04296
Beta –Theta	-0.00321	-0.00041	0.8707	0.9839	-0.04211	0.03568	-0.04041	0.03959
Delta – Theta	-0.01860	-0.00338	0.3469	0.8677	-0.05749	0.02030	-0.04338	0.03662

DIFFERENCE ESTIMATES

The estimates represent the difference between the means of treatment types, shown in the graph below (see Graph 2).

FORWARD

The biggest difference between session types is between Control and Delta (0.03176), followed by Control and Alpha (0.02982), Delta and Theta (0.0186), Alpha and Theta (0.01666), Control and Beta (0.01638), Beta and Delta (0.01538), Alpha and Beta (0.01344), Control and Theta (0.01315), Beta and Theta (0.00321) and finally Alpha and Delta (0.001939).

BACKWARD

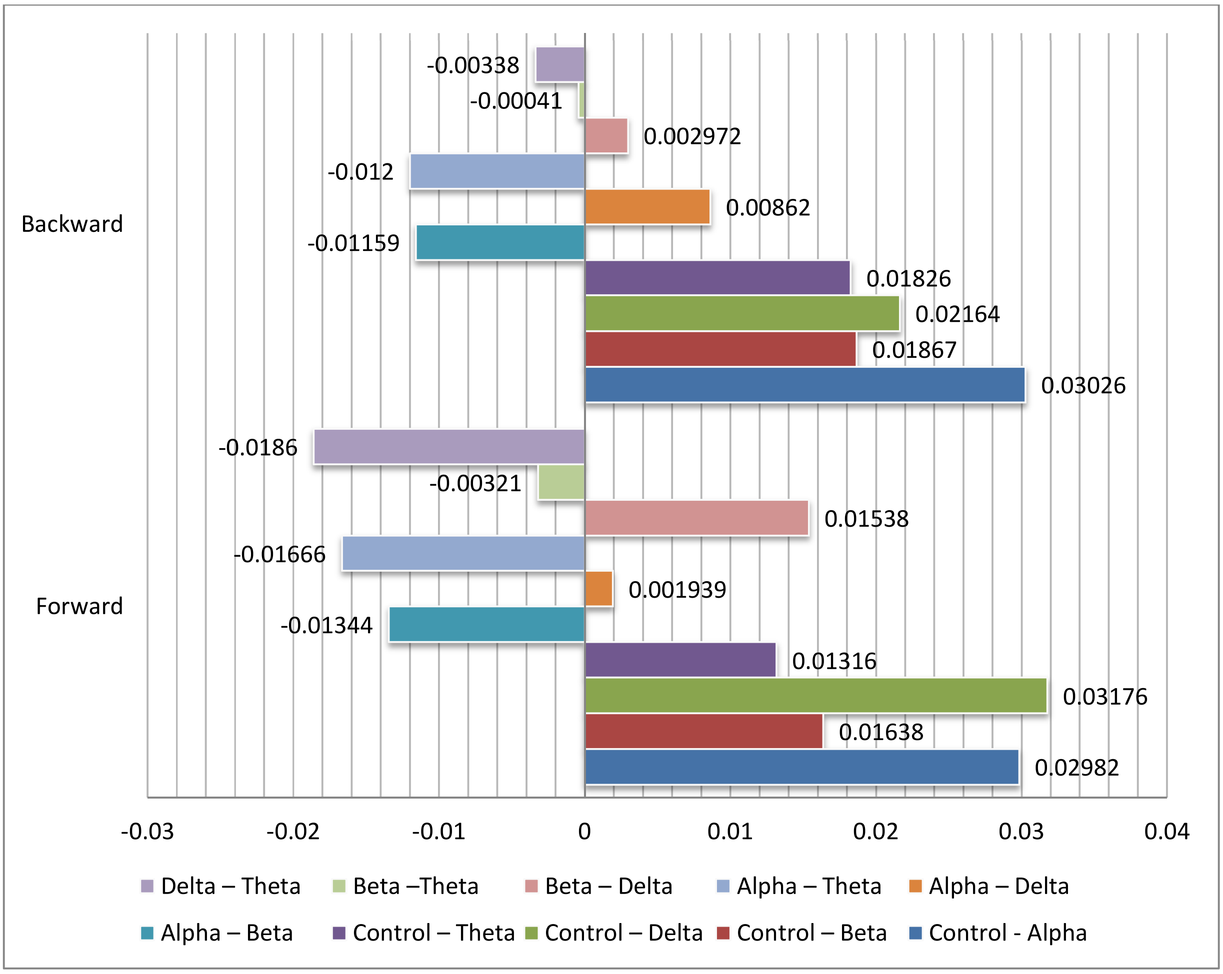
The biggest difference between session types is between Control and Alpha (0.03026), followed by Control and Delta (0.02164), Control and Beta (0.01867), Control and Theta (0.01826), Alpha and Theta (0.01200), Alpha and Beta (0.01159), Alpha and Delta (0.00862), Delta and Theta (0.00338), Beta and Delta (0.00041) and finally Beta and Theta (0.001939).

P-VALUE

The P-values associated with all differences were higher than 0.05 (see Table 13). This implies that there was no statistically significant difference between any of the mean values of sessions regarding long-term excitement.

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fall within the interval [-0.1, +0.1]. If a mean difference between sessions of 0.1 in long-term excitement can be considered not practically relevant, then it can be concluded that there are no practically relevant differences between any of the five sessions regarding long-term excitement.



Graph 2: Difference of means between treatments (long-term excitement)

FINDINGS

This study has failed to show statistically significant differences between the session types for long-term excitement. Furthermore, the confidence intervals for the mean differences suggest that there are no practically relevant differences between the treatments.

5.4.2. SHORT-TERM EXCITEMENT

MEAN VALUES

Considering the mean values of short-term excitement for the different session types, we find that for forward, Control had a mean value of 0.3371, Alpha 0.2890, Beta

0.3061, Delta 0.2912 and Theta 0.3178, and for backward Control had a mean value of 0.3251, Alpha 0.2956, Beta 0.3036, Delta 0.3074 and Theta 0.3064 (see Table 14 and Graph 3).

Table 14: Means for short-term excitement

Treatment	Estimate	
	Forward	Backward
Control	0.3371	0.3251
Alpha	0.2890	0.2956
Beta	0.3061	0.3036
Delta	0.2912	0.3074
Theta	0.3178	0.3064

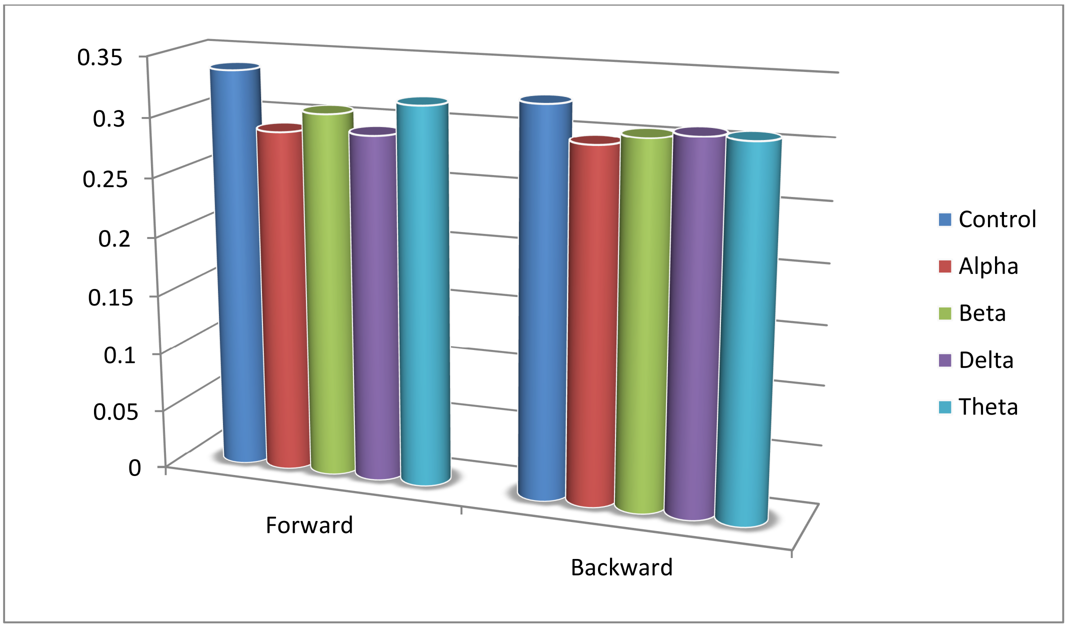
FORWARD

Short-term excitement during the Control session was the highest, followed by the Theta session, then the Beta session, the Delta session and finally the Alpha session. The difference between the highest value (0.3371) and the lowest value (0.2890) was 0.0481.

BACKWARD

Short-term excitement during the Control session was the highest, followed by the Delta session, then the Theta session, the Beta session and finally the Alpha session. The difference between the highest value (0. 3251) and the lowest value (0. 2956) was 0.0295.

These differences between treatments can thus far not be seen as significant or non-significant by the researcher.



Graph 3: Mean values of treatments (short-term excitement)

DIFFERENCES OF MEAN VALUES

The following table (see Table 15) presents the differences between the mean values for short-term excitement of the different session types, together with the associated P-values and 95% confidence intervals. The standard error for the mean differences for forward was 0.02235 and for backwards was 0.02103.

Table 15: Differences of least squares means (short-term excitement)

Treatments	Estimate		P-value		Confidence interval			
	F	B	F	B	F		B	
					Lower	Upper	Lower	Upper
Control – Alpha	0.04815	0.02942	**0.0325**	0.1634	0.004056	0.09224	-0.01205	0.07090
Control – Beta	0.03100	0.02144	0.1672	0.3092	-0.01309	0.07509	-0.02004	0.06292
Control – Delta	0.04594	0.01771	**0.0412**	0.4007	0.001861	0.09002	-0.02376	0.05918
Control – Theta	0.01930	0.01866	0.3889	0.3759	-0.02478	0.06338	-0.02281	0.06013
Alpha – Beta	-0.01715	-0.00798	0.4438	0.7047	-0.06123	0.02693	-0.04945	0.03349
Alpha – Delta	-0.00220	-0.01172	0.9216	0.5781	-0.04629	0.04189	-0.05319	0.02976
Alpha – Theta	-0.02884	-0.01076	0.1984	0.6093	-0.07293	0.01524	-0.05223	0.03071
Beta – Delta	0.01495	-0.00374	0.5045	0.8592	-0.02914	0.05903	-0.04520	0.03773
Beta –Theta	-0.01170	-0.00278	0.6014	0.8949	-0.05579	0.03239	-0.04426	0.03869
Delta – Theta	-0.02664	0.000953	0.2348	0.9639	-0.07073	0.01745	-0.04053	0.04243

DIFFERENCE ESTIMATES

The estimates represent the difference between the means of treatment types, shown in the graph below (see Graph 4).

FORWARD

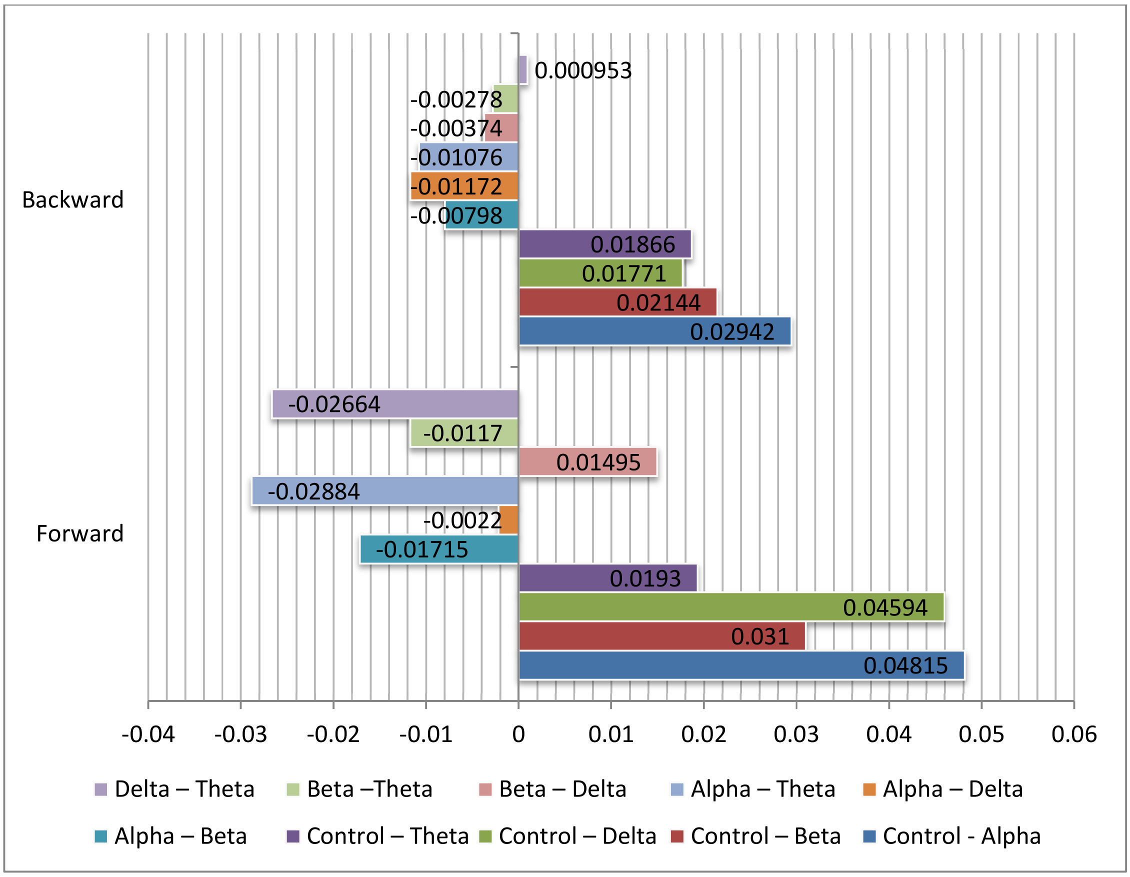
The biggest difference between session types was between Control and Alpha (0.04815) followed by Control and Delta (0.04594), Control and Beta (0.03100), Alpha and Theta (0.02884), Delta and Theta (0.02664), Control and Theta (0.0193), Alpha and Beta (0.01715), Beta and Delta (0.01495), Beta and Theta (0.0117) and finally Alpha and Delta (0.00220).

BACKWARD

The biggest difference between session types was between Control and Alpha (0.02942) followed by Control and Beta (0.02144), Control and Theta (0.01866), Control and Delta (0.01771), Alpha and Delta (0.01172), Alpha and Theta (0.01076), Alpha and Beta (0.00798), Beta and Delta (0.00374), Beta and Theta (0.00278) and finally Delta and Theta (0.000953).

P-VALUE

The P-values associated with all differences were higher than 0.05 except for Control – Alpha (0.0325) forward and Control – Delta (0.0412) forward (see Table 15). This means that the differences between these pairs of treatments were statistically significant. There was no statistically significant difference between any of the remaining mean values of sessions regarding short-term excitement.



Graph 4: Difference of means between treatments (short-term excitement)

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fell within the interval [-0.1, +0.1]. Even the confidence intervals for the statistically significant mean differences, namely Control – Alpha [0.004056, 0.09224] forward and Control – Delta [0.001861, 0.09002] forward fell within the interval [-0.1, +0.1]. If a mean difference between sessions of 0.1 in short-term excitement can be considered not practically relevant, then it can be concluded that there are no practically relevant differences between any of the five sessions regarding short-term excitement.

FINDINGS

This study has succeeded in showing statistically significant differences between the session types Control – Alpha forward and Control – Delta forward for short-term excitement, although those differences do not seem to be of practical relevance.

5.4.3. ENGAGEMENT

MEAN VALUES

Considering the mean values for engagement for the different session types, we find that for forward. Control had a mean value of 0.5482, Alpha 0.5526, Beta 0.5347, Delta 0.5582 and Theta 0.5345, while for backward, Control had a mean value of 0.5269, Alpha 0.5379, Beta 0.5241, Delta 0.5235 and Theta 0.5130 (see Table 16 and Graph 5).

Table 16: Means for engagement

Treatment	Estimate	
	Forward	Backward
Control	0.5482	0.5269
Alpha	0.5526	0.5379
Beta	0.5347	0.5241
Delta	0.5582	0.5235
Theta	0.5345	0.5130

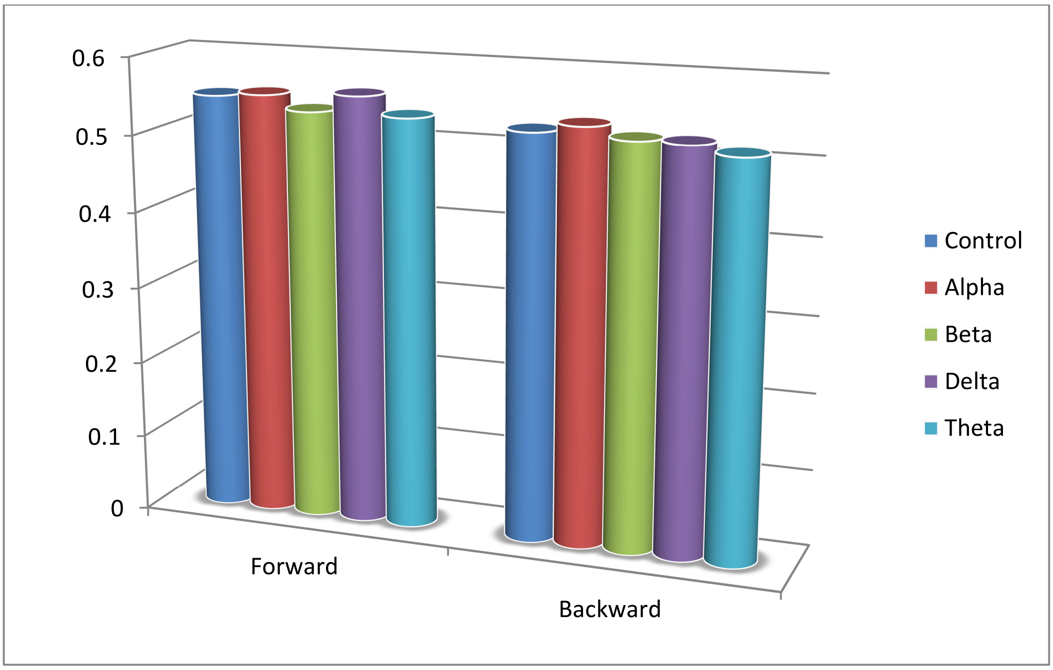
FORWARD

Engagement during the Delta session was the highest, followed by the Alpha session, then the Control session, the Beta session and finally the Theta session. These values can be judged against a scale from 0 to 1 (theoretical minimum and maximum values of the measurement). The difference between the highest value (0.5582) and the lowest value (0.5345) was 0.0237.

BACKWARD

Engagement during the Alpha session was the highest, followed by the Control session, then the Beta session, the Delta session and finally the Theta session. The difference between the highest value (0.5582) and the lowest value (0.5345) was 0.0237.

These observed mean differences between treatments seem relatively small. However, a formal statistical comparison of the mean differences is presented below.



Graph 5: Mean values of treatments (engagement)

DIFFERENCES OF MEAN VALUES

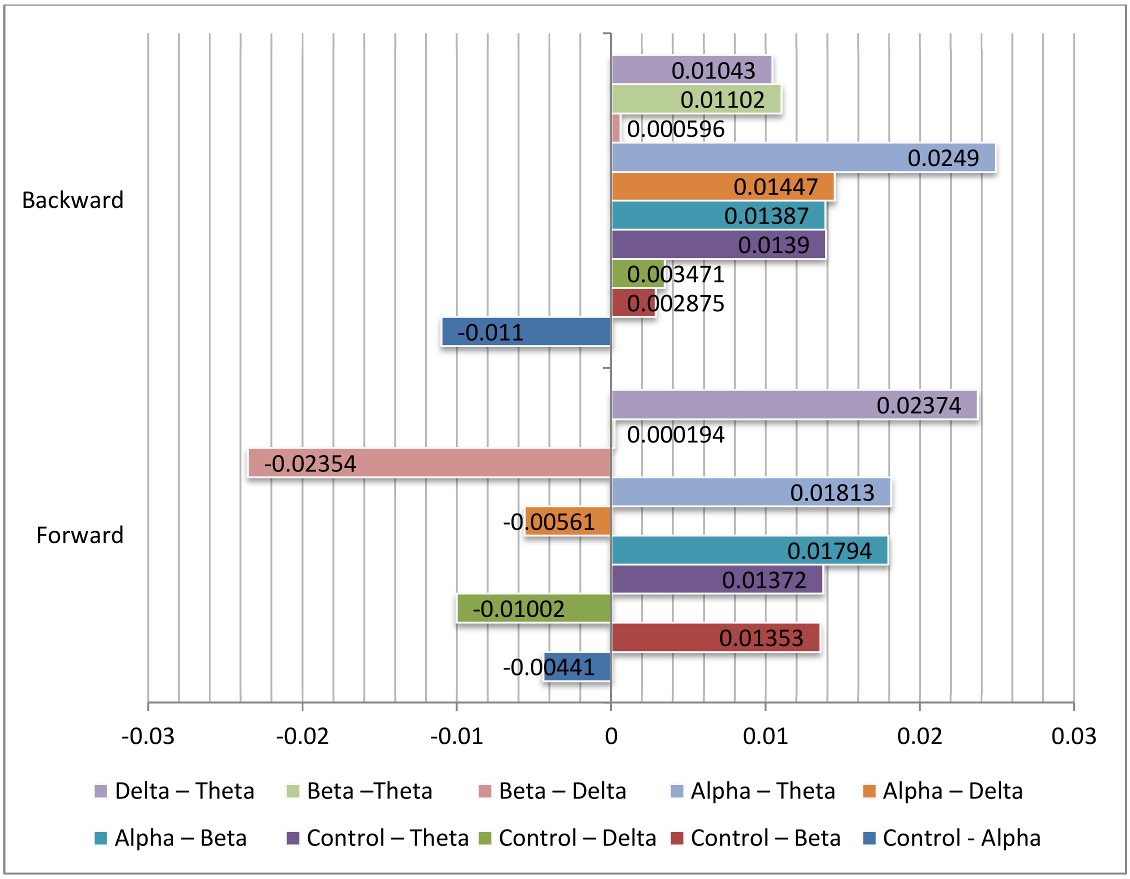
The following table (see Table 17) presents the differences between the mean values for engagement of the different session types, together with the associated P-values and 95% confidence intervals. The standard error for the mean differences for forward was 0.01600 and for backwards was 0.01378.

Table 17: Differences of least squares means (engagement)

Treatments	Estimate		P-value		Confidence interval			
					F		B	
	F	B	F	B	Lower	Upper	Lower	Upper
Control – Alpha	-0.00441	-0.01100	0.3920	0.4259	-0.03596	0.02714	-0.03818	0.01619
Control – Beta	0.01353	0.002875	0.2634	0.8350	-0.01802	0.04508	-0.02431	0.03006
Control – Delta	-0.01002	0.003471	0.7264	0.8014	-0.04156	0.02153	-0.02371	0.03065
Control – Theta	0.01372	0.01390	0.2583	0.3144	-0.01782	0.04527	-0.01328	0.04108
Alpha – Beta	0.01794	0.01387	0.1426	0.3153	-0.01360	0.04948	-0.01331	0.04105
Alpha – Delta	-0.00561	0.01447	0.9903	0.2951	-0.03716	0.02595	-0.01272	0.04165
Alpha – Theta	0.01813	0.02490	0.1394	0.0724	-0.01341	0.04968	-0.00228	0.05208
Beta – Delta	-0.02354	0.000596	0.3920	0.9655	-0.05509	0.00800	-0.02658	0.02778
Beta –Theta	0.000194	0.01102	0.2634	0.4248	-0.03136	0.03174	-0.01616	0.03821
Delta – Theta	0.02374	0.01043	0.7264	0.4502	-0.00781	0.05529	-0.01676	0.03761

DIFFERENCE ESTIMATES

The estimates represent the difference between the means of treatment types, shown in the graph below (see Graph 6).



Graph 6: Difference of means between treatments (engagement)

FORWARD

The biggest difference between session types was between Delta and Theta (0.02374), followed by Beta and Delta (0.02354), Alpha and Theta (0.01813), Alpha and Beta (0.01794), Control and Theta (0.01372), Control and Beta (0.01353), Control and Delta (0.01002), Alpha and Delta (0.00561), Control and Alpha (0.00441) and finally Beta and Theta (0.000194).

BACKWARD

The biggest difference between session types was between Alpha and Theta (0.02490), followed by Alpha and Delta (0.01447), Control and Theta (0.01390), Alpha and Beta (0.01387), Beta and Theta (0.01102), Control and Alpha (0.01100), Delta and Theta (0.01043), Control and Delta (0.003471), Control and Beta (0.002875) and finally Beta and Delta (0.000596).

P-VALUE

The P-values associated with all differences were higher than 0.05 (see Table 17). This implies that there was no statistically significant difference between any of the mean values of sessions regarding engagement.

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fell within the interval [-0.1, +0.1]. If a mean difference between sessions of 0.1 in engagement can be considered not practically relevant, then it can be concluded that there are no practically relevant differences between any of the five sessions regarding engagement.

FINDINGS

This study has failed to show statistically significant differences between the session types for engagement.

5.4.4. MEDITATION

MEAN VALUES

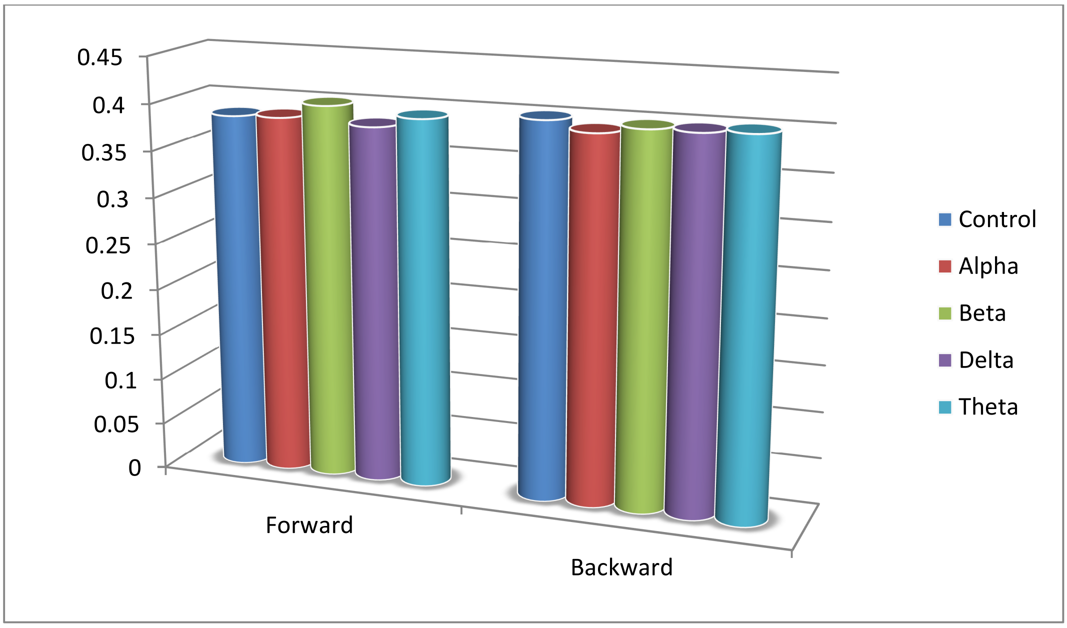
Considering the mean values of meditation for the different session types, we find that for forward, Control had a mean value of 0.3853, Alpha 0.3866, Beta 0.4021, Delta 0.3833 and Theta 0.3949; and for backward, Control had a mean value of 0.4019, Alpha 0.3921, Beta 0.3993, Delta 0.3991 Theta 0.4013 (see Table 18 and Graph 7).

Table 18: Means for meditation

Treatment	Estimate	
	Forward	Backward
Control	0.3853	0.4019
Alpha	0.3866	0.3921
Beta	0.4021	0.3993
Delta	0.3833	0.3991
Theta	0.3949	0.4013

FORWARD

Meditation during the Beta session was the highest, followed by the Theta session, then the Alpha session, the Control session and finally the Delta session. These values can be judged against a scale from 0 to 1 (theoretical minimum and maximum values of the measurement). The difference between the highest value (0.4021) and the lowest value (0.3833) was 0.0188.



Graph 7: Mean values of treatments (meditation)

BACKWARD

Meditation during the Control session was the highest, followed by the Theta session, then the Beta session, the Delta session and finally the Alpha session. The difference between the highest value (0.4019) and the lowest value (0.3921) was 0.0098.

These observed mean differences between treatments are relatively small. However, a formal statistical comparison of the mean differences is presented below.

DIFFERENCES OF MEAN VALUES

The following table (see Table 19) presents the differences between the mean values for meditation of the different session types, together with the associated P-values and 95% confidence intervals. The standard error of the mean differences for forward was 0.01014 and for backwards was 0.01041.

Table 19: Differences of least squares means (meditation)

Treatments	Estimate		P-value		Confidence interval			
	F	B	F	B	F		B	
					Lower	Upper	Lower	Upper
Control – Alpha	-0.00212	0.009880	0.9052	0.3438	-0.02121	0.01880	-0.01065	0.03041
Control – Beta	-0.03676	0.002637	0.1002	0.8003	-0.03676	0.003252	-0.01790	0.02317
Control – Delta	0.01791	0.002805	0.8369	0.7879	-0.01791	0.02209	-0.01772	0.02333
Control – Theta	-0.02952	0.000669	0.3489	0.9488	-0.02952	0.01048	-0.01986	0.02120
Alpha – Beta	-0.03554	-0.00724	0.1270	0.4873	-0.03554	0.004457	-0.02777	0.01329
Alpha – Delta	0.01670	-0.00708	0.7453	0.4975	-0.01670	0.02330	-0.02761	0.01346
Alpha – Theta	-0.02831	-0.00921	0.4133	0.3773	-0.02831	0.01169	-0.02974	0.01132
Beta – Delta	0.00116	0.000168	0.0647	0.9871	-0.00116	0.03884	-0.02036	0.02070
Beta –Theta	0.01277	-0.00197	0.4768	0.8503	-0.01277	0.02723	-0.02250	0.01857
Delta – Theta	-0.03162	-0.00214	0.2536	0.8377	-0.03162	0.008392	-0.02267	0.01840

DIFFERENCE ESTIMATES

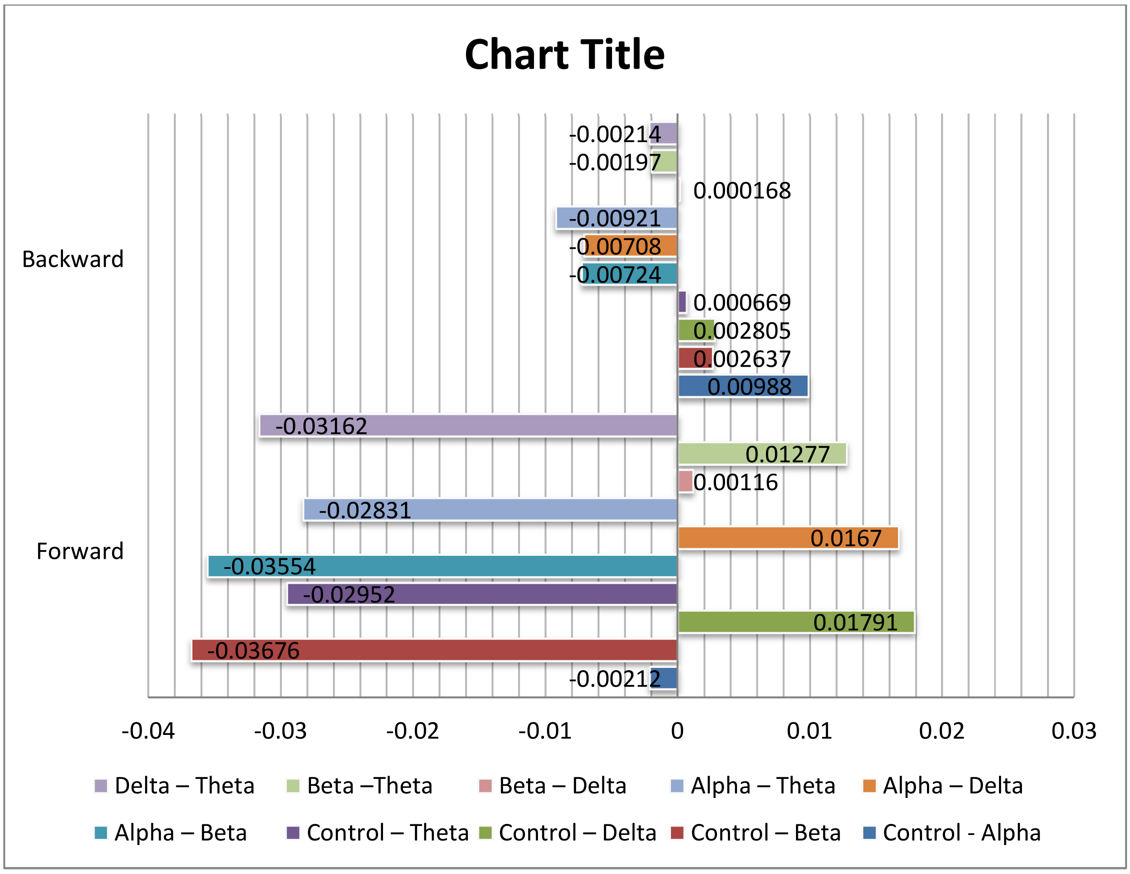
The estimates represent the difference between the means of treatment types, shown in the graph below (see Graph 8).

FORWARD

The biggest difference between session types was between Control and Beta (0.03676), followed by Alpha and Beta (0.03554), Delta and Theta (0.03162), Control and Theta (0.02952), Alpha and Theta (0.02831), Control and Delta (0.01791), Alpha and Delta (0.01670), Beta and Theta (0.01277), Control and Alpha (0.00212) and finally Beta and Delta (0.00116).

BACKWARD

The biggest difference between session types was between Control and Alpha (0.009880), followed by Alpha and Theta (0.00921), Alpha and Beta (0.00724), Alpha and Delta (0.00708), Control and Delta (0.002805), Control and Beta (0.002637), Delta and Theta (0.00214), Beta and Theta (0.00197), Control and Theta (0.000669) and finally Beta and Delta (0.000168).



Graph 8: Difference of means between treatments (meditation)

P-VALUE

The P-values associated with all differences were higher than 0.05 (see Table 19). This implies that there was no statistically significant difference between any of the mean values of sessions regarding meditation.

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fell within the interval [-0.1, +0.1]. If a mean difference between sessions of 0.1 in meditation can be considered not practically relevant, then it can be concluded that there are no practically relevant differences between any of the five sessions regarding meditation.

FINDINGS

This study has failed to show statistically significant differences between the session types for meditation. Furthermore, the confidence intervals for the mean differences suggest that there are no practically relevant differences between the treatments.

5.4.5. FRUSTRATION

MEAN VALUES

Considering the mean values of frustration for the different session types, we find that for forward, Control had a mean value of 0.5004, Alpha 0.5391, Beta 0.5039, Delta 0.5113 and Theta 0.5290, and for backward, Control had a mean value of 0.5428, Alpha 0.5141, Beta 0.5254, Delta 0.5151 and Theta 0.5335 (see Table 20 and Graph 9). These values can be judged against a scale from 0 to 1 (theoretical minimum and maximum values of the measurement).

Table 20: Means for frustration

Treatment	Estimate	
	Forward	Backward
Control	0.5004	0.5428
Alpha	0.5391	0.5141

Beta	0.5039	0.5254
Delta	0.5113	0.5151
Theta	0.5290	0.5335

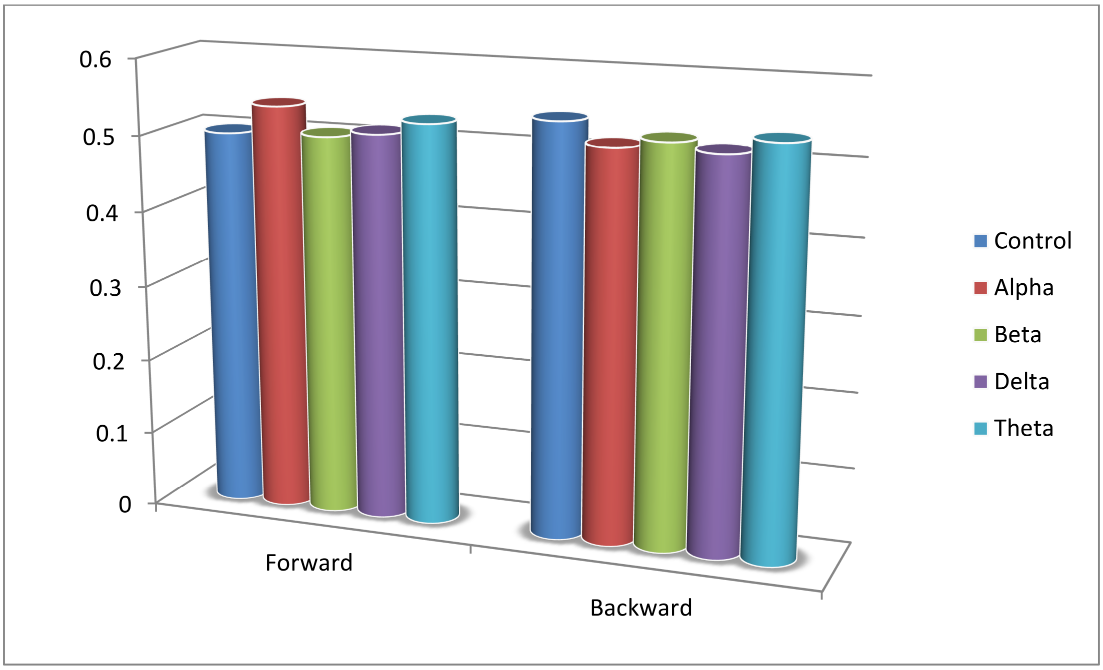
FORWARD

Frustration during the Alpha session was the highest, followed by the Theta session, then the Delta session, the Beta session and finally the Control session. The difference between the highest value (0.5391) and the lowest value (0.5004) was 0.0387.

BACKWARD

Frustration during the Control session was the highest, followed by the Theta session, then the Beta session, the Delta session and finally the Alpha session. The difference between the highest value (0.5428) and the lowest value (0.5141) was 0.0287.

These observed mean differences between treatments seem relatively small. However, a formal statistical comparison of the mean differences is presented below.



Graph 9: Mean values of treatments (frustration)

DIFFERENCES OF MEAN VALUES

The following table (see Table 21) presents the differences between the mean values for frustration of the different session types, together with the associated P-values and 95% confidence intervals. The standard error for forward was 0.02595 and the mean difference for backwards was 0.02292.

Table 21: Differences of least squares means (frustration)

Treatments	Estimate		P-value		Confidence interval			
					F		B	
	F	B	F	B	Lower	Upper	Lower	Upper
Control – Alpha	-0.03869	0.02873	0.1376	0.2115	-0.08987	0.01249	-0.01647	0.07394
Control – Beta	-0.00347	0.01740	0.8937	0.4486	-0.05465	0.04771	-0.02781	0.06261
Control – Delta	-0.01085	0.02775	0.6761	0.2273	-0.06202	0.04031	-0.01745	0.07295
Control – Theta	-0.02856	0.009292	0.2723	0.6856	-0.07973	0.02261	-0.03591	0.05449
Alpha – Beta	0.03522	-0.01133	0.1762	0.6215	-0.01595	0.08638	-0.05653	0.03387
Alpha – Delta	0.02783	-0.00098	0.2848	0.9659	-0.02334	0.07901	-0.04619	0.04423
Alpha – Theta	0.01013	-0.01944	0.6966	0.3973	-0.04104	0.06130	-0.06464	0.02576
Beta – Delta	-0.00738	0.01035	0.7763	0.6520	-0.05855	0.04379	-0.03485	0.05555
Beta –Theta	-0.02509	-0.00811	0.3348	0.7239	-0.07627	0.02609	-0.05332	0.03710
Delta – Theta	-0.01770	-0.01846	0.4958	0.4216	-0.06888	0.03347	-0.06367	0.02675

DIFFERENCE ESTIMATES

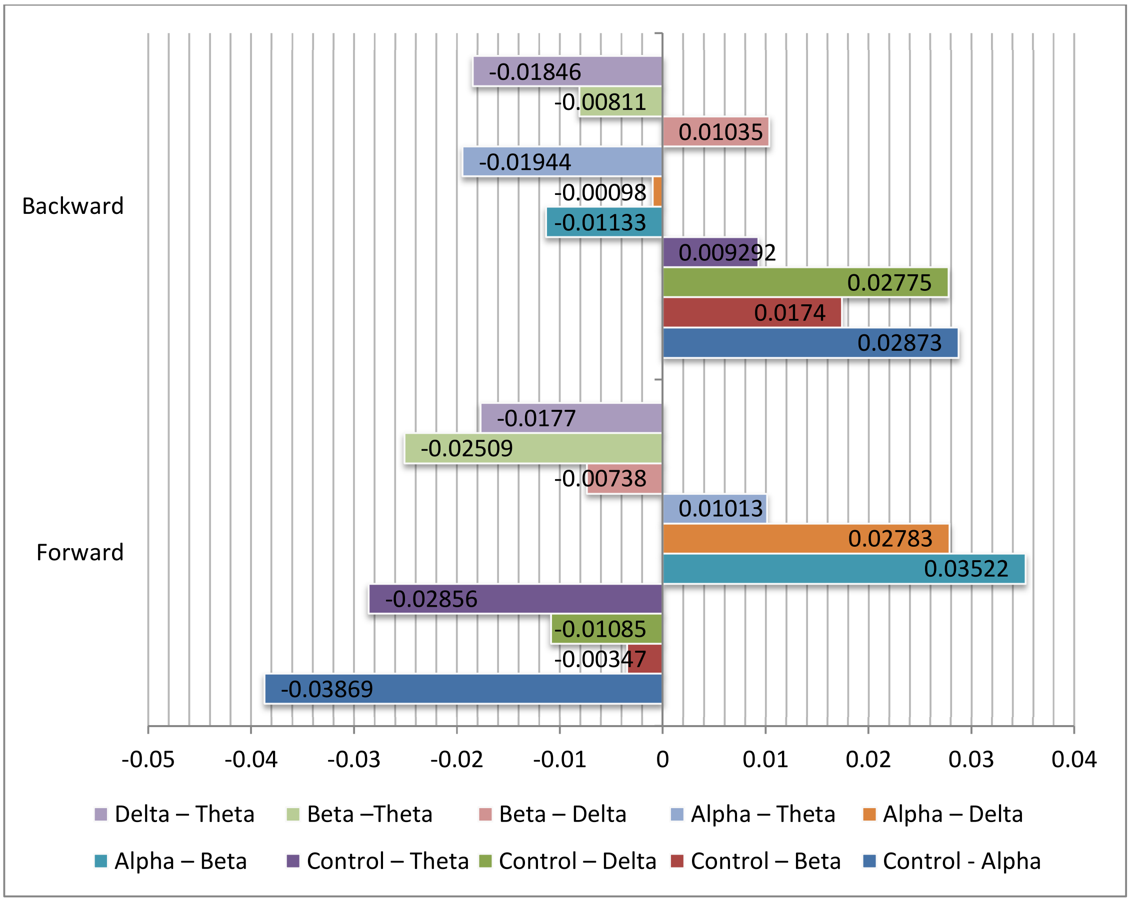
The estimates represent the difference between the means of treatment types, shown in Graph 10.

FORWARD

The biggest difference between session types was between Control and Alpha (0.03869), followed by Alpha and Beta (0.03522), Control and Theta (0.02856), Alpha and Delta (0.02783), Beta and Theta (0.02509), Delta and Theta (0.01770), Control and Delta (0.01085), Alpha and Theta (0.01013), Beta and Delta (0.00738) and finally Control and Beta (0.00347).

BACKWARD

The biggest difference between session types was between Control and Alpha (0.02873), followed by Control and Delta (0.02775), Alpha and Theta (0.01944), Delta and Theta (0.01846), Control and Beta (0.01740), Alpha and Beta (0.01133), Beta and Delta (0.01035), Alpha and Delta (0.009292), Beta and Theta (0.00811) and finally Control and Beta (0.00098).



Graph 10: Difference of means between treatments (frustration)

P-VALUE

The P-values associated with all differences were higher than 0.05 (see Table 21). This implies that there was no statistically significant difference between any of the mean values of sessions regarding frustration.

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fell within the interval [-0.1, +0.1]. If a mean difference between sessions of 0.1 in frustration can be considered not practically relevant, then it can be concluded that there are no practically relevant differences between any of the five sessions regarding frustration.

FINDINGS

This study has failed to show statistically significant differences between the session types for frustration. Furthermore, the confidence intervals for the mean differences suggest that there are no practically relevant differences between the treatments.

5.4.6. DURATION

MEAN VALUES

Considering the mean values of duration for the different session types, we find that for forward, Control had a mean value of 102.34, Alpha 91.3953, Beta 97.3545, Delta 95.2192 and Theta 95.0298, and for backward, Control had a mean value of 102.5, Alpha 101.94, Beta 101.35, Delta 102.55 and Theta 99.7394 (see Table 22 and Graph 11). The maximum duration for one session could have been 120 seconds.

Table 22: Means for duration

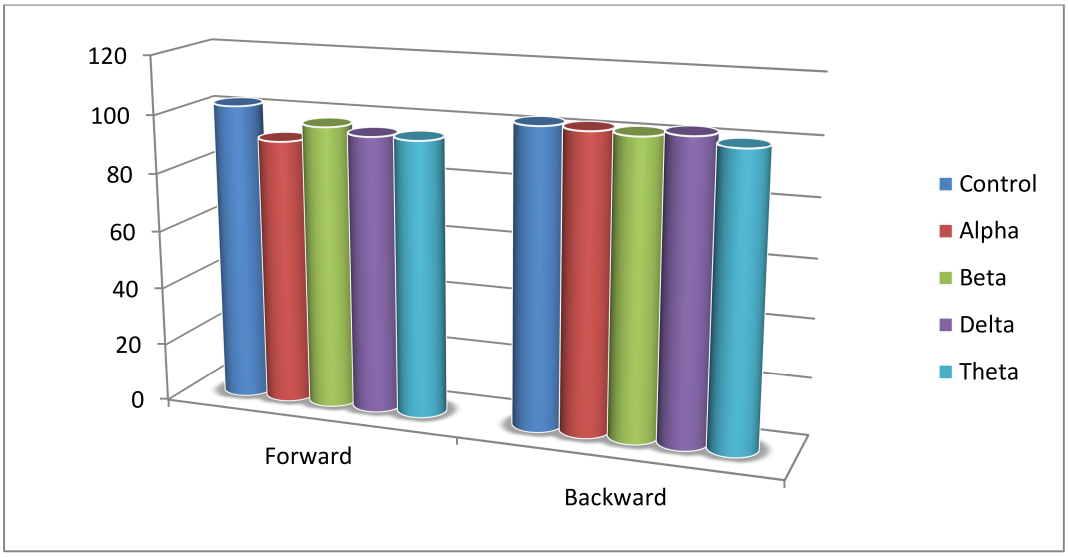
Treatment	Estimate	
	Forward	Backward
Control	102.34	102.5
Alpha	91.3953	101.94
Beta	97.3545	101.35
Delta	95.2192	102.55
Theta	95.0298	99.7394

FORWARD

The duration of the Control session was the longest, followed by the Beta session, then the Delta session, the Theta session and finally the Alpha session. These values are given in seconds. The maximum duration could have been 120. The difference between the highest value (102.34) and the lowest value (91.3953) was 10.9447.

BACKWARD

Duration of the Delta session was the longest, followed by the Control session, then the Alpha session, the Beta session and finally the Theta session. These values are given in seconds. The difference between the highest value (102.55) and the lowest value (99.7394) was 2.8106.



Graph 11: Mean values of treatments (duration)

DIFFERENCES OF MEAN VALUES

The following table (see Table 23) presents the differences between the mean values for the duration of the different session types, together with the associated P-values and 95% confidence intervals. The standard error for the mean differences for forward was 2.3961and for backwards was 2.1898.

DIFFERENCE ESTIMATES

The estimates represent the difference between the means of treatment types, shown in Graph 12.

Table 23: Differences of least squares means (duration)

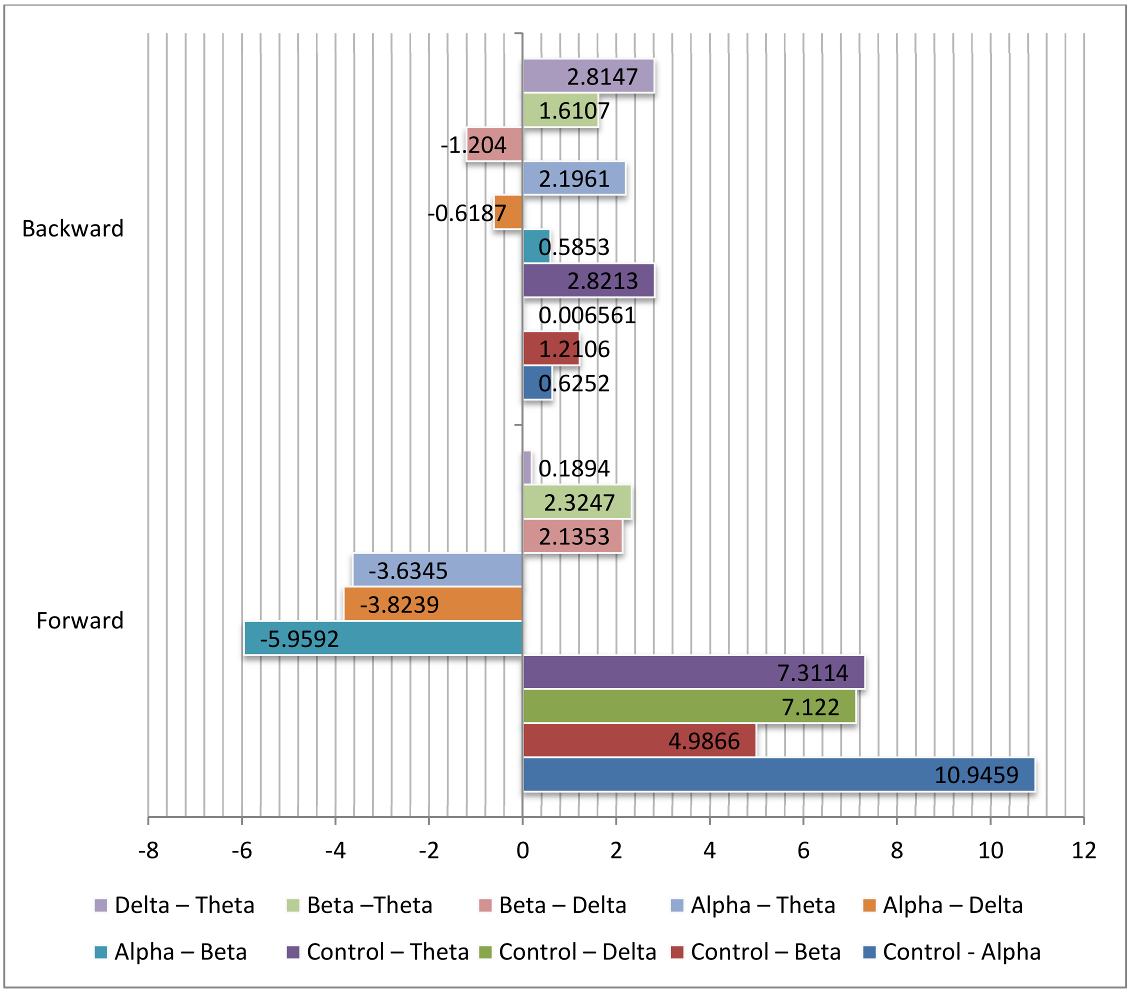
Treatments	Estimate		P-value		Confidence interval			
					F		B	
	F	B	F	B	Lower	Upper	Lower	Upper
Control – Alpha	10.9459	0.6252	**<.0001**	0.7756	6.2199	15.6719	-3.6939	4.9444
Control – Beta	4.9866	1.2106	**0.0387**	0.5810	0.2606	9.7127	-3.1086	5.5297
Control – Delta	7.1220	0.006561	**0.0033**	0.9976	2.3969	11.8470	-4.3117	4.3248
Control – Theta	7.3114	2.8213	**0.0026**	0.1991	2.5863	12.0365	-1.4970	7.1396
Alpha – Beta	-5.9592	0.5853	0.0137	0.7895	-10.6843	-1.2342	-3.7329	4.9036
Alpha – Delta	-3.8239	-0.6187	0.1122	0.7778	-8.5499	0.9021	-4.9378	3.7005
Alpha – Theta	-3.6345	2.1961	0.1309	0.3171	-8.3596	1.0906	-2.1222	6.5144
Beta – Delta	2.1353	-1.2040	0.3739	0.5830	-2.5897	6.8604	-5.5223	3.1143
Beta –Theta	2.3247	1.6107	0.3332	0.4629	-2.4013	7.0508	-2.7084	5.9299
Delta – Theta	0.1894	2.8147	0.9371	0.2002	-4.5366	4.9154	-1.5044	7.1339

FORWARD

The biggest difference between session types was between Control and Alpha (10.9459), followed by Control and Theta (7.3114), Control and Delta (7.1220), Alpha and Beta (5.9592), Control and Beta (4.9866), Alpha and Delta (3.8239), Alpha and Theta (3.6345), Beta and Theta (2.3247), Beta and Delta (2.1353) and finally Delta and Theta (0.1894).

BACKWARD

The biggest difference between session types was between Control and Theta (2.8213), followed by Delta and Theta (2.8147), Alpha and Theta (2.1961), Beta and Theta (1.6107), Control and Beta (1.2106), Beta and Delta (1.2040), Control and Alpha (0.6252), Alpha and Delta (0.6187), Alpha and Beta (0.5853) and finally Control and Delta (0.006561).



Graph 12: Difference of means between treatments (forward)

P-VALUE

The P-values associated with all differences were smaller than 0.05 (see Table 23), except for Alpha – Delta forward, Alpha – Theta forward, Beta – Delta forward, Beta – Theta forward, and Delta – Theta forward. This implies that there were statistically significant differences between the mean values of sessions Control – Alpha forward, Control – Beta forward, Control – Delta forward, Control – Theta forward, and Alpha – Beta forward regarding the duration.

CONFIDENCE INTERVAL

For sessions Control – Alpha forward [6.2199, 15.6719], Control – Beta forward [0.2606, 9.7127], Control – Delta forward [2.3969, 11.8470], Control – Theta forward [2.5863, 12.0365] and Alpha – Beta forward [-10.6843, -1.2342] the confidence intervals were not grouped around the value zero (no difference). Either the upper or the lower confidence limits exceeded the value of 10, which implies that these statistically significant differences might be of practical relevance. For the rest of the sessions, the confidence intervals were grouped around the value zero (no difference).

FINDINGS

Regarding the forward motion, the results suggest that all sessions had statistically significant shorter durations than the control session, although those differences do not seem to be of practical relevance. The shortest duration was observed for the Alpha session. In contrast, for the backward motion, no statistically significant differences were observed.

5.4.7. ERRORS

MEAN VALUES

Considering the mean values of errors for the different session types, we find that for forward, Control had a mean value of 5.3956, Alpha 3.8768, Beta 5.3052, Delta 4.6258 and Theta 4.8057 and for backward, Control had a mean value of 5.8002, Alpha 5.6219, Beta 6.2021, Delta 5.8093 and Theta 5.5335 (see Table 24 and Graph 13). There was a minimum value of 0 and no maximum value of the measurement.

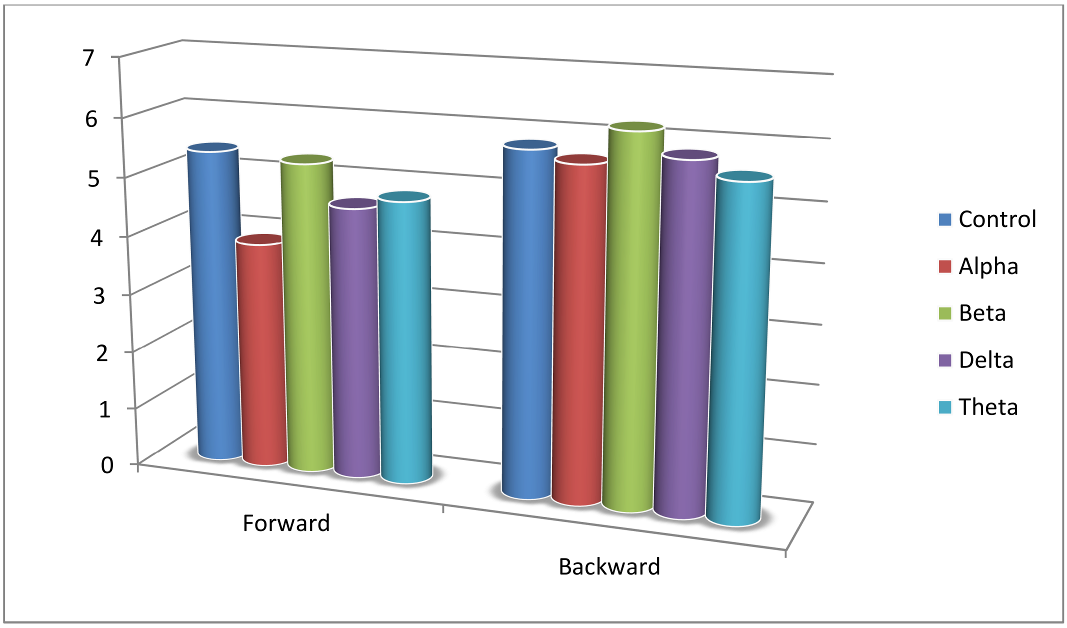
Table 24: Geometric means for errors

Treatment	Estimate	
	Forward	Backward
Control	5.3956	5.8002
Alpha	3.8768	5.6219
Beta	5.3052	6.2021

Delta	4.6258	5.8093
Theta	4.8057	5.5335

FORWARD

The mean number of errors during the Control session was the highest, followed by the Beta session, then the Theta session, the Delta session and finally the Alpha session. There is a minimum value of 0 and no maximum value of the measurement. The difference between the highest value (5.3956) and the lowest value (3.8768) was 1.5188.



Graph 13: Mean values of treatments (errors)

BACKWARD

The mean number of errors during the Beta session was the highest, followed by the Delta session, then the Control session, the Alpha session and finally the Theta session. The difference between the highest value (6.2021) and the lowest value (5.5335) was 0.6686.

DIFFERENCES OF MEAN VALUES

The following tables (see Table 25 and 26) present the differences between the mean values for the errors of the different session types on the logarithmic scale, together with the associated standard errors and P-value. The antilog of the differences is reported as the mean ratios of the number of errors, together with 95% confidence intervals for those ratios.

The mean ratios of errors allow one to judge the differences in errors between sessions on the percentage scale: for instance, the Control / Alpha ratio was 1.3918. This means that the Control session had 39.18% more errors than the Alpha session did.

Table 25: Ratios of geometric mean number of errors (forward)

Treatments	Estimate (log-scale)	P-value	Standard error (log scale)	Confidence interval (ratio scale)		Ratios (ratio scale)
				Lower	Upper	
C – A	0.3306	**0.0001**	0.08695	1.1737	1.6504	1.3918
C – B	0.01690	0.8338	0.08056	0.8685	1.1910	1.0170
C – D	0.1539	0.0644	0.08325	0.9908	1.3732	1.1664
C – T	0.1158	0.1598	0.08236	0.9554	1.3194	1.1228
A – B	-0.3137	**0.0003**	0.08767	0.6154	0.8678	0.7308
A – D	-0.1766	0.0503	0.09025	0.7022	1.0003	0.8381
A – T	-0.2148	0.0164	0.08950	0.6769	0.9614	0.8067
B – D	0.1370	0.1007	0.08349	0.9738	1.3508	1.1469
B – T	0.09888	0.2344	0.08316	0.9379	1.2994	1.1039
D – T	-0.03816	0.6572	0.08600	0.8133	1.1393	0.9626

Table 26: Ratios of geometric mean number of errors (backward)

Treatments	Estimate (log-scale)	P-value	Standard error (log scale)	Confidence interval (ratio scale)		Ratios (ratio scale)
				Lower	Upper	
C – A	0.03123	0.6956	0.07981	0.8823	1.2064	1.0317
C – B	-0.06699	0.3915	0.07818	0.8023	1.0901	0.9352
C – D	-0.00156	0.9843	0.07960	0.8542	1.1670	0.9984
C – T	0.04707	0.5582	0.08039	0.8954	1.2271	1.0482
A – B	-0.09822	0.2137	0.07900	0.7764	1.0582	0.9064

A – D	-0.03279	0.6836	0.08048	0.8265	1.1331	0.9677
A – T	0.01584	0.8442	0.08058	0.8675	1.1898	1.0160
B – D	0.06543	0.4017	0.07802	0.9162	1.2316	1.0676
B – T	0.1141	0.07983	0.07983	0.9585	1.3106	1.1208
D – T	0.04863	0.5505	0.08145	0.8949	1.2316	1.0498

DIFFERENCE ESTIMATES

The estimates represent the difference between the means of treatment types, shown in Graph 14.

FORWARD

The biggest difference (on the logarithmic scale) between session types was between Control and Alpha (0.3306), followed by Alpha and Beta (0.3137), Alpha and Theta (0.2148), Alpha and Delta (0.1766), Control and Delta (0.1539), Beta and Delta (0.1370), Control and Theta (0.1158), Beta and Theta (0.09888), Delta and Theta (0.03816) and finally Control and Beta (0.01690).

BACKWARD

The biggest difference (on the logarithmic scale) between session types was between Beta and Theta (0.1141), followed by Alpha and Beta (0.09822), Control and Beta (0.06699), Beta and Delta (0.06543), Delta and Theta (0.04863), Control and Theta (0.04707), Alpha and Delta (0.03279), Control and Alpha (0.03123), Alpha and Theta (0.01584) and finally Control and Delta (0.00156).

P-VALUE

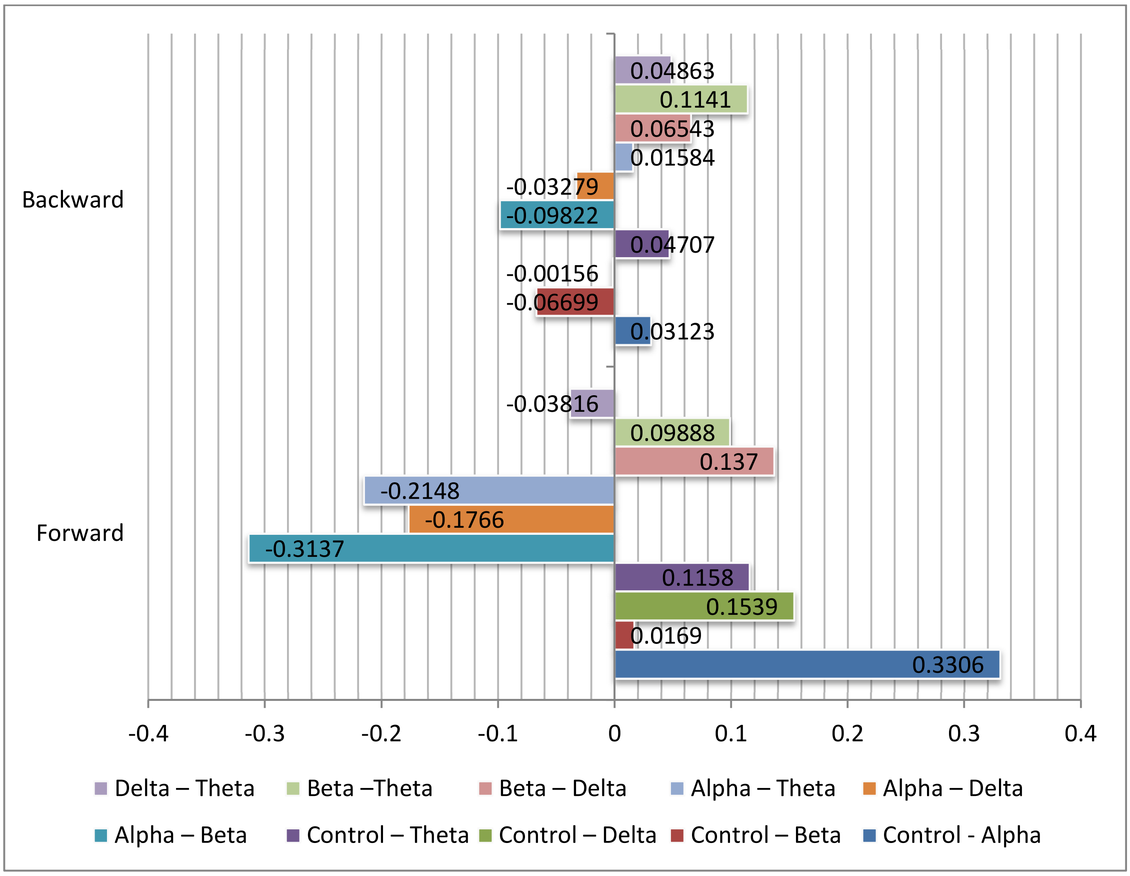
The P-values associated with all differences were higher than 0.05 except for Control – Alpha forward (< 0.0001), Alpha – Beta forward (0.0003) and Alpha – Theta forward (0.0164) (see Table 25). This means that the difference between these treatments was statistically significant. There was no statistically significant difference between any of the remaining mean values of sessions regarding number of errors.

CONFIDENCE INTERVAL

All confidence intervals for the mean ratios in errors were grouped around the value 1 (no difference) except for Control – Alpha forward [1.1737, 1.6504], Alpha – Beta [0.6154, 0.8678] and Alpha – Theta forward [0.6769, 0.9614]. The differences in errors for these three pairs of sessions can be considered practically relevant because the mean number of errors differ by at least 20%; otherwise the differences between sessions in mean number of errors are relatively small.

RATIOS

The researcher observed that a ± 20% or more difference in errors between sessions could be seen as practically relevant. Control – Alpha forward had a 39% difference, Alpha – Beta forward 26.92% difference and Alpha – Beta forward had a 19.33% difference in number of errors.



Graph 14: Difference of means between treatments (errors)

FINDINGS

This study succeeded in showing a statistically significant difference between the Control and Alpha forward session types for number of errors in the forward motion. The alpha session was associated with a significant drop in mean number of errors relative to the Control and Beta sessions. In contrast, the study failed to show statistically significant differences between the remainder of the session types for errors.

5.5. BETWEEN DIRECTIONS

Here the researcher compared the different directions (backward and forward) to each other. Long-term excitement, short-term excitement, engagement, meditation and frustration can be judged on a scale from 0 to 1 (theoretical minimum and maximum values of the measurement).

5.5.1. LONG-TERM EXCITEMENT

MEAN VALUES

The mean values of long-term excitement for the different directions can be seen in Table 12 and the data is also visually available as Graph 1.

DIFFERENCES OF MEAN VALUES

Table 27 presents the differences between the mean values for long-term excitement in relation to the different directions, together with the associated standard error, P-value and 95% confidence intervals.

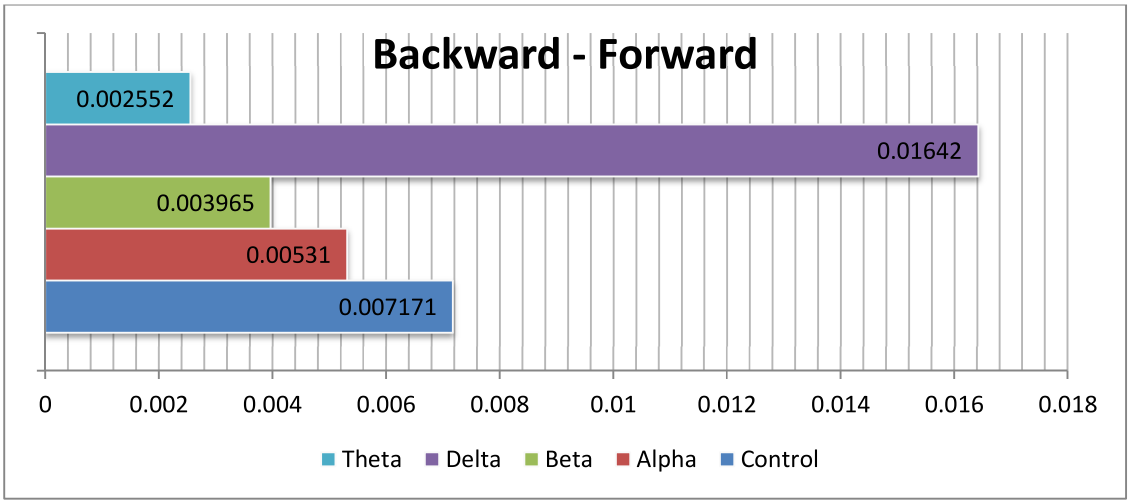
Table 27: Differences of least squares means (long-term excitement)

Direction	Treatment	Estimate	Standard error	P-value	Confidence interval	
					Lower	Upper
Backward - Forward	Control	0.007171	0.01747	0.6833	-0.02794	0.04228
	Alpha	0.005310	0.01886	0.7795	-0.03259	0.04321
	Beta	0.003965	0.01753	0.8220	-0.03126	0.03919

	Delta	0.01642	0.01435	0.2583	-0.01243	0.04526
	Theta	0.002552	0.01638	0.8768	-0.03036	0.03546

DIFFERENCE ESTIMATES

The biggest difference between directions was session type Delta (0.01642), followed by Control (0.007171), Alpha (0.005310), Beta (0.003965) and finally Theta (0.002552) (see Graph 15).



Graph 15: Difference of means between treatments (long-term excitement)

P-VALUE

The P-values associated with all differences was higher than 0.05 (see Table 27). This implies that there was no statistically significant difference between any of the mean values of direction regarding long-term excitement.

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fell within the interval [-0.1, +0.1]. If a mean difference between sessions of 0.1 in long-term excitement can be considered not practically relevant, then it can be concluded that there are no practically relevant differences between any of the five sessions regarding long-term excitement.

FINDINGS

This study has failed to show statistically significant differences between directions for long-term excitement. Furthermore, the confidence intervals for the mean differences suggest that there were no practically relevant differences between the treatments.

5.5.2. SHORT-TERM EXCITEMENT

MEAN VALUES

The mean values of short-term excitement for the different directions can be seen in Table 14 and the data is also visually available as Graph 3.

DIFFERENCES OF MEAN VALUES

Table 28 presents the differences between the mean values for short-term excitement in terms of the different directions, together with the associated standard error, P-value and 95% confidence intervals.

Table 28: Differences of least squares means (long-term excitement)

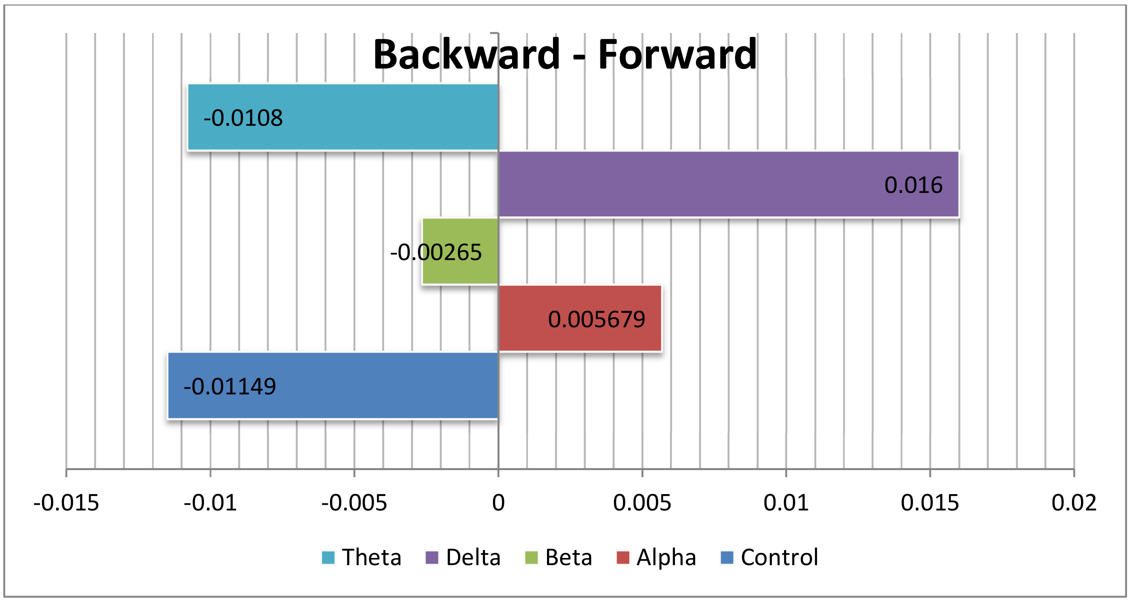
Direction	Treatment	Estimate	Standard error	P-value	Confidence interval	
					Lower	Upper
Backward - Forward	Control	-0.01149	0.01925	0.5532	-0.05018	0.02719
	Alpha	0.005679	0.02158	0.7935	-0.03769	0.04904
	Beta	-0.00265	0.01868	0.8876	-0.04020	0.03489
	Delta	0.01600	0.01460	0.2784	-0.01334	0.04534
	Theta	-0.01080	0.01723	0.5338	-0.04544	0.02383

DIFFERENCE ESTIMATES

The biggest difference in relation to direction is session type Delta (0.016), followed by Control (0.01149), Theta (0.0.0108), Alpha (0.005679) and finally Beta (0.00265) (see Graph 16).

P-VALUE

The P-values associated with all differences were higher than 0.05 (see Table 28). This implies that there was no statistically significant difference between any of the mean values of direction regarding long-term excitement.



Graph 16: Difference of means between treatments (short-term excitement)

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fell within the interval [-0.1, +0.1]. If a mean difference between sessions of 0.1 in short-term excitement can be considered not practically relevant, then it can be concluded that there were no practically relevant differences between any of the five sessions regarding short-term excitement.

FINDINGS

This study has failed to show statistically significant differences between the directions for short-term excitement.

5.5.3. ENGAGEMENT

MEAN VALUES

The mean values of engagement for the different directions can be seen in Table 16 and the data is also visually available as Graph 5.

DIFFERENCES OF MEAN VALUES

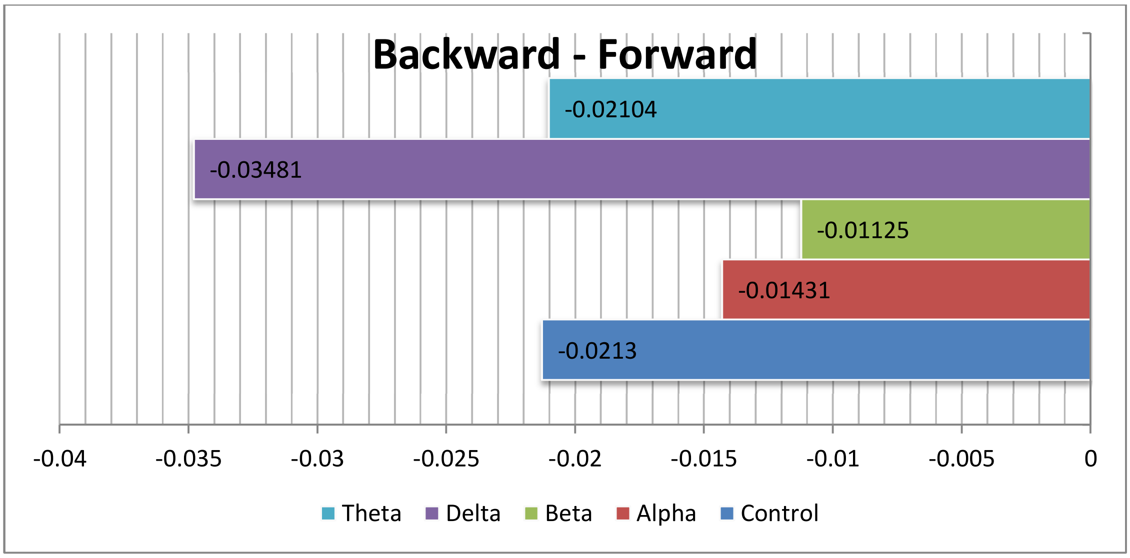
Table 29 presents the differences between the mean values for engagement of the different directions, together with the associated standard error, P-value and 95% confidence intervals.

Table 29: Differences of least squares means (long-term excitement)

Direction	Treatment	Estimate	Standard error	P-value	Confidence interval	
					Lower	Upper
Backward - Forward	Control	-0.02130	0.01129	0.0652	-0.04399	0.001392
	Alpha	-0.01431	0.01263	0.2629	-0.03969	0.01108
	Beta	-0.01125	0.01563	0.4749	-0.04266	0.02015
	Delta	-0.03481	0.01294	**0.0097**	-0.06081	-0.00881
	Theta	-0.02104	0.01236	0.0950	-0.04588	0.003796

DIFFERENCE ESTIMATES

The biggest difference in relation to direction is session type Delta (0.03481), followed by Control (0.0.0213), Theta (0.02104), Alpha (0.01431) and finally Beta (0.01125) (see Graph 17).



Graph 17: Difference of means between treatments (engagement)

P-VALUE

The P-values associated with all differences were higher than 0.05 (see Table 29), except for Delta (0.0097). This means that the difference between these directions was statistically significant for this treatment. There was no statistically significant difference between any of the remaining mean values of sessions regarding direction.

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fell within the interval [-0.1, +0.1]. Even the confidence intervals for the statistically significant mean differences, namely Delta session [-0.06081, -0.00881] fell within the interval [-0.1, +0.1]. If a mean difference between sessions of 0.1 in engagement can be considered not practically relevant, then it can be concluded that there are no practically relevant differences between any of the sessions.

FINDINGS

This study has succeeded in showing a statistically significant difference between the directions for engagement session Delta, although those differences do not seem to be of practical relevance.

5.5.4. MEDITATION

MEAN VALUES

The mean values of meditation for the different directions can be seen in Table 18 and the data is also visually available as Graph 7.

DIFFERENCES OF MEAN VALUES

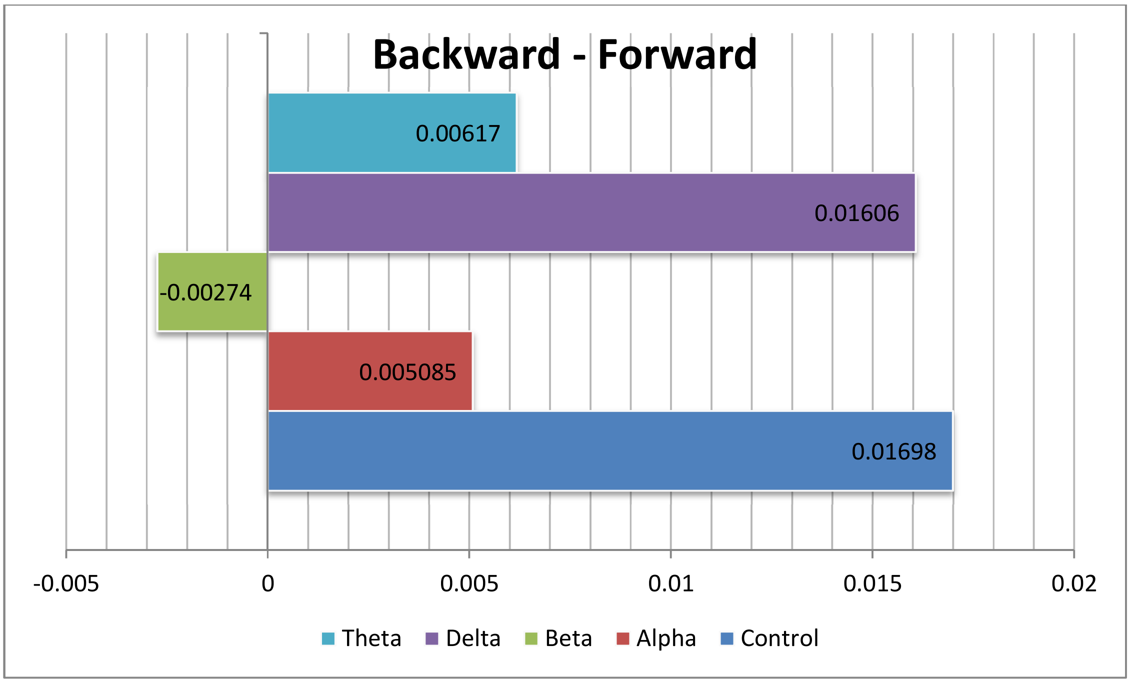
Table 30 presents the differences between the mean values of meditation for the different directions, together with the associated standard error, P-value and 95% confidence intervals.

Table 30: Differences of least squares means (meditation)

Direction	Treatment	Estimate	Standard error	P-value	Confidence interval	
					Lower	Upper
Backward - Forward	Control	0.01698	0.009197	0.0710	-0.00151	0.03546
	Alpha	0.005085	0.007621	0.5078	-0.01023	0.02040
	Beta	-0.00274	0.01111	0.8062	-0.02507	0.01958
	Delta	0.01606	0.009259	0.0892	-0.00255	0.03466
	Theta	0.006170	0.007716	0.4278	-0.00934	0.02167

DIFFERENCE ESTIMATES

The biggest difference in mean values related to direction is session type Control (0. 01698), followed by Delta (0. 01606), Theta (0. 006170), Alpha (0. 005085) and finally Beta (0. 00274) (see Graph 18).



Graph 18: Difference of means between treatments (meditation)

P-VALUE

The P-values associated with all differences were higher than 0.05 (see Table 30). This implies that there is no statistically significant difference between any of the mean values of meditation direction regarding.

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fall within the interval [-0.1, +0.1]. If a mean difference between sessions of 0.1 in meditation can be considered not practically relevant, then it can be concluded that there are no practically relevant differences between any of the five sessions regarding meditation.

FINDINGS

This study has failed to show statistically significant differences for meditation with regard to the directions.

5.5.5. FRUSTRATION

MEAN VALUES

The mean values of frustration for the different directions can be seen in Table 20 and the data is also visually available as Graph 9.

DIFFERENCES OF MEAN VALUES

Table 31 presents the differences between the mean values of frustration for the different directions, together with the associated standard error, P-value and 95% confidence intervals.

Table 31: Differences of least squares means (frustration)

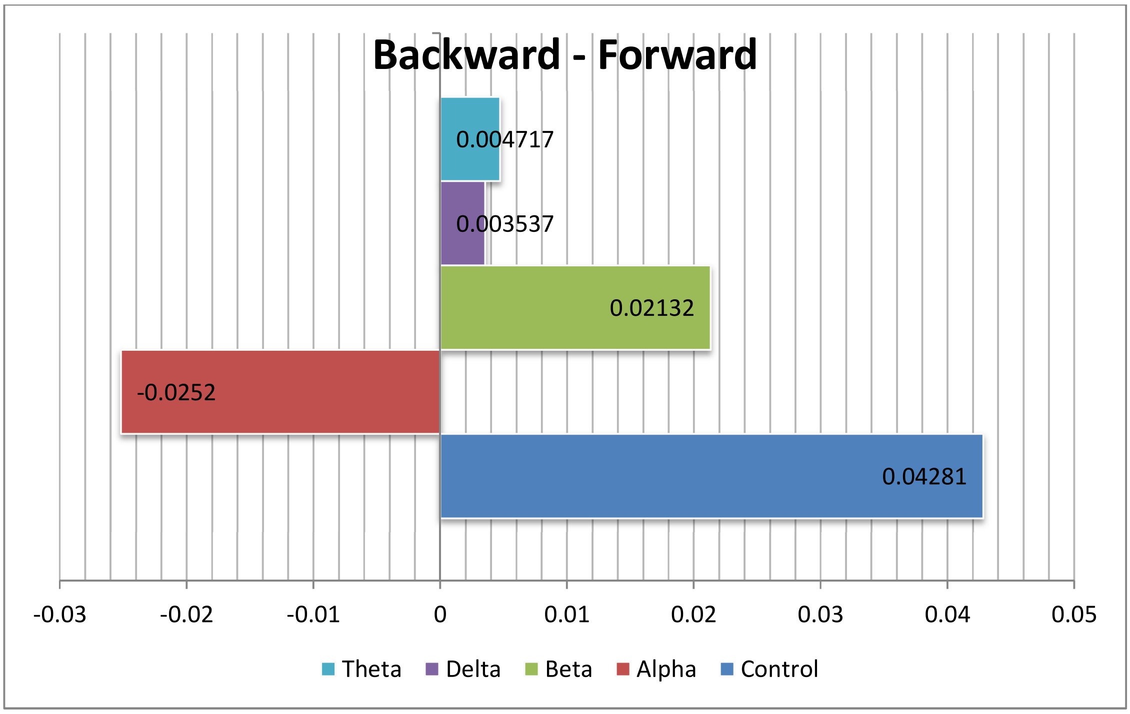
Direction	Treatment	Estimate	Standard error	P-value	Confidence interval	
					Lower	Upper
Backward - Forward	Control	0.04281	0.01646	**0.0123**	0.009727	0.07590
	Alpha	-0.02520	0.02041	0.2228	-0.06621	0.01581
	Beta	0.02132	0.02179	0.3327	0.02132	0.02179
	Delta	0.003537	0.02129	0.8688	-0.03925	0.04633
	Theta	0.004717	0.01763	0.7901	-0.03070	0.04014

DIFFERENCE ESTIMATES

The biggest difference between directions was in session type Control (0.04281), followed by Alpha (0.0252), Beta (0.02132), Theta (0.004717) and finally Delta (0.003537) (see Graph 19).

P-VALUE

The P-values associated with all differences was higher than 0.05 (see Table 31), except for Control, which was 0.0123. This means that the difference between these directions was statistically significant for this treatment. There was no statistically significant difference between any of the remaining mean values of sessions regarding direction.



Graph 19: Difference of means between directions (frustration)

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fell within the interval [-0.1, +0.1], including the confidence interval for Control [0.009727, 0.07590]. If a mean difference between sessions of 0.1 in frustration can be considered not practically relevant, then it can be concluded that there are no practically relevant differences between any of the sessions.

FINDINGS

This study has succeeded in showing a statistically significant difference between the directions for frustration session Control.

5.5.6. DURATION

MEAN VALUES

The mean values of duration for the different directions can be seen in Table 22 and the data is also visually available as Graph 11.

DIFFERENCES OF MEAN VALUES

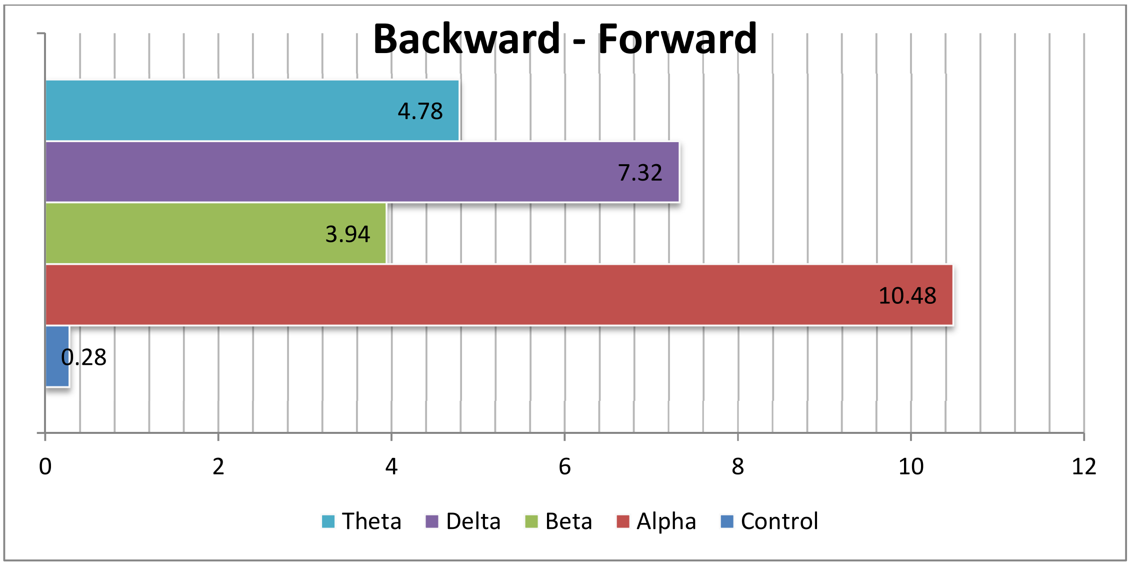
Table 32 presents the differences between the mean values for duration of the different directions, together with the associated standard error, P-value and 95% confidence intervals.

Table 32: Differences of least squares means (duration)

Direction	Treatment	Estimate	Standard error	P-value	Confidence interval	
					Lower	Upper
Backward - Forward	Control	0.2800	2.4920	0.9110	-4.7278	5.2878
	Alpha	10.4800	2.6997	**0.0003**	5.0548	15.9052
	Beta	3.9400	2.5979	0.1358	-1.2806	9.1606
	Delta	7.3200	2.7314	**0.0100**	1.8310	12.8090
	Theta	4.7800	3.0213	0.1201	-1.2916	10.8516

DIFFERENCE ESTIMATES

The biggest difference in mean values for duration in regard to the directions was session type Alpha (10.4800), followed by Delta (7.3200), Theta (4.7800), Beta (3.9400) and finally Control (0.2800) (see Graph 20).



Graph 20: Difference of means between treatments (duration)

P-VALUE

The P-values associated with all differences were higher than 0.05 (see Table 32), except for Alpha (0.0003) and Delta (0.0100). This means that the difference between the directions was statistically significant for these treatments. There was no statistically significant difference between any of the remaining mean values of sessions regarding direction.

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference, except for Alpha [5.0548, 15.9052] and Delta [1.8310, 12.8090]. There might be practically relevant differences between the backward and forward motions for Alpha and Delta, regarding duration.

FINDINGS

This study has succeeded in showing a statistically significant difference between the directions for duration sessions Alpha and Delta.

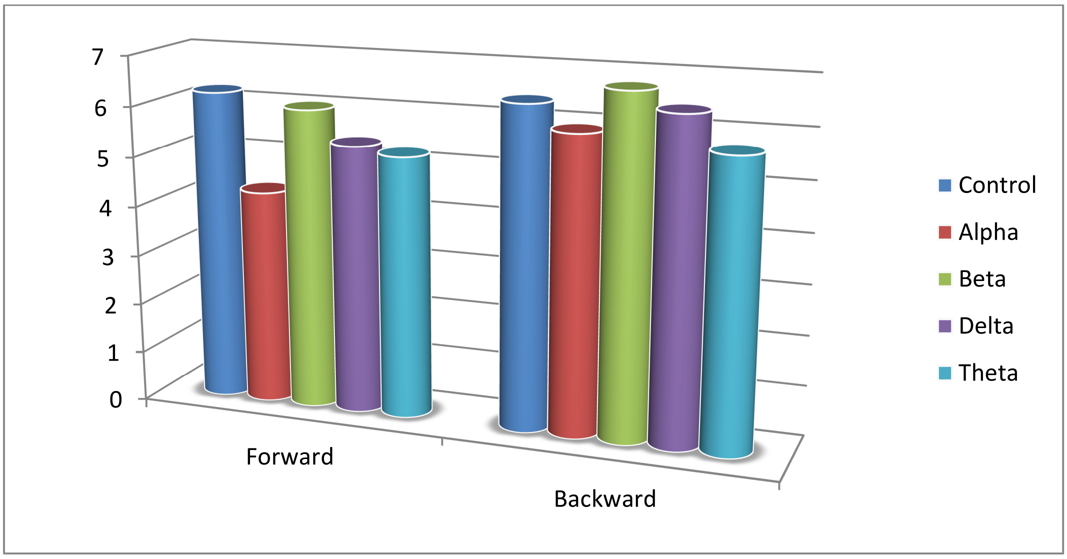
5.5.7. ERRORS

MEAN VALUES

The mean values of errors for the different directions can be seen in Table 33 and the data is also visually available as Graph 21.

Table 33: Geometric means for errors

Treatment	Estimate	
	Forward	Backward
Control	6.2370	6.4013
Alpha	4.2995	5.9097
Beta	6.0129	6.7551
Delta	5.3672	6.3981
Theta	5.2289	5.7122



Graph 21: Mean values of direction (errors)

DIFFERENCES OF MEAN VALUES

Table 34 presents the differences between the mean values for errors of the different directions on the logarithmic scale, together with the associated standard error, P-value.

The antilog of the differences is reported as the mean ratios of the number of errors, together with 95% confidence intervals for the ratios.

Table 34: Ratios of geometric mean number of errors

Treatments		Estimate (log-scale)	Standard error (log scale)	P-value	Confidence interval (ratio scale)		Estimate (ratio-scale)
					Lower	Upper	
Backward - Forward	Control	0.02598	0.07969	0.7459	0.8742	1.2049	1.0263
	Alpha	0.3181	0.08746	**0.0007**	1.1528	1.6389	1.3745
	Beta	0.1164	0.07898	0.1475	0.9583	1.3169	1.1235
	Delta	0.1757	0.08322	**0.0402**	1.0082	1.4095	1.1921
	Theta	0.08839	0.08335	0.2945	0.9237	1.2920	1.0924

DIFFERENCE ESTIMATES

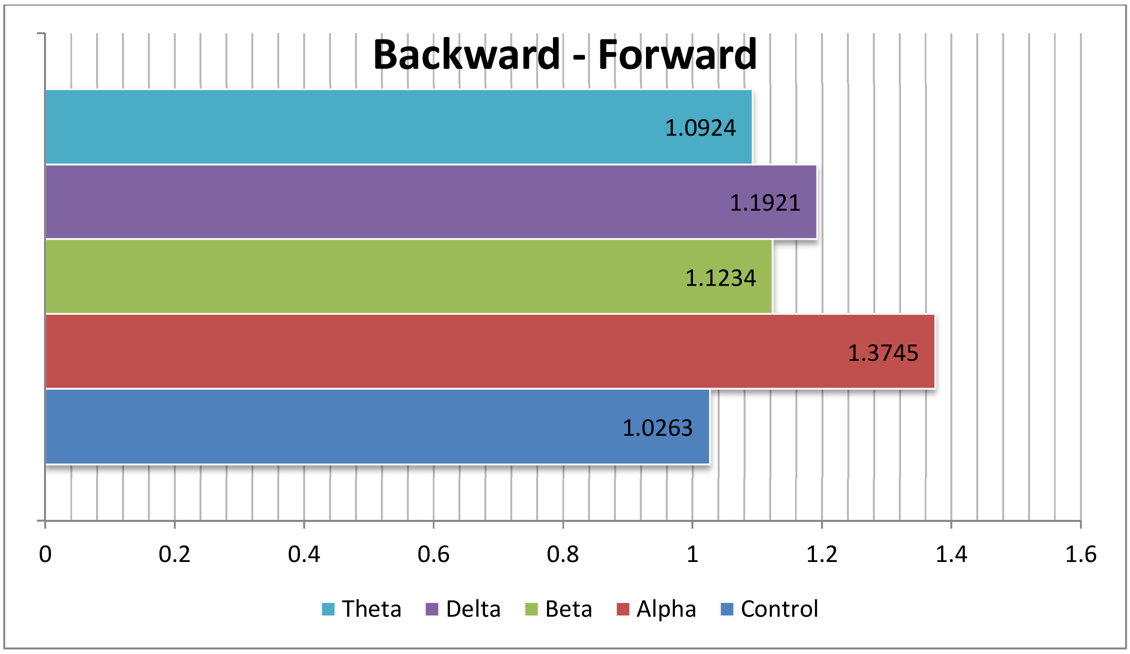
The biggest difference (on the logarithmic scale) between the directions is session type Alpha (1.3745), followed by Delta (1.1921), Beta (1.1234), Theta (1.0924) and finally Control (1.0263) (see Graph 22).

P-VALUE

The P-values associated with all differences were higher than 0.05 (see Table 34), except for Alpha (0.0007) and Delta (0.0402). This means that the difference between directions was statistically significant for these treatments. There is no statistically significant difference between any of the remaining mean values of sessions regarding errors.

CONFIDENCE INTERVAL

The Alpha and Delta sessions seem to have a significantly lower mean number of errors in regard to the forward direction compared to the backward direction. All confidence intervals were grouped around the value 1 (no difference), except for Alpha [1.1528, 1.6389] and Delta [1.0082, 1.4095]. The differences for the Alpha and Delta sessions can be considered practically relevant as the mean number of errors differ by at least 20%.



Graph 22: Difference of means between treatments (errors)

RATIOS

The researcher observed that a ± 20% or more difference in errors between directions can be seen as practically relevant. Alpha had a 37.45% difference and Delta had a 19.21% difference in number of errors.

FINDINGS

This study has succeeded in showing a statistically significant difference between the directions for error sessions Alpha and Delta.

5.6. BETWEEN GENDERS

Here the researcher compared the different genders (male and female) to each other. Long-term excitement, short-term excitement, engagement, meditation and frustration can be judged against a scale from 0 to 1 (theoretical minimum and maximum values of the measurement).

5.6.1. MEANS

MEAN VALUES

The mean values of long-term excitement, short-term excitement, engagement, meditation, frustration, duration and errors for the different directions and genders can be seen in Table 35 and the data is also visually available as Graphs 23, 24 and 25.

Table 35: Means for different genders

Treatment	Estimate			
	Forward		Backward	
	Female	Male	Female	Male
Long-term excitement	0.3286	0.3615	0.3358	0.3687
Short-term excitement	0.2870	0.3295	0.2907	0.3248
Engagement	0.5487	0.5423	0.5272	0.5232
Meditation	0.3901	0.3908	0.3957	0.4023
Frustration	0.5130	0.5218	0.5214	0.5330
Duration	94.1502	98.1913	100.39	102.82
Errors	5.2069	4.9838	6.1700	6.0153

FORWARD

There was a minimum value of 0 and a maximum value of 1 for long-term excitement, short-term excitement, engagement, meditation and frustration. For duration there was a minimum of 0 and a maximum of 120. Errors could have a minimum of 0 and no maximum value.

LONG-TERM EXCITEMENT

Long-term excitement was highest for males. The difference between the highest value (0. 3615) and the lowest value (0. 3286) was 0.0329.

SHORT-TERM EXCITEMENT

Short-term excitement was highest for females. The difference between the highest value (0. 3295) and the lowest value (0. 2870) was 0.0425.

ENGAGEMENT

Engagement was highest for females. The difference between the highest value (0. 5487) and the lowest value (0. 5423) was 0.0064.

MEDITATION

For meditation, males were again the highest. The difference between the highest value (0. 3908) and the lowest value (0. 3901) was 0.0007.

FRUSTRATION

Frustration was highest for males, once again. The difference between the highest value (0. 5218) and the lowest value (0. 5130) was 0.0088.

DURATION

Duration was highest for males. The difference between the highest value (98.1913) and the lowest value (94.1502) was 4.0411.

ERRORS

Errors were highest for females. The difference between the highest value (5.2069) and the lowest value (4.9838) was 0.2231.

BACKWARD

LONG-TERM EXCITEMENT

For long-term excitement, the highest values were for males. The difference between the highest value (0.3687) and the lowest value (0.3358) was 0.0329.

SHORT-TERM EXCITEMENT

Short-term excitement was highest for males. The difference between the highest value (0. 3248) and the lowest value (0. 2907) was 0.0341.

ENGAGEMENT

For engagement, the highest values were for females. The difference between the highest value (0. 5272) and the lowest value (0. 5232) was 0.004.

MEDITATION

Meditation was highest for males. The difference between the highest value (0. 4023) and the lowest value (0. 3957) was 0.0066.

FRUSTRATION

For frustration the highest values were for males. The difference between the highest value (0. 5330) and the lowest value (0. 5214) was 0.0116.

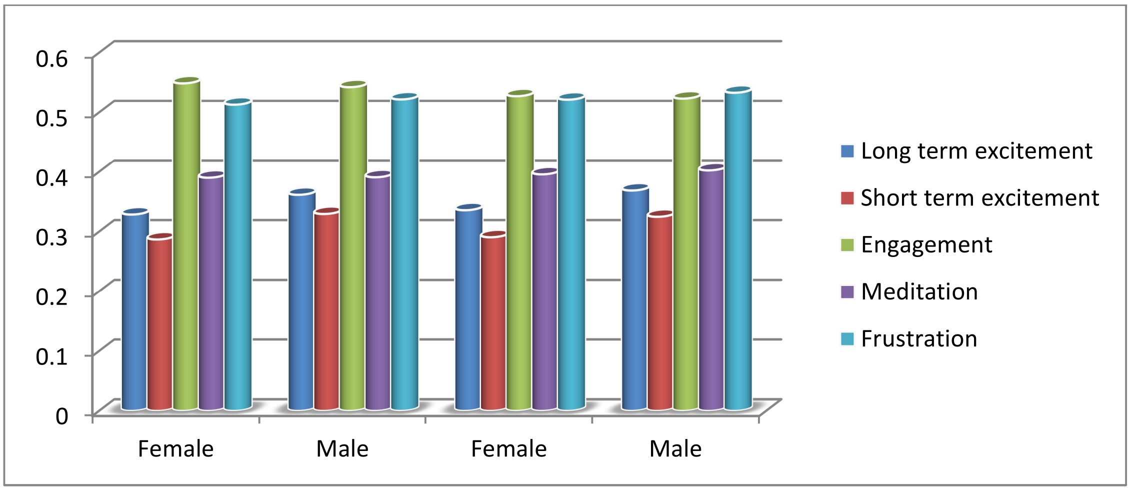
DURATION

Duration was highest for males. The difference between the highest value (102.82) and the lowest value (100.39) was 2.43.

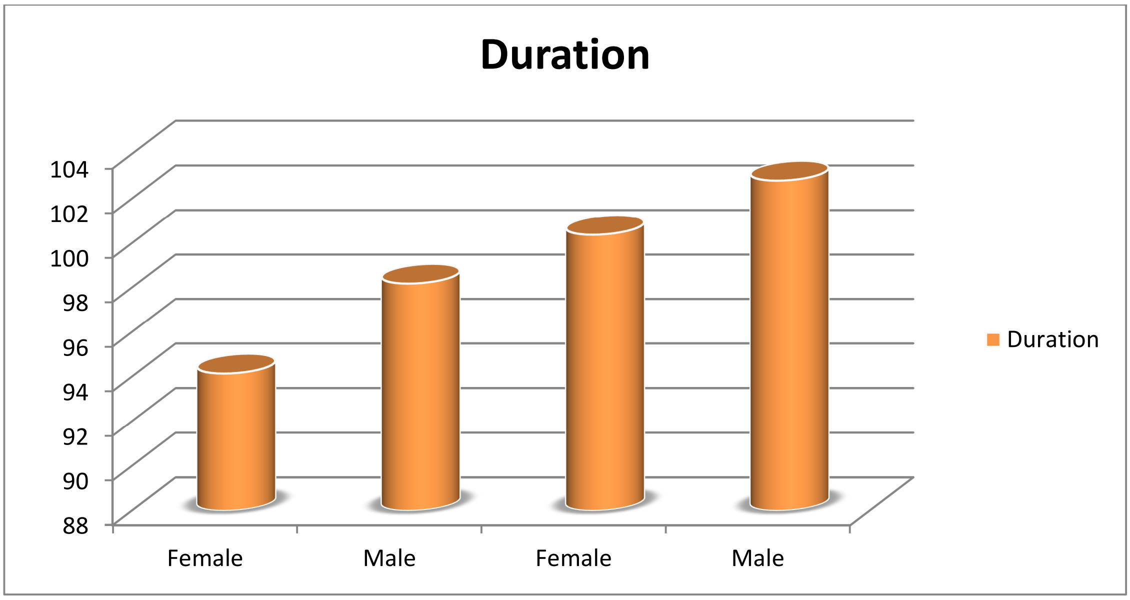
ERRORS

Errors were highest for females. The difference between the highest value (6.1700) and the lowest value (6.0153) was 0.1547.

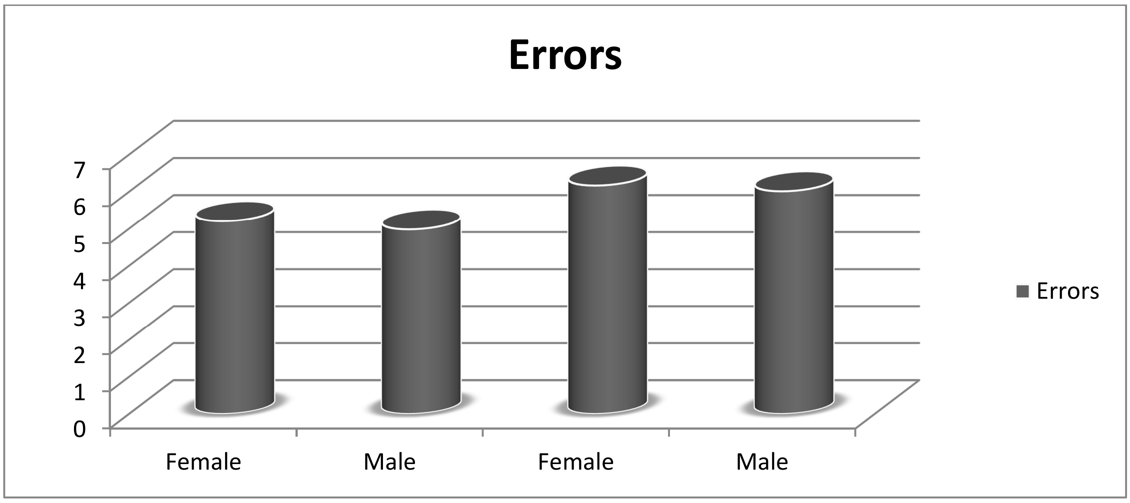
These differences between treatments can thus far not be seen as significant or non-significant by the researcher.



Graph 23: Means between genders



Graph 24: Means between genders (duration)



Graph 25: Means between genders (errors)

DIFFERENCES OF MEAN VALUES

Table 36 presents the differences between the mean values for long-term excitement, short-term excitement, engagement, meditation and frustration of the different genders, together with the associated standard error, P-value and 95% confidence intervals (see Graph 26).

Table 36: Differences of least squares means (female – male).

Direction	Treatment	Estimate	Standard error	P-value	Confidence interval	
					Lower	Upper
Forward	Long-term excitement	-0.03289	0.02537	0.2013	-0.08396	0.01818
	Short-term excitement	-0.04255	0.02483	0.0934	-0.09254	0.007438
	Engagement	0.006413	0.02555	0.8029	-0.04501	0.05783
	Meditation	-0.00074	0.01975	0.9702	-0.04050	0.03902
	Frustration	-0.00887	0.03653	0.8093	-0.08240	0.06467
Backward	Long-term excitement	-0.03292	0.02589	0.2098	-0.08503	0.01918
	Short-term excitement	-0.03412	0.02530	0.1840	-0.08504	0.01680
	Engagement	0.004045	0.02343	0.8637	-0.04313	0.05122
	Meditation	-0.00659	0.02016	0.7451	-0.04716	0.03398
	Frustration	-0.01163	0.03844	0.7637	-0.08900	0.06575

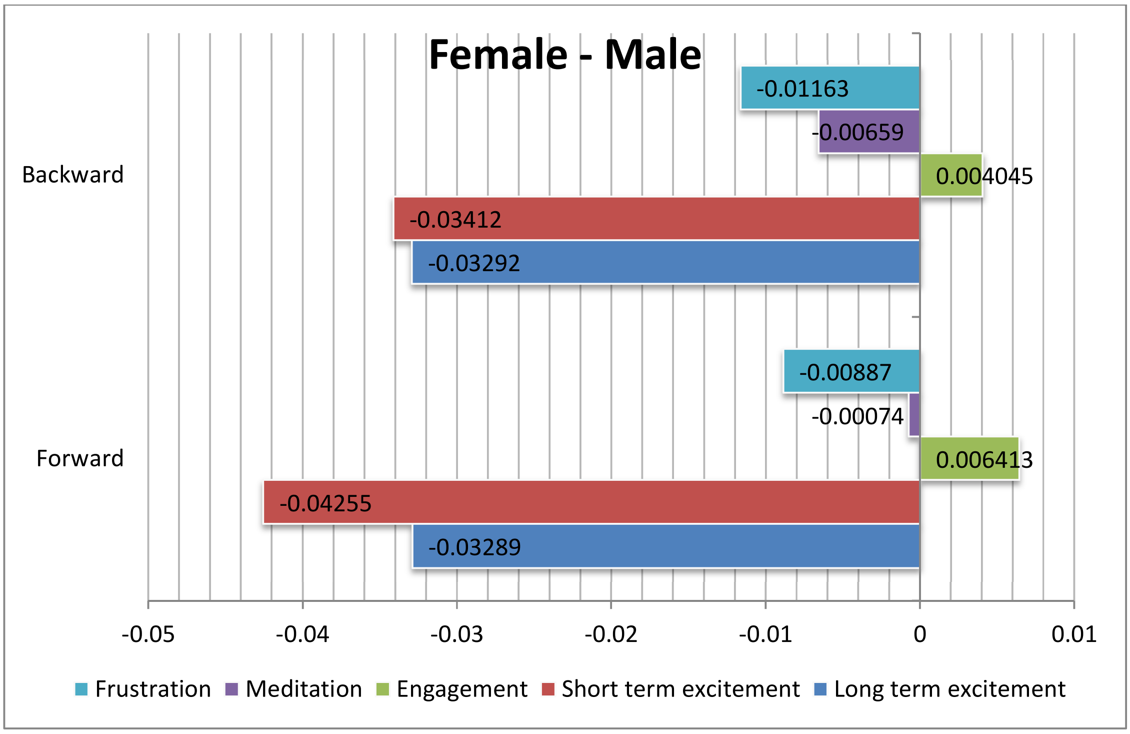
DIFFERENCE ESTIMATES

FORWARD

The biggest difference between genders was evident in session type short-term excitement (0.03412), followed by long-term excitement (0.03292), frustration (0.01163), meditation (0.00659) and finally engagement (0.004045).

BACKWARD

The biggest difference between genders was evident in session type short-term excitement (0.04255), followed by long-term excitement (0.03289), frustration (0.00887), engagement (0.006413) and finally meditation (0.00074).



Graph 26: Difference of means between genders

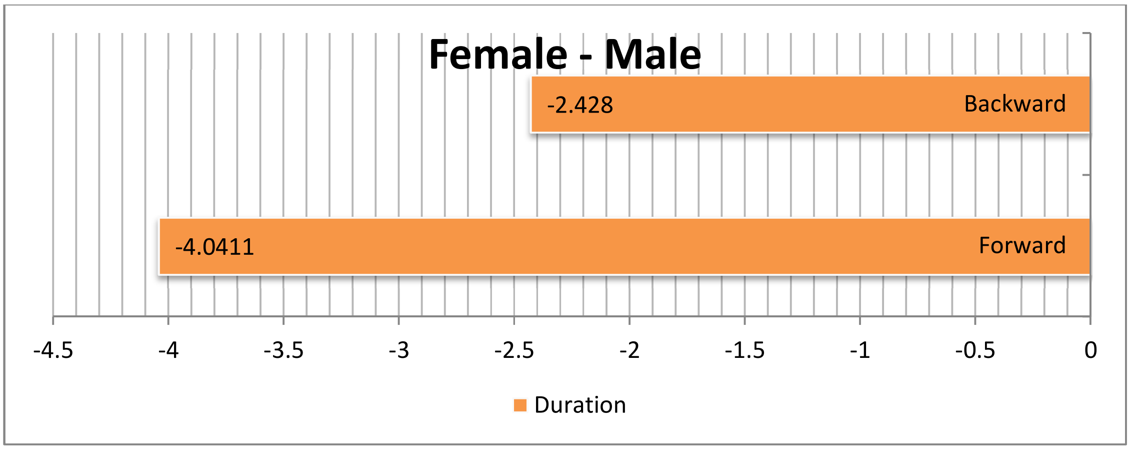
Table 37 presents the differences between the mean values for duration and errors of the different genders, together with the associated standard error, P-value and 95% confidence intervals (Graphs 27 and 28).

Table 37: Differences of least squares means for duration and errors (female – male)

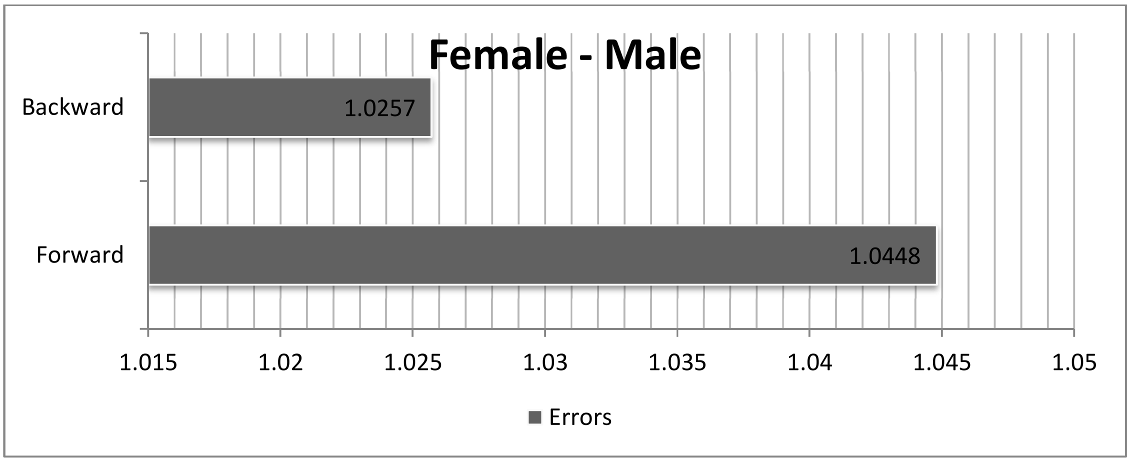
Direction	Treatment	Estimate	Standard error	P-value	Confidence interval	
					Lower	Upper
Forward	Duration	-4.0411	5.7202	0.4835	-15.5553	7.4731
	Errors	1.0448	0.1695	0.7964	0.7477	1.4598
Backward	Duration	-2.4280	5.2616	0.6466	-13.0190	8.1630
	Errors	1.0257	0.1405	0.8567	0.7775	1.3532

P-VALUE

The P-values associated with all differences were higher than 0.05 (see Table 37). This implies that there was no statistically significant difference between any of the mean values for different genders.



Graph 27: Difference of means between genders (duration)



Graph 28: Difference of means between genders (errors)

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fell within the interval [-0.1, +0.1]. If a mean difference between sessions of 0.1 in long-term excitement, short-term excitement, engagement, meditation and frustration can be considered not practically relevant, then it can be concluded that there are no practically relevant differences between any of the five sessions. There does not seem to be any statistically significant difference between genders for duration or errors.

FINDINGS

This study has failed to show statistically significant differences between different genders.

5.7. BETWEEN AGE GROUPS

Here the researcher compared the different age groups to each other. Long-term excitement, short-term excitement, engagement, meditation and frustration can be judged against a scale from 0 to 1 (theoretical minimum and maximum values of the measurement).

5.7.1. MEANS

MEAN VALUES

The mean values of long-term excitement, short-term excitement, engagement, meditation, frustration, duration and errors for the different directions and age groups can be seen in Table 38 and the data is also visually available as Graphs 29 to 31. As previously mentioned in section 3.2.4, the groups range as follows:

- Group 1: 13 – 18
- Group 2: 19 – 24
- Group 3: 25 – 50.

Table 38: Means for different age groups

Treatment	Estimate					
	Forward			Backward		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Long-term excitement	0.3513	0.3359	0.3478	0.3419	0.3513	0.3635
Short-term excitement	0.3287	0.2882	0.3079	0.3079	0.3018	0.3135
Engagement	0.5543	0.5426	0.5397	0.5245	0.5218	0.5293
Meditation	0.4041	0.3750	0.3922	0.4012	0.3819	0.4141
Frustration	0.5362	0.4645	0.5515	0.5577	0.4441	0.5798

Duration	100.06	97.1400	91.3099	104.57	99.7051	100.55
Errors	5.0445	5.9984	4.3684	6.2096	6.2770	5.8002

FORWARD

There was a minimum value of 0 and a maximum value of 1 for long-term excitement, short-term excitement, engagement, meditation and frustration. For duration there was a minimum of 0 and a maximum of 120. Errors could have a minimum of 0 and no maximum value.

LONG-TERM EXCITEMENT

Group 1's long-term excitement was the highest, followed by group 3 and group 2. The difference between the highest value (0.3287) and the lowest value (0.3359) was 0.0154.

SHORT-TERM EXCITEMENT

Group 1's short-term excitement was the highest, followed by that of group 3 and group 2. The difference between the highest value (0.3513) and the lowest value (0. 2882) was 0.0631.

ENGAGEMENT

Group 1's engagement was the highest, followed by that of group 2 and group 3. The difference between the highest value (0.5543) and the lowest value (0. 5397) was 0.0146.

MEDITATION

Group 1's meditation was the highest, followed by that of group 3 and group 2. The difference between the highest value (0.4041) and the lowest value (0.3750) was 0.0291.

FRUSTRATION

Frustration for group 3 was the highest, with group 1 and group 2 following. The difference between the highest value (0.5515) and the lowest value (0. 4645) was 0.087.

DURATION

Group 1's duration was the highest, followed by that of group 2 and group 3. The difference between the highest value (100.06) and the lowest value (91.3099) was 8.7501.

ERRORS

For errors, group 2 was the highest, followed by group 1 and then group 3. The difference between the highest value (5.9984) and the lowest value (4.3684) was 1.63.

BACKWARD

LONG-TERM EXCITEMENT

Group 3's long-term excitement was the highest, followed by that of group 2 and group 1. The difference between the highest value (0. 3635) and the lowest value (0. 3419) was 0.0216.

SHORT-TERM EXCITEMENT

Group 3's short-term excitement was the highest, followed by group 1 and then group 2. The difference between the highest value (0.3135) and the lowest value (0.3018) was 0.0117.

ENGAGEMENT

Group 3's engagement was the highest, followed by that of group 1 and group 2. The difference between the highest value (0.5293) and the lowest value (0.5218) was 0.0075.

MEDITATION

For meditation, group 3 was the highest, followed by group 1 and group 2. The difference between the highest value (0. 4141) and the lowest value (0. 3819) was 0.0322.

FRUSTRATION

Group 3's frustration was the highest, followed by that of group 1 and group 2. The difference between the highest value (0. 5798) and the lowest value (0. 4441) was 0.1357.

DURATION

Group 1's duration was the highest, followed by that of group 3 and group 2. The difference between the highest value (104.57) and the lowest value (99.7051) was 4.8649.

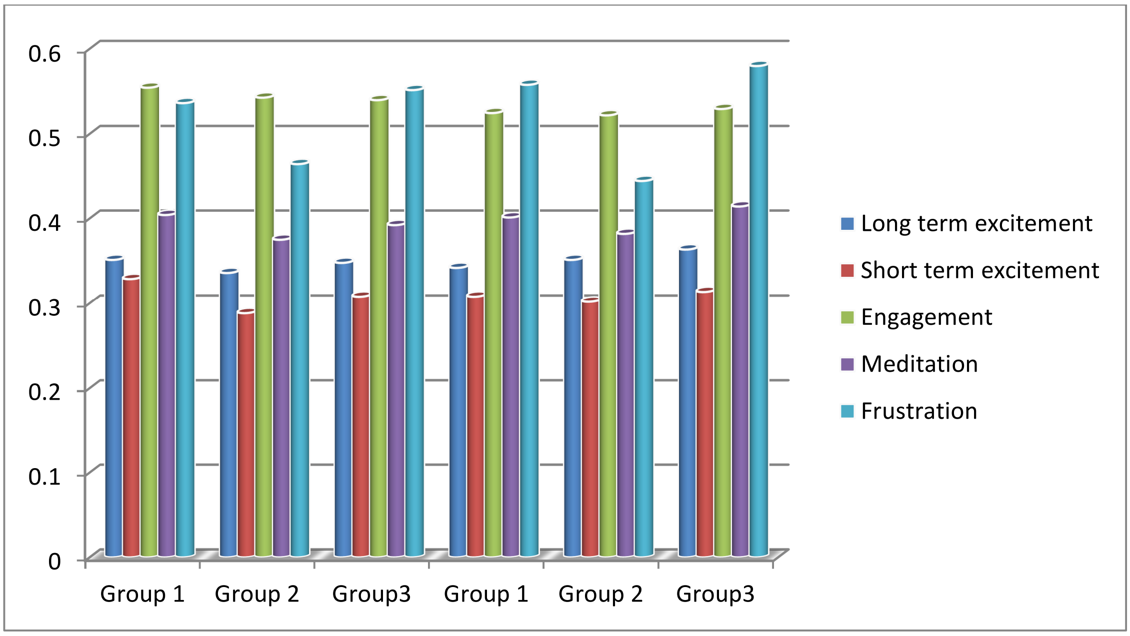
ERRORS

Group 2's errors were the highest, followed by those of group 1 and group 3. The difference between the highest value (6.2770) and the lowest value (5.8002) was 0.4768.

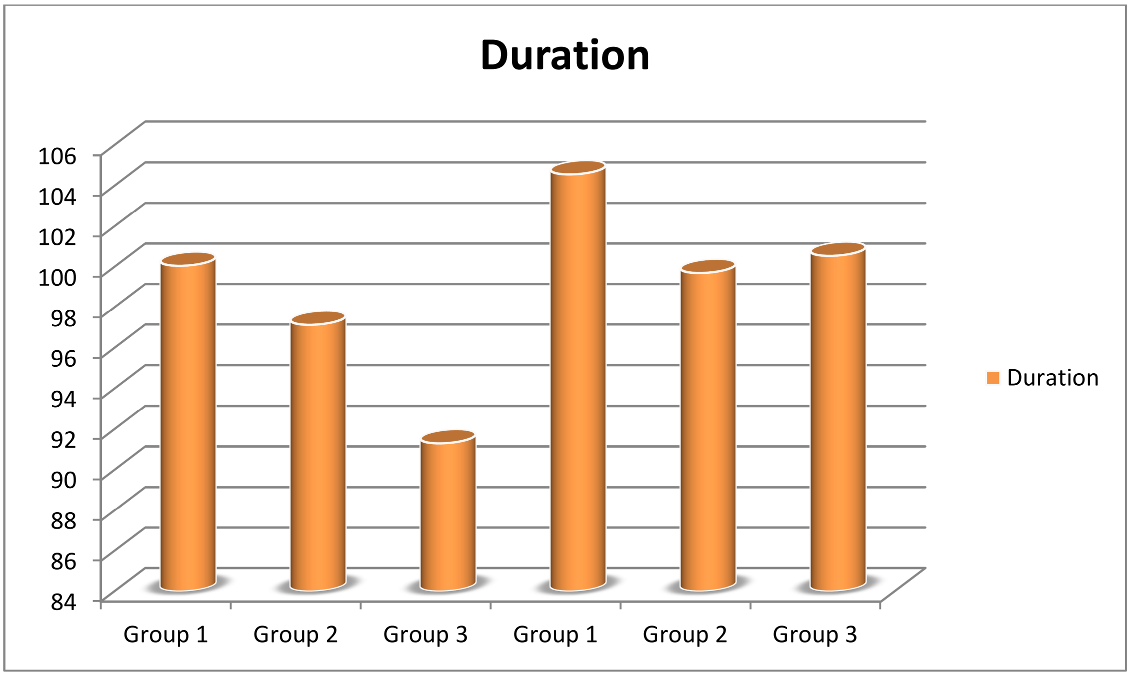
These differences between treatments can thus far not be seen as significant or non-significant by the researcher.

DIFFERENCES OF MEAN VALUES

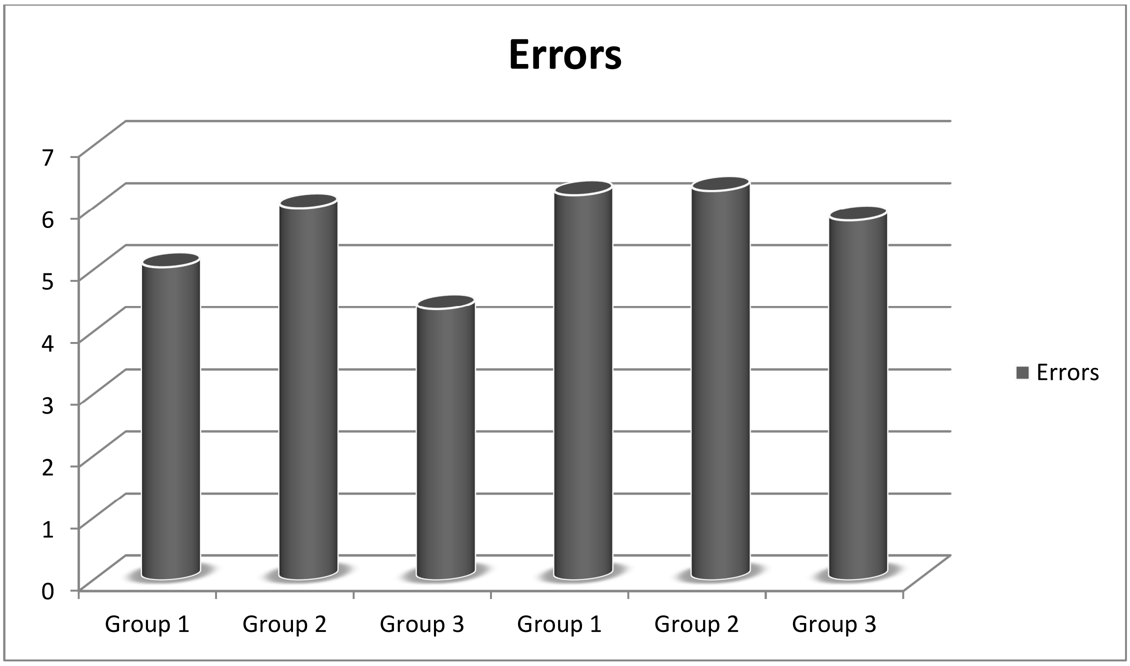
Tables 39 and 40 presents the differences between the mean values for long-term excitement, short-term excitement, engagement, meditation, frustration, duration and errors of the different age groups (see Graphs 32 - 37), together with the associated standard error, P-value and 95% confidence intervals.



Graph 29: Means between age groups



Graph 30: Means between age groups (duration)

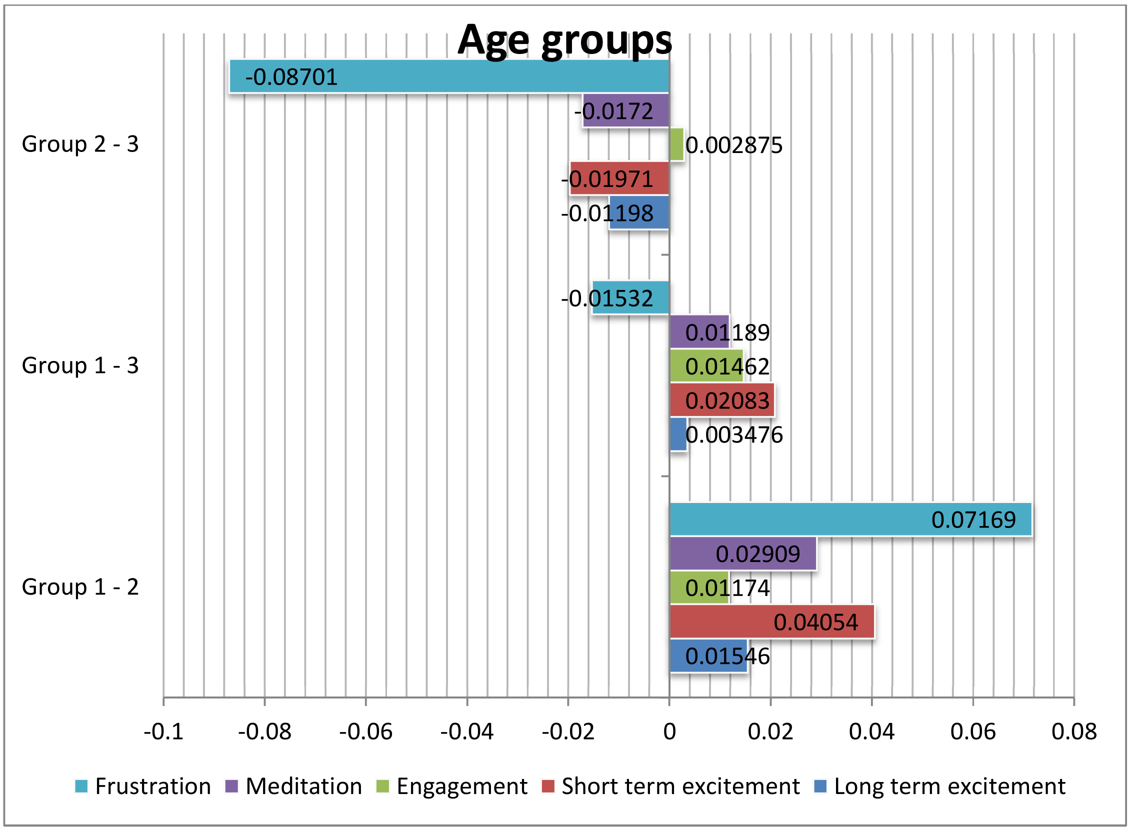


Graph 31: Means between age groups (errors)

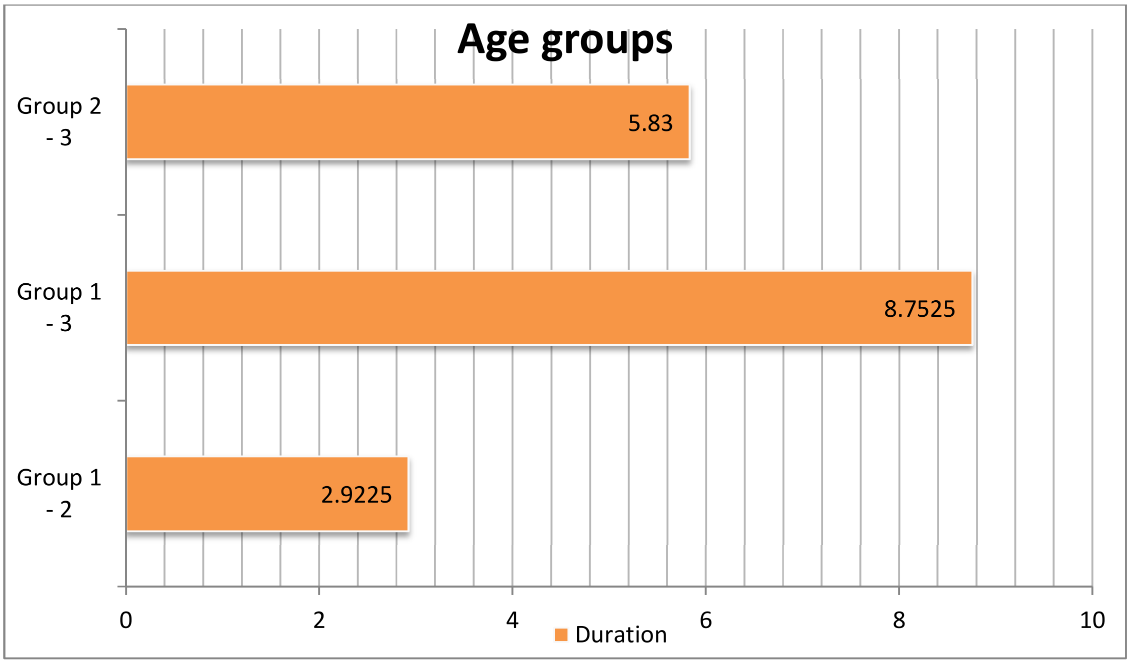
Table 39: Differences of least squares means (age groups/forward)

Direction	Treatment	Age group	Estimate	Standard error	P-value	Confidence interval	
						Lower	Upper
Forward	Long-term excitement	1 - 2	0.01546	0.03065	0.6164	-0.04624	0.07716
		1 - 3	0.003476	0.03121	0.9118	-0.05936	0.06631
		2 - 3	-0.01198	0.03099	0.7008	-0.07436	0.05040
	Short-term excitement	1 - 2	0.04054	0.03001	0.1833	-0.01986	0.1009
		1 - 3	0.02083	0.03056	0.4988	-0.04067	0.08234
		2 - 3	-0.01971	0.03034	0.5192	-0.08077	0.04136
	Engagement	1 - 2	0.01174	0.03086	0.7053	-0.05038	0.07387
		1 - 3	0.01462	0.03143	0.6440	-0.04865	0.07789
		2 - 3	0.002875	0.03121	0.9270	-0.05994	0.06569
	Meditation	1 - 2	0.02909	0.02387	0.2290	-0.01894	0.07713
		1 - 3	0.01189	0.02430	0.6269	-0.03703	0.06081
		2 - 3	-0.01720	0.02413	0.4795	-0.06577	0.03137

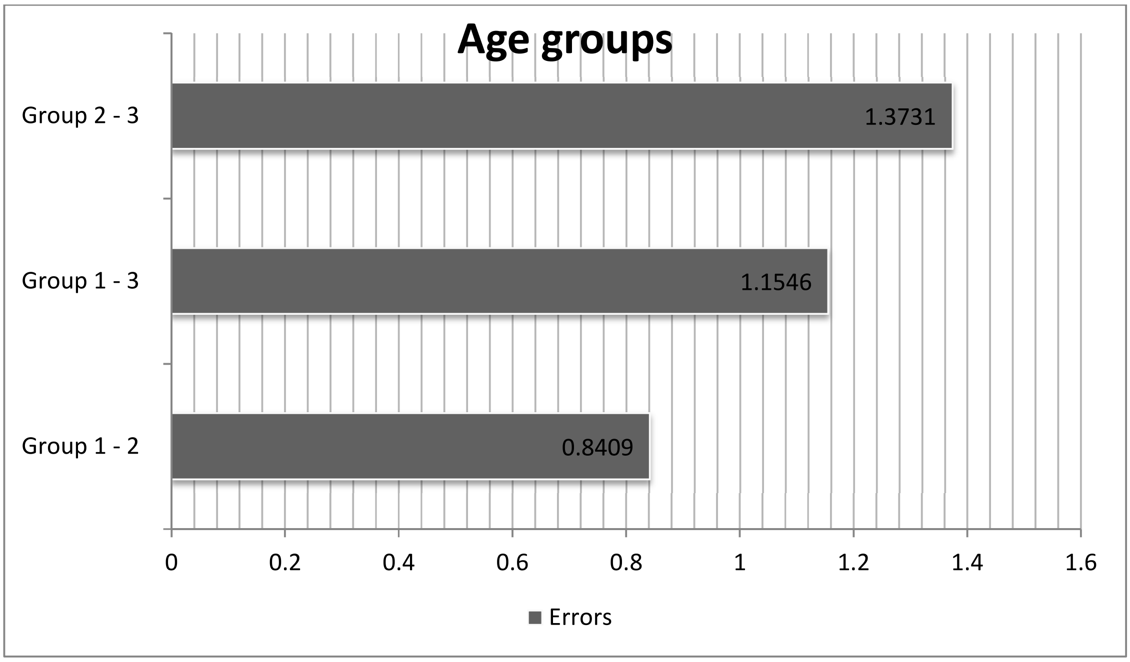
	Frustration	1 - 2	0.07169	0.04414	0.1112	-0.01716	0.1605
		1 - 3	-0.01532	0.04495	0.7348	-0.1058	0.07515
		2 - 3	-0.08701	0.04463	0.0573	-0.1768	0.002820
	Duration	1 - 2	2.9225	6.9112	0.6744	-10.9891	16.8341
		1 - 3	8.7525	7.0380	0.2199	-5.4143	22.9194
		2 - 3	5.8300	6.9876	0.4084	-8.2353	19.8953
	Error	1 - 2	0.8409	0.2055	0.4002	0.5607	1.2612
		1 - 3	1.1546	0.2067	0.4874	0.7680	1.7362
		2 - 3	1.3731	0.2067	0.1267	0.9133	2.0645



Graph 32: Difference of means between age groups (forward)



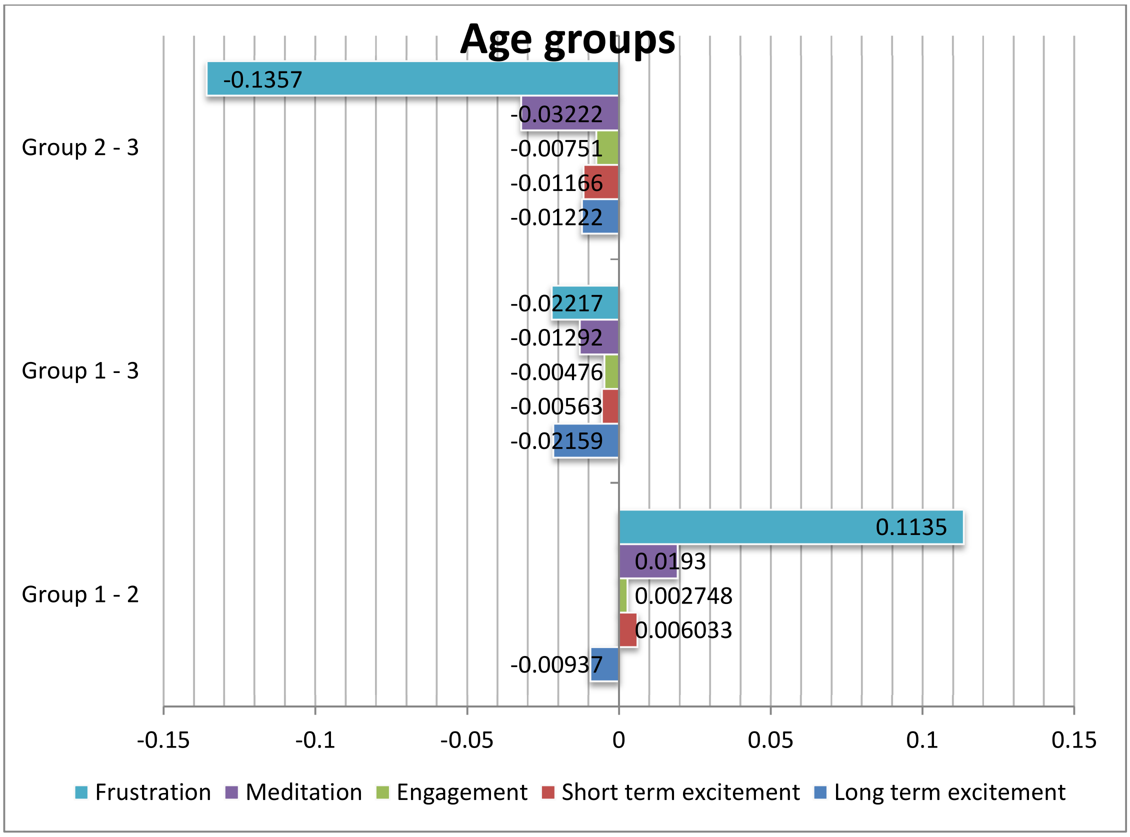
Graph 33: Difference of means for duration between age groups (forward)



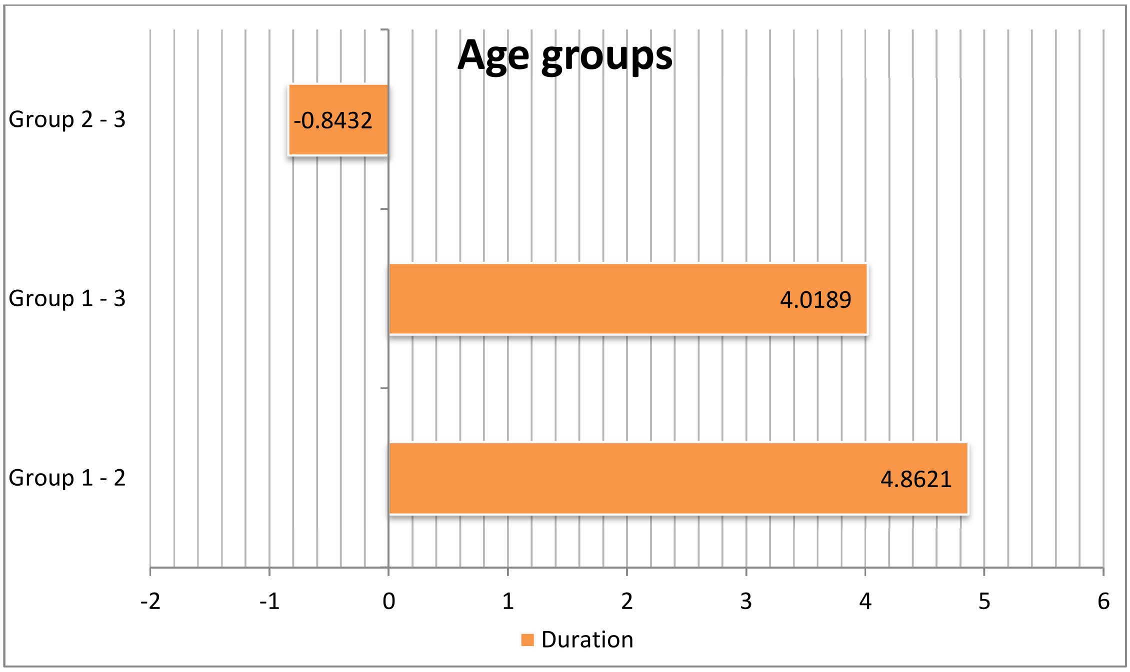
Graph 34: Difference of means for errors between age groups (forward)

Table 40: Differences of least squares means (age groups/backward)

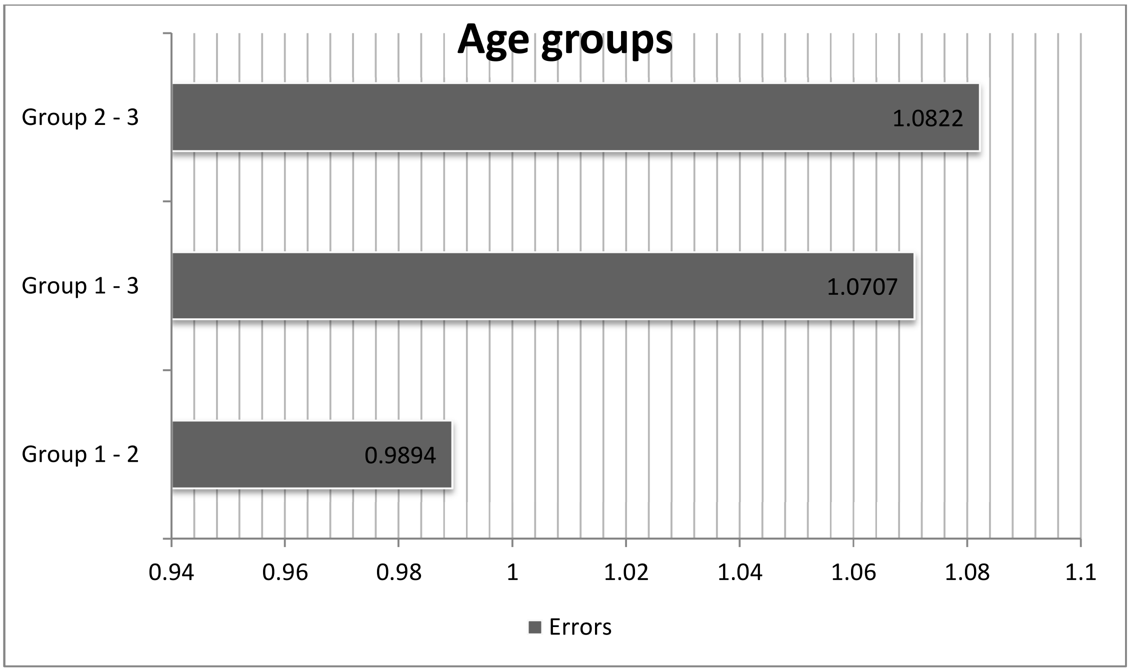
Direction	Treatment	Age group	Estimate	Standard error	P-value	Confidence interval	
						Lower	Upper
Backward	Long-term excitement	1 - 2	-0.00937	0.03128	0.7658	-0.07233	0.05358
		1 - 3	-0.02159	0.03185	0.5012	-0.08570	0.04252
		2 - 3	-0.01222	0.03162	0.7010	-0.07587	0.05143
	Short-term excitement	1 - 2	0.006033	0.03056	0.8444	-0.05549	0.06755
		1 - 3	-0.00563	0.03112	0.8573	-0.06828	0.05702
		2 - 3	-0.01166	0.03090	0.7076	-0.07386	0.05054
	Engagement	1 - 2	0.002748	0.02831	0.9231	-0.05424	0.05974
		1 - 3	-0.00476	0.02883	0.8695	-0.06280	0.05328
		2 - 3	-0.00751	0.02863	0.7942	-0.06513	0.05011
	Meditation	1 - 2	0.01930	0.02435	0.4321	-0.02972	0.06832
		1 - 3	-0.01292	0.02480	0.6049	-0.06284	0.03700
		2 - 3	-0.03222	0.02462	0.1972	-0.08178	0.01734
	Frustration	1 - 2	0.1135	0.04644	0.0184	0.02005	0.2070
		1 - 3	-0.02217	0.04730	0.6414	-0.1174	0.07303
		2 - 3	-0.1357	0.04696	0.0059	-0.2302	-0.04119
	Duration	1 - 2	4.8621	6.3571	0.4483	-7.9340	17.6582
		1 - 3	4.0189	6.4737	0.5378	-9.0120	17.0499
		2 - 3	-0.8432	6.4273	0.8962	-13.7807	12.0943
	Error	1 - 2	0.9894	1 0.1708	0.9501	0.7063	1.3857
		1 - 3	1.0707	0.1741	0.6953	0.7595	1.5094
		2 - 3	1.0822	0.1700	0.6427	0.7738	1.5133



Graph 35: Difference of means between age groups (backward)



Graph 36: Difference of means for duration between age groups (backward)



Graph 37: Difference of means for errors between age groups (backward)

P-VALUE

The P-values associated with all differences was higher than 0.05, except for the difference in frustration between groups 1 and 2 (0.0184) and groups 2 and 3 (0.0059) direction backward (see Table 40). This implies that there was no statistically significant difference between any of the mean values for different age groups, except for frustration between age groups 1 and 2, and between 2 and 3.

CONFIDENCE INTERVAL

All confidence intervals were grouped around the value zero (no difference), and fall within the interval [-0.1, +0.1], except for frustration between groups 1 and 2 [0.02005, 0.2070] and 2 and 3 [-0.2302, -0.04119] direction backward. If a mean difference between sessions of 0.1 in long-term excitement, short-term excitement, engagement, meditation and frustration can be considered not practically relevant, then it can be concluded that there are no practically relevant differences between any of the five sessions.

FINDINGS

This study has failed to show statistically significant differences between different age groups. There might be statistically significant differences between different age groups 1 and 2, and groups 2 and 3 for frustration while moving the robot backward.

5.8. OVERALL SIGNIFICANT FINDINGS

All the significant findings of this research study are summarised in Table 41 below.

Table 41: Overall significant findings

Test	Treatment	Direction	Finding	Statistical significant	Practically relevant
Between treatments	Control – Alpha	Forward	Lower short-term excitement for Alpha compared to Control	Yes	No
	Control – Delta	Forward	Lower short-term excitement for Delta compared to Control	Yes	No
	Alpha	Forward	Shorter duration compared to Control	Yes	No
	Beta	Forward	Shorter duration compared to Control	Yes	No
	Delta	Forward	Shorter duration compared to Control	Yes	No
	Theta	Forward	Shorter duration compared to Control	Yes	No
	Control – Alpha	Forward	Alpha had fewer errors compared to Control	Yes	Yes
	Alpha – Beta	Forward	Alpha had fewer errors compared to Beta	Yes	Yes
	Alpha – Theta	Forward	Alpha had fewer errors compared to Theta	No	Yes
Between directions	Delta	Forward	Higher engagement	Yes	No
	Control	Forward	Lower frustration	Yes	Yes
	Alpha	Forward	Shorter duration	Yes	Yes
	Delta	Forward	Shorter duration	Yes	Yes
	Alpha	Forward	Fewer errors	Yes	Yes
	Delta	Forward	Fewer errors	Yes	Yes
Between age groups	Group 1 – 2	Backward	Lower frustration for age group 2 compared to age group 1	No	Yes
	Group 2 – 3	Backward	Higher frustration for age group 3 compared to age group 2	No	Yes

5.9. CONCLUSION

In this chapter the researcher discussed and provided an analysis of the data. In the next chapter the researcher will present an overview of the study as well as the final findings.

6. CONCLUSION AND RECOMMENDATIONS

6.1. INTRODUCTION

In the previous chapter the research results were analysed and discussed. This chapter will give an overview of the study and the findings. Some proposals for future research are made, followed by a conclusion.

6.2. OVERVIEW

In the first chapter the background on which the study is based was given. This chapter also included the problem statement, research question, aims and objectives, hypotheses, study design, challenges and the outline of the dissertation. Chapter 2 summarised contemporary literature, prior research and some relevant theories in the area of this study. Details of the research design and methodology used were provided in Chapter 3, and in Chapter 4 the tools needed to complete the study were discussed. Chapter 5 reported on the empirical research data and findings.

The research question identified for this study was suggested by claims that certain sounds or music could increase a person's learning abilities and performance. These claims, however, have never been tested in the way that this research study has done. To answer the question of whether sounds can affect a person engaged in a specific task, the aim of this research study was to establish, through a BCI, whether binaural beats can affect the performance of users performing tasks. The participants had to move a robot forward and backward using the BCI while listening to different binaural beats with different frequencies. Each of the 50 participants was asked to move the robot forward and backward for each of the 5 different sessions. The different sessions could be distinguished by the different binaural beats, while the control session had no binaural beat. The usability methods used to evaluate the system were 1) interviews, 2) physiological usability evaluation (using the Emotiv), 3) questionnaires and 4) observations. The problem statement led to four hypotheses.

In the following section the researcher will present a summary of the findings from the questionnaires.

6.3. QUESTIONNAIRE DATA

The following information was collected through the pre-test questionnaire, post-test questionnaire and from observations of the participants.

6.3.1. BRAIN-COMPUTER INTERFACE (BCI)

The majority of the participants described the BCI by means of phrases such as "easy to use", "good response time", "enjoyable to use", "comfortable" and "not invasive".

6.3.2. ROBOT

The majority of the participants described the robot by means of phrases such as "easy to use" and "very enjoyable to use".

6.3.3. BINAURAL TONES (BT)

Most of the participants stated that the BTs were "reasonably comfortable" and that they were moderately aware of them during testing.

6.3.4. EMOTIONS

Participants felt excited, moderately frustrated, engaged and relaxed during the testing.

6.3.5. THOUGHTS

To move the robot forward or backward the participants had to imagine something of their choosing to represent the forward or backward action. Most of the participants used *common* thoughts to move the robot forward and backward, for example:

- visualise the robot moving forward or backward;
- running forward or backward;
- pulling or pushing objects;

- driving forward or backward in a car.

A few of the more interesting thoughts that the participants used in this research study were:

- the forward and backswing of a golf swing;
- pushing in a rugby scrum or a scrum that is moving backwards;
- climbing up or down a mountain;
- counting forwards or backwards;
- thinking of the words “forward” and “backward”.

6.4. STATISTICAL ANALYSIS

The users’ experience was statistically analysed to compare the five sessions. The following outcome variables were analysed

- Engagement
- Short-term Excitement
- Long-term Excitement
- Frustration
- Meditation
- Duration
- Errors

6.5. SIGNIFICANT FINDINGS

6.5.1. BETWEEN TREATMENTS

In this section the hypotheses are given followed by the results of the statistical comparison of the five sessions. There were no statistically significant differences between sessions for the backward direction. The following information refers only to the forward direction.

ALPHA WAVE

H_0: A dominant Alpha brainwave does not affect participants' excitement, engagement meditation, frustration or performance when using the Emotiv EPOC neuroheadset to control a robot.

- The Alpha sessions seemed to have a lower short-term excitement compared to the Control sessions though this difference does not seem to be of a practically relevant magnitude.
- During Alpha sessions the participant needed a shorter duration to complete a task compared to Control sessions, but it did not seem to be practically relevant.
- Participants made less errors in Alpha sessions compared to Control, Beta and Theta sessions.

BETA WAVE

H_1: A dominant Beta brainwave does not affect participants' excitement, engagement meditation, frustration or performance when using the Emotiv EPOC neuroheadset to control a robot.

- Beta sessions needed a shorter duration to complete a task compared to Control sessions though this difference does not seem to be of a practically relevant magnitude.
- Participants made more errors in Beta sessions compared to Alpha sessions.

DELTA WAVE

H_2: A dominant Delta brainwave does not affect participants' excitement, engagement meditation, frustration or performance when using the Emotiv EPOC neuroheadset to control a robot.

- The Delta sessions seemed to have a lower short-term excitement compared to the Control sessions though this difference does not seem to be of a practically relevant magnitude

- Delta sessions had a shorter duration needed to complete a task compared to Control sessions, but it was not seen as practically relevant.

THETA WAVE

H3: A dominant Theta brainwave does not affect participants' excitement, engagement meditation, frustration or performance when using the Emotiv EPOC neuroheadset to control a robot.

- Theta sessions needed a shorter duration to complete a task compared to Control sessions though this difference does not seem to be of a practically relevant magnitude
- It was not statistically significant that participants made more errors in Theta sessions compared to Alpha sessions, but the potential magnitude of the difference might be practically relevant.

6.5.2. BETWEEN DIRECTIONS

In this section the results of comparing directions are given. According to the questionnaire data the participants found the forward direction *easy* while for the backward direction their experience was *neutral.*

ALPHA WAVE

Participants moving the robot forward needed a shorter duration to complete the task and made fewer errors.

BETA WAVE

There were no statistically significant differences between backward and forward for session Beta.

DELTA WAVE

Participants moving the robot forward seemed to be more engaged but the difference did not seem to be practically relevant. Participants needed less time to complete the task and they made fewer errors.

THETA WAVE

There was no statistically significant difference between backward and forward for session Theta.

6.5.3. BETWEEN AGE GROUPS

The results of the comparison between the age groups are given. There were no statistically significant differences between age groups for the forward direction. The following information refers only to the backward direction.

AGE GROUP 1 (AGE 13 - 18) – AGE GROUP 2 (AGE 19 - 24)

Age group 2 participants had lower levels of frustration compared to participants from age group 1. This finding was not statistically significant, but the potential magnitude of the difference might be practically relevant.

AGE GROUP 1 (AGE 13 - 18) – AGE GROUP 3 (AGE 25 - 50)

There were no statistically significant differences between age group 1 and age group 3.

AGE GROUP 2(AGE 19 - 24) – AGE GROUP 3 (AGE 25 - 50)

Age group 2 participants had lower levels of frustration compared to participants form age group 3. This finding was not statistically significant, but the potential magnitude of the difference might be practically relevant.

6.6. HYPOTHESES

By taking 6.3, 6.4 and 6.5 into consideration, the following conclusions were reached.

Alpha: There were statistically significant differences in the *short-term excitement*, *duration* and *errors* in completing tasks, therefore the H_0 hypothesis can be rejected and we can conclude that the Alpha brainwave does affect the participants' short-term excitement, duration to complete the task and the number of errors made.

Beta: There were statistically significant differences in the *duration* and *errors* in completing tasks, therefore the H_1 hypotheses can be rejected and we can conclude that the Beta brainwave does affect the participants' duration to complete the task and the number of errors made.

Delta: There were statistically significant differences in the *short-term excitement* and *duration* in completing tasks, therefore the H_2 hypotheses can be rejected and we can conclude that the Delta brainwave does affect the participants' short-term excitement and duration to complete the task.

Theta: There were statistically significant differences in the *duration* and *errors* in completing tasks, therefore the H_3 hypotheses can be rejected and we can conclude that the Theta brainwave does affect the participants' duration to complete the task and the number of errors made.

In summary, we can conclude that invoking a participant's dominant brainwave through binaural tones can change his/her state of mind. This in turn can affect the long-term excitement, short-term excitement, engagement, meditation, frustration or performance of the participant while performing a task.

6.7. LIMITATIONS AND POSSIBLE FUTURE RESEARCH

Some limitations that might have had an effect on the study need to be mentioned. This study included some participants who had previously used a BCI, thus giving them a slight advantage over inexperienced BCI users.

Even though the Emotiv headset is innovative technology, various other BCIs or systems could be used to provide a comprehensive analysis of physiological data.

It might have been more meaningful to look at each participant's physiological data individually to obtain an indication of the individual's emotional state. This could then be compared to their corresponding performance.

These future research opportunities did, however, fall outside the scope of this dissertation.

6.8. CONCLUSION

Taking into consideration the aim and hypotheses of this study, it has been found that the different sound frequencies do affect the participants. The core finding of this study is that the *No sound frequency* (Control session) was associated with more errors and longer durations for task completion than all the other frequencies.

Much remains to be learned, in particular regarding the combination of brain-computer interfaces and human-computer interaction. Major improvements still need to be made on a physiological as well as a technical level. The possibility of new cutting-edge technologies that could provide a platform for further in-depth research, is an exciting prospect. Future research might uncover more consequences of binaural beats, as such consequences will become clearer as brain-computer interface technology become more pronounced.

7. REFERENCES

ABC Institute of Applied Mathematics (2012.). What Is an Interface? Retrieved 9 February 2012, from http://www.iam.ubc.ca/guides/javatut99/java/more /interfaceDef.html.

ABC News (2011). Brain Power Flies Helicopters. Retrieved 29 November 2012, from http://abcnews.go.com/meta/search/imageDetail?format=plain&source=http://abcnews.go.com/images/GMA/abc_ann_YO_big_111001.

About.com Psychology (2012(a)). Naturalistic Observation – Psychology Definition of the Week. Retrieved 16 February 2012, from http://psychology.about.com/b/2011/04/01/naturalistic-observation-psychology-definition-of-the-week.htm.

About.com Psychology (2012(b)). Survey - Psychology Definition of the Week. Retrieved 16 February 2012, from http://psychology.about.com/b/2009/11/16/survey-psychology-definition-of-the-week.htm.

About.com Psychology (2012(c)). What Is Cross-Sectional Research? Retrieved 16 February 2012, from http://psychology.about.com/od/cindex/g/cross-sectional.htm

About.com Grammar & Composition (2012). Literature Review. Retrieved 16 February 2012, from http://grammar.about.com/od/il/g/literaturereviewterm.htm.

Activeden (2012). Galvanometers. Retrieved 29 November 2012, from http://activeden.net/item/galvanometers/85813.

Adelson, M. (2011). Emotiv Experimenter: An experimentation and mind-reading application for the Emotiv EPOC. Princeton University.

Akshay, S., Lokesh, V. & Shashidhara, H.L. (n.d.). Innovation in Medical Electronic Devices and Technologies. Retrieved 17 February 2012, from http://www.scribd.com/doc/7317189/Innovations-in-Medical-Electronics.

Alleydog.com (2012(a)). Longitudinal Study. Retrieved 16 February 2012, from http://www.alleydog.com/glossary/definition.php?term=Longitudinal%20Study.

Alleydog.com (2012(b)). Quasi Experimental Design. Retrieved 16 February 2012, from http://www.alleydog.com/glossary/definition.php?term=Quasi%20Experimental%20 Design.

Alleydog.com (2012(c)). True Experimental Design. Retrieved 16 February 2012, from http://www.alleydog.com/glossary/definition.php?term=True%20Experimental%20 Design.

Alloy, L.B., Riskind, J.H. & Manos, M.J. (2005). Abnormal Physiology-Current Perspectives. Retrieved 15 March 2011, from http://highered.mcgraw-hill.com/sites/007242298x/student_view0/glossary.html.

Anderson, D.J. (1989). The treatment of migraine with variable frequency photo-stimulation. Headache. 1989;29(3):154-155.

Anderson, D.J., Legg, N.J. & Ridout, D.A. (1997). Preliminary trial of photic stimulation for premenstrual syndrome. J Obstet Gynaecol. 1997;17(1):76-79.

Answers.com (n.d.). Answers.com - Referenced answers. Retrieved 14 February 2011, from http://www.answers.com/topic/behavior.

A-N-T (2012). ASA-Lab – A complete system for recording and analysis in cognitive and clinical research. Retrieved 29 November 2012, from http://www.ant-neuro.com/products/asa-lab.

AskDefine.com (2012). Define electrocardiographically. Retrieved 14 February 2012, from http://electrocardiography.askdefine.com/.

AQR (2012). Pilot Study. Retrieved 16 February 2012, from http://www.aqr.org.uk/glossary/?term=pilotstudy.

Baecker, R.M. and Buxton, W.A.S. (1987). *Readings in human-computer interaction: A multidisciplinary approach*. California: Morgan Kaufan.

Baldauf, M. & Fröhlich, P. (2009). Supporting Hand Gesture Manipulation of Projected Content with Mobile Phones. Retrieved 15 November 2012, from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.149.8260.

Barland, G. H. & Raskin, D. C. (1973). Detection of perception. In W. F. Prokasy (Eds). *Electrodermal activity in psychological research*. New York: Academic Press.

Basmajian, J.V. (1978). *Muscles alive: Their functions revealed by electromyography.* 4th ed. Baltimore: Williams and Wilkins.

Basmajian, J.V. & Stecko, G. (1962). A new bipolar electrode for electromyography: *Journal of Applied Physiology*. 17, 849.

Biodevices (2010). Wearable ECG. Retrieved 07 March 2011, from http://www.biodevices.pt.

Bio-medical.com (2002(a)). EEG or Electroencephalography. Retrieved 22 March 2011, from http://bio-medical.com/news/2002/05/eeg-or-electroencephalography.

Bio-medical.com (2002(b)).GSR or Galvanic Skin Response. Retrieved 17 March 2011, from http://bio-medical.com/news/2002/05/gsr-or-galvanic-skin-response.

Bio-medical.com (n.d.). GSR2 Biofeedback Relaxation System. Retrieved 17 May 2011, from http://bio-medical.com/products/gsr2-biofeedback-relaxation-system.html.

BMedival (2012). ActiWave. Retrieved 29 November 2012, from http://www.bmedical.com.au/shop/activity-heat-research/actiwave.htm.

Book Rags (2006). Galvanic skin response. Retrieved 17 March 2011, from http://www.bookrags.com/wiki/Galvanic_skin_response.

BPR OnLine Learning Center Series (n.d.) How to Measure Success: Uncovering the Secrets of Effective Metrics. Retrieved 9 February 2012, from http://www.prosci.com/metrics.htm.

Bretzner, L. & Lindeberg, T. (1998). *Use your hand as a 3-D mouse, or, Relative orientation from extended sequences of sparse point and line correspondences using the Affine Trifocal Tensor.* Proc. 5th European Conference on Computer Vision (H. Burkhardt and B. Neumann, eds.), vol. 1406 of Lecture Notes in Computer Science, (Freiburg, Germany), pp. 141--157, Springer Verlag, Berlin.

Budzynski, T., Jordy, J., Budzynski, H.K., Tang, H. & Claypoole, K. (1999). Academic performance enhancement with photic stimulation and EDR feedback. J Neurother. 1999;3(3-4):11-21.

BusinessDictionary.com (2012). Field experiment. Retrieved 16 February 2012, from http://www.businessdictionary.com/definition/field-experiment.html.

California State University – Long Beach. (n.d.). PPA 696 research methods. Retrieved 31 July 2011, from http://www.csulb.edu/~msaintg/ppa696/696quali.htm.

CamnTech (2012). The Actiwave. Retrieved 2 May 2011, from http://www.camntech.com/products/actiwave/actiwave-overview.

Cardiac Science (2011(a)). Burdick 8500 ECG. Retrieved 5 May 2011, from http://www.cardiacscience.com/cardiology-products/ecg-devices/burdick-8500-ecg.php.

Cardiac Science (2011(b)). Quinton Eclipse Premier ECG. Retrieved 11 May 2011, from http://www.cardiacscience.com/cardiology-products/ecg-devices/quinton-eclipse-premier.php.

Carnegie Mellon – School of Computer Science (1996). Robotics Frequently Asked Questions List. . Retrieved 13 October 2011, from http://www.cs.cmu.edu/~chuck/robotpg/robofaq/1.html.

Castellina, E. (2009). Assistive Technology and Applications for the independent living of severe motor disabled users. Retrieved 14 February 2012, from http://elite.polito.it/files/castellina_phd_tesi.pdf.

Chakraborty, R.C. (2010). Fundamentals of neural networks. Retrieved 12 September 2012, from http://www.myreaders.info/08_Neural_Networks.pdf.

CleveMed B.V. (2011). KinetiSense. Retrieved 29 April, 2011, from http://www.clevemed.com/products/kinetisense_hardware.shtml.

CleveMed Blogs (2010). Posts Tagged ‘KinetiSense’. Retrieved 29 November 2012, from http://blog.clevemed.com/index.php/tag/kinetisense/.

Cochrane Collaboration (2002). What is meta-analysis? Retrieved 16 February 2012, from http://www.cochrane-net.org/openlearning/html/mod12-2.htm.

Cram, J.R. & Durie, M.D. (n.d.). The history of muscle dysfunction and SEMG. *Journal of Applied Psychophysiology and Biofeedback*. Retrieved 11 April 2011, from http://bio-medical.com/news/2003/02/the-history-of-muscle-dysfunction-and-semg.

De Luca, C.J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13, 135-163.

Den Uyl, M.J. & Van Kuilenburg, H. (2005). The face reader: Online facial expression recognition. Proceedings of Measuring Behaviour 2005. VicarVision, Sentient Systems B.V., Amsterdam

Dictionary.com (2012(a)). Interface. Retrieved 9 February 2012, from http://dictionary.reference.com/browse/interface.

Dictionary.com (2012(b)). Interface. Retrieved 16 February 2012, from http://dictionary.reference.com/browse/consent.

Dodge, R. & Cline, T.S. (1901). The angle velocity of eye movements. *Psychological Review*, 8, 145-157

Duchowski, A. (2007). *Eye-tracking Methodology: Theory and Practice, Second Edition*. New York: Springer.

Educational Communications and Technology (2001). What Is Descriptive Research? Retrieved 16 February 2012, from http://www.aect.org/edtech/ed1/41/41-01.html.

ElectronicsTeacher.com (n.d.(a)). Robotics – What is Robotics? Retrieved 12 October 2011, from http://www.electronicsteacher.com/robotics/what-is-robotics.php.

ElectronicsTeacher.com (n.d.(b)). All about Electronic & Robots. Retrieved 12 October 2011, from http://www.electronicsteacher.com/robotics/type-of-robots.php.

eMED Healthcare (2012). Burdick 8500 ECG by Cardiac Science-Burdick 8500 ECG. Retrieved 29 November 2012, from http://www.emedhealthcare.com/diagnostic-products/burdick-8500-ecg-by-cardiac-science-burdick-8500-ecg-interpretation-300-storage-communications-drop-ship-onl.

Emedicinehealth (2011). Electroencephalography (EEG). Retrieved 17 March 2011, from http://www.emedicinehealth.com/electroencephalography_eeg/article_em.htm

Emotiv (2010). EPOC neuroheadset. Retrieved 3 May 2011, from http://www.emotiv.com/store/hardware/epoc-bci/epoc-neuroheadset.

Emotiv Software Development Kit (2011). User manual for release 1.0.0.3. Retrieved 29 March 2011, from http://emotiv.com/developer/SDK/UserManual.pdf.

Engadget (2010). Eye tracking Tobii Glasses enable 'fully valid research' from a bodaciously styled pair of shades. Retrieved 29 November 2012, from http://www.engadget.com/2010/06/23/eye-tracking-tobii-glasses-enable-fully-valid-research-from-a/.

Engadget (2008). Standard Dell mouse gets GSR electrode implant. Retrieved 29 November 2012, from http://www.engadget.com/2008/11/09/standard-dell-mouse-gets-grs-electrode-implant/.

Experiment-Resources.com (2012(a)). Research Population. Retrieved 28 November 2012, from http://explorable.com/within-subject-design.html.

Experiment-Resources.com (2012(b)). Research Population. Retrieved 16 February 2012, from http://www.experiment-resources.com/research-population.html.

Experiment-Resources.com (2012(c)). Research Designs. Retrieved 16 February 2012, from http://www.experiment-resources.com/research-designs.html.

Experiment-Resources.com (2012(d)). Pilot Study. Retrieved 16 February 2012, from http://www.experiment-resources.com/pilot-study.html.

Eyegaze (2012). Eyegaze Edge Communication Systems. Retrieved 29 November 2012, from http://www.eyegaze.com/applications/eye-controlled-assistive-technology/.

F.A.B.R.I.CATORS (2005). Robotic+VR+Interactivity. Retrieved 14 February 2012, from http://www.fabricat.com/ENG/intsec_c.html.

Fidis (n.d.). Brain computer interfaces. Retrieved 29 November 2012, from http://www.fidis.net/resources/deliverables/hightechid/d122-study-on-emerging-ami-technologies/doc/8/.

Fitts, P.M., Jones, R.E. & Milton, J.L. (1950). Eye movements of aircraft pilots during instrument-landing approaches. *Aeronautical Engineering Review*, 9(2), 24-29.

Fenz, W.D. & Epstein, S. (1967). Gradients of psychological arousal of experienced and novice parachutists as a function of an approaching jump. *Psychosomatic Medicine*, 29, 33 – 51.

Freeman, W.T & Weismann, C.D. (1994). Television control by hand gestures, Mitsubishi Electric Research Labs, 201 Broadway, Cambridge, MA 02139, USA.

Galitz, W.O. (2002). *The essential guide to user interface design*. New York: Wiley Computer Publishing.

GAP (2011). Gentle awakening program. Retrieved 19 April 2011, from http://www.gentleawakening.com/FAQ.html.

Gaus, W. & Högel, J. (1992). Arzneimittel-Forschung. Biodesign-CRF, Institut für Klinische Pharmakologie, Freiburg, Fed. Rep. of Germany. 1992, vol. 42, No. 2, pages 163-172.

Ghaoui, C. (2006). *Encyclopaedia of human computer interaction*. Hershey: Idea Group Inc.

Groh, D. (2008). Electromyography (EMG) Instrumentation. Retrieved 6 April 2011, from http://faculty.unlv.edu/jmercer/Seminar%20presentation/Instrumentation.ppt.

Guba, E.G & Lincoln, Y.S. (1994). Competing paradigms in qualitative research. In Denzin & Lincoln (1994) *Handbook of Qualitative Research.* Ch 6. Thousand Oaks: Sage Publishers.

Haag, Stephen, Maeve Cummings, Donald J. McCubbrey, Alain Pinsonneault & Richard Donovan (2006). *Management Information Systems for the Information Age*. Canada: McGraw-Hill Ryerson.

Hack a day (2010). Head mounted camera tracks with your eyes. Retrieved 29 November 2012, from http://hackaday.com/2010/05/25/head-mounted-camera-tracks-with-your-eyes/.

Hartridge, H. & Thompson, L.C. (1948). Methods of investigating eye movements. *British Journal of Ophthalmology*. 32:581-591.

Hazlett, R.L. (2003). *Measurement of User Frustration: A Biologic Approach*. Proceedings of CHI‘ 2003 Conference on Human Factors in Computing Systems v2 (2003), ACM Press, 560-561.

Hazlett, R. & Benedek, J. (2005). *Incorporating Facial EMG Emotion Measures as Feedback in the Software Design Process*. Human Computer Interaction Consortium, February, Colorado.

HealthKnowledge (2009). Case Control Studies. Retrieved 16 February 2012, from http://www.healthknowledge.org.uk/public-health-textbook/research-methods/1a-epidemiology/cs-as-is/case-control-studies.

Henning, E., Van Rensburg, W. & Smit, B. (2004). *Finding your way in Qualitative Research*. Van Schaik: Pretoria.

Hirose, Y., Yamashita, K. & Hijiya, S. (1991). Back-propagation algorithm which varies the number of hidden units. *Neural Networks*, *4*(1), 61–66.

Hopkins, W.G. (2000). *Quantitative Research Design.* Dunedin, New Zealand: Department of Physiology and School of Physical Education, University of Otago.

Hossain, J. (2011). Laws of Humanics – The Zero-th Law! Retrieved 14 February 2012, from http://jamihossain.com/articles/science-spirituality/laws-of-humanics-the-zero-th-law/.

Horikawa, S. I., Furuhashi, T. & Uchikawa, Y. (1992). On fuzzy modeling using fuzzy neural networks with the back-propagation algorithm. *Neural Networks, IEEE Transactions on*, 3(5), 801–806.

Howard, C.E., Graham, L.E. & Wycoff, S.J. (1986). A comparison of methods for reducing stress among dental students. J Dent Educ. 1986;50(9):542-544.

Hyönä, J., Radach, R. & Deubel, H. (2003) The mind's eye: cognitive and applied aspects of eye movement research. Retrieved 16 October, 2012 from http://books.google.co.za/books/about/The_Mind_s_Eye.html?id=SekrKK95ep4C&redir_esc=y.

Hyperphysics. (n.d.). The Sinoatrial Node: The Body's Natural Pacemaker. Retrieved 15 February, 2012, from http://hyperphysics.phy-astr.gsu.edu/hbase/biology/sanode.html.

Jacko, J.A. (2009). *Human-Computer Interaction. Interacting in Various Applications Domains.* 13th International Conference, HCI International 2009, San Diego, CA, USA, July 19-24, 2009, Proceedings. Lecture Notes in Computer Science. Part 4 of Human-computer Interaction: 13th International Conference, HCI International 2009, San Diego, CA, USA, July 19-24, 2009. New York: Springer.

Jacob, R.J.K. & Karn, K.S. (2003). Eye Tracking in Human-Computer Interaction and Usability Research: Ready to Deliver the Promises (Section Commentary). In J. Hyona, R. Radach & H. Deubel (eds).,*The Mind's Eye: Cognitive and Applied Aspects of Eye Movement Research.*, pp. 573-605, Amsterdam: Elsevier Science.

Joyce, M. & Siever, D. (2000). Audio-Visual Entrainment (AVE) program as a treatment for behavior disorders in a school setting. J Neurother. 2000; 4(2):9-25.

Judd, C.H., McAllister, C.N. & Steel, W.M. (1905). General introduction to a series of studies of eye movements by means of kinetoscopic photographs. In J.M. Baldwin, H. C. Warren & C.H. Judd (eds). *Psychological Review, Monograph Supplements*. 7:1-16. Baltimore: The Review Publishing Company.

Jun-Hyeong, D., Jin-Woo, J., Jung, S.H., Hyoyoung, J. & Zeungnam, B. (2006). *Advanced soft remote control system using hand gesture*. Mexican International Conference on Artificial Intelligence.

Javal, E. (1878). Essai sur la physiologie de la lecture. *Annales d'Oculistique*, 79, 97-117, 155-167, 240-274; 80 (1879), 61-73, 72-81, 157-162, 159-170, 242-253.

Keeley, P. (2006). *Stress-proof your life.* Infinity Publishing, United States, 2006.

Krippendorff, K. (1980). *Content Analysis: An Introduction to Its Methodology*. Newbury Park: Sage Publishers.

Kue-Bum Lee, Jung-Hyun Kim & Kwang-Seok Hong (2007). *An Implementation of Multi-Modal Game Interface Based on PDAs*. Fifth International Conference on Software Engineering Research, Management and Applications.

Kumar, R. and Kumar, R. (2005). *Human Computer Interaction*. USA: Firewall Media.

Lane J.D., Kasian S.J., Owens, J.E. & Marsh, G.R. (1998). Binaural auditory beats affect vigilance performance and mood. Physiol Behav. 1998;63(2):249-252.

LC Technologies (2009). Assistive Technologies. Retrieved 13 May 2011, from http://www.eyegaze.com/content/assistive-technology.

Le Scouarnec, R.P., Poirier, R.M., Owens, J.E., Gauthier, J., Taylor, A.G. & Foresman, P.A. (2001). Use of binaural beat tapes for treatment of anxiety: a pilot study of tape preference and outcomes. Altern Ther Health Med. 2001; 7(1):58-63.

Lew, M.S., Sebe, N. and Huang, T.S. (2007). *Human-computer interaction*. IEEE International Workshop, HCI 2007, Rio de Janeiro, Brazil, October 20, 2007: proceedings, Volume 4796 of Lecture Notes in Computer Science. LNCS sublibrary: Information systems and applications, incl. internet/web, and HCI .New York: Springer.

Little Dreams (2010). Create Robots with Microsoft Robotics Developer Studio 2008 R3. Retrieved on 29 November, 2012, from http://mydreamsinside.blogspot.com/2010_12_01_archive.html.

Mackworth, J.F. & Mackworth, N.H. (1958). Eye fixations recorded on changing visual scenes by the television eye-marker. *Journal of the Optical Society of America*. 48:439-445.

Manns, A., Miralles, R. & Adrián, H. (1981). The application of audiostimulation and electromyographic biofeedback to bruxism and myofascial pain-dysfunction syndrome. Oral Surg Oral Med Oral Pathol. 1981;52(3):247-252.

McCulloch, W. S. & Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity. *Bulletin of Mathematical Biology*, *5*(4), 115–133.

Mechanical eBook.com (2009). Electrocardiograph. Retrieved on 14 February 2012, from http://www.mechanicalebook.com/topics/topice/ecardiograph.htm.

Medicallabtech.com (2012) Medical Teknika. Retrieved on 29 November 2012, from http://medicallabtech.digi2.jp/mobilejacket/.

Medical Machines Online (2008). ECG history. Retrieved 7March, 2011, from http://www.medicalmachinesonline.com/articles/ecg-history.html.

MediceneNet.com (2010).Definition of dilation. Retrieved 8 March, 2011, from http://www.medterms.com/script/main/art.asp?articlekey=2999.

MedicineNet.com (2001). Definition of EEG. Retrieved 16 February 2011, from http://www.medterms.com/script/main/art.asp?articlekey=11195/.

MedicineZine (2010). What is Biofeedback and Neurofeedback? Retrieved 29 November 2012, from http://medicinezine.com/mental-health/biofeedback-software-therapy-deepak-chopra-wild-divine/.

Medline (2012). Quinton Eclipse Premier ECG with Cart. Retrieved 29 November 2012, from http://www.medline.com/product/Quinton-Eclipse-Premier-ECG-with-Cart/EKG/ECG-Monitors/Z05-PF04182.

Medscape Reference. (2011). Ambulatory EEG**.** Retrieved 2 May 2011, from http://emedicine.medscape.com/article/1139483-overview.

Medved, V. (2001). *Measurement of human locomotion*. Boca Raton, FL: CRC Press.

Metro Technology Centres (2012). Pre-engineering Manufacturing Technology. Retrieved 6 September 2011, from http://home.earthlink.net/~okwagoner /pltw/glossaries/frames/cims_glossarytext.html.

Mind Media (n.d.). NeXus-10 Mark II. Retrieved 27 April 2011, from http://www.mindmedia.nl/CMS/index.php.

Mind Media B.V. (2006). NeXus-10 Mark II. Retrieved 27 April 2011, from http://www.mindmedia.nl/english/nexus10.php.

Molina, G.E. (2003). Joint Time-Frequency-Space Classification of EEG in a Brain-Computer Interface Application. *EURASIP Journal on Applied Signal Processing* , 713 - 729.

Morse, D.R. & Chow, E. (1993). The effect of the Relaxodont brain wave synchronizer on endodontic anxiety: evaluation by galvanic skin resistance, pulse rate, physical reactions, and questionnaire responses. Int J Psychosom. 1993;40(1-4):68-76.

MSDN Library (2012(a)). Best Practices for Implementing the Event-based Asynchronous Pattern. Retrieved 28 November 2012, from http://msdn.microsoft.com/en-us/library/ms228974.aspx.

MSDN Library (2012(b)). DSS Introduction. Retrieved 28 November 2012, from http://msdn.microsoft.com/en-us/library/bb483056.aspx.

Mystic Mindpower (2010). What is brainwave entrainment? Retrieved 11 July 2011, from http://mysticmindpower.com/what-is-brainwave-entrainment.

National Institute of General Medical Sciences (2006). Medicines by design: Glossary. Retrieved 15 February 2011, from http://publications.nigms.nih.gov/medbydesign/glossary.html.

Nefeg.com (n.d.). Acer TravelMate 5742 Laptop. Retrieved 28 November 2012, from http://nefegg.com/acer-travelmate-5742-laptop-4gb-ram-320gb-hdd-156.

Nickel, K. & Stiefelhangen, R. (2006). *Visual recognition of pointing gestures for human–robot interaction*. Karlsruhe, Germany: Interactive Systems Labs, Universitaet Karlsruhe, 76131.

No sweat public speaking (2012). Non-Verbal Communication Element #2 – Facial Expressions. Retrieved 29 November 2012, from http://www.nosweatpublicspeaking.com/non-verbal-communication-element-2facial-expressions/.

Nomura, T., Higuchi, K. & Yu, H. (2006). Slow-wave photic stimulation relieves patient discomfort during esophagogastroduodenoscopy. J Gastroenterol Hepatol. 2006;21(1 Pt 1):54-58.

Noton, D. (2000). Migraine and photic stimulation: report on a survey of migraineurs using flickering light therapy. Complement Ther Nurs Midwifery. 2000;6(3):138-142.

Nursingcrib (2011). Electromyography (EMG). Retrieved 29 November 2012, from http://nursingcrib.com/nursing-notes-reviewer/medical-surgical-nursing/electromyography-emg/.

Ohioline (n.d.). Bulletin. Retrieved 16 February 2012, from http://ohioline.osu.edu/b868/pdf/b868.pdf

Olmstead, R. (2005). Use of auditory and visual stimulation to improve cognitive abilities in learning-disabled children. J Neurother. 2005; 9(2):49-61.

Ossebaard, H.C. (2000). Stress reduction by technology? An experimental study into the effects of brainmachines on burnout and state anxiety. Appl Psychophysiol Biofeedback. 2000; 25(2):93-101.

Oster, G. (1973) Auditory Beats in the Brain. Scientific American. Retrieved 19 March 2012, from http://www.amadeux.net/sublimen/documenti/G.OsterAuditoryBeatsintheBrain.pdf.

Oxford Journals (2006). ECG diagnosis of acute ischaemia and infarction: past, present and future. Retrieved 14 February 2012, from http://qjmed.oxfordjournals.org/content/99/4/219.extract.

Padmanabhan, R., Hildreth, A.J. & Laws, D. (2005). A prospective, randomised, controlled study examining binaural beat audio and pre-operative anxiety in patients undergoing general anaesthesia for day case surgery. Anaesthesia. 2005; 60(9):874-877.

Patrick, G.J. (1996). Improved neuronal regulation in ADHD: An application of 15 sessions of photic-driv-en EEG neurotherapy. J Neurother. 1996; 1(4):27-36.

Picasa (2011). Electrolux UltraSilencer Sleep Clinic Test. Retrieved 29 November 2012, from https://picasaweb.google.com/lh/photo/Lzx1x0SoeSSY8behn-E7Ew.

POPCSI (2010). Infrared Eyetracker keeps drivers awake at a fraction of the cost. Retrieved 29 November 2012, from http://www.popsci.com/cars/article/2010-10/eyetracker-keeps-you-alert-road-be-available-spring.

Princeton University (2012(a)). Wordnet – A lexical database for English. Retrieved 15 February 2011, from http://wordnetweb.princeton.edu/perl/webwn?s=emg.

Princeton University (2012(b)) Wordnet – A lexical database for English. Retrieved 14 March 2011, from http://wordnetweb.princeton.edu/perl/webwn?s=galvanic skin response.

Princeton University (2012(c)). Wordnet – A lexical database for English. Retrieved 15 February 2011, from http://wordnetweb.princeton.edu/perl/webwn?s= physiology.

Princeton University (2012(d)). Wordnet – A lexical database for English. Retrieved 14 February 2011, from http://wordnetweb.princeton.edu/perl/webwn?s=behavior.

Proteus family network (1998). Proteus: Glossary. Retrieved 16 February 2011, from http://www.proteus-uk.org/glossary.html.

Psychologyandsociety.com (2012). Correlational Study. Retrieved 16 February 2012, from http://www.psychologyandsociety.com/correlationalstudy.html.

PubMed Health (2012). U.S. National Library of Medicine - The World's Largest Medical Library. Retrieved 27 November 2012, http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0002518/.

QualSight-Lasik (2010). Glossary. Retrieved 8 March, 2011, from http://www.qualsight.com/laser_vision_correction/glossary.html.

Redmond Pie (2010). Visual Studio 2010 RC Now Available for Download. . Retrieved 29 November 2012, from http://www.redmondpie.com/download-visual-studio-2010-9140438/.

Renewal Technologies Inc. (2008). Helping people and organizations grow. Retrieved 29 November 2012, from http://www.renewal.ca/newsletter0804.html.

SAGE (2006). Choosing a mixed method design. Retrieved 5 March 2012, from http://www.sagepub.com/upm-data/10982_Chapter_4.pdf.

Schult, T. & Wand, M. (2010). Session-Adaptive Speech Recognition Based On Surface Electromyography. Retrieved 15 February 2012, from http://csl.anthropomatik.kit.edu/fileadmin/media/publication_files/SA_Elkara.pdf.

Schultz, K.F. & Grimes, D.A. (2002). "Case-control studies: research in reverse". The Lancet, 359, 431-34.

ScienceDaily (2010). 3-D Gesture-Based Interaction System Unveiled. Retrieved 29 November 2012, from http://www.sciencedaily.com/releases/2010/07/100721085354.htm.

Sciencedirect (2011) Pattern Recognition. Shape analysis of local facial patches for 3D facial expression recognition. Retrieved 29 November 2012, from http://www.sciencedirect.com/science/article/pii/S0031320311000756.

Sciencedirect (2005). Comparing the accuracy of video-oculography and the scleral search coil system in human eye movement analysis. Retrieved 29 November 2012, from http://www.sciencedirect.com/science/article/pii/S0031320311000756.

Scribd (2001). Brain-Computer Interface. Retrieved 27 July 2011, from http://www.scribd.com/doc/15117879/Brain-Computer-Interface.

SearchSOA (2000). User Interface. Retrieved 9 February 2012, from http://searchsoa.techtarget.com/definition/user-interface.

Search Directories.com (n.d.). Definition of electromyogram. Retrieved 29 November 2012, from http://www.searchdictionaries.com/?q=electromyogram.

Sharp, H., Rogers, Y. & Preece, J. (2007). *Interaction Design.* 2nd edition. Sussex: John Wiley & Sons, Ltd.

SkyBlueCross (2012). Biofeedback. Retrieved 29 November 2012, from http://biofeedback.skybluecross.com/biofeedback-gsr.php.

Smart Device Central (n.d.). The Emotiv EPOC: Meeting the Future Head On - Control Panel Headset Expressiv Raised Brow. Retrieved 29 November 2012, from http://www.smartdevicecentral.com/slide/The+Emotiv+EPOC+Meeting+the+Future+Head+On/248749_248750_3_0.aspx.

Solomon, G.D. (1985). Slow wave photic stimulation in the treatment of headache - a preliminary report. Headache. 1985;25(8):444-446.

SoundRevedies.com (2001). Binaural Beat Frequencies (BBFs): A Natural Process of Brainwave Entrainment. Retrieved 19 May 2011, from http://www.sound-remedies.com/binbeatfreq.html.

SoundRevedies.com (2008). Brain waves. Retrieved 20 May 2011, from http://www.sound-remedies.com/whatstorwitb.html.

Sourceforge (2012). Gnaural. Retrieved 29 November 2012, from http://sourceforge.net/projects/gnaural/.

Starner, T. & Pentland, A. (1995). Visual Recognition of American Sign Language Using Hidden Markov Models. Thad Starner and Alex Pentland Perceptual Computing Section, The Media Laboratory, Massachusetts Institute of Technology.

Student's Gumkhana IIT Kanpur (2012). Brain_braindecoding. Retrieved 29 November 2012, from http://students.iitk.ac.in/projects/brain_brainDecoding.

ITstressControl.com (2011). Stress Control for the IT Professional. Retrieved 29 November 2012, from http://itstresscontrol.com/.

Tel Aviv University (2006). Shifting Gears: A NXT Vehicle with a Transmission. Retrieved 29 November 2012, from http://www.tau.ac.il/~stoledo /lego/ShiftingGears.

Tan, D.S. & Nijholt, A. (2010). *A Brain-Computer Interface (Applying our Minds to Human-Computer Interaction)*. New York: Springer.

The Canadian Medical Hall of Fame (2011). Dr Herbert Jasper. Retrieved 7 April 2011, from http://www.cdnmedhall.org/dr-herbert-jasper.

The free dictionary (2009(a)). Farlex. Retrieved 14 February 2011, from http://www.thefreedictionary.com/behavior.

The free dictionary (2009(b)). Farlex. Retrieved 16 February 2012, from http://www.thefreedictionary.com/double-blind+experiment.

The free dictionary (2009(c)). Farlex. Retrieved 14 February 2011, from http://www.thefreedictionary.com/triangulation.

The George Washington University (2011). Study Design 101. Retrieved 16 February 2012, from www.gwumc.edu/library/tutorials/studydesign101/cohorts.html.

The history of ISEK (n.d.).Retrieved 8 April 2011, from http://isek.bu.edu.

The Morry Method (2011). Re-train your brain for a better life. Retrieved 16 April 2011, from http://www.themorrymethod.com/tmm.php?id=4.

Tjsk.org.cn (n.d.). CMS Series Ambulatory Digital EEG (AEEG System) with 3-lead ECG, SPO2 Function. Retrieved 29 November 2012, from http://www.tjskl.org.cn/productssearch/cz50ace5b/cms_series_ambulatory_digital_eeg_aeeg_system_with_3_lead_ecg_spo2_function-pz53f89c9.html.\

Tobii – Eye-tracking research (2011). Tobii Glasses Eye Tracker. Retrieved 16 May 2011, from http://www.tobii.com/analysis-and-research/global/products/hardware/tobii-glasses-eye-tracker.

Tobii – Looking forward. (2011). The basics of eye tracking. Retrieved 07 March 2011, from http://www.tobii.com/en/eye-tracking-integration/global/eye-tracking/the-basics-of-eye-tracking.

Traynor, V. (2006) Mixed Methods: UNSW Research Capacity Building Program. Retrieved 05 March 2012, from http://www.nswphc.unsw.edu.au/pdf/ShortCourseResMetJul06/PPts/Mixedmethods_VanessaTraynor.pdf.

Tricom solutions (2007). SignWiiver. Retrieved 4 April 2011, from http://www.tricomsolutions.com/signwiiver.html.

Tullis, T. and Albert, B. (2008). *Measuring the User Experience: Collecting, Analyzing and Presenting Usability Metrics*. Amsterdam: Morgan Kaufmann Publishers.

U.S. Department of Health and Human services. (n.d.). Glossary of Terms. Retrieved 16 February 2011, from http://www.effectivehealthcare.ahrq.gov /index.cfm/glossary-of-terms/?pageaction=showterm&termid=70.

University of Texas at Austen (n.d.). Robotics Research Group. Retrieved 14 February 2012, from http://www.robotics.utexas.edu/rrg/learn_more/history/.

Van Nimwegen, C. & Uyttendaele, A. J. (2009). *Unobtrusive physiological measures to adapt system behaviour: The GSR mouse.* Key Issues in Sensory Augmentation Workshop, Brighton, Sussex.

Van Ooyen, A. & Nienhuis, B. (1992). Improving the convergence of the back-propagation algorithm. *Neural Networks*, *5*(3), 465–471.

Wahbeh, H., Calabrese, C., Zwickey, H. & Zajdel, D. (2007(a)). Binaural beat technology in humans: a pilot study to assess neuropsychologic, physiologic, and electroencephalographic effects. J Altern Complement Med. 2007;13(2):199-206.

Wahbeh, H., Calabrese, C. & Zwickey, H. (2007(b)). Binaural beat technology in humans: a pilot study to assess psychologic and physiologic effects. J Altern Complement Med. 2007;13(1):25-32.

Wei Du & Hua Li (2000). *Vision based gesture recognition system with single camera*. 5th International Conference on Signal Processing Proceedings. Inst. of Comput. Technol., Acad. Sinica, Beijing.

WebMD (2011(a)). Better information. Better health. Retrieved 6 March 2011, from http://www.webmd.com/heart-disease/electrocardiogram.

WebMD (2011(b)). Electrocardiogram (EKG) Components and Intervals. Retrieved 29 November 2012, from http://www.webmd.com/heart/ekg-components-and-intervals.

WebMD (2011(c)). Better information. Better health. Retrieved 17 March 2011, from http://www.webmd.com/epilepsy/electroencephalogram-eeg-21508.

web-us.com (n.d.). The Science of Audio Based Binaural Beat Brainwave Entrainment. Retrieved 15 August 2011, from http://web-us.com/thescience.htm.

Whatis.com (2011). Brain-computer Interface. Retrieved 18 March 2011, from http://whatis.techtarget.com/definition/0,,sid9_gci521113,00.html.

Whittle, M. W. (1999). *Gait analysis: An introduction.* 2nd ed. Oxford: Butterworth-Heinemann.

WhyWeProtest (2008). The Miracle of Scientology's E-Meter. Retrieved 29 November 2012, from https://whyweprotest.net/community/threads/the-miracle-of-scientologys-e-meter.9170/.

Williams, J., Ramaswamy, D. & Oulhaj, A. (2006). 10 Hz flicker improves recognition memory in older people. BMC Neurosci. 2006 Mar 5; 7:21.

Wolpaw, J.R., Schalk, G., McFarland, D.J. & Pfurtscheller, G. (2000). *EEG-based communication: presence of an error potential*. Graz, Austria: Department of Medical Informatics, Institute of Biomedical Engineering, Graz University of Technology.

Writing@csu (2012). Case Study: Introduction and Definition. Retrieved 16 February 2012, from http://writing.colostate.edu/guides/research/casestudy/pop2a.cfm.

Yang Liu & Yunde Jia (2004). *A Robust Hand Tracking and Gesture Recognition Method for Wearable Visual Interfaces and Its Applications*. Proceedings of the Third International Conference on Image and Graphics (ICIG'04).

Zhou, L. (2010). *The Emotiv EPOC Headset: the feasibility of a cheaper, more accessible neural imager*. Princeton: Princeton University Independent Work.

8. ABBREVIATIONS

ANOVA: Analysis of Variance

BCI: Brain-Computer Interface

CSUQ: Computer System Usability Questionnaire

ECG: Electrocardiogram

EEG: Electroencephalogram

EMG: Electromyogram

EOG: Electrooculography

GHz: Gigahertz

GSR: Galvanic Skin Response

GUI: Graphical User Interface

HCI: Human-Computer Interaction

Hz: Hertz

ISO: International Organisation for Standardisation

ISEK: International Society of Electrophysiological Kinesiology

IT: Information Technology

LCD: Liquid Crystal Display

NA: Not Applicable

PC: Personal Computer

QUIS: Questionnaire for User Interaction Satisfaction

SCP: Slow Cortical Potentials Sensor

SDK: Software Development Kit

SUS: System Usability Scale

UCD: User-Centred Design

UFS: University of the Free State

USB: Universal Serial Bus

UXD: User Experience Design

APPENDIX A

RULES

The following general rules must be read to each participant being tested:

1. Please switch off your phone.
2. Please be seated when using the devices.
3. Only use the dedicated systems to complete the required tasks.
4. Do not switch off the systems before, during or after use.

APPENDIX B

CONSENT FORM

Assessing a BCI's performance by evoking the auditory cortex through binaural beats

Reference number ____________

What are we testing?

As part of my Master's studies, the impact of binaural beats on user performance using a brain-computer interface to control a robot will be assessed. The Emotiv will be used to capture the physiological aspects of the user in order to evaluate brain-computer interfaces. The Emotiv will also be used to control the Lego Mindstorm robot. The physiological aspects include the participant's excitement, engagement and frustration levels. A conclusion on the participant's performance with different binaural tones will then be determined.

What will you be asked to do?

A pre-test will be completed to gather personal information from the participant. The participant will be asked to perform a task using the Emotiv and the Lego Mindstorm robot while listening to different binaural beats. The Emotiv headset will be worn while tasks are being completed. Thereafter a post-test questionnaire is to be completed. The training session is expected to last approximately thirty minutes and the testing session is expected to last approximately sixty minutes.

How your information will be treated

The data will be collected anonymously and will not be linked to your name. All data will be identified and linked together by a number and not by your name. We will not have or use your name in any of the data or the reporting. The pre- and post-tests will be destroyed once the data analysis is complete. The recordings will not be used for any purposes outside this study.

Your identity will be protected to the extent permitted by law, including the Freedom of Information Act. The people who will be able to review individual records from the test will be limited to members of the Information Technology Department at the University of the Free State.

Usability test

- We expect no fewer than 48 test participants to take part.
- You may leave the test at any time. If you acquire a break during the course of the test, please inform the person in charge.
- There are no risks to you in participating in this test, nor are there any immediate benefits. Each participant will receive a Kloppers voucher to the value of R50 if they have completed a full test session.

For more information

For questions about this test, please contact: Dr Lizette de Wet, 051 4013705, lizette@ufs.ac.za

Your agreement to participate

Please read the following and sign if you are willing to participate in this test.
"I have read the above description of this usability test. I have also spoken to the test administrator, who answered any questions I had about this test. I agree to participate in this usability test and I understand that I may withdraw without penalty at any time."

Participant
Full name ______________________
Signature________________________
Date ___/___/ 2012

Researcher
Full name ______________________
Signature ______________________
Date ___/___/ 2012

APPENDIX C

PRE-TEST QUESTIONNAIRE

Assessing a BCI's performance by evoking the auditory cortex through binaural beats

Reference number ____________

The purpose of this questionnaire is to obtain personal and experience information from the participants. You may skip questions that are not applicable to you.

Personal Information

1.1 Name: ______________________________

1.2 Surname: ______________________________

1.3 Contact number: ______________________________ (cell)

1.4 Age: ______

1.5 Gender: ☐Male ☐Female

1.6 Home language: ☐Afr ☐Eng ☐Sotho ☐Xhosa ☐Other______

1.7 Date of birth: DD | MM | YYYY

1.8 Occupation: ☐Student ☐Lecturer Other: _________________

Computer

2.1 Have you ever used a computer before? ☐Yes ☐No

2.2 If "Yes", when was the last time you used a computer?

☐More than 1 year ago.

☐6 months – 1 year ago

☐Less than 6 months ago

2.3 For what purpose did you use a computer? (You may select more than one option)

☐Surfing the web

☐Studying / Work

☐Movies

☐Games

☐Online shopping

☐Other ____

Robot

3.1 Have you ever controlled a robot before? ☐Yes ☐No

3.2 If "Yes", when did you do this? YYYY

3.3 How did you do this?

____

____

Brain-Computer Interface

4.1 Have you ever used a Brain-Computer Interface before? ☐Yes ☐No

4.2 If "Yes", when did you do this? YYYY

4.3 For what purpose did you use it?

____

____

Binaural Beats

5.1 Have you ever used binaural beats before? ☐Yes ☐No

5.2 If "Yes", when did you use them? YYYY

5.3 For what purpose did you use them?

____

____

Music

6.1 Do you ever listen to music while you are concentrating on something else, e.g. studying or working?

☐Yes ☐No

6.2 If "Yes", when did you do this? YYYY

6.3 For what duration do you do this? (Tick only one)

☐More than 5 hours

☐3 – 5 hours

☐1 – 3 hours

☐less than an hour

....

Thank you for completing this questionnaire and for being prepared to take part in this research study.

APPENDIX D

TASKS TO COMPLETE

A task will be given to a participant to complete for the study.

You will be stopped after you have completed the task or if the time limit has been reached. Please make sure you are comfortable and relaxed.

1. Sit quietly for one minute while listening to the binaural tone. The researcher will tell you when the minute has expired.

2. You have two minutes to complete each task. Keep trying to complete the task until you are told to stop.

3. Using only the Emotiv Neuroheadset, move the robot from the beginning line on the track to the end line. To move the robot forward, think of pushing the robot forward.

4. Move the robot back to the beginning line. To move the robot backwards, think of pushing the robot backwards.

APPENDIX E

POST-TEST QUESTIONNAIRE

Assessing a BCI's performance by evoking the auditory cortex through binaural beats

Reference number _____________

Please complete the following questions on how you experienced the usability test. Indicate your choice with a mark (X) in the boxes provided next to the statements. You may take your time and ask for assistance at any time.

1. Brain-Computer Interface (BCI)

Statement/Question	Answer		
1.1 I was confident in using the Emotiv.	Agree	Don't know	Disagree
1.2 It was easy to learn how to use the Emotiv.	Agree	Don't know	Disagree
1.3 The Emotiv's response time was satisfactory.	Agree	Don't know	Disagree
1.4 The Emotiv did everything I expected it to do.	Agree	Don't know	Disagree
1.5 The experience with the BCI was enjoyable.	Agree	Don't know	Disagree

2. Robot

Statement/Question	Answer		
2.1 I was confident using the robot.	Agree	Don't know	Disagree
2.2 It was easy to learn how to use the robot.	Agree	Don't know	Disagree
2.3 The robot did everything I expected it to do.	Agree	Don't know	Disagree
2.4 The experience with the robot was enjoyable.	Agree	Don't know	Disagree

3. Binaural beats

Statement/Question	Answer		
3.1 I was confident using the binaural beats.	Agree	Don't know	Disagree
3.2 The experience with the binaural beats was enjoyable.	Agree	Don't know	Disagree

4. Physical and personal experience

In this section BCI = Brain-Computer Interface and BT = Binaural tones.

Statement/Question	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
4.1 I found it difficult to complete the task with the Emotiv.	1	2	3	4	5
4.2 I found wearing the Emotiv very uncomfortable.	1	2	3	4	5
4.3 I was constantly aware of headset.	1	2	3	4	5
4.4 I found listening to the BT very uncomfortable.	1	2	3	4	5
4.5 I was constantly aware of the BT.	1	2	3	4	5
4.6 It was difficult to switch from one BT to the next.	1	2	3	4	5

5. SUS questionnaire

In this section BCI = Brain-Computer Interface and BT = Binaural tones.

Statement/Question		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
5.1 I would like to use this tool frequently.	**BCI**	1	2	3	4	5
	BT	1	2	3	4	5
5.2 I found the tool unnecessarily complex.	**BCI**	1	2	3	4	5
	BT	1	2	3	4	5
5.3 The tool was easy to use.	**BCI**	1	2	3	4	5
	BT	1	2	3	4	5
5.4 I would need the support of a technical person to be able to use this tool.	**BCI**	1	2	3	4	5
	BT	1	2	3	4	5
5.5 I found the various functions in this tool to be well integrated.	**BCI**	1	2	3	4	5
	BT	1	2	3	4	5

5.6 I thought there was too much inconsistency in using this tool.	**BCI**	1	2	3	4	5
	BT	1	2	3	4	5
5.7 I would imagine that most people would learn to use this tool very quickly.	**BCI**	1	2	3	4	5
	BT	1	2	3	4	5
5.8 I found the tool very awkward to use.	**BCI**	1	2	3	4	5
	BT	1	2	3	4	5
5.9 I felt very confident using the tool.	**BCI**	1	2	3	4	5
	BT	1	2	3	4	5
5.10 I needed to learn a lot of things before I could get going with this tool.	**BCI**	1	2	3	4	5
	BT	1	2	3	4	5

6. Thoughts

6.1 What was the thought that you associated with the **push** action?

____

____

6.2 What was the thought that you associated with the **pull** action?

____

____

7. Tasks

How difficult was the task?

	Very easy	**Easy**	**Neutral**	**Hard**	**Very hard**
7.1 **Forward**	☐	☐	☐	☐	☐
7.2 **Backward**	☐	☐	☐	☐	☐

8. Emotions

Statement/Question	Answer		
8.1 I was excited during the test.	Agree	Don't know	Disagree
8.2 I was frustrated during the test.	Agree	Don't know	Disagree
8.3 I was engaged during the test.	Agree	Don't know	Disagree
8.4 I was relaxed during the test.	Agree	Don't know	Disagree

9. After test

How did you feel physically after using the device?

	None	**Droopy shoulders**	**Headache**	**Earache**	**Tired eyes**	**Other**
9.1 **BCI**	☐	☐	☐	☐	☐	____________
9.2 **BT**	☐	☐	☐	☐	☐	____________

9.3 What was your overall experience of this study?

____

____

10. Comments

10.1 Please mention any **comments or suggestions** about your **experience** during the testing session.

____

____

10.2 Would you like to participate in other studies? ☐Yes ☐No

....

Thank you for completing this questionnaire and for being prepared to take part in this research study.

APPENDIX F

PHOTOS FROM STUDY

Figure 50: Robot on course

Figure 51: Participant holding the Emotiv headset

Figure 52: Participant about to be tested for the research study

Figure 53: Participant filling out a questionnaire

Figure 54: Participant with BCI on his head and earphones for the binaural tones

Figure 55: Participant filling out the post-test questionnaire

Figure 56: Female participant ready for the test

Figure 57: Female participant commencing in test

Figure 58: Participant participating in study

Figure 59: Participant moving the robot forward

SUMMARY

Why can some people study, read books, and work while listening to music or with noise in the background while other people simply cannot? This was the question that prompted this research study.

The aim of this project was to assess the impact of binaural beats on participants during the performance of a task. The participants were exposed to different binaural beats that changed the dominant brainwaves while they were engaging in the task. A brain-computer interface was used to monitor the performance of the task in which a Lego Mindstorm robot was controlled as it moved through a course. To accomplish the aim of the project, the effects of binaural tones on participants' task performance were investigated in relation to participants' levels of frustration, excitement, engagement, meditation and performance. Participants were monitored by means of using an Emotiv EPOC neuroheadset.

Although previous studies on binaural beats have been done, most of these studies were done on Attention deficit-hyperactivity disorder (ADHD) children, with users performing everyday tasks. In these studies, time was the only metric used.

The researcher collected data by means of questionnaires that were completed by the participants to obtain personal information and measure the user experience. The aspects of frustration, excitement, engagement, meditation and performance were determined using the Emotiv headset in combination with the Emotiv software development kit, Microsoft Robotics Studio and software created by the researcher.

After intensive statistical analysis, the researcher found that different sound frequencies did indeed affect user performance. Sessions where no sound frequency was applied were associated with more errors and longer time durations compared with all other frequencies. It can be concluded that invoking a participant's dominant brainwave by means of binaural tones can change his/her state of mind. This in turn can affect the

long-term excitement, short-term excitement, engagement, meditation, frustration or performance of a participant while performing a task.

Much remains to be learned, in particular regarding the combination of brain-computer interfaces and human-computer interaction. The possibility of new cutting-edge technologies that could provide a platform for further in-depth research is an exciting prospect

OPSOMMING

Waarom kan sommige mense studeer, boek lees, of werk terwyl hulle na musiek luister of geraas in die agtergrond het, terwyl ander stilte nodig het terwyl hulle sulke take doen?

Die doel van hierdie navorsingstudie was om hierdie verskynsel te ondersoek.
Die doel van hierdie projek was om die impak van binaurale ritmes op die gebruikers, tydens die uitvoering van 'n taak, te assesseer. Die gebruikers is aan verskillende binaurale ritmes blootgestel wat die dominante breingolwe verander terwyl hulle betrokke was by die taak. 'n Brein-rekenaar-koppelvlak is gebruik om die uitvoer van 'n taak te monitor: die taak was om ’n Lego Mindstorm robot deur ‘n baan te laat beweeg. Om die doel van die projek te bereik is die effek van binaurale ritmes op deelnemers se taakprestasie ondersoek met betrekking tot die deelnemers se vlakke van frustrasie, opwinding, betrokkenheid, meditasie en prestasie. Deelnemers is gemonitor deur middel van 'n Emotiv EPOC neuro-kopstuk.

Hoewel vorige studies op binaurale ritmes gedoen is, is die meeste daarvan op kinders met aandag tekort hiperaktiwiteit versteuring (ADHD) gedoen, terwyl die gebruikers alledaagse take uitgevoer het. Tyd was die enigste maatstaaf wat gebruik was in hierdie studies.

Vraelyste is deur die gebruikers voltooi om data te versamel. Persoonlike inligting is verkry en die gebruiker se ervaringsvlakke is gemeet. Die vlakke van frustrasie, opwinding, betrokkenheid, meditasie en prestasie is bepaal deur gebruik te maak van ‘n kombinasie van die Emotiv kopstuk, die Emotiv sagteware-ontwikkeling pakket, Microsoft Robotics Studio en sagteware geskep deur die navorser.

Na intensiewe statistiese analise het die navorser gevind dat verskillende klankfrekwensies wel gebruikerprestasie beïnvloed. Sessies waar geen frekwensie toegepas is nie het groter getalle foute opgelewer, en hierdie sessies het ook langer geneem om uit te voer in vergelyking met sessies waarin frekwensies wel toegepas is.

Daar kan afgelei word dat die verandering van 'n gebruiker se dominante breingolf deur middel van binaurale ritmes wel die bewussynstaat van die gebruiker kan verander. Dit kan dan die langtermyn-opwinding, korttermyn-opwinding, betrokkenheid, meditasie, frustrasie of prestasie van 'n gebruiker beïnvloed, terwyl hy/sy die taak uitvoer.

Daar is baie wat nog geleer moet word, in besonder met betrekking tot die kombinasie van brein-rekenaar koppelvlakke en mens-rekenaar-interaksie. Die moontlikheid van nuwe baanbrekertegnologie wat 'n platvorm kan voorsien vir verdere in-diepte navorsing is 'n opwindende vooruitsig.