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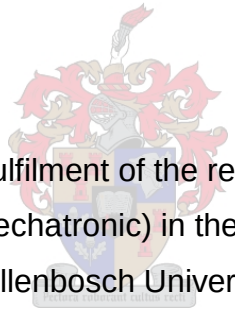
EEG Investigation into the neural mechanisms involved in higher order decision-making

Julianne Blignaut



Thesis presented in partial fulfilment of the requirements for the degree of Master of Engineering (Mechatronic) in the Faculty of Engineering at Stellenbosch University

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April 2019

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Abstract

Decision-making forms a fundamental part of executive cognition. Our lives are a series of choices: some are simple, while others require more deliberation. Unravelling the neural networks that underlie the decision-making process plays an integral part in understanding to what extent these networks are informed by conscious perception and to what extent they rely on internal neural mechanisms. Our choices are the product of an interaction between our genetic makeup and subjective experiences. Failure to understand the individual's brain has led us to a scientific impasse. We have some understanding of what happens in the brain when making arbitrary choices, but the intricacies of higher order, deliberate decision-making remain unclear. Recent studies suggest that the choices we make are deterministically formed, prior to conscious awareness of intent. This limits the role of consciousness in the decision-making process and challenges the notion of conscious free will. However, most of these studies rely on arbitrary choices devoid of real-world relevance. In 2017, Maoz et al. introduced deliberate, higher order decisions into the existing realm of studies on free will. The aim of the current research was to further investigate the neural mechanisms underlying higher order decision-making. Moreover, this research aimed to investigate the influence of traumatic subjective experiences on neurophysiological responses. The study developed an experiment that measured participants' electro-encephalographic potentials while performing both arbitrary and deliberate choice tasks. Thereafter, the neural correlates of both decision types were evaluated and compared. Participants were presented with legal cases and had to acquit or convict one out of two criminal offenders per choice trial. The neurophysiological data was evaluated with a specific focus on the readiness potential and the P300 potential. The readiness potential has previously been used to prove the absence of free will in self-initiated action, whereas the P300 is a potential associated with the reaction to a decision. Clear readiness potentials and P300 potentials were observed for both arbitrary and deliberate decisions. Furthermore, participants who had been victims of violent crimes showed increased readiness potential amplitudes and decreased P300 potential amplitudes. Participants with close relatives who had been victims of violent crimes also showed increased readiness potentials, however, they showed increased P300 potentials too. The spatial distribution of electrical activity demonstrated greater prefrontal cortex activation for participants with close relatives who had been victims of violent crimes, compared to participants without close relatives who had been victims of violent crimes. These findings are demonstrative of how traumatic subjective experiences influence the neuro-physiology of decision-making.

Keywords: decision-making; readiness potential; P300 potential; trauma

Uittreksel

Besluitneming is 'n belangrike deel van ons menswees. Ons lewens is 'n reeks van besluite en gevolge. Sommige besluite is maklik om te neem, terwyl ander meer oorweging verg. Dit is belangrik om te verstaan tot watter mate ons keuses onderhewig is aan neurologies prosesse en tot watter mate ons eksterne omgewing ons keuses beïnvloed. Die menslike besluitnemingsproses is ‘n fyn wisselwerking tussen ons genetika en lewenservarings. Daar is egter tans geen maatstaf om te kan kwantifiseer tot watter mate subjektiewe ondervindings die neurologiese besluitnemingsproses beïnvloed nie. Alhoewel ons tot ‘n groot mate verstaan watter neurlogiese meganismes betrokke is wanneer ons arbitrêre besluite neem, is daar steeds baie onduidelikheid oor die onderliggende netwerke betrokke by hoërorde-besluitneming. Onlangse studies stel voor dat ons besluite deterministies gevorm word voor ons bewuswording van die gekose uitkoms. Hierdie bevindinge beperk dus die rol wat ons bewussyn speel in die besluit-nemingsproses. Dit bevraagteken ook die bestaan van vrye wil. Tog het meeste van hierdie studies slegs met arbitrêre keuses te make. Die doel van die huidige studie was om the neurologiese merkers, betrokke by hoërorde-besluitneming, te ondersoek. Verder wou hierdie studie ook bewys wat die potensiële invloed van traumatise ondervindings op die neurologiese besluitnemingsproses is. Tydens die studie is daar ‘n besluitnemingstaak ontwerp waartydens deelnemers gevra is om beide arbitrêre en hoër-orde besluite te neem. Die uitkoms van die twee tipies keuses is vervolgens vergelyk. Deelnemers moes, vir verskillende gevalle, een van twee misdadigers kwyt skeld of skuldig bevind. Spesifieke neurologiese merkers wat ondersoek is, is die gereedheidspotential en die P300 breinpotensiaal. Die gereedheidspotential word geredelik in die literatuur gebruik om vrye will teen te staan en die P300 potensiaal word geassosieer met die neurologiese nagevolg van ‘n besluit. Na afloop van die eksperiment, was daar ‘n duidelike gereedsheids- en P300 potensiaal vir beide arbitrêre en hoërorde besluite. Nog ‘n merkbare tendens het gewys dat die deelnemers wat al self slagoffers van geweldsdade was, gereed-heidspotensiale met groter amplitudes vertoon het. In teenstelling, was die P300 pieke van hierdie groep deelnemers kleiner. Deelnemers met familielede wat slagoffers van geweldsdade was, se gereedheidspotentiale was ook groter. Die verspreiding van elektriese breinpotensiale vir die groep deelnemers met familielede wat slagoffers was, het meer aktivering in die prefrontale korteks van die brein vertoon as vir deelnemers sonder familielede wat slagoffers was. Hierdie bevindinge ondersteun die hipotese dat traumatise ondervindings die neuro-fisiologie van hoërorde-besluitneming beïnvloed.

Kernwoorde: besluitneming; gereedheidspotensiaal; P300 potensiaal; trauma

Acknowledgements

I would like to express my gratitude to Professor Dawie van den Heever, my supervisor, for his expert guidance, advice and time over the course of this project. I would also like to thank him for enabling my transition into this field. Furthermore, I would like to thank the staff at the Neuromechanics Unit, Mr Adam Struben, and all the participants who volunteered to take part in this study.

Lastly, a special thanks to my parents for their support throughout the course of my studies.

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Nomenclature

Abbreviations

ANOVA	analysis of variance
AP	action potential
APN	approximately normally distributed data
AR	average reference
arb	arbitrary
BCI	brain computer interface
BP	Bereitschaftspotential
CAF	Central Analytics Facility
CI	confidence interval
CNS	central nervous system
delib	deliberate
EEG	electroencephalography
ECG	electrocardiography / electrocardiogram
EMG	electromyography / electromyogram
EOG	electrooculography / electrooculogram
ERP	event-related potential
FIR	finite impulse response
fMRI	functional magnetic resonance imaging
fNIRS	functional near-infrared spectroscopy
FPC	frontopolar cortex
HAPPE	Harvard Automated Processing Pipeline for EEG

HREC	Health Research & Ethics Committee
IC	independent component
ICA	independent component analysis
IIR	infinite impulse response
LED	light emitting diode
LM	linked mastoid
LRP	laterized readiness potential
MARA	multiple artefact rejection algorithm
MRC	Medical Research Council
N	normally distributed data
NN	non-normally distributed data
NPO	non-profit organisation
P300	positive potential visible 300 ms post stimulus
PFC	prefrontal cortex
REST	reference electrode standardization technique
RMP	resting membrane potential
RP	readiness potential
S	long-tail distributed data
SMA	supplementary motor area
WRS	Wilcoxon rank sum

Symbols

$\hat{\pi}$	probability
dB	decibel

F-value	variation between sample means
Hz	hertz
kΩ	kilo-ohm
n	sample size
p-value	level of marginal significance
z_{α}	standard-normal table alpha value
z_{β}	standard-normal table beta value
α	alpha (probability of rejecting the null hypothesis)
Δμ	mean difference
σ	standard deviation

1 Introduction

1.1 Background to the research

A core goal in understanding the human brain is to characterise the neural mechanisms involved in the process of making deliberate conscious decisions. As humans we tend to make decisions that generally promote individual wellbeing and the wellbeing of the greater community. Though inferred from an accumulation of evidence, memories and past experiences, we recognise these decisions to be free and of our own volition. Conversely, recent studies suggest that our choices are deterministically formed up to several seconds prior to conscious awareness of intent (Libet, et al., 1983) (Soon, et al., 2008) (Soon, et al., 2013). These existing studies are limited to choosing between arbitrary alternatives. This study aimed to show that the same neural precursors informing arbitrary choices are present when making higher order deliberate decisions.

Our brain is responsible for our every thought, action, memory, feeling and subjective experience. Our brains are also what set us apart from other primates. It allows us to identify as free moral agents: we have the ability to choose between outcomes and the mental capacity to understand the implications of those choices. Although we observe, process and react to the world around us in the same way other animals do, we distinguish ourselves by way of possessing freedom and ownership over our thoughts, feelings and actions.

Because we have language and technology at our disposal – both of which are a product and measure of human intellect – we are able to communicate, record and analyse our thoughts and feelings. We are also able to transform our neurobiological impulses into statistically quantifiable data that allow for comparison between the similarities and differences in individuals' brains when presented with similar scenarios. However, our technology also limits us in our current understanding of the brain. Because the brain leaves so much to be discovered, we need novel ways to explore the human mind. This means new methods of interpreting the data we collect using existing tools. With electroencephalography (EEG) systems and functional Magnetic Resonance Imaging (fMRI) machines, we enable ourselves to glimpse beyond consciousness at what the unconscious mind reveals. One such group of studies specifically relates to our perception of free will.

1.2 Statement of the problem

Understanding the brain is the next frontier of scientific discovery. Our failure to understand the individual's brain has led us to a scientific impasse. We have some understanding of what happens in the brain on a synaptic level when performing arbitrary choice tasks, but the architecture underlying deliberate decision-making remains unclear. The way we tend to make decisions is in part shaped by our subjective conscious experiences. Moreover, it is the interaction between the conscious and unconscious mind that motivates behaviour.

There is an undeniable link between human decision-making and our current understanding of conscious action. Unravelling the theory of decision-making and consciousness cannot be done in isolation, without including fields of study that lie outside the traditional realm of science. It is the focus of this research to link the biology of the brain to its applied philosophy. At the intersection between philosophy and science lie the questions this research aims to address: How do we make the choices we make? What informs our decisions? And how does this relate to subjective experience?

1.3 Aim of the research

This study supposed that even for higher-order decisions, there are neural markers indicative of the outcome of the choice, preceding conscious awareness of the decision. The research aimed to measure the neural mechanisms associated with free, higher order decisions in a quantitative manner. Previous studies specifically focused on the neural markers found when making arbitrary choices, but this research aimed to investigate these models by expanding the scope of the choices considered. The study is partially based on an existing study by Maoz et al., who introduced the concept of deliberate decisions into the Libet-paradigm (Maoz, et al., 2017). Similarly to the study conducted by Maoz et al., the choices presented in this research were adapted to have real world applications and evoke uniquely human responses, because the choices we make in everyday life cannot be separated from their emotional context. While shifting the focus to deliberate decision-making, this research aimed to compare the neural correlates associated with both arbitrary and deliberate decisions. To achieve this, the investigation was extended to consider environmental factors alongside the neurology informing arbitrary choices. This provided the framework to enable an investigation into the presence or absence of conscious will in decisions that matter.

In order to investigate these decision-making mechanisms, an EEG experiment was developed wherein participants were presented with a higher order choice task. It is important to understand how we, as a human collective, think, do and decide. It is also important to discover whether our thinking can be collectively defined at all, or if subject-specific factors influence decision-making to such an

extent that there is no one-size-fits-all model to decode cognizant decision-making. Studying environmental factors, as well as subjective internal and external models, may demonstrate how these models and factors influence an individual's mental state of being. This may reveal to what extent neural development is predisposed to genetics and to what extent the brain is a product of its suggested environment. This, in turn, may add further evidence to the debate on whether we truly possess free will or whether our perceived conscious involvement in our choices is merely an illusion. Moreover, such findings have the potential to point scientists in new directions of research in the pursuit of understanding the basis of consciousness. Ultimately, the aim of this research was to provide more conclusive evidence informing the debate between determinism and free will. Conceptual free will was investigated by determining the unconscious effect of traumatic subjective experiences on the decision-making process.

1.4 Importance of the research

The fundamental principles underlying a civilised society is dependent on our basic belief in free choice and the ethical responsibility associated with the neural mechanisms of those choices. Understanding the link between morality, higher order decision-making and reactions to arbitrary choices is therefore important across multiple fields of study. Advancing the field of neuroscience may inspire radical change in medicine, engineering, economics, politics, sociology and psychology. Neural research has the potential to pioneer novel ways to treat brain disease, improve quality of life, revolutionize current computing technologies and redefine the boundaries of knowledge.

1.5 Scope and limitations of the research

When considering a neural process as intricate as that of deliberate decision-making, there are multiple variables to consider. Although this study aimed to investigate some of these variables, it is important to understand that the focus of this study also limited its scope. This study focused on investigating the neural differences between arbitrary and deliberate decisions. Subjective past experiences, specifically relating to trauma, were evaluated to provide insights into neural differences found between participants. These experiences were qualitatively evaluated using a short questionnaire (see Appendix A). However, the extent to which distinctive internal and external models form the basis of higher order decision-making cannot be fully explained without also studying the memory centres in the brain. Undoubtedly, semantic and episodic memory play an important role in evidence-based decision-making. Investigating the physiological role of memory in higher order decision-making is beyond the scope of this research.

The aim of this study was to build on many previous studies that have tested similar hypotheses. This is not a novel study, but rather a study altered from its predecessors in order to add a new layer to the existing body of knowledge relating to the neural correlates of human decision-making.

2 Literature review

2.1 Introduction to neuroscience

Neuroscience describes a multidisciplinary science centred around studying the physiology and anatomy of the nervous system. This relates to the fundamental emergent properties of memory, behaviour, learning, perception and consciousness. The brain is the most complex organ within the human body and is responsible for every physiological process that happens inside the body, as well as enabling interactions with the external world. The brain regulates our breathing, heartbeat and voluntary muscle movements, is responsible for our thoughts, actions and behaviour, and it is the central unit of the nervous system. The smallest functional unit of the human nervous system is the neuron. Neuroscience can therefore, at its core, be considered a study of the synaptic activity between different neurons.

The nervous system is a network of neurons that interact in different ways to produce different biological responses to the world around us. Humans are born with approximately 10^{11} neurons (Sanei & Chambers, 2007). Each neuron has receptors and transmitters. Different neurons communicate using electrical and chemical signals (White, 2013). Figure 1 shows a graphical representation of the functional microanatomy of a neuron.

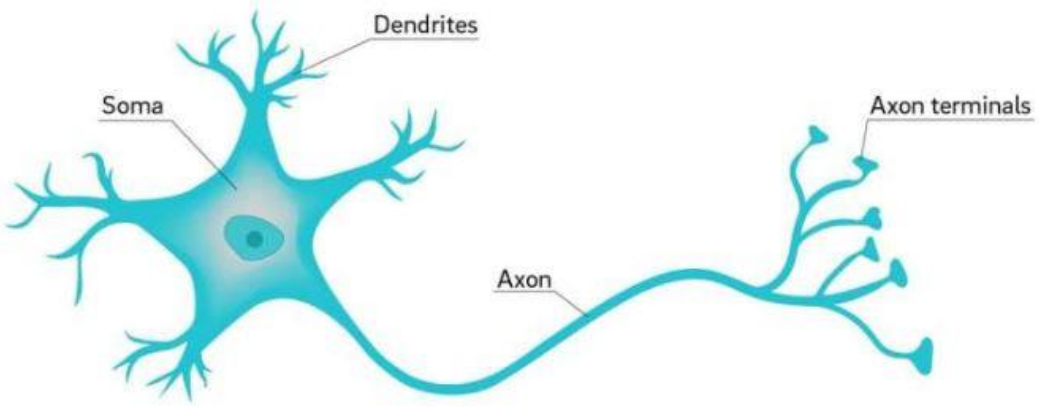


Figure 1: Basic anatomy of a neuron (Medical Xpress, 2018)

The labelled parts in Figure 1 illustrate the simplest anatomy of a neuron. The dendrites typically act as receptors and the axon as a transmitter. The axon terminals then transmit the signal to the receiving dendrites of a subsequent neuron. Furthermore, there are different classes and types of neurons. Neuron

types can be visually identified, whereas neuron classes relate to different neuron functions. Table 1 shows the different classes of neurons.

Table 1: Different neuron classes, their functions and types (Queensland Brain Institute, 2018)

Neuron class	Function	Type
Sensory neuron	Receives sensory input (physical or chemical) from environment	Pseudo-unipolar
Motor neuron	Connects to muscles (skeletal and smooth), glands and organs throughout body	Multipolar
Interneurons	Connect the sensory and motor neurons	Multipolar

As seen in Table 1, the different neuron classes serve different physiological functions. A neuronal pathway typically consists of sensory, motor and interneurons. Neuron classes describe neuron functionality. However, not all neurons look anatomically identical. Neuron types therefore describe the structural diversity among neurons. Figure 2 shows the different types of neurons.

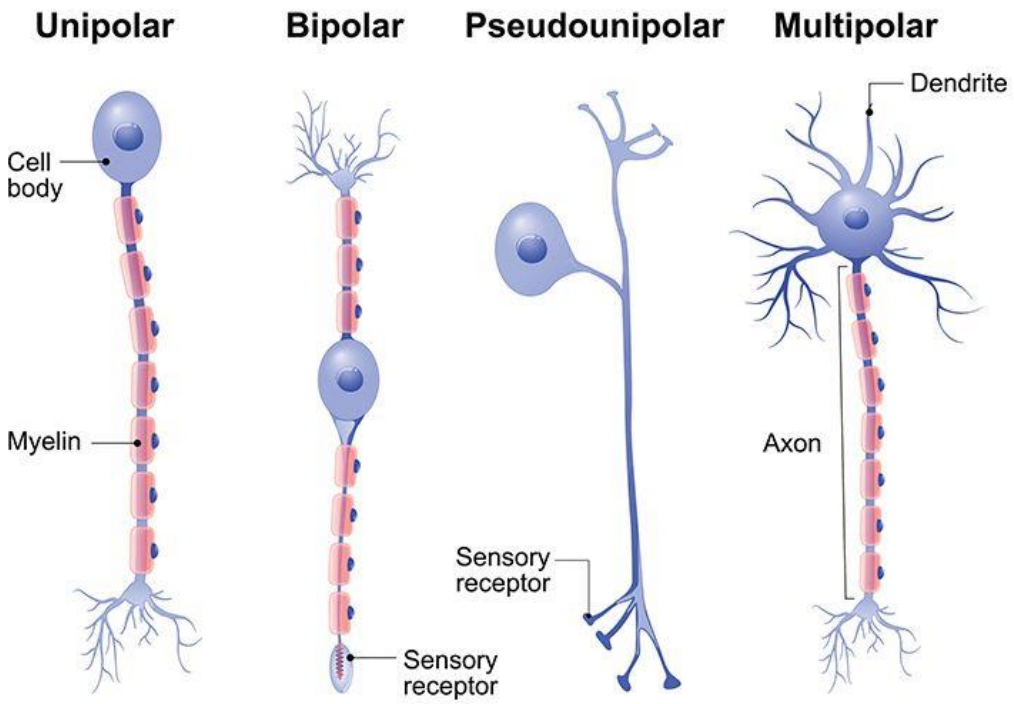


Figure 2: Different types of neurons (Queensland Brain Institute, 2018)

The structural diversity between different types of neurons relate to the functions that the neurons respectively serve (see Figure 2). Table 1 also lists the neuron types that are most commonly associated with each of the different neuron classes.

The neuron types not listed in Table 1 are still found throughout the respective neuron classes, but they are less prevalent than pseudo-unipolar and multipolar neurons. Bipolar neurons, for example, are rare specialised sensory neurons found in the olfactory and retinal cells. However, a greater understanding of the different neuron classes and types is not required for the purposes of this study.

For this research, it is important to understand how information travels between different neurons. The interaction between different neurons in a neuronal pathway occur across the synaptic cleft between the axons of one neuron and the dendrites of the next. The synaptic cleft describes the region between the membranes of the pre- and postsynaptic neurons and is typically 30 to 50 nm in breadth (Malmivuo & Plonsey, 1995). Information travels along a sensory neuron as an electrical impulse and is transferred between different neurons by means of chemical neurotransmitters. The arrival of the electrical impulse at the synaptic cleft activates the release of neurotransmitters that chemically trigger the forward propagation of the electrical impulse along the subsequent neuron. This forward propagation of an electrical impulse continues along the chain of the neuronal pathway until it reaches the destination central nervous system (CNS) neuron. The CNS neurons then transform the information into a neural response, generating a reaction chain along a motor neuron pathway (Queensland Brain Institute, 2017).

The electrical impulse travelling along a neuron is called an action potential (AP). The propagation of an AP along the neuronal pathway will only persist if the postsynaptic membrane is depolarized enough to evoke an AP in the postsynaptic neuron. The intracellular fluid of a neuron is normally more negative than the fluid found in the interstitial spaces between neurons. Neurons can therefore be quantified as having an intracellular potential of -70 mV compared to the outside of the cell. This is referred to as the neuron's resting membrane potential (RMP) (Queensland Brain Institute, 2017). This potential constantly changes as neurons receive new inputs and transmit new impulses. There are inputs that make the cell's potential more positive and others that make it more negative, depending on the excitatory and inhibitory effect of the input. These inputs consequently either promote or inhibit the production of APs. The AP threshold for neurons is roughly -50 mV. All excitatory and inhibitory inputs are summed to produce an active potential at the dendrites of a neuron. If this active potential reaches the -50 mV threshold, an AP will be propagated along the postsynaptic neuron. This chain of events is repeated at each synaptic cleft along the neuronal pathway. Figure 3 illustrates the process at a specific synaptic cleft.

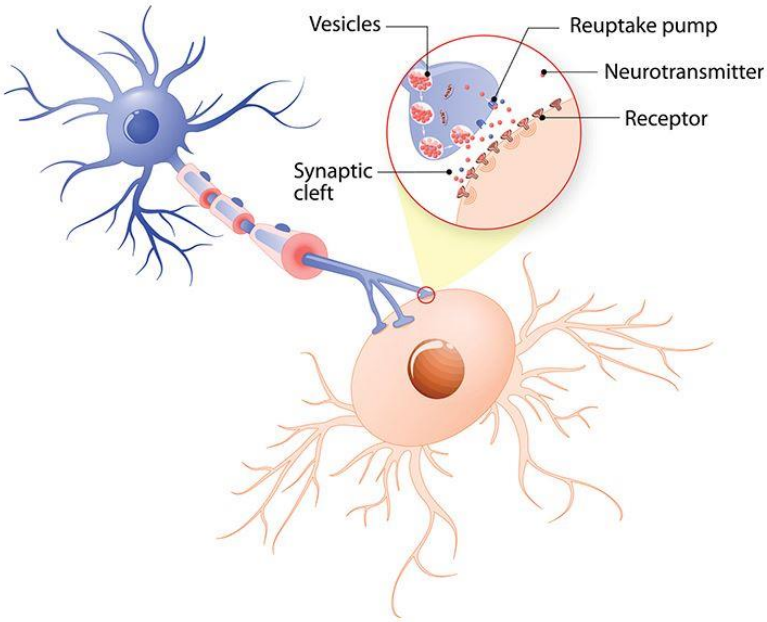


Figure 3: Micro physiology of a synapse (Queensland Brain Institute, 2017)

Neurotransmitters play an important part in AP generation, since the neurotransmitters influence the membrane potential of a neuron. Neurotransmitters are either excitatory or inhibitory, depending on the receptor it binds to. Excitatory neurotransmitters promote AP generation and inhibitory neurotransmitters prevent it (Queensland Brain Institute, 2017).

AP generation can be divided into six steps. These steps are outlined below (Sanei & Chambers, 2007):

1. The dendrites of a neuron receive an input and the Na^+ channels open. If there is a great enough influx of positive Na^+ ions into the cell to change the RMP from -70 mV to -50 mV, the following step continues.

2. As soon as the -50 mV threshold is reached, additional voltage-gated channels open, creating an even greater influx of Na^+ ions into the cell. The sudden influx of positive ions causes the membrane potential to rise to roughly +30 mV. This step is called cell depolarization.

3. Once the cell has been depolarized, the Na^+ channels close and K^+ channels open. However, the K^+ channels open much slower thereby allowing the depolarization process to complete.

4. Since the inside of the cell is now more positive than the outside, the open K^+ channels allow the cell to repolarize along the diffusion gradient.

5. Typically, the repolarization process first overshoots the RMP of -70 mV by 20 mV, reaching a minimum potential of -90 mV. This is referred to as the hyperpolarization step. It is an important step since hyperpolarization prevents the neuron from receiving another input signal, seeing as it raises the potential required to reach the -50 mV threshold. This step also ensures the signal propagation occurs solely in the forward direction along the neuronal pathway.

6. Following hyperpolarization, the Na^+/K^+ pumps balance the cell potential and return the cell to its RMP of -70 mV. Once this resting state is reached, and a refractory period of 2 ms has passed, the cell can generate a new AP.

Figure 4 graphically illustrates these steps, and the roman numerals in the figure correspond to the numbered steps outlined above. The following section will describe how the cellular activity of neurons can be measured and quantified to produce usable neurophysiological data.

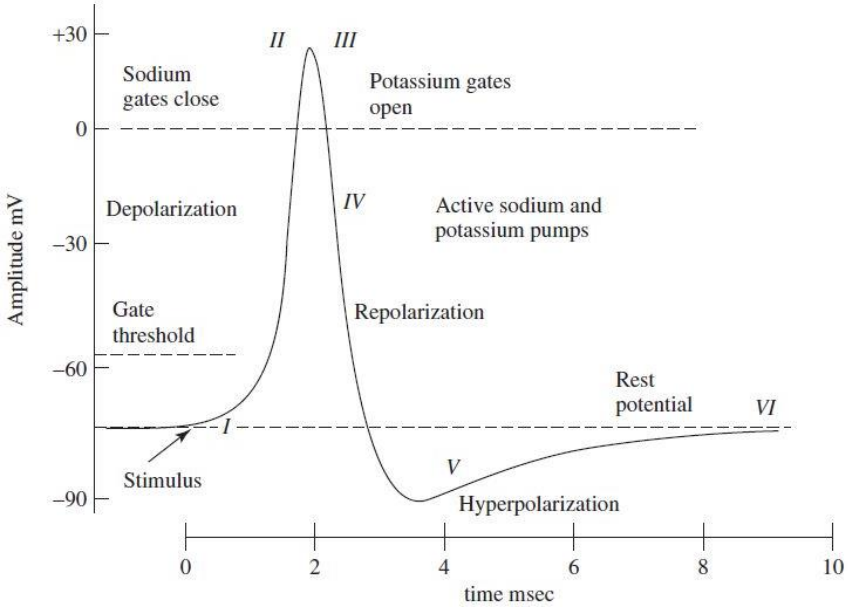


Figure 4: Action potential (Sanei & Chambers, 2007)

2.2 Physiological basis of EEG

EEG is the electrophysiological scalp measurement of electrical activity in the brain. It is a non-invasive method by which electrodes placed in different positions around the scalp measure the currents generated during synaptic activity between

the presynaptic axon terminals and the postsynaptic dendrites. These currents produce magnetic fields that can be measured by electromyogram (EMG) and EEG systems. The magnetic fields are a result of the differences in electrical potentials between the neuronal cell body and the dendrites. These differences create electrical dipoles. Current flow is generated by the ion pumps, such as the Na^+/K^+ pumps, that constantly change the cell polarity during AP propagation (Sanei & Chambers, 2007).

Since there are several layers between the intracranial neuronal activity and the scalp electrodes used for EEG systems, the signal is greatly reduced between being produced and being measured. Figure 5 shows the different attenuation layers and their respective impedances and thicknesses. Considering Figure 5, the skull reduces the signal a hundred times more than the soft tissue of the brain and the scalp. The implication of this is that only a summation of active neurons generates a large enough potential that is recordable with scalp electrodes.

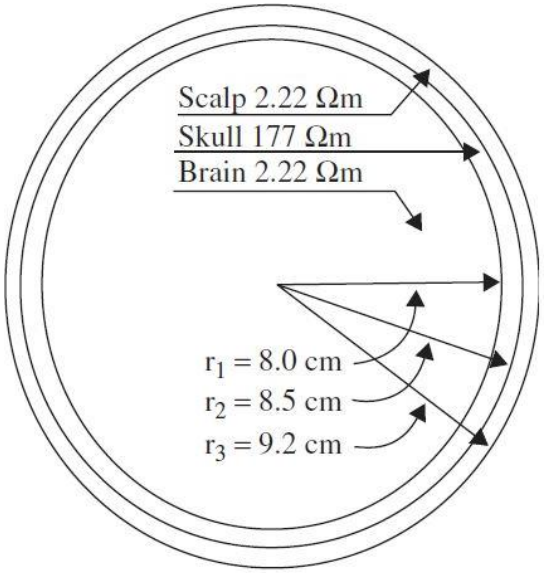


Figure 5: Different layers of attenuation between neural activity and scalp electrodes (Sanei & Chambers, 2007)

The 10^{11} neurons present in the human brain at birth translate to roughly 10^4 neurons/mm^2. These neurons are interconnected through synapses into different neural networks. Approximately 5 x 10^{14} synapses can be found in the adult human brain. Each neuron is connected via different synapses to different neural networks. Even though the number of neurons in the brain decrease with age, the number of synapses per neuron increase (Sanei & Chambers, 2007). This addresses one of the biggest limitations of scalp EEG: with all these connections constantly generating signals inside the brain, it is improbable for scalp EEG to

produce comprehensive measurements of the activity within deeper brain structures.

To understand how EEG works, it is necessary to be familiar with the anatomy of the brain. The brain can be divided into three parts, namely the cerebellum, the cerebrum and the brain stem (see Figure 6a). Considering Figure 6, the cerebral hemisphere directly underlies the scalp. Consequently, the activity in the cerebral cortex is the activity recorded with EEG. The cerebral cortex can further be divided into four lobes: frontal, parietal, occipital and temporal (see Figure 6b). The cerebrum is also split into a left hemisphere and a right hemisphere, connected by the corpus callosum. The cerebrum is responsible for conscious awareness, movement, reasoning, behaviour and emotional expression. The cerebellum coordinates movement and maintains balance, and the brainstem is responsible for involuntary respiratory, hormone and cardiac functions (Sanei & Chambers, 2007). For this research, only the anatomy and physiology of the cerebrum will be discussed in further detail. Table 2 lists the different brain functions associated with the respective cerebral lobes.

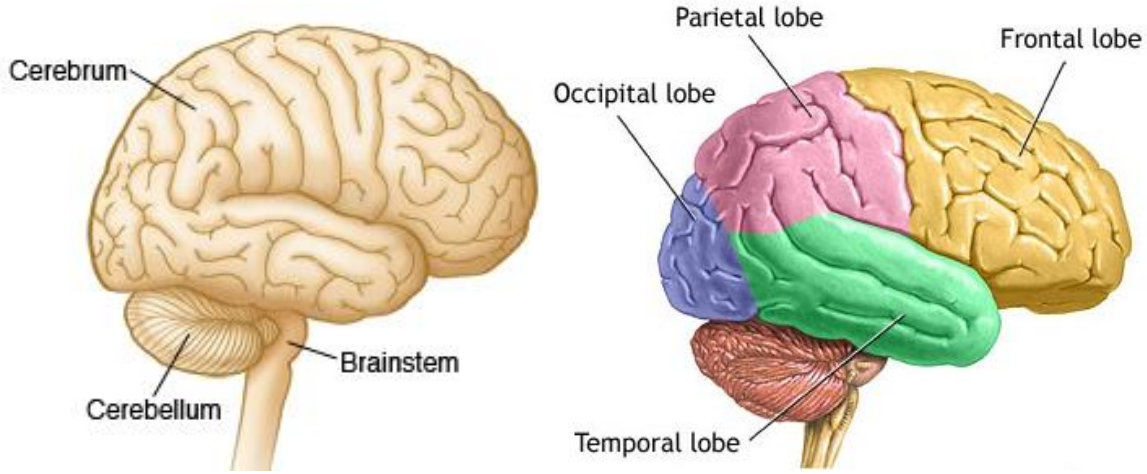


Figure 6: (a) Basic anatomy of the human brain (Fairview, 2017) and (b) the four principle lobes (Adam, 2017)

Table 2: The principle brain lobes and their associated functions (Adam, 2017)

Cerebral lobe	Brain function
Frontal lobe	Reasoning, motor skills, higher cognition and language
Parietal lobe	Processing sensory information (pressure, touch, pain)
Temporal lobe	High level auditory processing and memory formation
Occipital lobe	Interpretation of visual information

Since this research relates to decision-making and the motoric execution of a choice task, the relevant brain regions considered for this study lie in the frontal lobe. The frontal lobe relates to higher order processing, cognition and the execution of motor tasks (see Table 2). The scalp electrodes are labelled in relation to their placement across the scalp. EEG electrode placement typically follows the international 10/20 system positioning. This system is based on the correlation between the electrode location and its underlying cerebral cortex (Trans Cranial Technologies, 2012). The system name refers to the distances between the adjacent electrodes that are either 10% or 20% of the total nasion to inion (front-to-back) or ear to ear (left-to-right) distance of the skull. Figure 7 shows the typical scalp map topography for a 64-channel electrode setup.

The labels at each electrode site refer to the lobe and hemisphere from where the electrode is recording. Table 3 lists the different electrode labels used in the 10/20 system layout. Even though no anatomical central lobe exists, the “central lobe” label “C” is used to identify electrodes that surround the cerebral midline (see Figure 7). The letter “z” in the labels identify labels positioned on the anterior to posterior cranial midline (see Figure 7). Furthermore, all even numbers are associated with electrodes located in the right cerebral hemisphere and all odd numbers are associated with electrodes located in the left cerebral hemisphere (see Figure 7).

Table 3: The 10/20 electrode labelling system (Trans Cranial Technologies, 2012)

Electrode	Associated lobe
F	Frontal
T	Temporal
C	Central
P	Parietal
O	Occipital

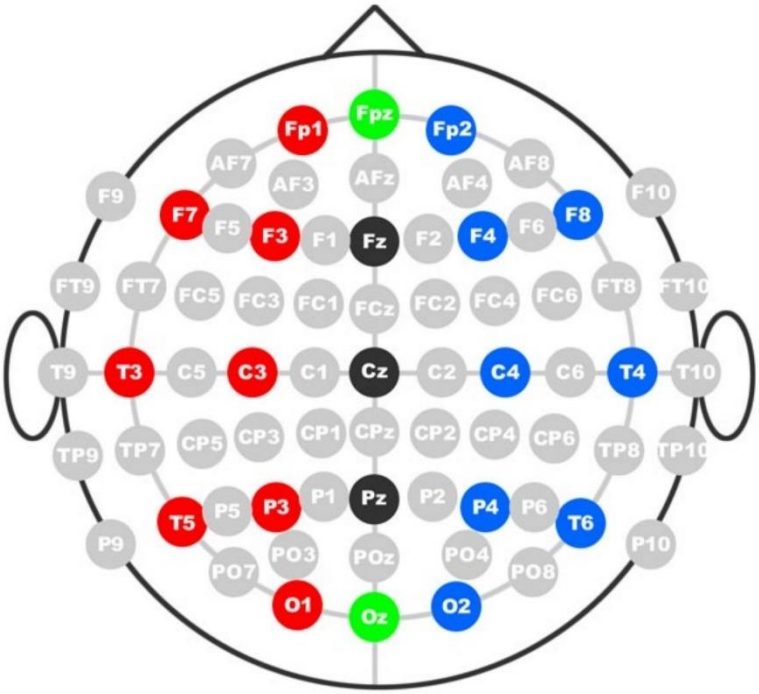


Figure 7: 10/20 electrode system positioning (Trans Cranial Technologies, 2012)

The 10/20 system positioning of electrodes ensures that the recordings from the respective electrodes correspond to the activation of different brain centres. Table 4 lists some of the centres associated with some of the principle electrode sites. It is important to mention the limitations of using scalp EEG to record intracranial activity. The effective bandwidth of EEG recordings is limited to 100 Hz. However, this is not a disqualifying criterion since relevant EEG frequencies typically lie between 0.1 Hz and 45 Hz. Section 4.2.1 of this report will further discuss the different EEG frequency bands and their associated neurophysiology. One clear advantage of EEG lies in its temporal accuracy. It can record brain changes in the millisecond domain. However, spatially it is not as robust as alternative methods. With scalp EEG, source localization is difficult and the activity measured at different electrode sites is often a poor representation of the activity originating within the deeper brain structures that give rise to the measurable scalp potentials. For example, fMRI is still the preferred method to produce spatially precise results. On the other hand, fMRI lacks temporal accuracy. Due to these respective limitations of EEG and fMRI, the two methods are sometimes used in conjunction within a single study. For this research, EEG was used. EEG is widely used in a clinical setting for brain activity monitoring and has many research applications in neuroscience, cognitive science, psychology, psychophysiology, brain computer interfacing (BCI) and as a diagnostic tool. EEG is currently experiencing a renaissance as the ultimate tool for imaging temporal dynamics of large-scale brain networks in real-life situations (Michel & Murray, 2012). This

research made use of EEG's strength in imaging temporal dynamics to investigate the large-scale brain networks involved in higher order decision-making.

Since the task presented to participants in this study was a decision-making task, the brain centres associated with decision-making and information integration needed to be evaluated using EEG. The activity at electrode sites Cz, Fz, Fp1 and Fp2 were considered relevant. Electrode Fz was important to consider because Fz records responses from the intentional and motivational centres of the brain, and the presented choice task had an ethical component. Moreover, since the choice task was recorded with a left- or right-hand button press, Cz recorded the motor component of the task. Lastly, electrode sites Fp1 and Fp2 were evaluated. These electrodes are respectively associated with the left and right hemispheres of Brodmann area 10 and relate to executive brain functions, such as the higher cognition associated with reasoning and problem-solving models (Barbey & Barsalou, 2009). The next section of this report will discuss the neuroscience of human decision-making.

Table 4: Different electrode sites and their associated brain centres (Teplan, 2002) (Barbey & Barsalou, 2009)

Electrode site	Associated brain centre
F7	Rational activities
Fz	Intentional and motivational centres
F8	Regulation of emotional impulses
Fp1, Fp2	Brodmann area 10
Cz, C3, C4	Sensory and motor function
Pz, P3, P4	Perception and differentiation
T3, T4	Emotional processors
T5, T6	Memory functions
O1, O2	Primary visual areas

2.3 Human decision-making

The most important function of the frontal lobes in the human brain, is decision-making. This is also the anatomical brain region that sets us apart from other primates. Our frontal lobes are bigger and more complex than the frontal lobes found in other primates (Semendeferi, et al., 2001). The decisions for which the frontal lobe in our brains are responsible range from simple left-right choices to complex decisions with multiple variables and outcomes. The following stages are the suggested stages of the sequential decision-making process: identifying the problem, gathering information related to the problem, generating possible solutions, evaluating different solutions and selecting a solution for execution (Demongeot & Volpert, 2015). Any human action, including the process of making informed decisions, is the result of large-scale information integration from both

external and internal sources (Bode, et al., 2014). Decision-making can therefore be considered a multi-layered complex network of neurons, constantly and simultaneously, operating in parallel (Smith, 2011).

The frontopolar cortex (FPC), located at the most anterior part of the prefrontal cortex (PFC) forms the critical centre for decision-making (Koechlin & Hyafil, 2007). However, the FPC is not the sole proprietor for higher order decision-making in the human brain. It has rather developed to overcome the limitations of more primal brain areas also involved in the execution of decisions. The FPC is therefore demonstrative of the evolution of human intelligence. Recent studies show that the FPC contributes to human cognition through means of learning, exploration, memory retrieval, relational reasoning and multitasking behaviours (Semendeferi, et al., 2001). The FPC's contribution to memory retrieval and relational reasoning were the focus of this study. Memory retrieval was considered relevant since the choice tasks with which participants were presented required them to rely on an accumulation of past experiences to inform their decision-making process. Relational reasoning is also an important part of higher order decision-making since it relates to the integration of information. Information integration with regards to higher order decision-making relates to the evaluation of multiple potential outcomes and the selection of an appropriate response. These cognitive functions correspond to activity at the Fp1 and Fp2 electrode sites.

The region in the PFC slightly posterior to the FPC correspond to the intentional and motivational centres of the brain (Teplan, 2002). Since the decision-making task presented in this study asked participants to make a choice based on moral principles, the activity in the brain centres informing the morality of these decisions were considered relevant. Electrode Fz is responsible for recording activity related to intentional reasoning. The last area of interest considered during this study, was the cerebral midline that marks the posterior end of the PFC. Electrode Cz measures neural activity related to motor function and was investigated due to the instructed button press in executing the choice task.

EEG data generated and recorded as a response to a specific event or stimulus is known as an event related potential (ERP) (Sur & Sinha, 2009). This usually means that the EEG data is time-locked to a stimulus so that the continuous data can be averaged to reveal trends surrounding the stimulus onset. ERPs represent the summed postsynaptic potentials that result from a group of neurons firing together. This neuron firing can be the result of a variety of sensory, cognitive and motor events (Sur & Sinha, 2009). There are several well-known ERP components and waveforms. Two such components that specifically relate to decision-making are the P300 wave and the *Bereitschaftspotential* (BP). These potentials are observable at electrode sites Cz, Fz, Fp1 and Fp2. The BP is also widely discussed when considering the role causal free will has to play in the conscious decision-

making process. Both these components will be discussed in more detail in the following subsections.

2.3.1 P300 wave

The P300 wave can be described as a positive deflection with a broad peak and large amplitude. The peak typically occurs between 300 and 400 ms following a recorded event (Sutton, et al., 1965) and is generally associated with the process of decision-making. However, it has been found that the P300 component shows greater correlation to an individual's reaction to a stimulus than the stimulus itself. Moreover, it has been found that the P300 latency is not correlated with the duration of the associated motor processes (Donchin, 1981).

Since this peak is the result of an ERP, it is usually presented as the average of several ERP trials, however, it can also be measured and identified as a waveform in a single trial (Nieuwenhuis, et al., 2005). Studies show that the P300 amplitude is highly correlated to the motivational significance of the presented stimulus (Nieuwenhuis, et al., 2005). This means that stimuli with strong emotional content – whether it is perceived as positive or negative – concur with larger P300 amplitudes than stimuli that are emotionally neutral. Figure 8 shows a typical P300 peak at electrode sites Fz, Cz and Pz. The upward deflection is positive and reaches a peak of roughly 10 µV.

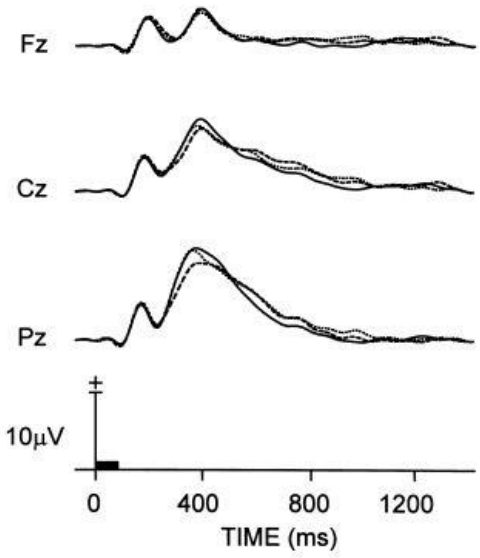


Figure 8: P300 wave peaks (Ilan & Polich, 1998)

2.3.2 A history of EEG studies in free will

The Stanford Encyclopaedia of Philosophy defines free will as "a philosophical term of art for a particular sort of capacity of rational agents to choose a course of action from among various alternatives" (O'Connor, et al., 2018). The concept of free will has been debated for over two millennia. Famous philosophers such as Plato, Aristotle and Nietzsche spent their lives arguing for and against the existence of conscious free will. The debate has always been met with contention due to the undeniable link between free will and moral agency (Bonn, 2013). Free will can only exist if the following criteria are met: there exists the possibility to act differently if the external and internal circumstances at the moment of choice remain unchanged; if the free moral agent herself wills one choice over another; and if the choice is motivated by rational thought (Lavazza, 2016). From this definition of free will, it follows that conscious decision-making forms an integral part of free will, because conscious will is a function of higher order decision-making and vice versa. No choice, as it is plainly defined, can exist if we do not possess free will. Likewise, free will has no way to manifest itself without a given choice between alternatives. There is therefore not a definitive difference or similarity between conceptual free will and higher order decision-making, but rather an inter-dependency.

In philosophy, the model of free will is contrasted by causal determinism. Determinism describes the doctrine that individual free will does not exist, and as a result no person can be rightfully held accountable for their actions. Determinism exempts individuals from the implications of their choices because it supposes that no person has the capacity to act differently than they do. Instead, determinism links human action to the empirical laws of nature. Until recently, this debate has been confined to a study of philosophy. These days, it is widely addressed scientifically.

2.3.2.1 The Bereitschaftspotential

In 1964, Hans Helmut Kornhuber and Lüder Deecke were the first scientists to effectively extend the study of free will to within the scientific realm. They discovered a cortical potential visible moments before a self-initiated, voluntary action. They called this the BP, also known as the Readiness Potential (RP) (Kornhuber & Deecke, 1965). The RP is identifiable as a slow cortical build-up preceding motor action. Following their initial experiments, Kornhuber and Deecke further concluded that the RP is a neurophysiological trend observable when a person plans, prepares and initiates movement (Kornhuber & Deecke, 1990). In 1980, Kutas and Donchin discovered that the moment when recorded brain activity became asymmetrical was related to the moment of reported awareness and also to the moment participants became aware whether their left or right hand would be used in response to the presented stimulus (Kutas & Hillyard, 1980). Based on these findings, Smid et al. and Coles & Gratton

concurrently and independently inferred that the RP was more pronounced in the cranial hemisphere contralateral to the side of muscle contraction (Coles, et al., 1988) (Eimer & Coles, 2003). This phenomenon was later renamed the Lateralized Readiness Potential (LRP) (Eimer & Coles, 2003). For all these experiments, a voluntary action was defined as an action executed by the supplementary motor areas (SMAs) of the brain. Voluntary actions, as they are defined here, relate to neuronal activity in the basal ganglia, the SMA and pre-SMA, and the parietal lobes. Of these areas involved in the execution of a voluntary task, the SMA and pre-SMA form part of the brain's motor cortex. Subsequently, it was found that the RP originates in the motor cortex of the PFC - more specifically, in the SMA and the pre-SMA.

However, these studies did not yet extend their findings to inform debates about the presence or absence of free will in human decision-making. It was for the first time in 1983, when Benjamin Libet pioneered his most famous study on free will, that the RP was used to disqualify causal free will.

2.3.2.2 Libet & Soon

In 1983, during his studies of human consciousness, Libet designed an experiment wherein 30 participants were asked to act on the urge to flex the wrist of their dominant hand. While waiting for the urge to occur, they watched a clock face specifically designed to record the time of conscious intent (see Figure 9). The clock had a rotating dot moving at 2560 ms per cycle. Using the moving dot as temporal reference, participants were to report the position of the dot on the clock the moment they became aware of the urge to move. This position was marked W, or awareness of intent. The data was time-locked to the moment of movement, as recorded with EMG signalling. The moment of movement was marked "action" and signified time zero. The experiment was conducted while participants wore an EEG cap that recorded their scalp potentials (Libet, et al., 1983).

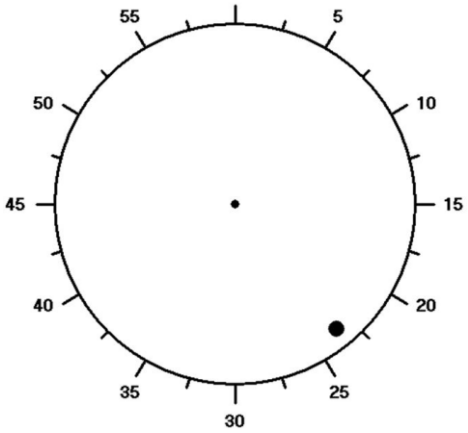


Figure 9: Libet clock paradigm (Garaizar, et al., 2016)

Each subject completed 40 trials for which the data was averaged to produce a trend approximating Kornhuber and Deecke's RP. Libet further grouped the RPs recorded during his study into Type I and Type II RPs. RPs were categorised as Type I when participants reported a "preplanning" phase before reacting on the urge to move. Type II RPs described scenarios where participants reported that the movement urge occurred "spontaneously" and "capriciously". Physiologically, the difference between Type I and Type II RPs can be seen in the earlier, but slower, rise of the cortical potential for Type I RPs (Libet, et al., 1983). For Type II RPs, where no reported "preplanning" occurred, the recorded EEG-data showed a clear spike in neural activity 350 ms before the reported urge to move and 550 ms prior to movement (see Figure 10). Libet concluded that the rise of the RP observable 350 ms prior to awareness of intent in this "free" self-initiated task, proved that free will is an illusory construct absent in self-initiated human action. However, Libet received a lot of criticism following this claim. One of the main criticisms argued that to act on the urge to flex a muscle cannot be considered a true measure of free choice.

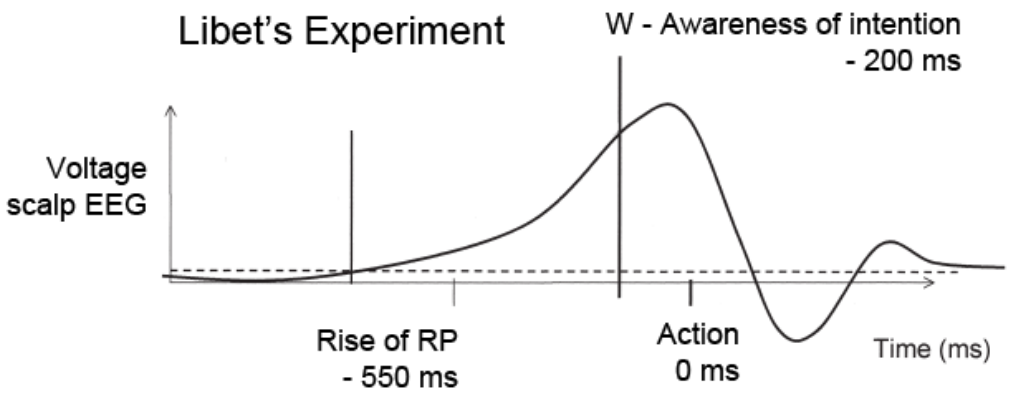


Figure 10: Libet Experiment RP (The Information Philosopher, n.d.)

In 2008 Soon et al. conducted a similar experiment using fMRI. The experiment was adapted to include a choice task, thereby addressing one of the main criticisms of the original Libet study. Choice is central to the philosophical conceptualization of free will and this experiment succeeded in presenting participants with a choice amongst alternatives (Imhof & Fangerau, 2013). Participants were asked to press a button using either their left or right index finger when they experienced the urge to do so. Similarly to Libet's study, participants were positioned in front of a screen and asked to report the time of conscious awareness of intent. During this task, conscious awareness was time-locked to the reported letter that appeared on the screen at the precise moment of awareness of intent. The screen displayed different letters with a refresh rate of 2 Hz. From these recordings, Soon and his group were able to decode the areas

in the frontal cortex executing the motor action. Their data enabled them to predict the outcome of the choice, with relative accuracy, up to seven seconds prior to the participants' subjective awareness (Soon, et al., 2008). Another criticism of the original Libet study was the millisecond time scale on which the difference between reported awareness and action execution was measured. Soon et al. addressed this criticism as well, since their predictive choice model expanded the measured difference between conscious awareness and action to seven seconds. Moreover, Soon et al. considered brain areas beyond the SMA and pre-SMA to inform a more holistic understanding of the neural networks underlying decision-making.

Since then, the Libet and Soon experiments have been recreated for other EEG and fMRI studies. The EEG protocol for the original Libet study has been replicated and altered numerous times by different researchers, only to support the original findings (Lavazza, 2016). In a later study, Soon et al. adapted their own original study by increasing the complexity of the choice task. Participants were asked to add or subtract two number per choice trial. Once again, they were able to predict the outcome of the choices roughly four seconds prior to reported awareness of intent (Soon, et al., 2013). A different study found that the RP is present even in the absence of movement and that motor-related neural processes do not significantly affect the RP. This suggests that the RP might not be correlated to the onset of movement, as previously suggested, but may be more related to neural processes informing the decision to act (Alexander, et al., 2016). Another study corroborated these findings by setting up an experiment with a self-initiated movement condition as well as a no-movement condition (Jo, et al., 2013). They found that there was no significant difference between the movement condition RP and the no-movement condition RP. Herrmann et al. also observed a clear RP build-up prior to stimulus presentation in a task where participants had to press one of two buttons depending on the stimulus presented (Herrmann, et al., 2008). Since participants were instructed to perform numerous trials of this choice task, the researchers concluded that the RP might be more indicative of the expectation to choose and react than being inherently related to the choice and reaction.

However, all these experiments only relate to arbitrary left/right choices without any real-world significance. Decidedly, in the debate on free will, it should not matter whether you experience an urge to flex your left instead of your right wrist, for it describes the effect of an urge without implication. An urge can be classified as a passive event and therefore has no bearing on an act of will (Batthyany, 2009). The problem with the choices presented in these studies remain their practical relevance. It is ineffectual to determine the underlying neuroscience of arbitrary choices in a study of free will. The following section will address this criticism by introducing the concept of deliberate decisions.

2.3.3 Deliberate and arbitrary decision-making

In 2017, Maoz et al. for the first time introduced the concept of deliberate decisions into RP studies. They argued that the arbitrary decisions presented in previous studies were void of purpose, reason and consequence and that it therefore remains unknown to what extent the previous findings are applicable to decisions that matter. They opposed these original arbitrary decisions with deliberate decisions. Maoz et al. described deliberate decisions as decisions of interest, with ecological and real-life relevance. They developed a choice task in which participants were instructed to donate money to one out of two non-profit organisations (NPOs). The chosen NPO would receive a donation of $1000 and the remaining NPO would receive $0. Participants were led to believe that their chosen charities would really receive the funds (Maoz, et al., 2017). The experiment consisted of deliberate and arbitrary trials and the above criteria defined deliberate decisions. For the arbitrary trials, participants were informed that, regardless of their choice of NPO, both NPOs would receive an equal amount of $500. For arbitrary choice trials, clear RPs were observed – however, the deliberate choice trials were marked by an absence of RPs. The researchers concluded that the neural correlates underlying arbitrary and deliberate decisions differ. They criticised that, paradoxically, deliberate decisions have mostly been studied in the field of neuroeconomics, while arbitrary decisions have been the basis of studies in free will (Glimcher, et al., 2009). It is the aim of this research to further investigate the differences between these two types of decisions, with a greater focus on the neural correlates of deliberate decisions.

2.3.4 Morality in decision-making

There is an undeniable link between higher order deliberate decisions with real world consequences, and morality. As humans we tend to make decisions that generally promote individual wellbeing and the wellbeing of the greater community. We have the mental capacity to choose between right and wrong, and we possess a moral understanding of what these choices imply about our perceived character. We live and interact in a community where other's actions and choices inform our own. Decision-making can therefore not be investigated or understood in isolation from these environmental factors. On the other hand, morality is also a neurological mechanism – and even though the biology of morality is not very well understood, we gain some insights when we consider cases where neurological impairment resulted in behavioural changes. One such case is when a 40-year-old man with no prior psychological afflictions suddenly developed uncontrollable paedophilia (Choi, 2002). They later found that these tendencies developed as the result of a brain tumour in his right orbifrontal cortex. His sex-obsession disappeared after they surgically removed the tumour. Another case chronicles the story of Charles Whitman, who was known as the Texas Tower Sniper. He killed his mother and his wife, and then proceeded to kill 14 people and

wound an additional 31 people before he was shot dead by police officers. He noted, in letters found in his home, that he experienced intense headaches and crippling violent impulses prior to the incident. Upon examining his body, coroners found a brain tumour pressing against his amygdala. The amygdala is a known site for the regulation of emotion and aggression (Rosenwald, 2016). Extensive studies have been done between neurological impairment and sexual or behavioural misconduct. A strong link has been found between the emotional processing centres in the brain and moral judgment (Greene, et al., 2001). The neural mechanisms mostly associated with morality and moral cognition arise in the subcortical limbic structures and the prefrontal temporal cortex (Moll, et al., 2008). No clear link has been found between moral judgment and deliberate decision-making.

Higher order decisions are informed by an accumulation of evidence from internal and external models. This research aims to link decision-making to the environment and subjective framework in which the choices occur by measuring the RP response to a given choice task, to effectively measure the presence of free will in decisions that matter. The following chapter outlines the experiment that was developed to enable this investigation.

3 Research design and methodology

3.1 Introduction

This study was designed to investigate and measure the neurophysiological differences between arbitrary and deliberate decisions. More specifically, the aim was to investigate the presence or absence of the RP when executing both deliberate and arbitrary choice tasks to demonstrate the role free will has to play in higher order decision-making. A recent study suggests that the RP is observable when a person executes an arbitrary choice task, but not when making a deliberate decision (Maoz, et al., 2017). However, if the presence of the RP objectively disqualifies free will, then the RP should arguably be present in all cases, i.e. where either deliberate decisions or arbitrary choices are being made. The experiment was designed to test this hypothesis.

3.2 Research approach

The experiment developed for this study was based on an ERP study conducted by Maoz et al. In 2017, Maoz and his group made the distinction between arbitrary and deliberate decisions, and investigated the neural precursors associated with both types of choices. In the original experiment, subjects had to choose between making donations to one of two NPOs. For the arbitrary decision trials, equal amounts of $500 were allotted to both NPOs regardless of the choice. For the deliberate trials, the charity of choice received $1000 and the opposing charity received $0. Participants completed 360 trials that were divided into 40 blocks of 9 trials each (Maoz, et al., 2017).

The current study focused the choices in a legal context and, similarly to the 2017 study, adapted the choices to be of a higher order than other existing Libet-type studies. The distinction between arbitrary and deliberate choices aimed to measure the neural responses associated with making “real” choices with consequences and moral implications versus making choices devoid of consequence. This study altered the choice task to choosing who should be acquitted or convicted between two criminal offenders when presented with the specifics of their crimes. For each trial, participants either had to acquit or convict one out of two criminal offenders. Participants completed 360 trials, divided into 6 blocks of 60 trials each. The participants were also divided into two equal groups: one group had to choose who to acquit, while the other group had to choose who to convict. The details of the different criminals and their crimes were presented in the form of summarised legal case studies.

Participants performed the task under the impression that the experiment was designed to evaluate whether EEG can be used to improve on the jury selection

process for prospective legal trials. This misdirection was necessary to maintain the integrity of the study, since knowledge of the free will investigative component may have influenced participants' responses and biased the results (Bode, et al., 2014). The informed consent forms therefore only demonstrated the details of the study to the extent of EEG being used to evaluate jury selection. Stellenbosch University's Health Research & Ethics Committee (HREC) approved this omission in the informed consent forms. Although the reason for the study remained unknown to participants, the consent forms illustrated the experimental procedure accurately enough to validate their informed consent. Not knowing the full scope of the study did not pose any harm to the participants.

The details provided to participants explained that the task served as an audition for compiling a jury of 12 jurors for a mock legal trial. These details stipulated that the EEG task would serve as the preliminary phase of the jury selection process. They were told that, following the analysis of their neural responses during these legal choice tasks, they might be selected to serve as one of 12 jurors on a jury for a mock legal trial. Some of the legal case studies presented during these choice tasks were reconstructed using existing cases found in the Legal Case Database, others were fabricated from fragmented details of existing cases. The idea was to use cases that were credible but unknown to participants. Using well known existing cases may have resulted in skewed results since individuals may have already formed personal opinions about these cases prior to the EEG sessions. It was imperative that everyone would be presented with the cases for the first time during their EEG sessions. The cases related to criminal scenarios such as theft, arson, murder, rape, assault, attempted crimes and self-defence. A list of the cases can be found in Appendix B.

Similar to the 2017 study, there needed to be a clear distinction between arbitrary and deliberate choices. In this case, this distinction was made based on whether the details presented in the different legal case studies related to solved or unsolved cases. Furthermore, participants were informed that for deliberate blocks, their responses would be evaluated for the jury selection process whereas for the arbitrary blocks their responses would not be evaluated for the jury selection process. The distinction made between arbitrary and deliberate decisions was discussed with and validated by Mr Adam Struben, a qualified clinical psychologist, as being a viable classification for the two categories.

3.3 Experimental design

3.3.1 Participants

Twenty-nine healthy participants, aged 21 to 28, volunteered for the study. Participants were recruited via email (see Appendix A) and institutional permission from Stellenbosch University was obtained to support the recruitment process. All

participants were students from Stellenbosch University and most, but not all, participants were engineering students. Table 5 shows a summary of the demographics of the participants.

Table 5: Participant demographics

Description		Frequency	Percent (%)
Trial Type	**Convict**	14	48.28
	Acquit	15	51.72
Gender	**Male**	22	75.86
	Female	7	24.14
Handedness	**Left**	3	10.34
	Right	26	89.66
Race	**Black**	2	6.90
	Coloured	3	10.34
	White	23	79.31
	Indian	1	3.45
Nationality	**South African**	27	93.10
	Other	2	6.90

Participants were awarded R100 for their participation. All participants were provided with participant numbers ranging from 1 to 29. Since the answers recorded were of a personal nature, all data was recorded anonymously and stored confidentially. Only participant numbers were used as means of identification on questionnaires and as reference on EEG datasets. The experiment was approved by HREC (see Appendix A) and was conducted in accordance with the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research. All participants provided informed consent before taking part in the study.

3.3.2 Stimuli and apparatus

For the EEG recordings, a 128-channel Brain Products active channel amplifier (actiCHamp) EEG system (Brain Products, Germany) was used. Active EEG electrodes refer to EEG electrodes with built-in circuitry, locally amplifying and buffering the EEG signals before conducting the signal. The advantage of using active electrodes is the reduction of noise due to cable motion artefacts (Xu, et al., 2017). The actiCHamp EEG system was used in conjunction with the Brain Products actiCAP. The EEG caps are manufactured in different sizes to accommodate different head sizes amongst participants. The standard sized are listed in Table 6. For this study, all participants effectively fit one of these four standard cap sizes. The sizes listed in Table 6 refer to the head circumference, measured from the

middle of the forehead, around the occipital bone protrusion at the back of the head and back around to the forehead.

Table 6: Standard EEG cap sizes

Standard EEG caps	Size (cm)
Cap 1	54
Cap 2	56
Cap 3	58
Cap 4	60

The electrode positions followed the international 10/20 system. A visual representation for this setup can be seen in Figure 11. The labels of electrodes arranged in the international 10/20 system, refer to the cerebral regions from where the electrodes record (see Section 2.2). For this study, the reference electrode was chosen as a common vertex reference located at Cz, i.e. electrode 24 in the standard 10/20 system positioning. Existing literature recommends the common vertex reference for active electrode systems (Teplan, 2002).

For this study, 64 electrode channels were utilised - with a separate ground electrode channel located at FPz (see green, yellow and black electrodes in Figure 11). The temporal and spatial resolution of a 64-channel setup adequately supported the data collection procedure for this experimental design. The 64-channel setup covered all the relevant brain structures considered in human decision-making tasks (Teplan, 2002). Moreover, because it does not cover the scalp as densely as a 128-channel setup would, it ensured a lower likelihood of bridging between neighbouring electrodes. Even though only four electrodes were considered for this research study, data was recorded from 64 electrodes for future research purposes. The selected electrodes of interest were based on existing literature. However, since there were no initial guarantees of what EEG trends might arise, recording data from the whole scalp enabled the investigation to extend to other potential sites of interest.

The EEG system amplifier measures electrode impedances during the system setup, before recording EEG data. Impedance refers to a resistance to the current flow measured by the EEG electrodes. High impedances often lead to distortions that convolute the EEG signals. These convoluted signals may be difficult to separate post hoc and may compromise the integrity of the captured data. For this study, an impedance below 25 kΩ at all electrode positions was considered acceptable. This threshold is suitable for active electrodes and therefore did not need to comply with the international acceptable standard of 5 kΩ for passive electrodes (Emmerling, 2017) (Jones, 2015).

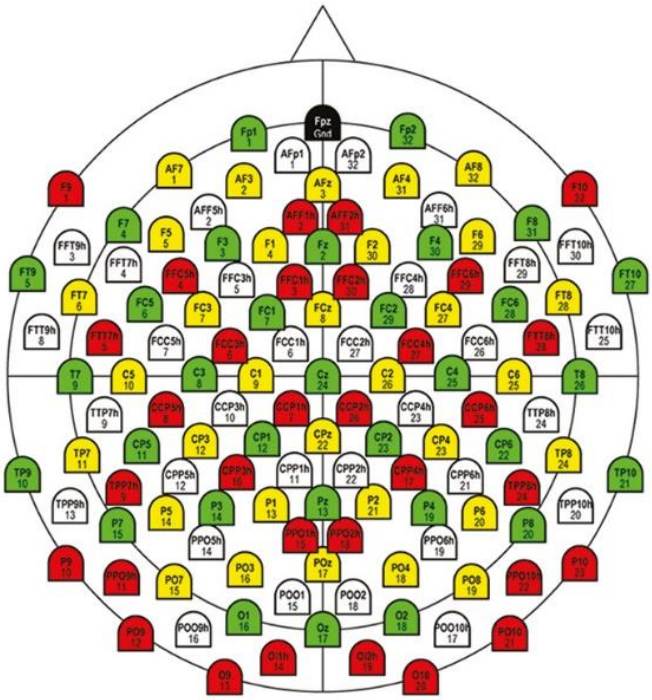


Figure 11: ActiCHamp electrode placement (Brain Products, Germany) (Emmerling, 2017)

During the EEG experiment, stimuli were presented on a 21-inch Dell monitor with a refresh rate of 60 Hz and a resolution of 1024x768 pixels. The script that presented the stimuli to participants was written using PsychoPy2 v1.90.2 (Peirce, 2009) – an open source programming Python package specifically designed for application in Neuroscience and Psychology experiments. The program sent triggers at the onset of the questions and recorded responses via button presses. The triggers and responses were sent from the PsychoPy software to the EEG system amplifier, and from the system amplifier to the Brain Vision recorder software (Brain Products, Germany) via a parallel port installed on a second computer. The second computer integrated the triggers into a live EEG data feed, recorded in the Brain Vision software on the second computer. The EEG data was sampled at 500 Hz. The sampling rate refers to the data capture rate. A sampling rate of 500 Hz indicates scalp potentials were captured 500 times per one second frame of data.

Participants completed the experiment while sitting in a dimly lit, quiet room. All distractions, such as cell phones and smart watches, were removed for the duration of the experiment. All participants had normal, or corrected to normal, vision and were positioned 60 cm from the screen. Stimuli were presented as text printed in Arial, as white text on a black screen. The study was conducted at the

Neuromechanics Unit (CAF Unit), located at the Coetzenburg Sport Complex in Stellenbosch.

3.3.3 Procedure

The study consisted of two parts, completed on two separate days. During the first part, participants were informed about the purpose and proceedings of the study. They were also required to fill out a questionnaire and provide their informed consent. This part took place at Stellenbosch University's Engineering Faculty. The second part of the study consisted solely of the EEG lab session and was conducted at the CAF Unit.

3.3.3.1 Part 1: Information session

The first part of the study required participants to fill out a questionnaire illustrating their relationship to crime and violent crime throughout their lives. Since the study addressed issues such as rape and murder, it was important to determine subject specific biases with regards to the legal case studies presented. Consequently, personal histories were considered relevant in the analysis of the resulting EEG data. Furthermore, since the summaries of the legal case studies described the criminal offences in the third person (using terms such as "the accused", "the victim", "a man" or "a woman"), it was necessary to understand which gender or race was inferred by each participant when these terms were used as descriptors. It was important to determine whether a participant was predisposed to believe that a man is more likely to commit a certain crime than a woman, or whether someone of a certain race is more likely to commit a specific crime. These factors were likely to affect participant choices and were therefore considered relevant. This part of the study was conducted on a different day to the respective EEG lab sessions. All participants were required to attend this one-hour session on a separate day. Participants completed the first session in groups of seven participants per group, whereas the EEG lab sessions were individual sessions. During these hour sessions, the experimental protocol was explained, the participant questionnaires were completed, and the informed consent forms were signed. Appendix A shows copies of the participant questionnaire and the informed consent form.

It was considered that, in addition to the questionnaire, participants should complete a standard psychometric test to qualify them for the second part of the study. The purpose of this test would have been to screen for psychopathic deviations in individuals. The relevance of such a screening relates to the nature of the questions presented in each of the trials. Since the presented case studies dealt with moral and ethical dilemmas, individuals without the emotional capacity for empathy or guilt would not be able to weigh the consequences of their choices against one another and would thereby invalidate the investigation. However, since only 1% of the world's population is afflicted with psychopathy (Boddy,

2011), and since this study only consisted of a sample size of 29 participants, it was considered statistically insignificant to include such an assessment.

3.3.3.2 Part 2: EEG lab session

The second part of this study related to the EEG data collection procedure. To schedule the EEG lab sessions, participants were sent a schedule with available slots for the months of June, July and August. Sessions were scheduled for four hours each. Most of the sessions were scheduled during the mornings from 08:30 to 12:30, unless participants specifically requested sessions to be scheduled in the afternoon of after hours. The EEG lab sessions took place from the 6th of June 2018 to the 9th of August 2018.

At the start of each session, all participants were informed of the session's proceedings and were encouraged to ask questions if anything was unclear to them. Participants were also reminded that it was within their rights to withdraw consent at any point during the study. Participants were always handled with respect and were offered beverages and snacks throughout the session. At the end of the session, participants were awarded R100 for their participation.

For the EEG lab sessions, the time was roughly divided in the ratio of 60:40 between setup time and testing time. The complete setup procedure is outlined below:

- First, the participant's head would be measured in order to find and fit the correct cap size (see Table 6). It was important to ensure that the EEG cap sizes were a near perfect fit for all participants. A cap that is too loose might compromise the integrity of the EEG data, while a cap that is too tight might cause discomfort for the wearer. All caps and electrodes were washed between uses in accordance with the Brain Products specifications and guidelines (Brain Products, Germany).

- Once the correct cap size was identified, the cap was populated with the EEG electrodes. As mentioned in Section 3.3.2, a setup with 64 electrodes (and an additional ground electrode located at FPz) was used. Since the electrodes could not be attached to the cap while the participant was wearing the cap, this was done using a Styrofoam mannequin head. At this time, participants were encouraged to move freely around the lab, seeing as they would be sitting still for long periods once testing started.

- The electrodes used with the Brain Products system were active electrodes. When using active electrodes, impedance is still important even though higher impedances are acceptable compared to when using passive electrodes (Emmerling, 2017). Obtaining acceptably low impedance levels when using active electrodes, required gel to be applied

to the respective electrode sites. The gel that was used is a high conductive gel. The gel served to establish a connection between the electrodes and the scalp. It was explained to participants that a blunt needle would be used to inject the gel into the proper positions in the cap. The needles were sterilized in between participants and participants were encouraged to feel the needle's end as reassurance of its bluntness. At this point, participants were again reminded that they could withdraw consent.

- Each electrode is equipped with a light emitting diode (LED) that ranges from red to yellow to green (see Table 7). As soon as a proper connection was established, the LEDs on the electrodes would gradually turn green. Green electrodes indicated acceptably low impedances. An impedance of 25 kΩ or lower was considered acceptable for this research (Brain Products, 2017) – this translated to a bright yellow or green display on the electrode LEDs. For every participant an impedance check was done before and after the test. Comparing the impedance before to the impedance after, it was found that the impedances improved with time, towards the end of the session. Figure 12 shows a comparative visual of the impedance measured before recording started and at the end of the recording session, for a participant. Table 7 shows how the different colours relate to the impedance scale. It is important to note that the yellow impedance class in Table 7, displayed in different shades of yellow – where a darker yellow indicated an impedance closer to 60 kΩ and a brighter yellow indicated an impedance close to 25 kΩ. The impedances of bright yellow electrodes were therefore considered appropriately low.

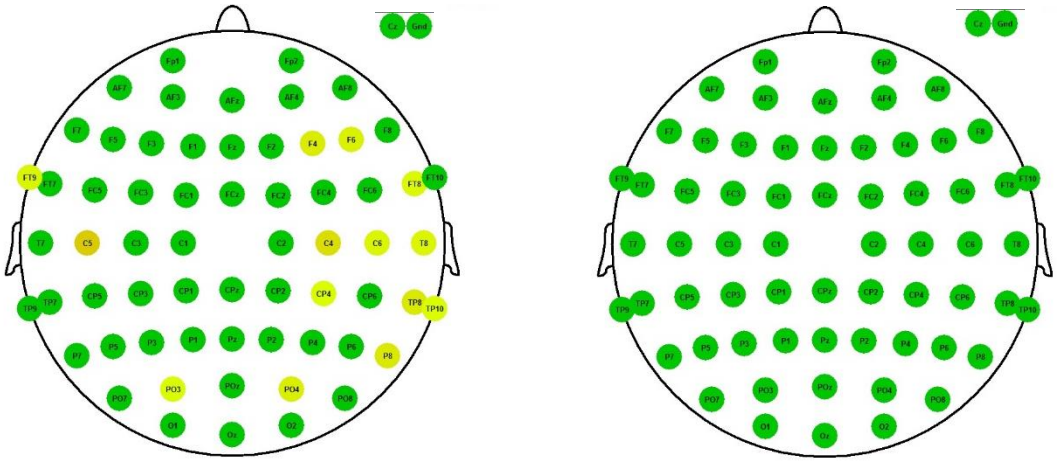


Figure 12: Scalp electrode impedances

Table 7: Default impedance thresholds (Brain Products, Germany) (Emmerling, 2017)

Colour	Default impedance thresholds
	greater than 60 kΩ
	between 25 and 60 kΩ
	less than 25 kΩ

Once the impedances of all the electrodes were within this range, the setup was complete and EEG testing could begin. Figure 13 (upper left) shows a graphical presentation of the EEG cap prior to the gelling procedure and Figure 13 (right) shows the cap while being gelled. Figure 13 (lower left) also shows the experimental setup with regards to the keyboard and screen.

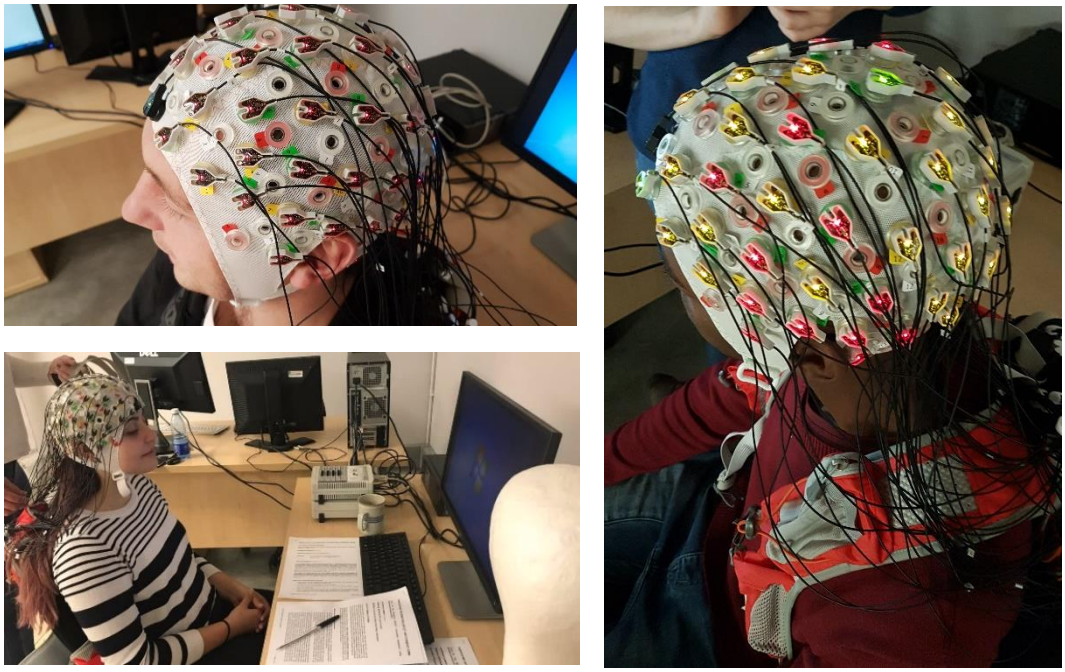


Figure 13: Photos of research participants wearing the EEG cap (permission was obtained from all participants shown in this figure)

Following the setup procedure, participants were again reminded that they could withdraw consent. Thereafter, the testing procedure was explained to them. They were told that they needed to place the index fingers of their left and right hands on the “f” and “j” keys, respectively. During the test, participants were presented with two criminal scenarios per trial – one was displayed on the left side of the screen and one on the right. The participants were randomly divided into two equal groups: the acquit group and the convict group. For each trial they needed to choose which perpetrator they would acquit/convict. There was a total of 360

trials, equally divided into six blocks of 60 trials each. All trials were displayed for 10 seconds, after which a different screen prompted participants to respond. This ensured that participants focused their attention on the task at hand.

Participants were encouraged to take breaks between blocks. During these breaks they were offered snacks and beverages. The EEG setup also made it possible to unplug the EEG cap so that participants could freely move about the lab or visit the restroom during breaks. This movement did not affect the electrode impedances. Additionally, there were two types of decision blocks. At the start of each block, the programme informed participants which type of block they were responding too. For arbitrary blocks, participants were told that they were being presented with the details of solved cases. They were also told that their responses during these blocks would not be evaluated for the jury selection process. For deliberate blocks, participants were told that they were being presented with unsolved cases. Here, they were told that their responses would be evaluated for the jury selection process. These distinctions ensured that participants would consider deliberate blocks of greater consequence than arbitrary blocks. The three deliberate blocks were placed at the beginning of the test, followed by the three arbitrary blocks. The reason the blocks were not interspersed was because the same cases were used for the deliberate-arbitrary block pairs. Since the deliberate blocks aimed to engage higher order decision-making mechanisms in the brain and arbitrary blocks aimed to simulate the original Libet reflex action, placing all the familiar arbitrary blocks at the end of the session facilitated this distinction. Participants were encouraged to take their time while responding to the deliberate and arbitrary trials. However, they were also told that the computer would prompt them to respond if they were unresponsive for too long. These prompts did not require an immediate reaction, but merely meant to refocus their attention on the task at hand. Before the testing procedure started, participants were provided with a sheet summarizing relevant legal terminology (see Appendix B). They had access to the sheet throughout the test, but most of the presented scenarios were self-explanatory. Participants were also instructed to keep as still and blink as little as possible. They were told to make themselves comfortable but to move only their corresponding index fingers as far as it was possible.

After all the instructions had been communicated to the participants, they were asked to assume their testing positions in front of the computer screen. All these verbal instructions were again presented to them in a written form, and they were encouraged to ask about any instructions that did not make sense to them. Following the instruction screens, participants were presented with a practice round, in which they responded to three trials. Once they understood how these practice trials worked, testing began. The scripts for the acquit and convict trial types followed the same logical sequence; “acquit” simply replaced “convict” for the one trial type.

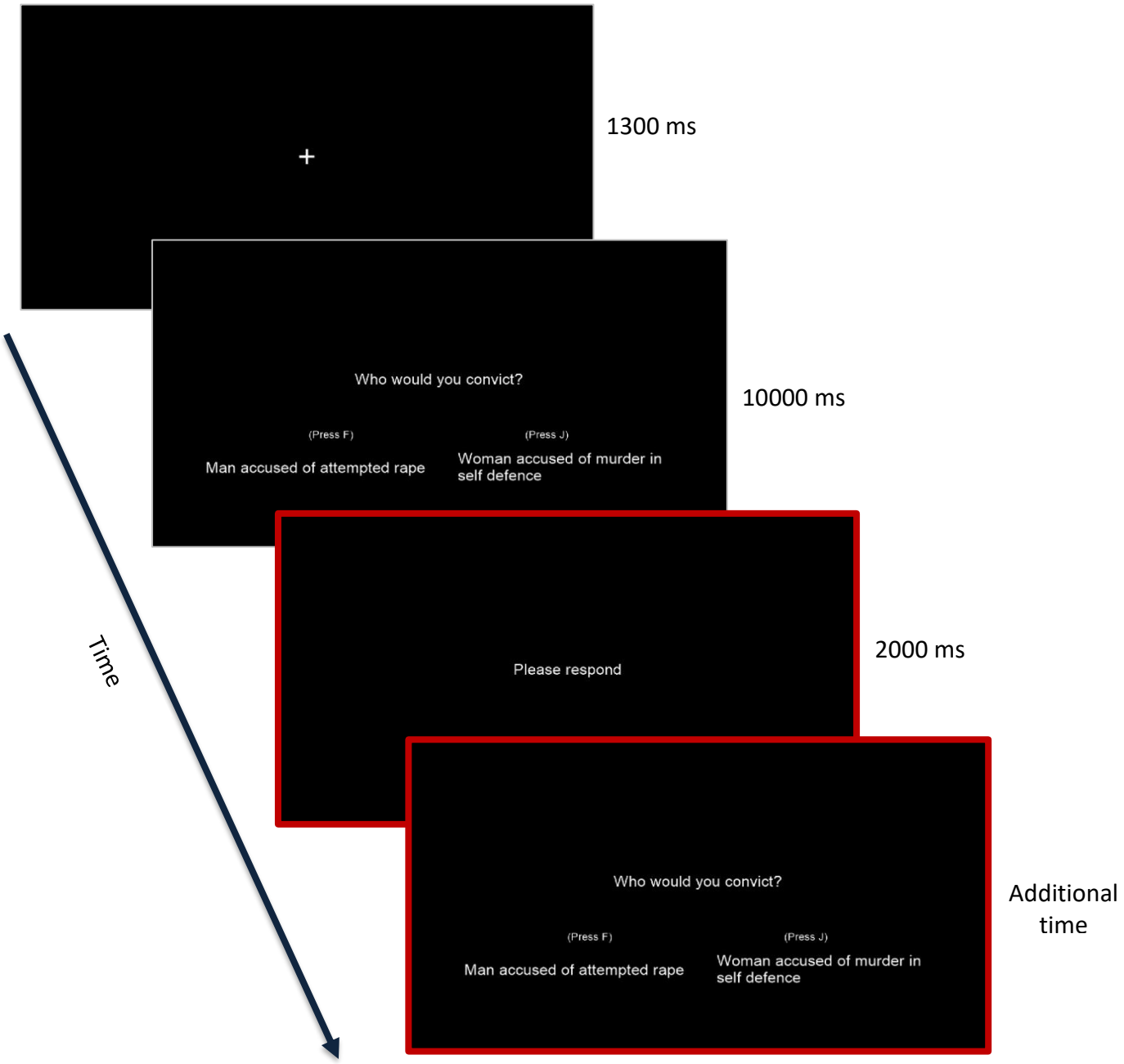


Figure 14: Experimental sequence

Figure 14 shows a diagrammatic representation of a single choice trial. Figure 14 also shows the display times of the different screens during the testing sequence. The practice round, as well as the other blocks and block types, followed the same design. The two red frames in Figure 14 indicate optional screens during a single

trial sequence: if participants responded within 10 seconds of being presented with the choice task, these two frames were omitted from the sequence. However, if participants exceeded the 10 second response time, then they were prompted to respond, as shown by the first red frame; and then redirected to the same question, as shown by the second red frame. The final block concluded with a screen informing participants that testing was complete and thanking them for their time. At the end of the session, participants were awarded R100 for their participation. The EEG cap was unplugged and removed from their head, after which they were free to leave. Additionally, there were shampoo and towels available at the lab for those who wanted to wash their hair before leaving.

This chapter concludes the discussion of the experimental design and lab setup for the information and EEG testing sessions. The following chapter will discuss the data analysis procedure.

4 Data analysis

4.1 Introduction

This chapter discusses the data analysis procedure that was applied to the captured EEG data. The chapter is divided into two parts. The first part discusses the pre-processing steps performed in MATLAB R2018a (MathWorks). The second part discusses the statistical analysis, performed in SAS (SAS Institute Inc., 2017), NCSS (Dawson & Trapp, 2004) and SAS Enterprise Miner (SAS Institute Inc., 2011). It should be noted again that even though only four electrodes were considered for this research report, all 64 electrode channels were processed to enable further research.

4.2 Pre-processing

For the ERP analysis of the EEG data, EEGLAB (a Mathworks MATLAB R2018a graphical user interface) was used (Delorme & Makeig, 2004). The recorded data was re-referenced to two mastoid electrodes, P7 and P8. A digital finite impulse response (FIR) filter was used to band-pass filter the data between 1 and 40 Hz. Using EEGLAB's built-in independent component analysis (ICA) function in conjunction with the multiple artefact rejection algorithm (MARA) plug-in, all marked artefacts were removed prior to analysis. Channels that were marked for rejection, were replaced using interpolation. Data epochs were extracted from 3000 ms before to 350 ms after the button press event for all the trials, and the data was time-locked to the button presses. The button press event was assumed to coincide with the moment of deciding since participants were informed to press the button as soon as a decision was made. Lastly, the epoched data was run through an artefact detection algorithm that eliminated trials with peak-to-peak amplitude differences exceeding 100 µV. Baseline adjustments were made for the epoched data.

For the pre-processing of the event related EEG data, EEGLAB and ERPLAB were used (Delorme & Makeig, 2004) (Lopez-Calderon & Luck, 2014). EEGLAB is a MATLAB toolbox with a focus on processing electrophysiological data, such as EEG, electrocardiography (ECG) and electromyography (EMG) data. Furthermore, ERPLAB is an EEGLAB plugin that specifically focuses on ERPs. The diagram depicted in Figure 15 illustrates the chronology of the steps that were followed during the pre-processing of the data. The blue diagram boxes show steps that were performed in EEGLAB and the purple diagram boxes show steps that were performed in ERPLAB. The chronology of these pre-processing steps closely resembles the steps outlined in the Harvard Automated Processing Pipeline for Electroencephalography (HAPPE) (Gabard-Durnam, et al., 2018).

The subsections of this chapter will elaborate on the different steps shown in Figure 15. These sections will discuss the logical sequence of the processing steps, as well as how the processing choices relate to the existing literature on EEG pre-processing.

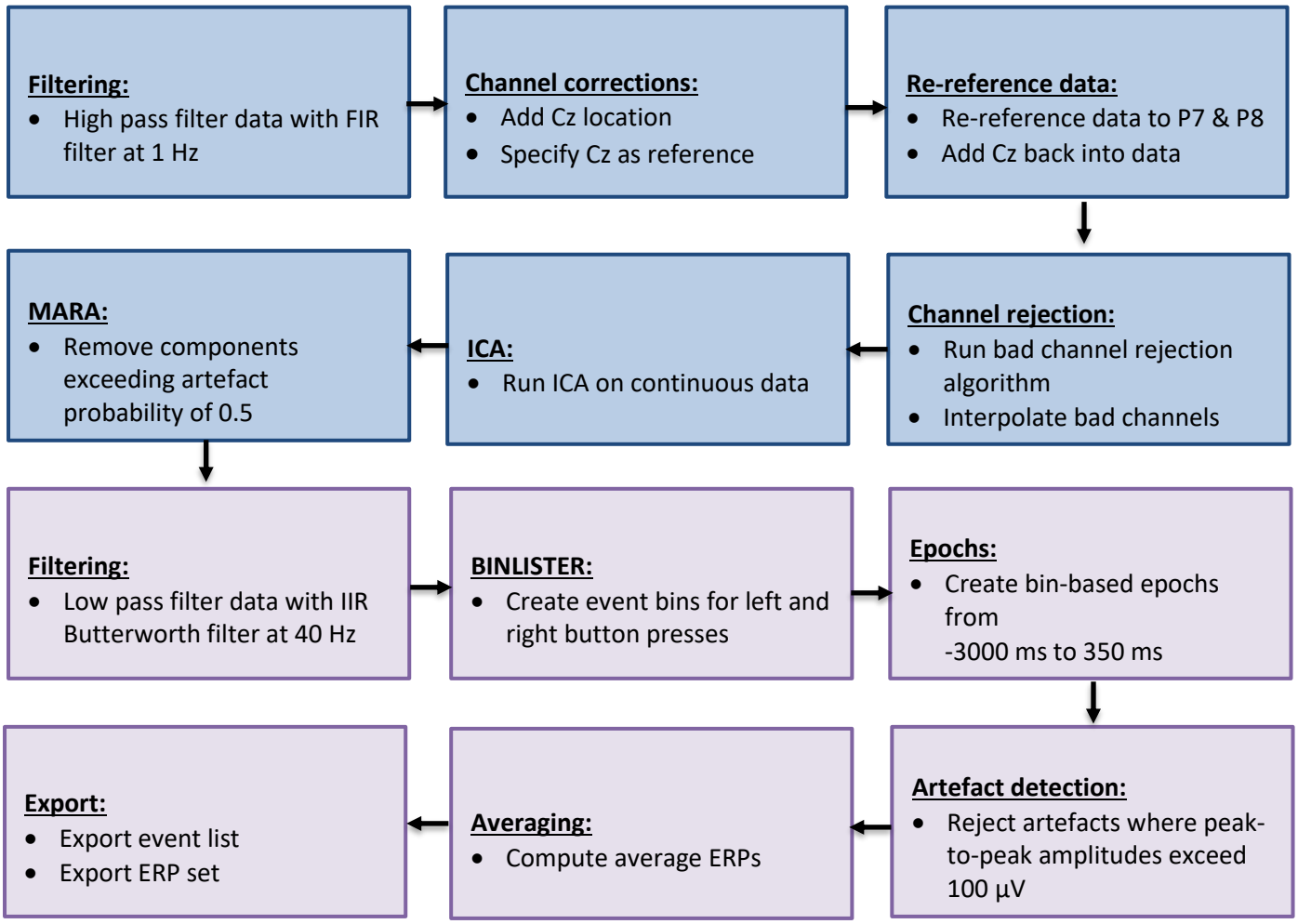


Figure 15: Pre-processing steps

4.2.1 Filtering

EEG data is typically divided into frequency bands that correspond to neural activity. Table 8 shows these frequency bands and their corresponding normal neurology.

Table 8: Different frequency bands and associated neurology (Abo-Zahhad, et al., 2015)

Frequency band name	Frequency band (Hz)	Normal neurology
Delta	less than 4	Slow-wave sleep state
Theta	4 to 7	Relaxed, meditative, creative states
Alpha	8 to 13	Eyes closed state
Beta	14 to 30	Active thinking and concentration state

For the associated EEG choice task, activity within the beta band was expected, since the task involved a thinking task. Moreover, ERP data is usually filtered between 0.1-1 Hz and 30-40 Hz (Acunzo, et al., 2012). It was recently shown that having a high pass filter with a cut-off value that is too high distorts the data. However, when running an ICA on continuous EEG data, it is strongly recommended that the minimum high pass cut-off should not be less than 1 Hz. It was found that a high pass filter cut-off between 1-2 Hz produces good signal-to-noise ratio when performing ICAs on continuous EEG datasets (Winkler, et al., 2015).

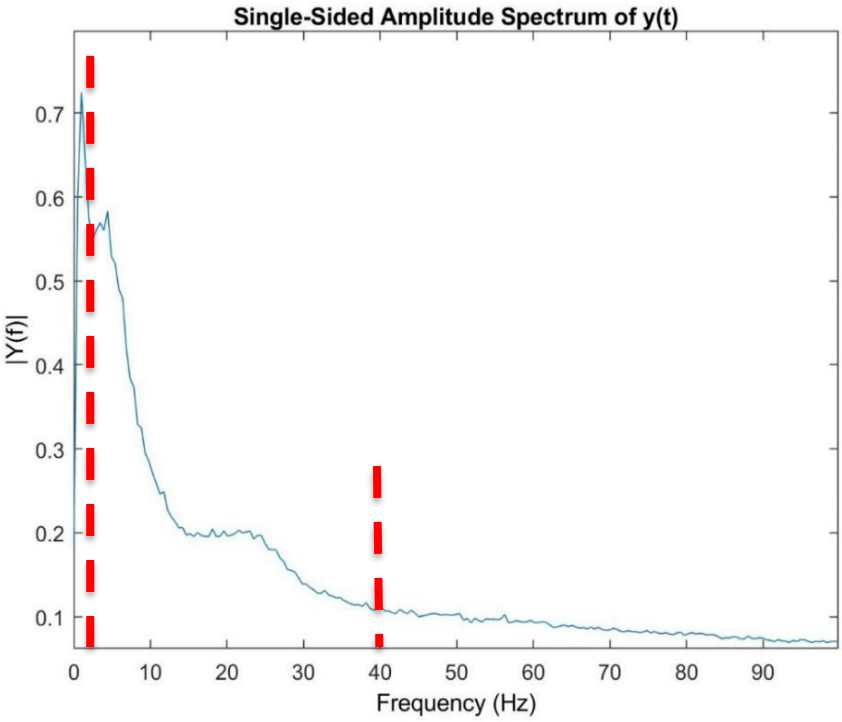


Figure 16: Frequency bandpass filter

Figure 16 shows the typical frequency distribution of the recorded EEG datasets for all participants. Considering the graphic depicted in Figure 16 and the literature associated with ERP filtering, it was decided to filter the data with a high pass filter of 1 Hz and a low pass filter of 40 Hz. The data was therefore band-pass filtered between 1 and 40 Hz. It is generally recommended to split the band-pass filtering procedure into two different pre-processing steps (Anon., 2015). The continuous raw EEG data was filtered using a FIR filter, after which an ICA was performed. Then, after ICA and MARA artefact rejection, an infinite impulse response (IRR) Butterworth filter with a 36 db roll-off was applied to the continuous processed data. The red dotted lines on Figure 16 indicate the filter band that was used to filter the data.

Performing a power spectrum analysis on a typical dataset in this study, produced the graph shown in Figure 17. From Figure 17, there are clear spikes in the alpha and beta frequency bands (see Table 8). This illustrates that most of the EEG activity recorded during the EEG sessions were distributed between active thinking and mental relaxation. Considering the experimental design, these phenomena make neurophysiological sense.

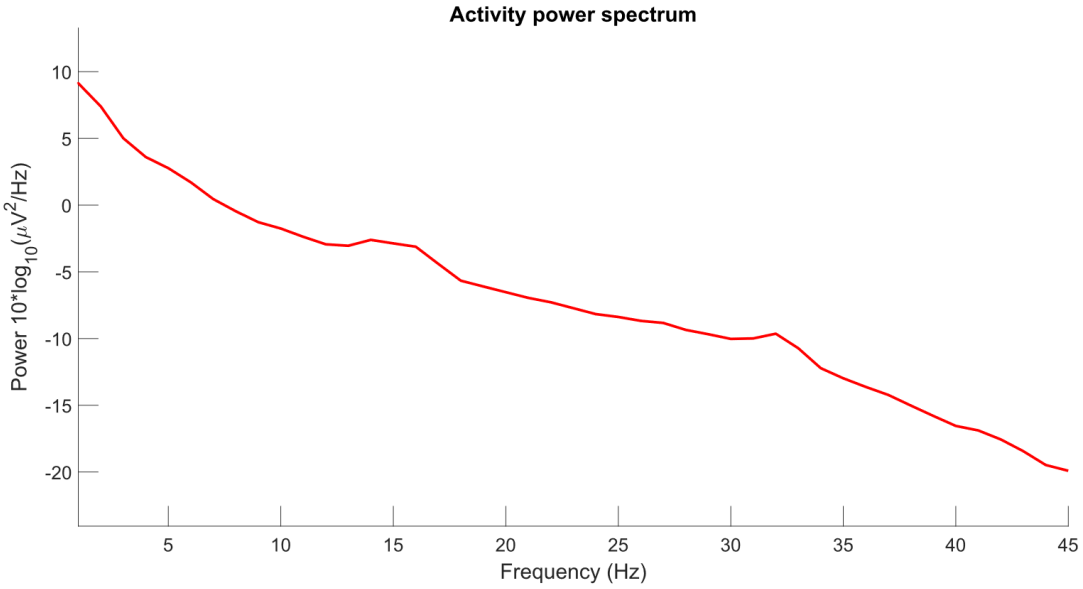


Figure 17: Power spectrum analysis of typical EEG dataset recorded during this study

4.2.2 Channel operations

After the high pass filter was applied to the raw data, channel corrections were made. Since the data file did not recognise the channel location information of electrode Cz, this information needed to be provided in the form of cartesian

coordinates. Since the location information for Cz was missing in the original data file, there was also no reference specified. Consequently, Cz needed to be specified as the reference electrode. Using Cz as common vertex reference meant that no recordings were displayed at the Cz reference site. However, since it is generally accepted that the RP originates and is most prominent in the motor cortex, Cz is most often the electrode site of interest when investigating the RP in human volition ERPs (Shibasaki & Hallett, 2006). Therefore, Cz needed to be added back into the data post hoc. This was done after re-referencing the data to different reference electrodes.

4.2.3 Re-referencing the data

The next step in preparing the data was using EEGLAB's re-referencing function to re-reference the data to different data channels, while selecting the option of adding the original reference back into the data. Electrode sites P7 and P8 were chosen as the new reference sites. They are symmetrically placed across the head and located just inward of the mastoid electrodes (see Figure 18). All areas of interest with regards to the re-referencing procedure are circled in Figure 18.

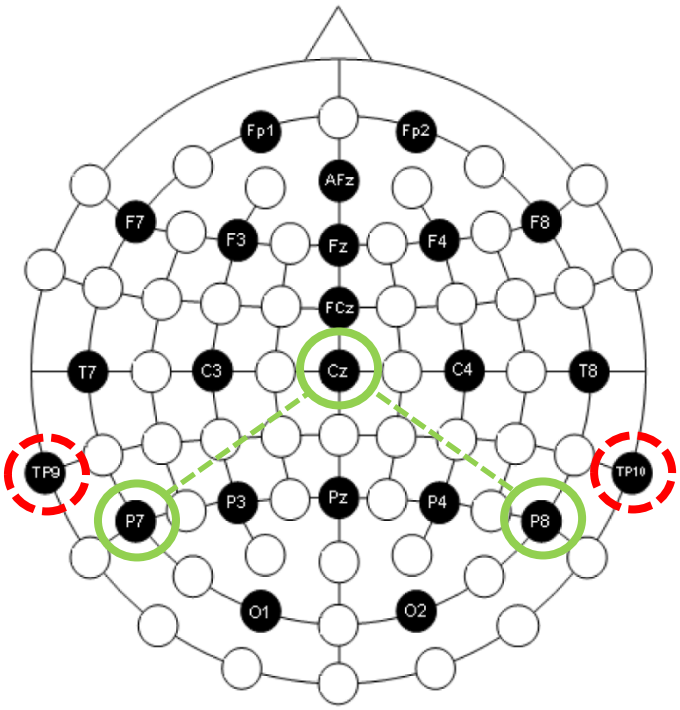


Figure 18: Re-referencing montage

Since Cz is a general area of interest when considering the RP, the mastoids are typically used as reference. The most common referencing techniques for EEG/ERP data include linked mastoid referencing (LM), common vertex

referencing (Cz), average referencing (AR) and the reference electrode standardization technique (REST). There are different researchers advocating for different preferences with regards to these different methods of referencing EEG/ERP data (Lei & Liao, 2017) – yet all four methods are generally expected to produce good results. For this study, the best results were obtained using LM referencing. The mastoid electrode sites are represented by electrodes TP9 and TP10 (see Figure 18). However, since the data that was recorded from the mastoid sites, TP9 and TP10, was on average too noisy to produce reliable results, electrode sites P7 and P8 were used instead. The data was re-referenced to P7 and P8 in the same way that single reference recorded data would be re-referenced to the LM electrodes. Equation 1 shows the formula for re-referencing data to linked electrodes (Lopez-Calderon & Luck, 2014).

$$ChX_{new} = ChX_{old} - \left(\frac{P7+P8}{2}\right) \quad (1)$$

The formula shown in Equation 1 is repeated for all the remaining electrodes - excluding P7 and P8. EEGLAB therefore incorporates this formula to calculate the new data points at each of the electrode sites in the international 10/20 positions for a 64-electrode setup, where "ChX" is replaced with the respective electrode labels from Fp1 to Cz.

4.2.4 Rejecting bad channels

Following the re-referencing procedure, the bad channels were rejected. This operation uses EEGLAB's built-in channel rejection algorithm. This algorithm evaluates the skewness of the continuous data for all the respective electrodes, using kurtosis as measure. All channels with a z-score threshold that exceeded 5, i.e. [-5 5], were eliminated from consideration. This procedure was repeated for all 29 participants' datasets. All channels marked for rejection were recorded in Excel (see Appendix C). Subsequently, the marked channels were interpolated using EEGLAB's electrode interpolation function. The spherical interpolation method was applied to the selected channels. This function uses the data from nearby electrodes on the spherical head map of the EEG configuration to produce more representative data values for the bad electrode channels. It is necessary to remove bad data from consideration before running an ICA on the continuous dataset, otherwise the component decomposition of the continuous dataset may not be representative of the recorded data.

It is advised to remove datasets with more than 10 bad channels from the study (Nolan, et al., n.d.). All datasets had less than 10 bad channels. The maximum number of bad channels found, was seven. Most datasets had on average three bad channels that needed to be interpolated. The reason for this exclusion criterion relates to the method of interpolation: since the function uses the remaining channels' data to produce more representative data for the bad

channels, there need to be enough good channels to justify such an interpolation. Once the marked channels were interpolated, and ICA could be performed.

4.2.5 Independent component analysis (ICA)

When considering ERPs, a component is defined as a distinct feature of the ERP waveform. However, when referring to ICA components, these include ERP components and artefacts. During an ICA, various components are extracted from the continuous dataset by means of linear decomposition. The neurophysiological ERP components are reserved, while the artefacts are rejected. In 1995, ICA decomposition was used for the first time to separate components in a continuous EEG dataset. Mekeig and Onton used the infomax algorithm to decompose continuous data into independent components (ICs) (Makeig & Onton, 2011). The way the algorithm decomposes ICs in EEG data is often likened to the "cocktail party problem" where blind source separation uses temporal independence to separate source signals. The analogy goes as follows: if you have a convoluted audio recording from a crowded room, the only way to make sense of the conversations is to separate and extract the different sources of noise production. Similarly, ICA extracts and separates different sources from the continuous dataset. Figure 19 illustrates blind source separation, which forms the basis for ICA.

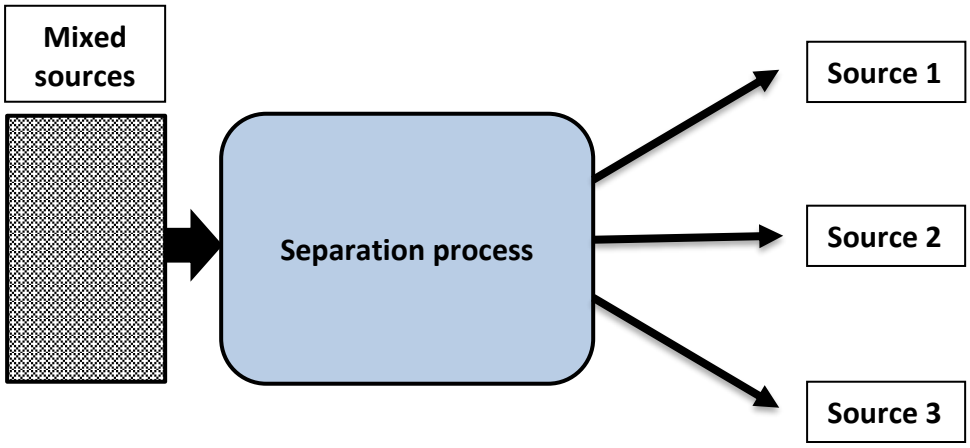


Figure 19: Blind source separation

Currently, there are two algorithms readily used to decompose the input data into separate ICs. These are the logistic infomax algorithm (that was originally used to perform the first ICA) and the extended ICA algorithm. The former uses the natural gradient feature and the latter uses sign estimation with training blocks equal to the number of input channels (Ahirwal & Londhe, 2012).

Considering the electrode scalp topography of EEG, an EEG source can be defined as being spatially stable. This means the component scalp maps produced during ICA remains constant over time (Makeig & Onton, 2011). Moreover, ICA can have any spatial pattern, i.e. simple or complex, depending on the nature of the continuous dataset. The following three components are typically found in an ICA decomposition (Jung, et al., 2000):

- Brain process components
- Non-neural, artefactual components
- Noise, such as eye blinks, eye movement potentials, EMG, ECG, EOG, line noise and single-channel noise

However, there is not always a clear differentiation to separate ICs into these three categories. There are sometimes "grey area cases" where components may be considered brain processes or non-neural artefacts – this especially occurs in the ocular region. Figure 20 graphically shows examples of typical ICs depicting noise.

Artefacts can also account for more than one IC, since one component may relate to the earlier phase of an eye blink and a second to the later phase associated with the same eyeblink.

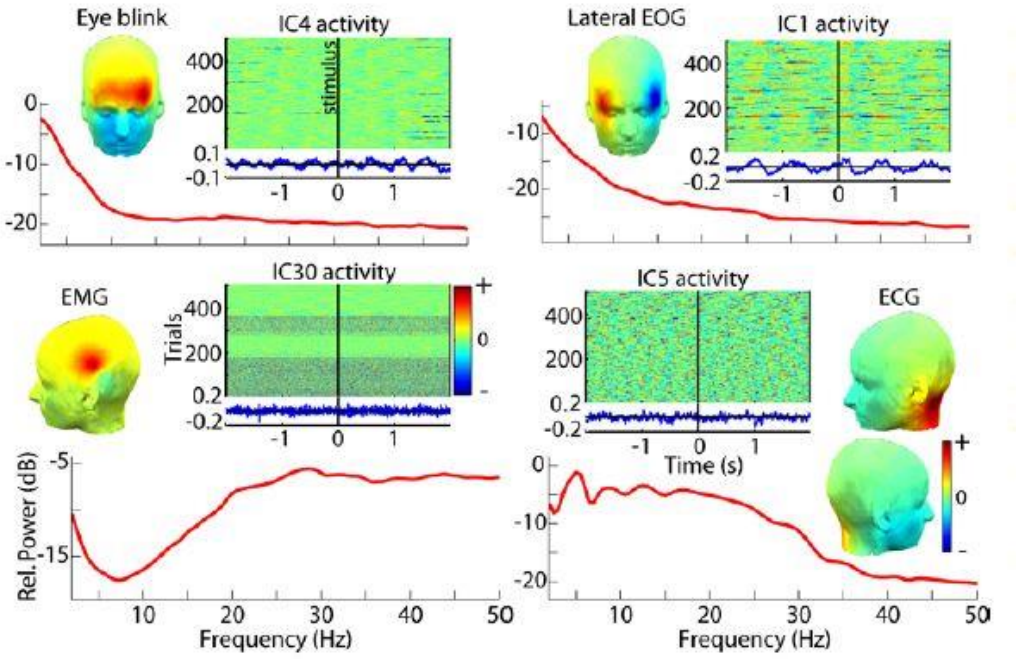


Figure 20: Typical artefactual ICA components (Makeig & Onton, 2011)

Mathematically, ICA can be described by the formulas in Equation 2, 3 and 4 (Makeig & Onton, 2011) (Ahirwal & Londhe, 2012).

$$U = WX \tag{2}$$

$$X = AU \tag{3}$$

Considering Equation 3 first, the X matrix represents the observed signals from the scalp data, where $X = [x_i; \ldots; x_n]^T$ and $i = 1; 2; \ldots; n$ is the number of electrodes. Each signal in X is a linear mixture of independent source signals. This is represented by U, also known as the component activation matrix, where $U = [u_i; \ldots; u_n]^T$ and $i = 1; 2; \ldots; n$ remains the number of electrodes. The matrix A is the unknown $N \times N$ component mixing matrix and can be further defined by Equation 4 as being the inverse of W.

$$A = W^{-1} \tag{4}$$

From Equation 2, the formula for calculating the source signal matrix U is represented by the product of W and the observed signal matrix X, where W is the separation matrix or the unmixing matrix of spatial filters learned by ICA from the EEG scalp data.

To rely on the validity of ICA decomposition, there are certain assumptions that need to be made. The reason that ICA is specifically useful when decomposing EEG data is because there exists an approximate fit between these assumptions and the electrophysiological nature of EEG data (Makeig, et al., 2004a) (Onton & Makeig, 2006) (Onton, et al., 2006). It is assumed that:

- The locations of the source components are fixed throughout the data – this means that the data is spatially fixed to the scalp topography and the electrode placements.
- The source components are summed at the sensor sites and this summation is linear.
- Delays are negligible when considering the projection of signals to the respective sensors.
- The probability distributions of the specific components and their source activity is non-Gaussian.
- All component source waveforms are independent from one another in the time domain.

Some of these assumptions have limitations, but in conjunction with one another they can readily be relied on to produce reliable component decompositions.

There is no real suggestion on how the sampling rate influences ICA and since ICA is reference free, the choice of reference does not compromise the decomposition.

The biggest mistake made when using ICA to decompose EEG data into components, is using datasets with too few data points. Since good IC decomposition relies on both the number of data channels and the length of the recorded data, it is typically better to use continuous EEG data. It should also be noted that ICA does not increase the dimensionality of the data. This means that the algorithm decomposes the data into the same number of components as there are data channels. Often there will be more sources than there are data channels – but a general rule to ensure effective decomposition states that the length of the recording should be 20 or more times the number of channels squared. The minimum required data length for the 62-channel setup used in this study (64-channels minus the P7 and P8 references) can therefore be calculated as follows:

Minimum length $= 20 \times 62^2$

$= 76880$ data points @ 62 points/s

~ 21 minutes

The suggested minimum time for an ICA with the setup used in this study is calculated as 21 minutes. Since the EEG recordings for this project were on average 60 minutes in length, this criterion was met and the results from the ICA could be considered reliable. After decomposing the data into ICs, artefactual components needed to be identified and removed.

4.2.6 Multiple artefact rejection algorithm (MARA)

After decomposing the data into 62 components per dataset, it was necessary to reject the components marked as artefacts. To do this, another EEGLAB plugin was used, i.e. the multiple artefact rejection algorithm (MARA). This algorithm makes use of the MATLAB statistics, optimization and signal processing toolboxes. MARA is a supervised machine learning algorithm that automates the classification process of marking components for rejection. The algorithm learns from 1290 components and extracts six features from all three relevant domains: spatial, spectral and temporal (Winkler, et al., 2011). The initial features that were extracted and considered to develop MARA are listed in Table 9. Table 9 categorizes these features according to the spatial, spectral and temporal domains. Since MARA extracts data from all three domains, the algorithm is not limited to identify only certain types of artefacts but has the processing capacity to effectively identify eye blinks, muscle movements and signal noise - such as loose electrodes.

Table 9: Extracted features for artefact identification in ICA components (Winkler, et al., 2011)

Spatial domain	Spectral domain	Temporal domain
Range within pattern	Fit error, describing the deviation of component's spectrum from the normal time curve	Variance of component time series
Spatial distance of extrema		Variance of local variance in different time intervals
Spatial mean activation of electrodes		Maximum first derivative for the discreet signal
2DDFT	Average log band power of the different frequency bands	Kurtosis
		Shannon entropy
Laplace-filter		Deterministic entropy
		Maximum amplitude
Border activation		Range of signal amplitude across time domain
Current density norm		Mean local variance
		Mean local skewness

Taking all the features listed in Table 9 into account, MARA labels artefactual components for rejection. The labelling system used by MARA is binary. Based on the features listed in Table 9, any component with an artefact probability exceeding 0.5 is marked for rejection, while components with an artefact probability lower than 0.5 is accepted. Since MARA allows the user to specify whether components should be marked for manual rejection or automatic rejection, it was possible to implement the algorithm to semi-automate the artefact rejection process. For the processing purposes of this study, the algorithm was only used to mark artefact components. Then, only after manual visual inspection, marked artefacts were rejected. Following this step, the remaining components were transformed back into the original channel data to produce an improved continuous dataset of 62-channels.

4.2.7 Epoching events (ERPLAB operations)

Completing the ICA and artefact rejection processes concluded the EEGLAB operations. The steps described in this subsection were performed in ERPLAB. ERPLAB has a suggested sequence of processing steps that optimizes the pre-processing procedure (Stewart, 2016). These steps follow below:

- The imported EEG data have associated event labels. For this study, these event labels correlated to the button presses. The first step in ERPLAB is to create an event list that describes the two types of events. This descriptor

creates bins into which the events are then sorted. For the purposes of this study, the two bins were labelled “Left” and “Right”.

- The next step was to convert the continuous EEG data into epochs surrounding the button press events. This step equally divides the continuous dataset into epochs of fixed lengths. The epoch length can be specified in ERPLAB. The data epochs for this study were extracted from 3000 ms before each button press to 350 ms after. While extracting the data epochs, baseline corrections are performed. The baseline correction removes the baseline leading up to the time-lock event, i.e. the baseline is removed from -3000 ms to time zero.

- After this, a final artefact detection algorithm processed the epoched data. This algorithm ensured that no data section exceeded a peak-to-peak amplitude difference of 100 µV. This threshold was chosen since EEG data should never exceed these bounds. EEG data mostly has peak values between -10 and 10 µV, and this step ensured to eliminate any final artefacts with higher amplitudes – such as eye blinks and muscle movements – that may have been misclassified during MARA. The rejection rates for this peak-to-peak rejection algorithm can be found in Appendix C of this report. The algorithm identified and marked sections where this criterion was not met. The moving window for evaluating the epoched data was 200 ms, with a step size of 100 ms. Sections that were marked for rejection were eliminated from consideration during the next step.

- After eliminating these final artefacts, the epochs were averaged over time to compute averaged ERPs. For all EEG and ERP studies, only the averaged data adequately illustrates neurophysiological trends. During this step, the artefacts marked for rejection in the previous step were also eliminated, while transforming the epochs to averaged ERPs.

- The final step was to export the event lists and ERP sets to readable text files.

These steps, performed in ERPLAB, concluded the pre-processing procedure. Following this, it was necessary to evaluate the integrity of the respective datasets based on the rejection criteria discussed in this section. The following subsection will summarise the data exclusions that followed data pre-processing.

4.2.8 Data exclusions

It is recommended that datasets with rejection rates exceeding 25% should be eliminated from the study (Lopez-Calderon & Luck, 2014). This criterion is only applicable when considering the trials rejected during the ERPLAB artefact rejection procedure mentioned in the third step in Section 4.2.7. The reason this elimination criterion does not apply to MARA is because MARA rejects components, not trials. Rejecting artefactual components does not compromise the integrity of the decomposed data, whereas rejecting too many artefactual trials reduces the dimensionality of the averaged data. Since EEG analysis relies on averaging enough trials in a dataset to produce a common trend, rejecting too many trials can lead to erroneous assumptions when considering the trends prevalent in the averaged data series. Two participants' data exceeded the maximum limit of 25% trial rejection.

Moreover, in the original Libet study, all participants were right-handed and performed a choice task using their dominant hand. It was therefore decided to eliminate participants who were left-handed, since most participants indicated that they were right-handed. This measure was taken to ensure better comparison between different participants. It also eliminated one redundant variable from consideration, since the participants were already divided into groups based on personal histories and trial type. Three participants were eliminated from the study for being left-handed.

Table 10: Rejected participants and parameters

Participant number	Rejection criteria
7	Left-handedness
13	Left-handedness
16	More than 25% rejected trials
27	Left-handedness
34	More than 25% rejected trials

Table 10 shows the data of the five participants that were eliminated from the study. This exclusion was due to their EEG recordings exceeding the 25% trial rejection criteria or being left-handed. No rejections were made based on bad channel data since no dataset had more than 10 channels marked for rejection. Table 11 shows a revised summary of the demographics of all remaining participants, aged 21 to 28.

Table 11: Post exclusion participant demographics

Description		Frequency	Percent (%)
Trial Type	**Convict**	12	50
	Acquit	12	50
Gender	**Male**	18	75
	Female	6	25
Handedness	**Left**	0	0
	Right	24	100
Race	**Black**	2	8.33
	Coloured	2	8.33
	White	19	79.17
	Indian	1	4.17
Nationality	**South African**	22	91.67
	Other	2	4.33

The following section will discuss the statistical analysis that was performed on the data. This section will highlight the data variables and parameters that were chosen as comparative measures for this study.

4.3 Statistical analysis

The statistical analysis phase was divided into four parts. Firstly, a power calculation was performed on the data to determine the power of the study when considering the full usable sample size, as well as different sample sizes for comparative groups. Thereafter, descriptive univariate statistics was used to identify the mean, median, standard deviation, interquartile range, minimum and maximum value per variable. During univariate analyses, tests for normality were performed in order to determine which bivariate analysis procedure needed to be followed in the subsequent analysis phase. Lastly, multivariate analyses were used to evaluate the differences between participant groups. The following subsections will describe these parts more comprehensively. All statistical analyses were done using SAS (SAS Institute Inc., 2017), NCSS (Dawson & Trapp, 2004) and SAS Enterprise Miner (SAS Institute Inc., 2011).

Participant data was divided into several different groups and counter groups. The different group pairs that were compared, as well as the chronological order in which the comparisons were made, are listed in Table 12. Firstly, the differences between the acquit and convict trials were evaluated, then the differences between the left and right button press responses, and thereafter the differences between the deliberate and arbitrary blocks. Lastly, the information gathered from the participant questionnaires was evaluated. The questionnaires were designed to determine the respective participants' relationship to crime and violent crime. Based on these findings, participants were divided into two groups

where (1) participants had personally been exposed to violent crime, assault or sexual assault; and (2) participants had close relatives who had been exposed to violent crime, assault or sexual assault. These groups were named Crime I and Crime II, respectively.

Table 12: Different group pairs relevant for data analysis

Group	Counter group
Acquit	Convict
Left button presses	Right button presses
Arbitrary	Deliberate
Crime I: Yes (Crime I: Y)	Crime I: No (Crime I: N)
Crime II: Yes (Crime II: Y)	Crime II: No (Crime II: N)

4.3.1 Power calculations

Firstly, a power calculation was performed to determine the sample size required for a mean difference of 1.5 and a standard deviation of 1 per group, with an alpha value of $\alpha = 0.05$. These values were determined retrospectively, where the mean difference was based on the values of the recorded EEG data. An alpha value of 0.05 and beta value of 0.2 is conventional in statistical power analyses (Noordzij, et al., 2010). Equation 5 shows the formula for calculating statistical power (Dawson & Trapp, 2004). The variables used in this formula are listed in Table 13.

$$n = 2\left[\frac{(z_\alpha - z_\beta)\sigma}{\mu_1 - \mu_2}\right]^2 \quad (5)$$

Table 13: Statistical variables used for power calculation

Variable	Value	Variable	Value
α	0.05	z_β	-0.84
β	0.20	$\Delta\mu$	1.50
z_α	1.96	σ	1.00

The post hoc power calculation showed that the sample size required to show a statistically significant difference with a power of 0.85, is roughly 10 participants. Figure 21 graphically illustrates the different power values given sample sizes ranging from 6 to 18 participants. Table 14 shows the respective statistical power values for the different comparative groups considered in this study (see Table 12).

Table 14: Different statistical power values for different groups

Group	Sample size	Statistical power
Acquit	12	0.95
Convict	12	0.95
Left button presses	24	0.99
Right button presses	24	0.99
Arbitrary	24	0.99
Deliberate	24	0.99
Crime I: Y	6	0.65
Crime I: N	18	0.98
Crime II: Y	13	0.96
Crime II: N	11	0.92

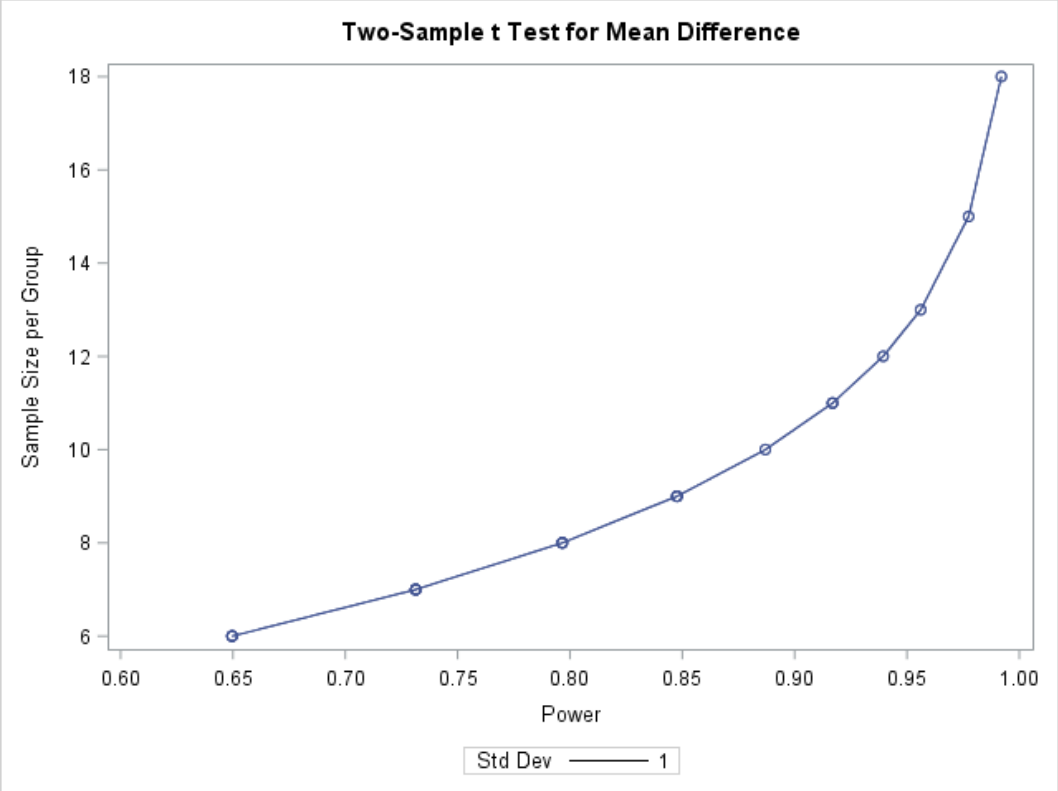


Figure 21: Power calculations showing correlation between statistical power and sample size

4.3.2 Descriptive statistics

This was one of the most important steps in the data analysis phase since it served to organise the data into an understandable format. The first step was to summarise the variable statistics and the second step was to test the different continuous variables for normality. The test for normality informs on which bivariate procedures should be followed in subsequent analysis step.

4.3.2.1 Summary statistics

For this study, univariate summary statistics was calculated per continuous variable. This included the mean, median, standard deviation, interquartile range, minimum and maximum values per variable.

4.3.2.2 Test for normality

The data was tested for normality using the Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises and Anderson-Darling tests. All these tests implemented a cut-off p-value of 0.05 to indicate a normal data distribution. Table 15 summarises the results for the normality tests for all relevant variables. Three classes of normality were demarcated: normally distributed data (N) with p-values greater than 0.05; not normally distributed data (NN) with p-values less than 0.05; and approximately normally distributed data (APN) with p-values bordering on 0.05. The following expression describes the labelling system used in Table 15 to define the variables:

$$peak\_electrode\_block\_response$$

For N and APN classes, an analysis of variance (ANOVA) test will be reported and for NN class data, a Wilcoxon rank sum (WRS) test will be reported. For this study an ANOVA test was performed on normally distributed datasets instead of a t-test. A two sample ANOVA is equal to a squared t-test. These tests were therefore not performed separately. The ANOVA is a more general test for two or more groups and reports the same results as a t-test (Mendenhall, et al., 1990). The WRS test is commonly used as a non-parametric test for the bivariate analysis of non-normally distributed data. The WRS test is also known as the Mann-Whitney U test.

Table 15: Summary of data distributions for RP and P300 peaks

Variable	Normality	Variable	Normality
RP_Cz_arb_left	N	P300_Cz_arb_left	N
RP_Cz_arb_right	N	P300_Cz_arb_right	N
RP_Cz_delib_left	N	P300_Cz_delib_left	N
RP_Cz_delib_right	APN	P300_Cz_delib_right	N
RP_Fz_arb_left	NN	P300_Fz_arb_left	NN
RP_Fz_arb_right	NN	P300_Fz_arb_right	N
RP_Fz_delib_left	N	P300_Fz_delib_left	NN
RP_Fz_delib_right	NN	P300_Fz_delib_right	N
RP_Fp1_arb_left	N	P300_Fp1_arb_left	NN
RP_Fp1_arb_right	N	P300_Fp1_arb_right	N
RP_Fp1_delib_left	N	P300_Fp1_delib_left	NN
RP_Fp1_delib_right	NN	P300_Fp1_delib_right	N
RP_Fp2_arb_left	NN	P300_Fp2_arb_left	NN
RP_Fp2_arb_right	N	P300_Fp2_arb_right	NN
RP_Fp2_delib_left	N	P300_Fp2_delib_left	NN
RP_Fp2_delib_right	NN	P300_Fp2_delib_right	N
Arb Left	N	Delib Left	N
Arb Right	N	Delib Right	N
Arb response times	APN	Delib response times	N

Table 15 shows that the data was mostly normally distributed, with some approximate- and non-normal distributions. For group comparisons where most variables reported a normal distribution, remaining variables were individually evaluated, and their distributions visually inspected, to determine whether tests assuming a normal distribution could be performed on the data. In all cases, this proved true and enabled confidence interval (CI) comparisons. The assumption of equality in variances were also tested and found to be true.

4.3.3 Bivariate analysis

Depending on the results of the normality tests, either parametric or non-parametric tests were performed next. The respective parametric and non-parametric tests used, were the ANOVA or WRS. These tests were used to evaluate and qualify the significance of the statistical differences between the different group pairs listed in Table 12. The findings from these tests formed an essential part of the results and will be discussed in the following chapter of this report.

4.3.4 Multivariate analysis

Lastly, following the bivariate analysis phase, multivariate analyses were performed. Decision trees and logistic regression models were fit to the data. The results of the multivariate methods are also discussed in the following chapter of this report.

5 Results and discussion

This chapter will present the results, along with a concurrent discussion of these results. The results will report on the electrophysiological data recorded at the respective electrode sites Cz, Fz, Fp1 and Fp2. The chapter will follow the layout depicted in Figure 22. The diagram in Figure 22 illustrates the different points that will be addressed throughout the various sections of Chapter 5. As shown in Figure 22, the discussion will be divided into two main groups: groups that showed an observable difference between two variables, and groups that showed no statistically significant difference. In Figure 22, the allocated frame describing the arbitrary versus deliberate block comparisons are positioned between the groups showing no statistically significant differences and the groups showing observable differences. This is because the comparative results between arbitrary and deliberate blocks showed significant differences with regards to response times, but no differences with regards to the EEG data. In all subsequent figures and tables, arbitrary and deliberate will be defined as arb and delib.

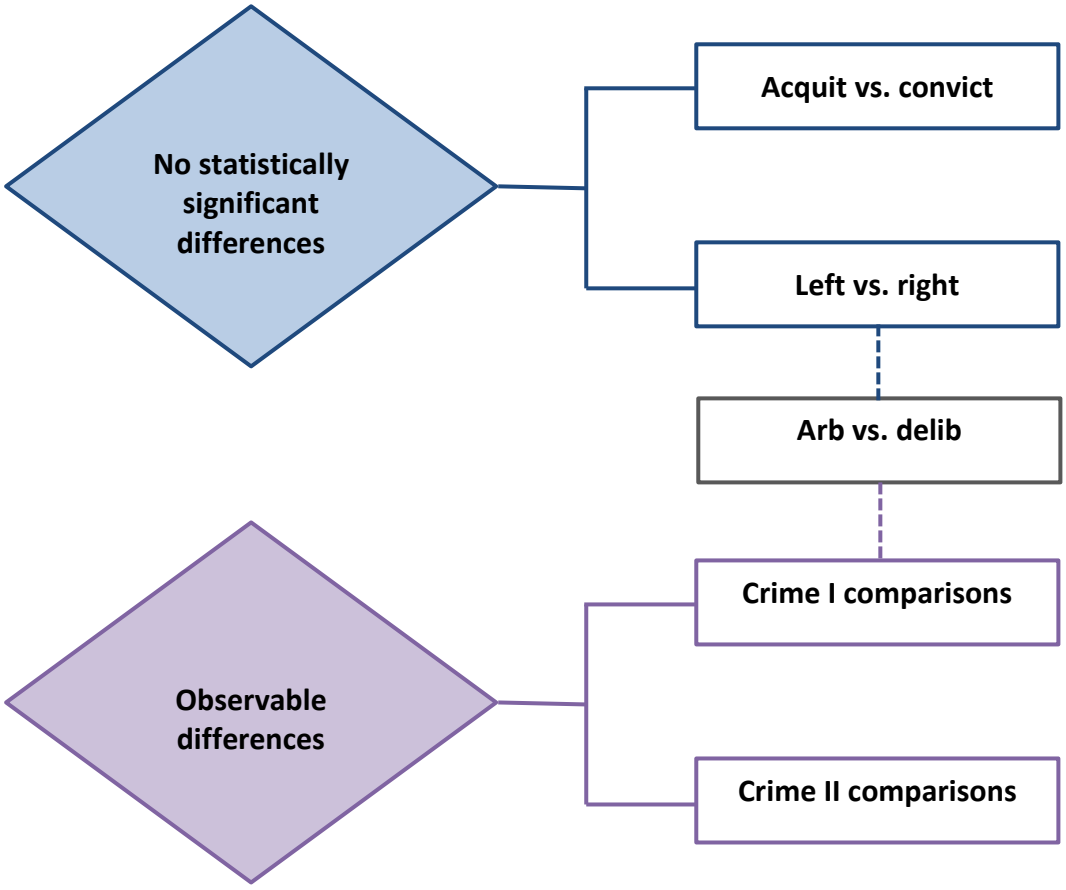


Figure 22: Logical layout of results and discussion

The EEG peaks considered relevant for analysis were the RP and P300 peaks. The RP peak was assumed to coincide with time zero, i.e. with the button press event (Maoz, et al., 2017). The P300 peak was taken as the maximum peak occurring at any position 250 to 350 ms post button press. Existing literature states that the P300 peak arises anywhere between 250 and 400 ms post time-lock event (Polich, 2007). Since the epochs were only extracted up to 350 ms post button press, this qualified the 250 to 350 ms bracket used for P300 peak classification.

5.1 Acquit vs. convict

The purpose of this section is to show that there was no statistically significant difference between the acquit and convict trial types. The differences between the trial types were investigated by comparatively looking at the average response times and the EEG scalp data of the respective trial types.

5.1.1 Average response times

Looking at the bivariate analysis of the average response times per participant for the acquit and convict trials, there was no significant difference between the two groups. The test for normality yielded that the average response times for deliberate decision blocks were normally distributed, while the average response times for arbitrary decision blocks were not normally distributed (see Table 15). The statistical difference between the acquit and convict trials for the deliberate and arbitrary block response times was therefore calculated using ANOVA and WRS, respectively. Table 16 shows the results for these tests. In both cases a p-value greater than 0.05 was obtained, indicating that there was no statistically significant difference between the acquit and convict trial types in terms of average response times.

Table 16: Bivariate analysis of different trial types for different decision blocks

Variable	Normality class	Test	Test statistic value	p-value
Arb response times	NN	WRS	0.12	0.7290
Delib response times	N	ANOVA	0.03	0.8587

From Figure 23 and Figure 24, the comparative data distribution between the acquit and convict trials can be seen for both arbitrary and deliberate decision blocks. The data distribution for both types of decision blocks show similar trends of overlap between the acquit and convict trials.

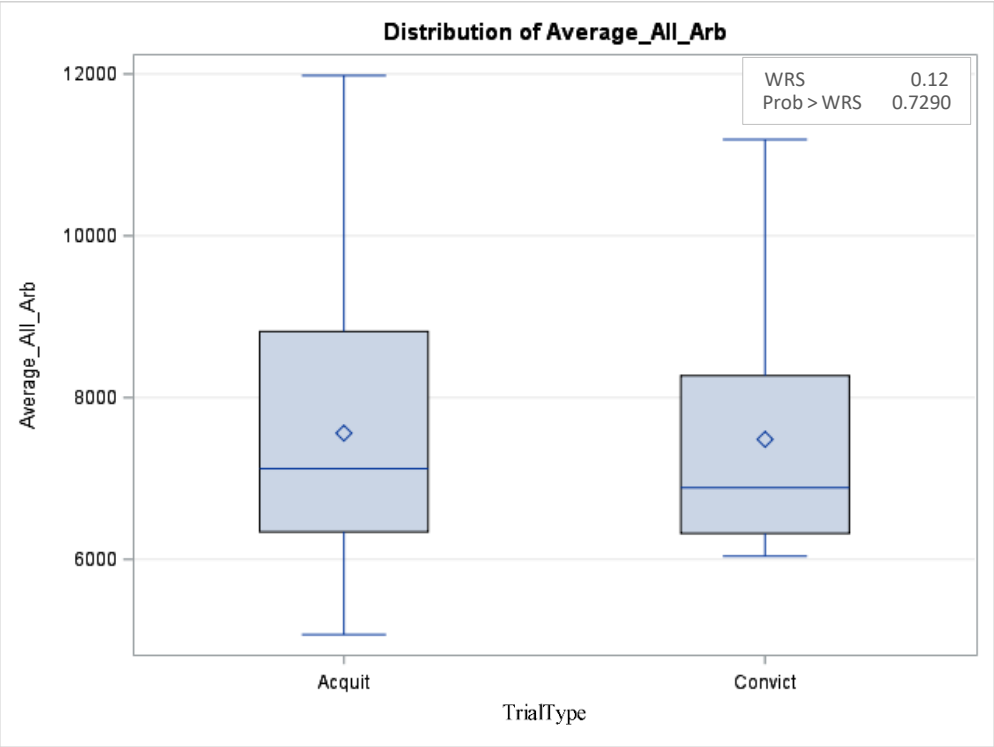


Figure 23: Data distribution of average response times for arbitrary blocks

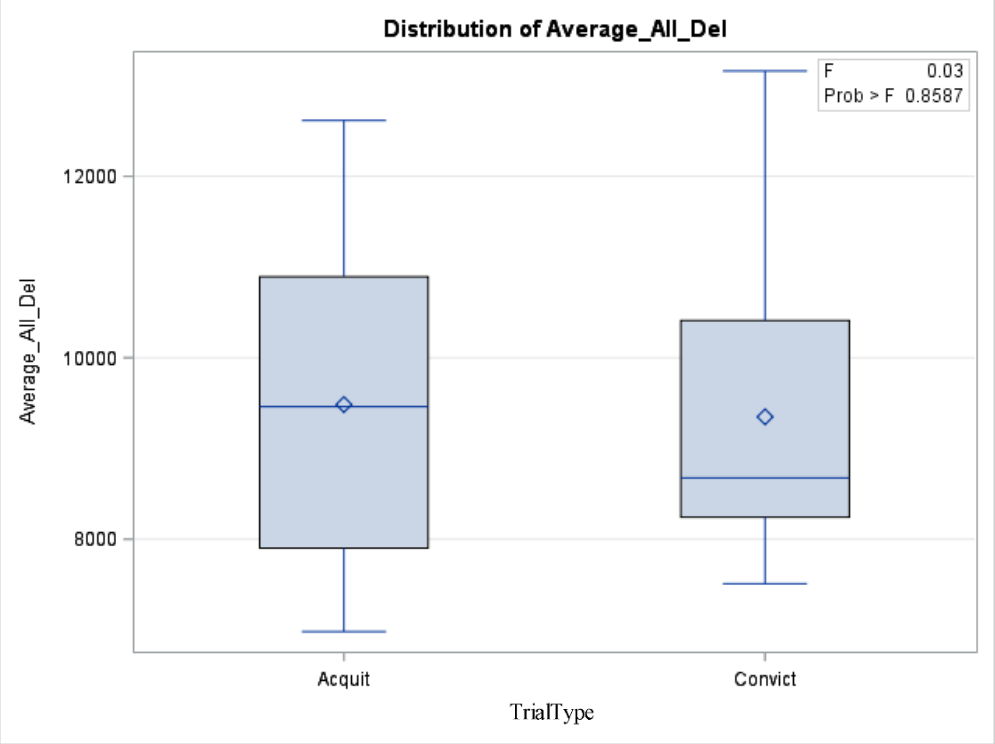


Figure 24: Data distribution of average response times for deliberate blocks

Table 17 shows the 95% CI of the mean for the acquit and convict trial types, for arbitrary and deliberate blocks. The cell colours in Table 17 show the values that were compared. Looking at Table 17, there is a clear concurrence between the 95% CI response times for the arbitrary blocks of the acquit and convict trials. This same concurrence exists between the response times of the deliberate blocks for the two trial types. Moreover, Figure 25 graphically shows the error bars for the average response times of the acquit and convict trials. Considering comparisons within a single decision block, i.e. within the arbitrary and deliberate blocks, there was no observable difference between the trial types. The clear differences between the different decision blocks will be discussed in Section 5.3.

Table 17: 95% CI of the mean for acquit and convict trial response times

Variable	Acquit (ms)		Convict (ms)	
	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI
Arbitrary	6312.06	8806.45	6459.15	8506.84
Deliberate	8224.94	10743.32	8272.59	10424.48

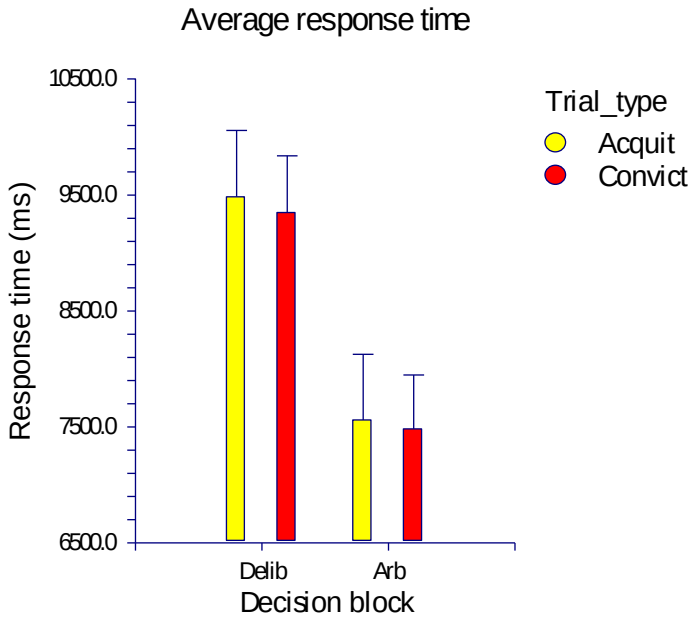


Figure 25: Comparison of average response times between acquit and convict trial types, as well as between arbitrary and deliberate blocks

From this data, it could be concluded that there was no statistically significant difference between the acquit and convict trial types with regards to response times.

5.1.2 EEG scalp data

For the EEG data, the statistical significance between the two trial types was a measure of the RP and P300 amplitudes at electrode Cz, Fz, Fp1 and Fp2. Looking at the 95% CI of the mean for data recorded at these electrode sites, there was no significant difference between the trial types. Table 18 and Table 19 compare the acquit and convict RP and P300 peaks for different variables. Table 18 shows the data for the RP peaks and Table 19 shows the data for the P300 peaks.

Table 18: 95% CI of the mean RP peaks for acquit and convict trial types

Variable	Acquit CI (µV)		Convict CI (µV)	
	Lower 95%	Upper 95%	Lower 95%	Upper 95%
RP_ Cz_arb_L	-2.96	-1.70	-3.19	-1.35
RP_ Cz_arb_R	-2.44	-1.31	-3.45	-1.19
RP_ Cz_delib_L	-3.35	-1.47	-2.94	-1.36
RP_ Cz_delib_R	-3.11	-1.59	-3.09	-1.25
RP_F z_arb_L	-4.28	-1.87	-5.36	-2.75
RP_Fz _arb_R	-4.10	-1.80	-5.87	-2.43
RP_Fz _delib_L	-4.07	-2.02	-4.21	-2.14
RP_Fz _delib_R	-3.99	-1.88	-4.26	-2.28
RP_Fp 1_arb_L	-3.03	-1.20	-4.48	-2.07
RP_Fp 1_arb_R	-2.82	-0.96	-5.13	-1.97
RP_Fp 1_delib_L	-2.70	-0.84	-3.02	-1.20
RP_Fp 1_delib_R	-2.52	-0.93	-4.54	-1.61
RP_Fp 2_arb_L	-3.41	-1.39	-4.96	-2.38
RP_Fp 2_arb_R	-3.06	-1.30	-4.66	-1.95
RP_Fp 2_delib_L	-3.15	-1.37	-3.69	-1.85
RP_Fp 2_delib_R	-2.91	-1.06	-3.09	-1.25

Figure 26 shows the graphical representation of the data listed in Table 18 and Table 19. Looking at the upper and lower CI limits for the acquit and convict trials, the CI limits for the two trial types were very similar for both the RP and P300 peaks. The data points plotted in Figure 26 represent the variables listed in Table 18 and Table 19. The CI limits for all these data points are depicted as a continuous data series on an XY-plot (see Figure 26). The lower and upper 95% CI limits are shown in different colours in Figure 26, for the different peaks and trial types.

Table 19: 95% CI of the mean P300 peaks for acquit and convict trial types

Variable	Acquit CI (µV)		Convict CI (µV)	
	Lower 95%	Upper 95%	Lower 95%	Upper 95%
P300_Cz_arb_L	0.38	3.57	1.05	2.60
P300_Cz_arb_R	0.38	3.43	1.00	2.82
P300_Cz_delib_L	1.78	4.51	1.34	3.18
P300_Cz_delib_R	1.92	4.40	1.48	3.17
P300_Fz_arb_L	0.39	3.77	0.62	3.04
P300_Fz_arb_R	0.51	3.77	0.75	3.47
P300_Fz_delib_L	1.59	4.33	1.00	3.62
P300_Fz_delib_R	1.62	4.58	1.79	4.28
P300_Fp1_arb_L	0.75	3.48	0.81	3.40
P300_Fp1_arb_R	1.08	3.75	1.11	4.14
P300_Fp1_delib_L	1.10	3.48	1.02	4.39
P300_Fp1_delib_R	1.42	3.73	1.30	4.40
P300_Fp2_arb_L	0.48	3.13	0.64	3.24
P300_Fp2_arb_R	0.67	3.19	0.86	4.10
P300_Fp2_delib_L	1.16	3.57	0.55	3.92
P300_Fp2_delib_R	1.30	3.91	1.98	4.98

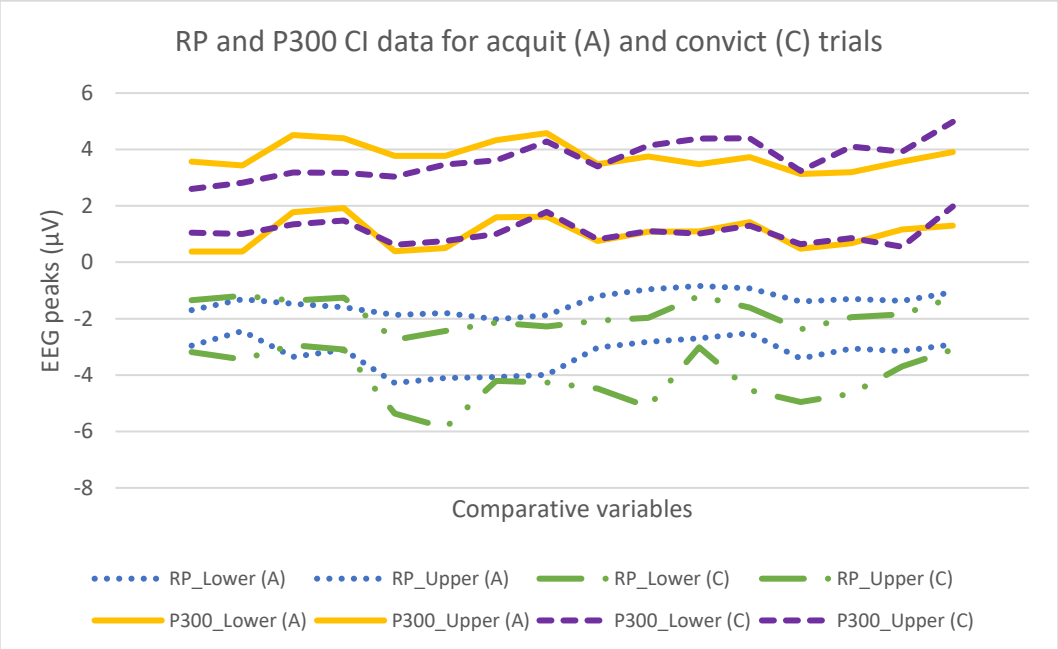


Figure 26: 95% CI of the mean RP and P300 peaks for acquit and convict trials

Considering that there was no statistically significant difference between the peak amplitudes at the positions of interest for the acquit and convict trials, the data from the two trials were grouped together for the following steps of analysis.

5.2 Left vs. right responses

This section, like Section 5.1, aimed to show that there were no neurophysiological differences in the EEG data between left and right responses. Maoz et al. also found no differences between left- and right-hand responses (Maoz, et al., 2017). Subsequently, the button press responses were combined to produce one group of results for the remaining analysis steps. To validate this, the 95% CIs of the mean RP and P300 peaks were used. Since the CI data overlapped, successfully proving that there was no significant difference between the left and right responses, the response times were not evaluated in this section.

Table 20 shows the 95% CI of the mean scalp data for the left- and right-hand button presses. The RP and P300 peak amplitudes at electrode Cz are listed for the arbitrary and deliberate blocks. Looking at the values presented in Table 20, the CIs for the left- and right-hand button presses show a near perfect likeness. Electrode Cz was considered the most important electrode for a comparison of button press responses since the button presses are directly related to motor function and electrode Cz overlays the motor cortex. Any differences between left and right responses were expected to present at this electrode site. However, the same trends were observed at electrode Fz, Fp1 and Fp2. These results can be found in Appendix D.

Table 20: 95% CI of the mean RP and P300 peaks for left and right button press responses

Variable	Left CI (µV)		Right CI (µV)	
	Lower 95%	Upper 95%	Lower 95%	Upper 95%
RP_Cz_arb	-2.81	-1.79	-2.69	-1.51
RP_Cz_delib	-2.84	-1.71	-2.81	-1.71
P300_Cz_arb	1.08	2.72	1.09	2.73
P300_Cz_delib	1.92	3.48	2.03	3.45

Figure 27 shows the CI limits for the left and right button press responses. In Figure 27 the RP and P300 peaks are shown at electrode Cz, for arbitrary and deliberate decision blocks. The different coloured lines indicate the upper and lower CI limits. Figure 27 emphasises the similarity between left- and right-hand button presses. This graphically confirms that there were no neurophysiological differences between left- and right-hand responses. The same trend was observed for EEG data recorded at electrode Fz, Fp1 and Fp2.

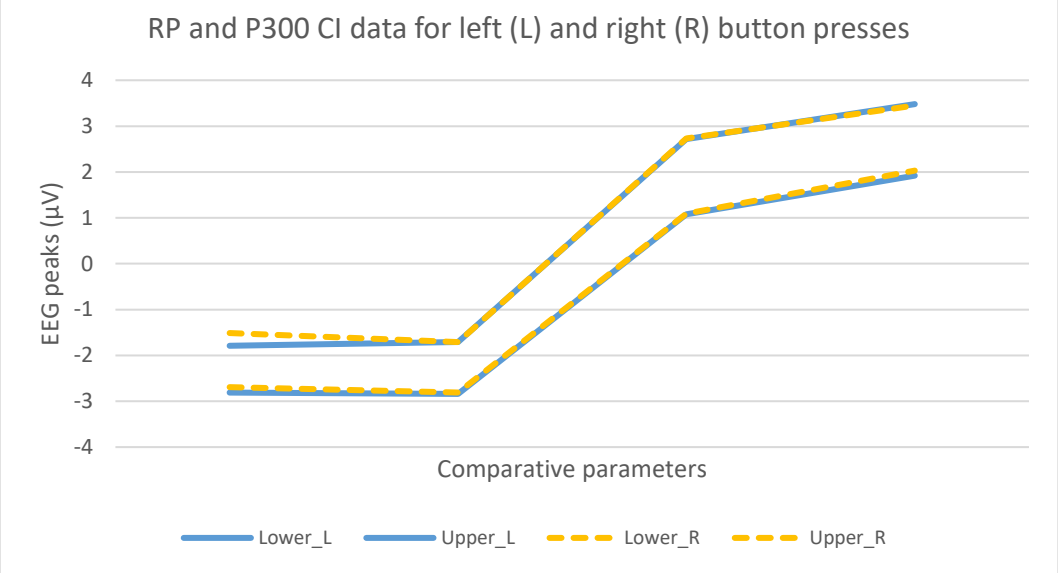


Figure 27: 95% CI of the mean RP and P300 peaks for left and right responses

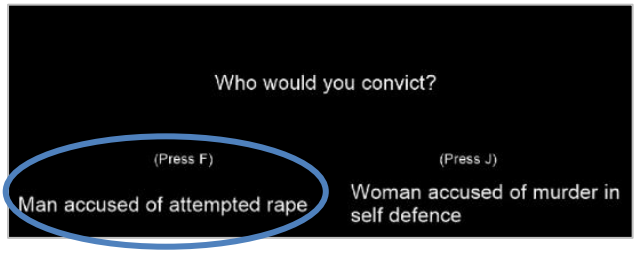
Since there was no significant difference between left and right button presses, the data for both response types was grouped together for the following steps of analysis. The next section will elaborate on the similarities and differences found between the arbitrary and deliberate decision blocks.

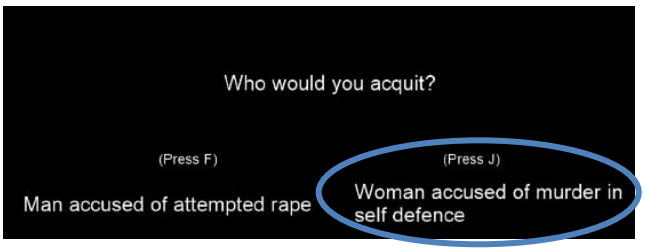
5.3 Arbitrary vs. deliberate

As described in Section 3.2, based on the study conducted by Maoz et al., a distinction was made between arbitrary and deliberate decisions. For this section, the differences and similarities between these two types of decisions were investigated. Maoz et al. was the first group to introduce deliberate decisions into RP studies. They investigated the relationship between RPs and different types of decisions. From their findings, a clear RP was found for arbitrary decisions, but no RP was detected for deliberate decisions. Maoz et al. investigated these neural responses at electrode Cz (Maoz, et al., 2017). In order to compare the results of this study to the findings of Maoz et al., several variables and parameters were evaluated. Firstly, the average response times and button press responses were used to determine whether the initial distinction made between arbitrary and deliberate decisions could be validated. Section 5.3.1 will report these results. Thereafter, the EEG scalp data at electrode Cz was evaluated to confirm the RP presence and absence for the respective decision blocks. These results will be reported in Section 5.3.2.

5.3.1 Decision block differences: response times and button presses

The two parameters that were used to qualify the distinction between arbitrary and deliberate blocks in this study, were the average response times per participant and button press responses. To evaluate the validity of the previously qualified distinction made between arbitrary and deliberate decisions, the logic of the responses during the two different block types were considered. Figure 28 illustrates the expected outcome for a typical acquit and convict trial. The trials were structured in a way that the questions in the convict trials exactly matched the questions in the acquit trials. Also, the responses were displayed on the same side for both trials (see Figure 28). Although there were technically no wrong or right answers, in most cases the questions favoured one answer over another. Figure 28 illustrates one such scenario. The anticipated outcomes relied wholly on participants being ethical individuals with normal mental health. The participant questionnaire screened for mental health, but not personality disorders (see Section 3.3.3.1 and Appendix A). In the case of Figure 28, it was logically expected that most participants – in the respective acquit and convict groups – would choose to convict the man accused of rape and acquit the woman accused of murder in self-defence. Therefore, since the acquit and convict groups consisted of 12 participants each, it was expected that across all trials the average number of left button presses for the acquit trials would roughly match the average number of right button presses for the convict trials. It was interesting to note that for the deliberate decision blocks this assumption proved correct. However, in the case of arbitrary decision blocks there was a far less pronounced correlation between the left button presses of one trial type and the right button presses of the other. Figure 29 graphically shows the similarity between deliberate blocks and the discrepancy between arbitrary blocks.





CONVICT
PRESS "F" = LEFT

ACQUIT
PRESS "J" = RIGHT

Figure 28: Comparative acquit and convict trials illustrating the expected logical outcome of the two trial types

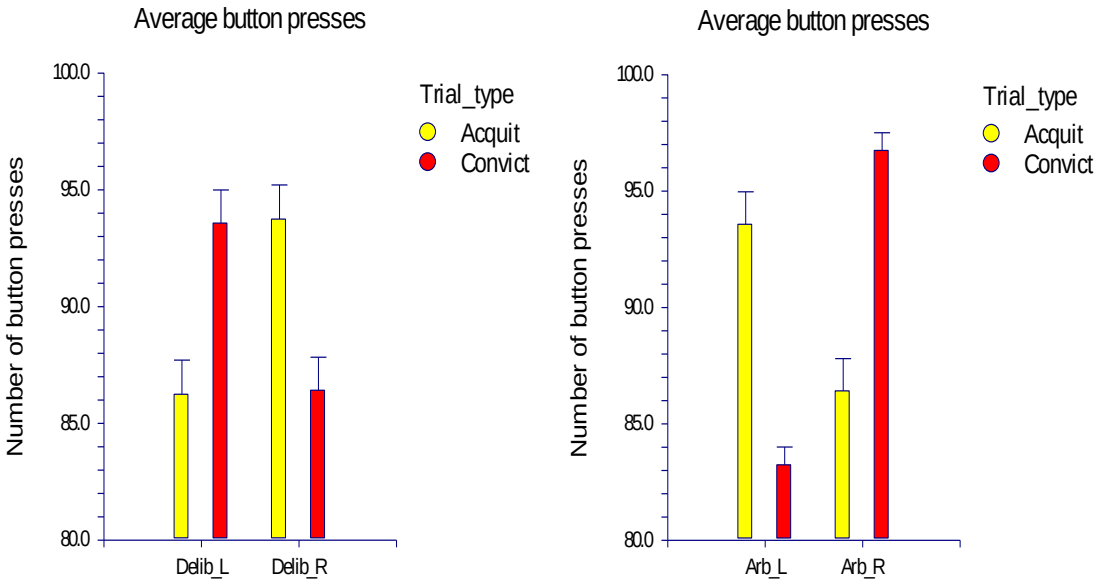


Figure 29: Graphical representation of the average button press responses for arbitrary and deliberate blocks

Table 21 shows the 95% CI of the mean for the different blocks and trial types. The coloured cells mark the values that were supposed to be similar if the logical test was adhered to. Table 21 confirms the findings of Figure 29: in the case of deliberate blocks, a clear trend could be seen; however, for the arbitrary blocks there was a distinct absence of this trend.

Table 21: 95% CI of the mean button presses for arbitrary and deliberate decision blocks across acquit and convict trial types

Variable	Acquit		Convict	
	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI
$Deliberate_{Left}$	83.03	89.47	90.47	96.70
$Deliberate_{Right}$	90.53	96.97	83.30	89.53
$Arbitrary_{Left}$	90.52	96.64	81.58	84.92
$Arbitrary_{Right}$	83.36	89.48	95.08	98.42

Table 17 and Figure 25, in Section 5.1.1, also show a clear discrepancy in terms of response times when considering the arbitrary and deliberate decision blocks. On average, participants responded two seconds faster to arbitrary decision blocks.

Taking all these findings into account, it follows that participants did not consider deliberate and arbitrary blocks with the same deliberation. The findings for the deliberate blocks concur with the anticipated outcome of the button press responses. The longer response times for deliberate decision blocks also support

the notion that participants categorically added more value to these decisions. The findings for the arbitrary blocks show a more random distribution in terms of button presses, as well as much shorter response times. This conceptualizes that choices in these blocks may have been made haphazardly instead of deliberately. Moreover, these findings confirmed that arbitrary choices were representative of the reaction to an urge to make a random choice and deliberate decisions employed a higher order thought process.

5.3.2 Decision block similarities: EEG scalp data

Considering the EEG scalp data, Maoz et al. found a clear RP at electrode Cz for arbitrary decision blocks, while the deliberate decision blocks were marked by the absence of an RP at the same electrode. As expected from the findings of Maoz et al., Figure 30 shows a clear RP build-up for the arbitrary decision blocks, with an onset roughly 500 ms before the button press event. Figure 30 also shows a pronounced P300 peak 250 ms post button press. The coloured lines in Figure 30 and Figure 31 show the EEG plots for individual participants. The black lines illustrate the averages for all participants for the considered decision block. The shaded grey areas in Figure 30, Figure 31 and Figure 32 show regions of significance where the p-values were less than 0.05. Since these areas of significance showed no correlation between different electrode sites at positions other than the RP and P300 peaks, they were not further investigated.

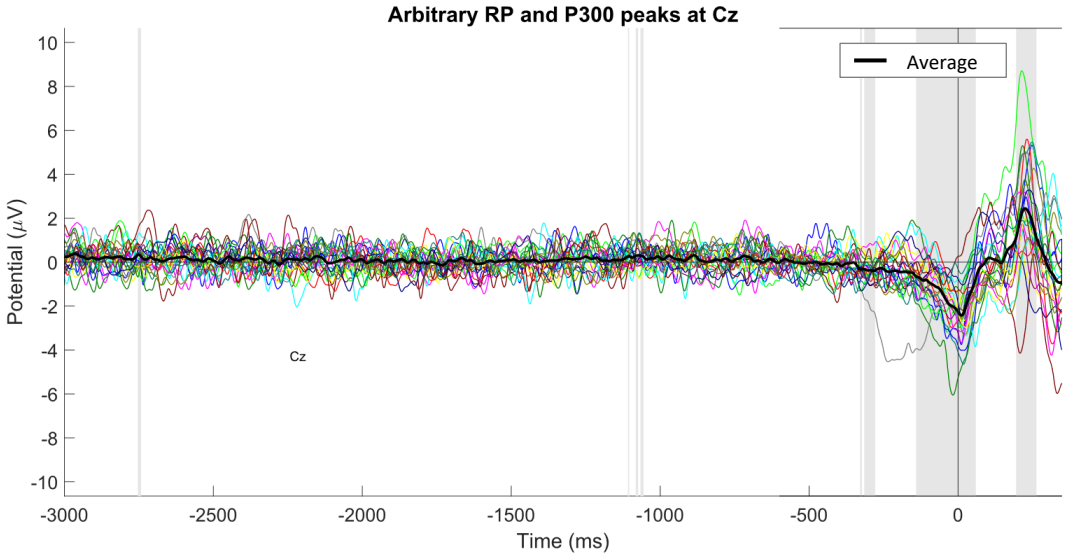


Figure 30: Individual participant plots and average RP and P300 peaks at Cz for arbitrary decision blocks

From Figure 31, the same RP build-up and P300 peak are present for the deliberate decision blocks. This finding visibly contradicts the finding of Maoz et al., showing

that there is a clear RP prior to the moment of making a decision for both arbitrary and deliberate decision blocks.

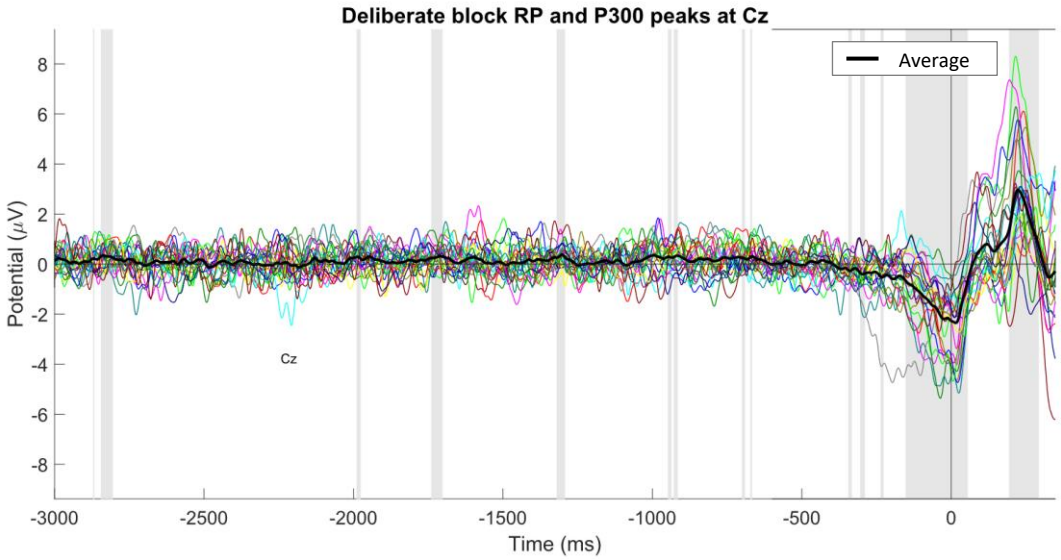


Figure 31: Individual participant plots and average RP and P300 peaks at Cz for deliberate decision blocks

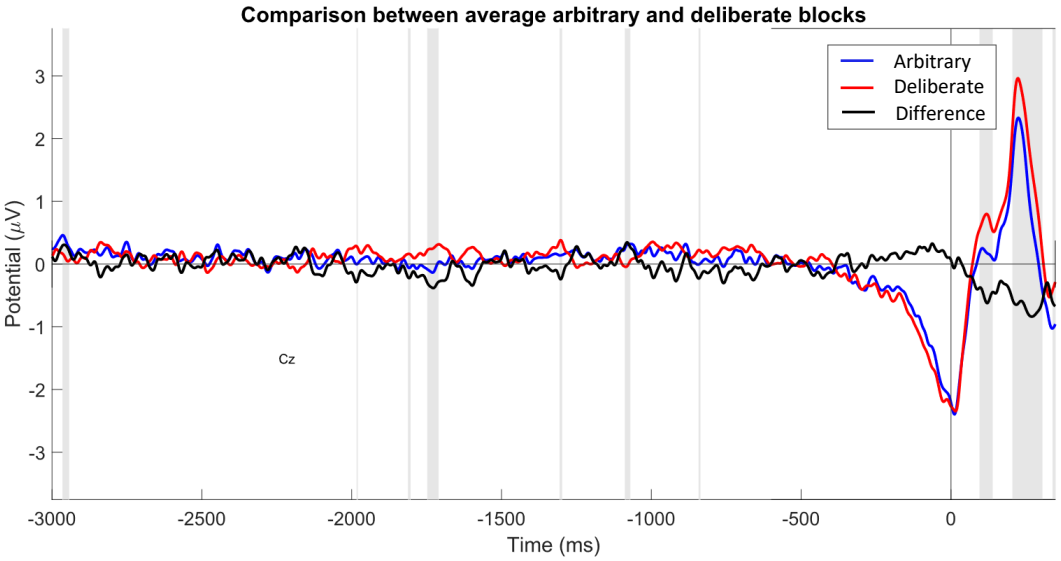


Figure 32: Comparison between average arbitrary and deliberate blocks for RP and P300 amplitudes at electrode site Cz for all participant, across all trial types

Figure 32 shows the near perfect fit between the average RP peaks for the two decision blocks, for all participants across all trial types. Although the P300 peak was slightly attenuated in the case of arbitrary blocks, the RP trends between the two blocks were very similar. The black line in Figure 32 shows the difference between the RP and P300 peaks for the two decision blocks. Looking at this line,

the difference is minimal at the points of interest, i.e. where the RP and P300 peaks occur. The calculated difference fluctuated around zero, with unremarkably small null line deviations. Table 22 summarises the values of the average peak RP and P300 amplitudes graphically shown in Figure 30, Figure 31 and Figure 32. From Table 22, a similarity in averages can be seen between the peak amplitudes for the arbitrary and deliberate decision blocks. Moreover, in both cases there is a close resemblance between the absolute values of the RP and P300 amplitudes. However, for the deliberate blocks, the P300 peak is on average larger than the absolute value of the peak RP amplitude for the same decision block. In the case of arbitrary decision blocks, the P300 peak is a positive mirror of the negative RP peak. It is unclear whether this is a recurring phenomenon in existing ERP studies since the RP and P300 peaks are rarely directly compared to one another. This finding was more pronounced at electrode Cz, Fp1 and Fp2 (see Appendix D). At electrode Fz the P300 peaks were much larger than the absolute values of the RP peaks (see Appendix D). It is unclear what the significance of this might be.

Table 22: Average RP and P300 peak values for arbitrary and deliberate blocks

Decision block	RP peak (µV)	P300 peak (µV)
Arbitrary	-2.333	2.332
Deliberate	-2.301	2.960

Even though Figure 30, Figure 31 and Figure 32 only show the RP and P300 trends at electrode Cz, the same trends were visible at electrode Fz, Fp1 and Fp2. Table 23 shows the comparative 95% CIs of the mean RP and P300 amplitudes for arbitrary and deliberate decision blocks. From Table 23, the CIs for arbitrary and deliberate decision blocks overlap.

Table 23: 95% CI of the mean RP and P300 peaks for arbitrary and deliberate blocks at electrode Cz, Fz, Fp1 and Fp2

Variable	Arbitrary CI (µV)		Deliberate CI (µV)	
	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Cz_{RP}	-2.75	-1.65	-2.83	-1.71
Cz_{P300}	1.07	2.73	1.98	3.47
Fz_{RP}	-4.48	-2.64	-3.78	-2.44
Fz_{P300}	1.08	3.00	1.97	3.74
$Fp1_{RP}$	-3.53	-1.88	-2.88	-1.46
$Fp1_{P300}$	1.42	3.22	1.69	3.53
$Fp2_{RP}$	-3.68	-2.10	-2.97	-1.77
$Fp2_{P300}$	1.14	2.94	1.73	3.62

Figure 33, Figure 34, Figure 35 and Figure 36 show the box plots comparing the data distributions of the RP and P300 peaks for the respective decision blocks at

electrode Cz, Fz, Fp1 and Fp2. From these plots, there is no observable difference between the data distributions for arbitrary and deliberate blocks. The green and red dots in the box plots are indicative of outliers. Green dots indicate mild outliers with a fence multiplier of 1.5 and red dots indicate severe outliers with a fence multiplier of 3.0. Data points exceeding the 25% and 75% interquartile ranges when multiplied with the respective fence multipliers, are classified as outliers.

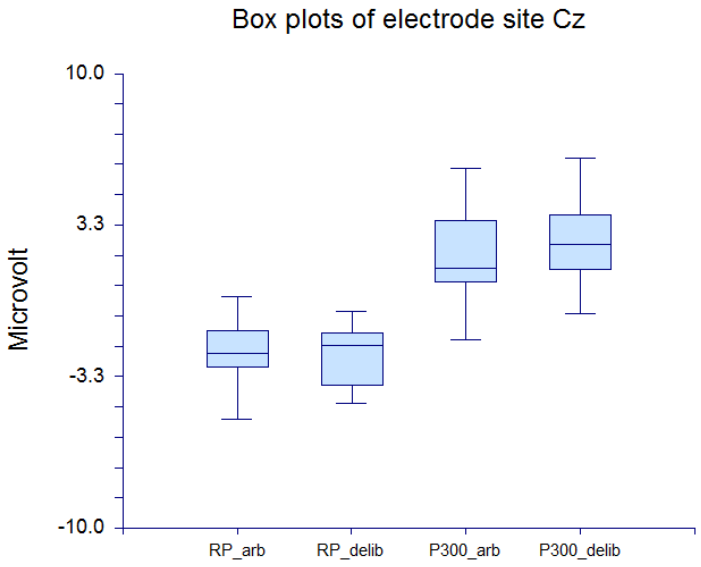


Figure 33: Box plots comparing the distributions of the arbitrary and deliberate peak amplitudes for the RP and P300 peaks at electrode Cz

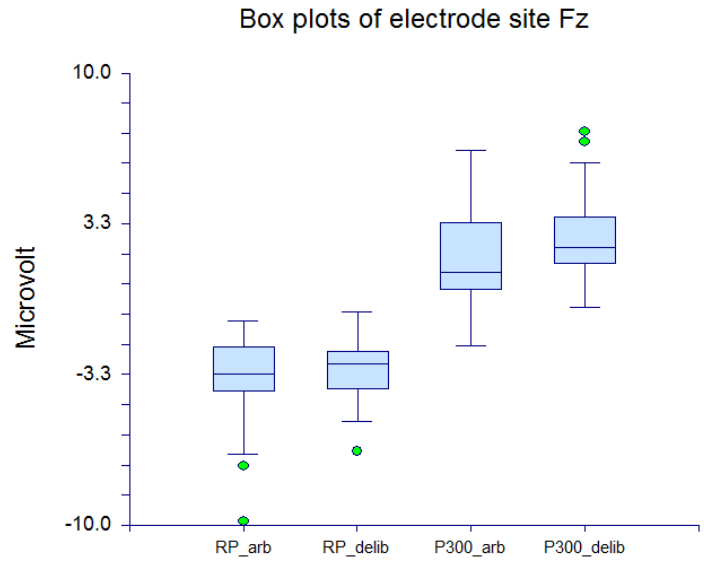


Figure 34: Box plots comparing the distributions of the arbitrary and deliberate peak amplitudes for the RP and P300 peaks at electrode Fz

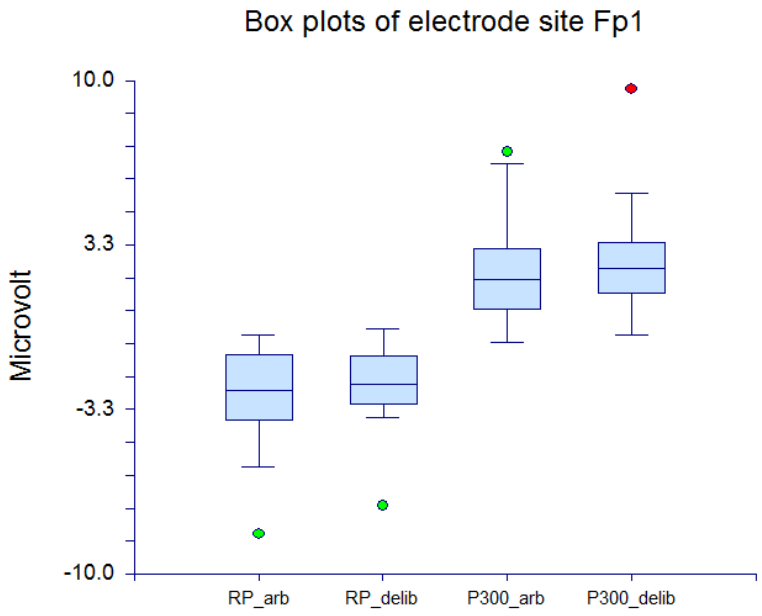


Figure 35: Box plots comparing the distributions of the arbitrary and deliberate peak amplitudes for the RP and P300 peaks at electrode Fp1

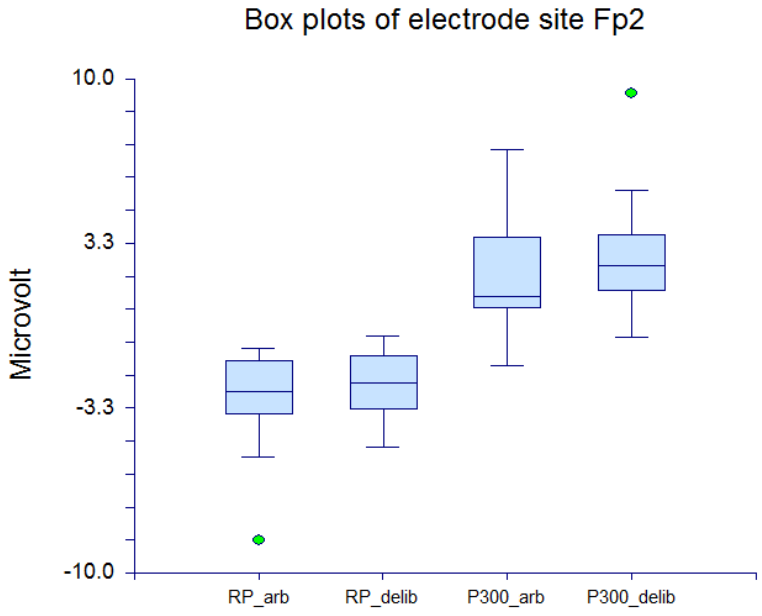


Figure 36: Box plots comparing the distributions of the arbitrary and deliberate peak amplitudes for the RP and P300 peaks at electrode Fp2

5.3.3 Discussion of differences and similarities

The findings in Section 5.3.1 suggest that participants were effectively influenced by the distinction made between arbitrary and deliberate blocks. However, the EEG data show no significant difference between the respective decision types. It may be that participants did not really consider arbitrary and deliberate decision blocks differently and that the distinction between the two blocks was not as pronounced as in the case of the study conducted by Maoz et al. As discussed in Section 2.3.3, the decision task in the Maoz et al. study asked participants to donate money to one out of two NPOs. For arbitrary decisions the same amount of money was allocated to both NPOs and for deliberate decisions the chosen NPO received $1000 while the other NPO received $0. The fact that the two decision classes were characterised by markedly different results in the study conducted by Maoz et al., validates their distinction between the two decision classes. Maoz et al. also showed that there was a clear discrepancy between the decision times of arbitrary and deliberate decisions. Like this study, participants responded faster to arbitrary decisions than to deliberate decisions. Their EEG results indicated that an RP was present for arbitrary decision but not for deliberate decisions (Maoz, et al., 2017). Still, this does not disqualify the findings of Section 5.3.2: there was a clear RP visible for deliberate decisions in this study. It is also important to note that a failed understanding of the decision types in the presented experiment would more likely result in both types of decisions being considered deliberate and not arbitrary. This is precisely because of the moral component present in the choices. These decisions can certainly be qualified as requiring greater deliberation than the questions presented in the original Libet-type studies. Even compared to the study conducted by Maoz et al., the choice task presented in the current study has a greater real-world relevance. The content of the choices presented in this study better relates to the emotional and moral components of real-world decision-making. It can therefore, without exception, be stated that the RP is present in the neurophysiological data of deliberate decision-making. However, other studies have previously suggested that the RP may be more indicative of the preparation to react (Alexander, et al., 2016) or the expectation to make a choice (Herrmann, et al., 2008) rather than the actual content of the choice. Therefore, the fact that there are no significant differences to report between the RP and P300 peaks for arbitrary and deliberate decision blocks may suggest that these peaks do not relate to decision content, but only to the presence or absence of an executive decision task.

Moreover, the shorter response times observed for arbitrary decision blocks (reported in Section 5.1.1) may be attributed to practice effects. The arbitrary decision blocks were placed at the end of the experiment and contained the same information as the deliberate decision blocks that preceded them. The participants were therefore presented with the same case studies for a second time. Practice effects describe how taking a test more than once may influence

the test results, since participants would have already had time to process the information initially presented to them. However, practice effects typically describe improvements in cognitive test performance (Duff, et al., 2007) and this experiment did not pose questions with definitive right or wrong answers. Nevertheless, practice effects may still explain the shorter response times prevalent in the arbitrary decision blocks since reading, processing and understanding time may be reduced for familiar text. In other words, participants may have recognised the first couple of words describing a specific case after having already been presented with the same case once. Still, participants were presented with the details of 60 novel cases, so it would not have been easy to remember the details of all the cases. There were too many different combinations of cases to remember all of them precisely.

Despite the findings reported in Section 5.3.1, from the EEG scalp data it was evident that no statistically significant difference existed between arbitrary and deliberate decision blocks. It was assumed that participants considered both decision blocks with deliberation and therefore the data from the two blocks was combined into a single dataset for the final analysis phase. The findings reported in this section redirected the principle investigation from looking for the presence or absence of an RP to studying the differences in peak RP and P300 amplitudes between different participant groups. Participants were divided into groups based on the data gathered from their participant questionnaires. The following subsection will discuss how different personal histories influenced the EEG data.

5.4 Crime I and II data groups

Reconsidering Table 12 in Section 4.3, the data sample was divided into different groups based on the participants' relationship to violent crime, assault and sexual assault throughout their lives. For Crime I comparisons, the original sample was split into participants who themselves had been exposed to violent crime, assault or sexual assault. Additionally, Crime II comparisons split the data between participants with close relatives who had been exposed to violent crime, assault or sexual assault and those without. The reason exposure to only violent crime, assault and sexual assault was considered related to the nature of these crimes: their commonality is violence and brutality. Although all victims respond differently, exposure to violent crimes generally have more severe and lasting psychological consequences than minor or non-violent crimes (Office for National Statistics, 2015). It was therefore considered that any neurophysiological differences between participants was more likely to be found while investigating the differences between emotionally neutral and emotionally motivated responses to violent crimes.

5.4.1 Revised normality tests

Since the previously separate variables for acquit/convict trials, left/right responses and arbitrary/deliberate blocks were all grouped together for this phase of data analysis, a new test for normality was performed on the revised variable groups. Table 24 and Table 25 illustrate the results of the revised normality tests for Crime I and Crime II groups. Again, the same three classes were defined, namely: normally distributed data (N) with p-values greater than 0.05, not normally distributed data (N) with p-values less than 0.05 and approximately normally distributed data (APN) with p-values bordering on 0.05. However, for these variable groups an additional class was added. This class defined skew data (S) where the p-value indicated a normal distribution, but upon visual inspection the data showed long-tailed distributions. The S data class was considered non-normal for analysis purposes.

Table 24: Test for normality for Crime I group data at different electrode sites for RP and P300 peaks

RP electrodes	Normality class	P300 electrodes	Normality class
Cz	S	**Cz**	S
Fz	S	**Fz**	S
Fp1	S	**Fp1**	NN
Fp2	S	**Fp2**	NN

Table 25: Test for normality for Crime II group data at different electrode sites for RP and P300 peaks

RP electrodes	Normality class	P300 electrodes	Normality class
Cz	S	**Cz**	S
Fz	N	**Fz**	NN
Fp1	S	**Fp1**	NN
Fp2	S	**Fp2**	S

Since more than half the data in Table 24 and Table 25 showed a non-normal data distribution, it was decided to use the WRS test instead of ANOVA for the bivariate analyses. Moreover, since the respective sample sizes for the Crime I (Y=6; N=18) and Crime II (Y=13; N=11) groups were so small, it was justified to perform non-parametric analyses on the data. Therefore, only the results from the WRS test will be reported for the Crime I and Crime II groups. Since these groups predominantly showed a non-normal distribution, CI intervals could not be evaluated.

5.4.2 Bivariate analysis: WRS test

Table 26 and Table 27 show the results for the WRS test. Table 26 shows the results for the Crime I group, and Table 27 shows the results for the Crime II group.

Table 26: Results from WRS test for the Crime I group

RP electrodes	WRS	p-value	P300 electrodes	WRS	p-value
Cz	1.7778	0.1824	**Cz**	0.4444	0.5050
Fz	0.5378	0.4634	**Fz**	0.0400	0.8415
Fp1	0.5378	0.4634	**Fp1**	0.0044	0.9468
Fp2	0.6400	0.4237	**Fp2**	0.0044	0.9468

Table 27: Results from WRS test for the Crime II group

RP electrodes	WRS	p-value	P300 electrodes	WRS	p-value
Cz	0.1015	0.7500	**Cz**	0.2425	0.6224
Fz	1.5516	0.2129	**Fz**	5.2372	0.0221*
Fp1	1.6993	0.1924	**Fp1**	4.2302	0.0397*
Fp2	1.5516	0.2129	**Fp2**	4.9754	0.0257*

**statistically significant difference $p < 0.05$*

From Table 26 and Table 27, there were statistically significant differences found within the Crime II group, but none within the Crime I group. This means that there was no statistically significant difference between participants who themselves had been exposed to violent crime, assault or sexual assault and participants who had not. However, there were some statistically significant differences between participants with close relatives who had been exposed to violent crime, assault or sexual assault and participants without. This finding contradicts logic, because if a participant with a close relative who had been exposed to violent crime responds differently to a decision related to violent crime than a participant without a close relative with the same history, it is expected that participants who themselves had been exposed to violent crime would also exhibit a different neurological response. The psychological trauma associated with experiencing violence and brutality first-hand certainly surpasses the trauma associated with having a loved one suffer the same experience. Yet, the statistical analysis denies this assumption. A possible explanation for this phenomenon might relate to the way the legal cases were formulated. The cases were described in the third person by using terms such as “a woman”, “a man” or “the victim”. It may be that it is unknowingly easier to associate these third person victims with a loved one rather than with oneself. It was also interesting to observe that the statistically significant differences found in the Crime II group, were not detected at electrode Cz but at

electrode Fz, Fp1 and Fp2. This means that there was no neurological difference in the data recorded from the motor cortex; differences were found for the data recorded from the motivational, reasoning and problem-solving brain centres.

It should be noted, however, that the sample size of six participants who themselves had been exposed to violent crimes is less than half the sample size of 13 participants with close relatives who had been exposed to violent crimes. Looking at Table 14 in Section 4.3.1, the statistical power for a sample size of six is only 0.65. This accuracy is not reliable to inform on the statistically significant differences between groups. The bivariate analysis results for the smaller Crime I group should therefore be considered in conjunction with the EEG scalp data for that same group. The following section will show the comparative EEG scalp graphs for the Crime I and Crime II groups.

5.4.3 EEG scalp data

In order to qualify and support the findings of the bivariate analysis in Section 5.4.2, the EEG scalp data was plotted at the electrodes that showed statistically significant differences for the Crime II group. Figure 37 and Figure 38 show the distribution of electrical activity at time zero (RP peak) and 200 ms (P300 peak) for the Crime II: Y and Crime II: N groups, respectively. It is interesting that the Crime II: Y group showed greater activation in the PFC, while the Crime II: N group showed activation in the motor cortex. This may be indicative of the more emotive responses of the Crime I: Y group participants compared to the perhaps purely motor responses of the Crime II: N group participants. It is also interesting to note that the maximum and minimum scalp potentials for the Crime II: Y group is almost double that of the Crime II: N group (See Figure 37 and Figure 38).

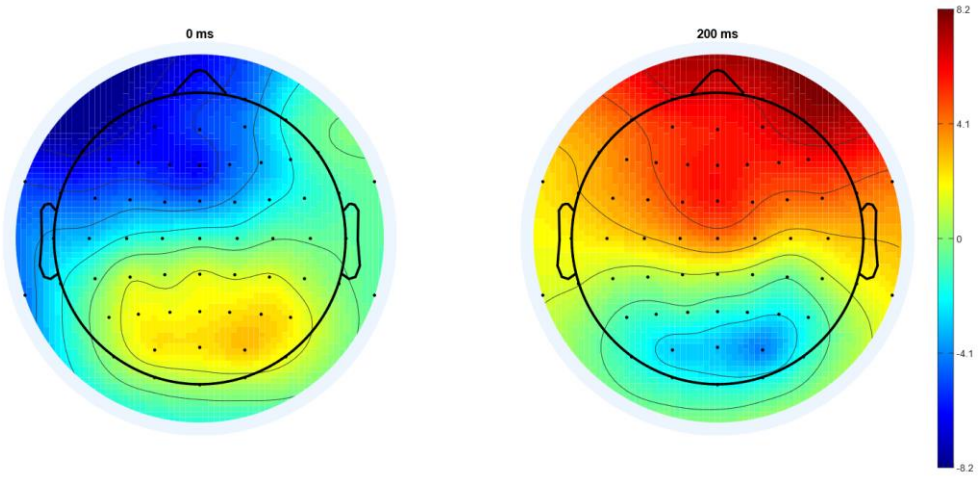


Figure 37: Electrical scalp activity distribution of Crime II: Y group at time zero and 200 ms post button press

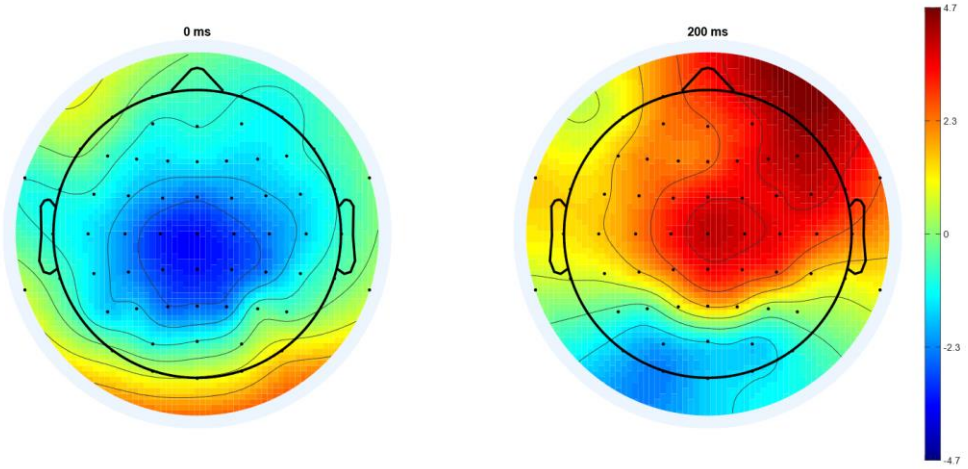


Figure 38: Electrical scalp activity distribution of Crime II: N group at time zero and 200 ms post button press

Figure 39, Figure 40 and Figure 41 show the scalp electrode data for participants with close relatives who had been exposed to violent crimes (Crime II: Y) plotted against the scalp data of participants without close relatives who had been exposed to violent crimes (Crime II: N). Figure 39, Figure 40 and Figure 41 respectively show these comparisons at electrode Fz, Fp1 and Fp2. These electrode sites showed statistically significant difference at the P300 peaks for the Crime II group.

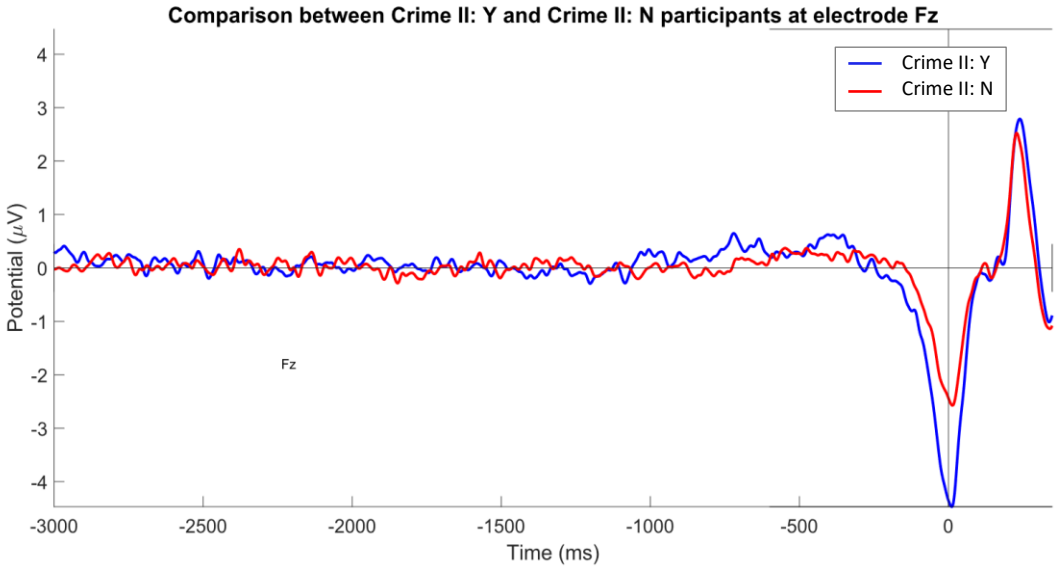


Figure 39: Crime II comparisons at electrode Fz

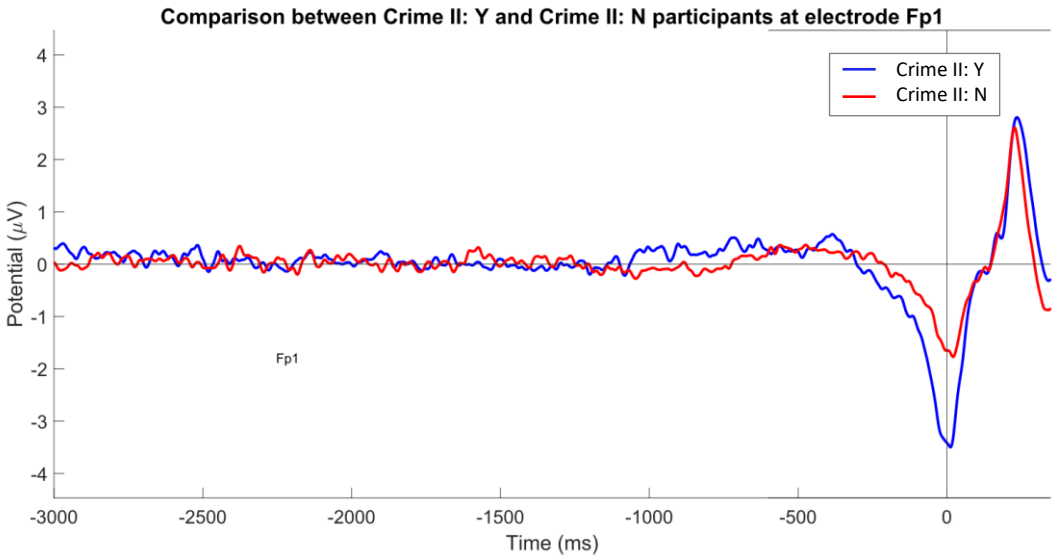


Figure 40: Crime II comparisons at electrode Fp1

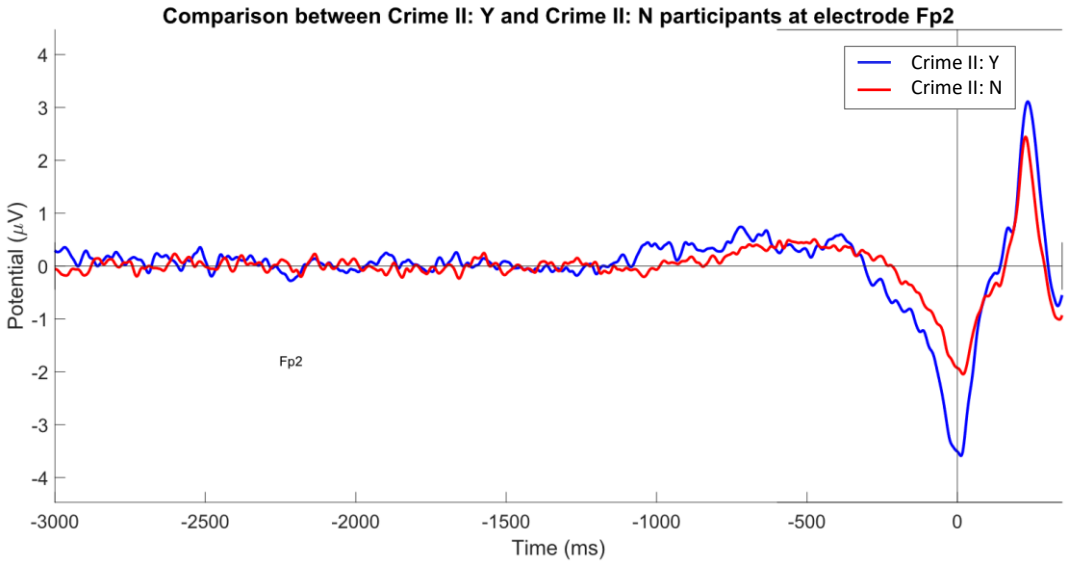


Figure 41: Crime II comparisons at electrode Fp2

Although there was no statistically significant difference found between the RP peaks for the Crime II: Y and Crime II: N groups; Figure 39, Figure 40 and Figure 41 show an observable difference between the peak RP amplitudes for the Crime II: Y and Crime II: N groups. The WRS test uses ranked values, whereas the electrode values graphically displayed in Figure 39, Figure 40 and Figure 41 depict the original values of the recorded scalp potentials. Thus, there was no significant difference found in the ranked values of the RP peaks for Crime II. Even though the difference in RP amplitudes seem more pronounced than the P300 peak

differences, the ranked values do not necessarily directly translate to the recorded values of the EEG data. At electrode Fz, Fp1 and Fp2, the RP and P300 peaks of the raw EEG data are larger for participants with close relatives who had been exposed to violent crime, assault or sexual assault. This same trend is not visible at electrode Cz, as is supported by the statistical data in Table 27. Appendix D shows the comparative EEG graph for the Crime II: Y and Crime II: N groups at Cz.

Despite the lack of significant differences found for the Crime I group, the same EEG trends emerged for the Crime I group as for the Crime II group, i.e. there was no observable difference in the RP amplitudes at Cz, but there was a clear observable increase in the RP amplitude at electrode site Fz (see Figure 42). However, within the Crime I group, the P300 amplitudes showed attenuation in the case of Crime I: Y. These same trends held true for data recorded at electrode Fp1 and Fp2 (see Appendix D). The EEG graph for the data recorded at electrode Cz can also be found in Appendix D.

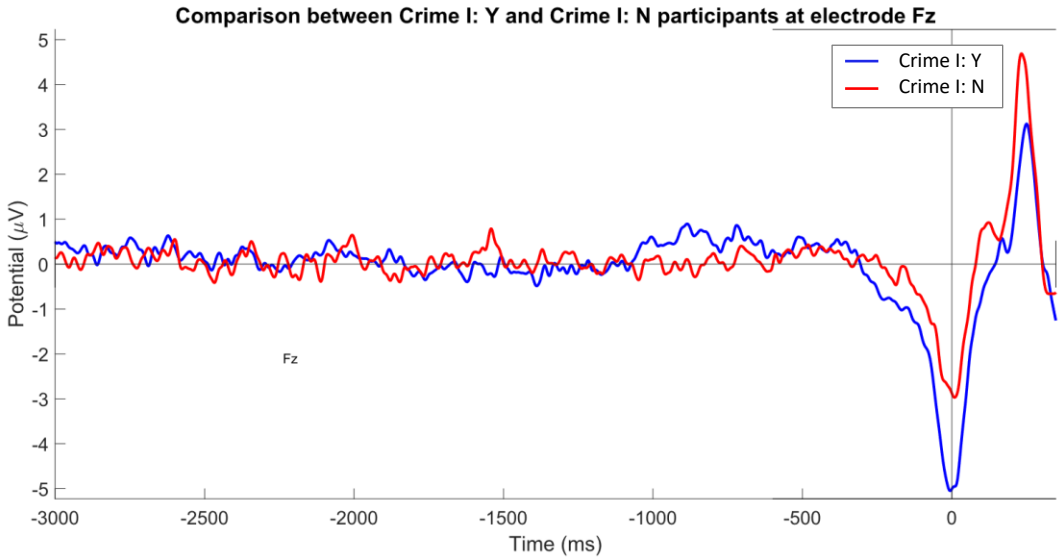


Figure 42: Crime I comparisons at electrode Fz

Lastly, Figure 43 compares the peak amplitude differences between participants who themselves had been exposed to violent crime, assault or sexual assault (Crime I: Y) and participants with close relatives who had been victims of violent crime, assault or sexual assault (Crime II: Y). For this comparison, participants who were part of both groups were removed from consideration. It was interesting to see that the peak RP amplitude for exclusive Crime I: Y only participants was slightly larger than for exclusive Crime II: Y only participants – with a slight attenuation in the P300 peak for the Crime II: Y group. The same trend was found at electrode Fp1 and Fp2, but not at electrode Cz (see Appendix D).

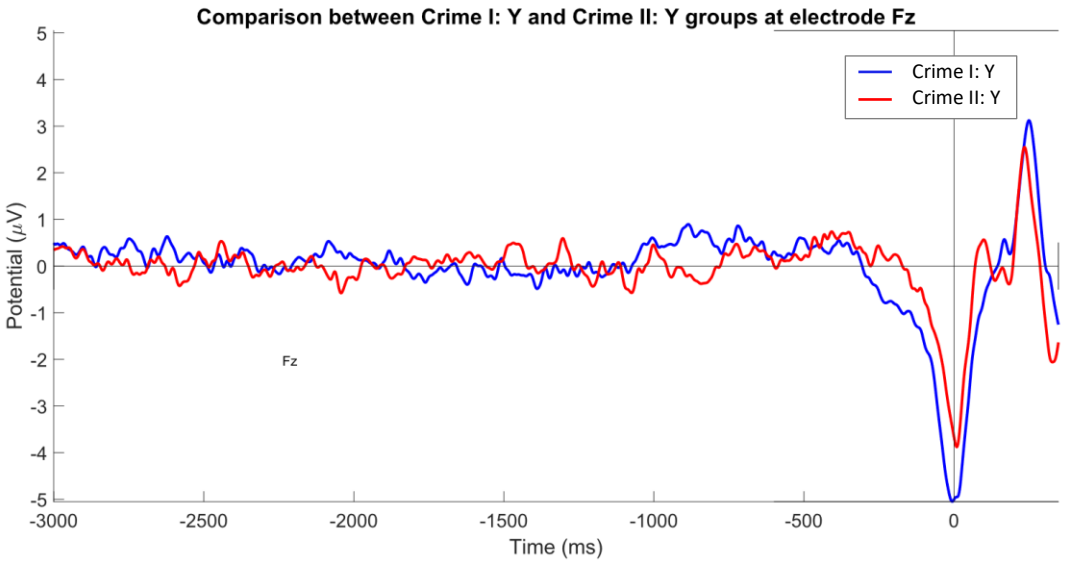


Figure 43: Crime I and Crime II comparisons at electrode Fz

5.4.4 Average response times

Next, the average response times for the deliberate decision blocks were considered for the Crime I and Crime II groups. The deliberate block response times were compared because they were more representative of the initial decision-making time, without practice effects. Since the response time data was normally distributed (see Table 15), the 95% CI of the mean response times could be used as a comparative measure. Table 28 shows the CI data for the Crime I and Crime II groups.

Table 28: 95% CI of the mean response times for Crime I and Crime II groups

Group	Yes (s)		No (s)	
	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI
Crime I	7.045	8.607	9.078	10.815
Crime II	8.423	10.876	8.102	10.185

Looking at the response times for Crime I and Crime II groups, it was interesting to see that participants who had been exposed to violent crimes responded on average 2 seconds faster than participants who had not been exposed to violent crimes. The difference in response times between Crime I: Y and Crime I: N participants was statistically significant. However, there was no significant difference between the response times of participants with close relatives who had been exposed to violent crimes compared to those without.

Contrary to the hypotheses formulated following Section 5.1 to Section 5.3 that stated that the RP and P300 peaks may not be related to response content, the

changes in RP and P300 peaks for the Crime I and Crime II groups suggest otherwise. Since electrode Fz, Fp1 and Fp2 showed observable differences between different participant groups, it was concluded that response content is related to neurophysiological EEG potentials, such as the RP and P300. Statistically integrating the differences found between the different participant groups, predictive models were created in order to further investigate the relationship between decision content and neurophysiological responses.

5.5 Predictive models

In the following section, the multivariate predictive models will be discussed. The models that were derived from the input variables include a decision tree and logistic regression.

5.5.1 Decision trees

Decision trees perform data splits on a log worth basis for the chi-squared values of different variable groups. The decision tree shown in Figure 44, used the RP and P300 peak amplitudes at electrode sites Cz, Fz, Fp1 and Fp2 as input variables. The target variable was the Crime II participants. The decision tree mechanism identified the P300 peak at electrode Fz as the principle variable split. At node 1, there was a 54.17% chance that a participant would fall into the Crime II: Y group. Following this split, there was a 72.22% chance that a participant would be a part of the Crime II: Y group if their P300 peak at electrode Fz was 1.1786 µV or more. Moreover, if this coincided with a peak P300 amplitude at Cz of less than 1.6835 µV, then there was a 100% chance that the participant had a close relative who had been exposed to violent crime, assault or sexual assault. Alternatively, if the P300 peak at Fz coincided with a P300 peak at Cz of 1.6835 µV or more, there was a 61.54% chance that the participant would be part of the Crime II: Y group. Following this branch, the final split qualified that there was an 85.71% chance that a participant would fall into the Crime II: Y group if the previously specified peak P300 amplitudes at Fz and Cz coincided with an Fp2 amplitude of 2.9159 µV or more. Alternatively, a Fp2 amplitude less than 2.9159 µV predicted that there was a 33.33% chance that a participant would have a close relative who had been exposed to violent crime, assault or sexual assault. It is interesting to note that the P300 peaks at electrode Fz and Fp2, which were also identified as variable splits, both showed statistically significant difference within the Crime II group (see Table 27). The misclassification rate for the tree in Figure 44 is 12.5%.

For the Crime I group no significant splits were identified, possibly due to the sample size being too small for multivariate analysis. Even for the decision tree shown in Figure 44, it should be noted that the sample size under consideration was still very small. However, the tree provides some insights into variable importance for the selected target group.

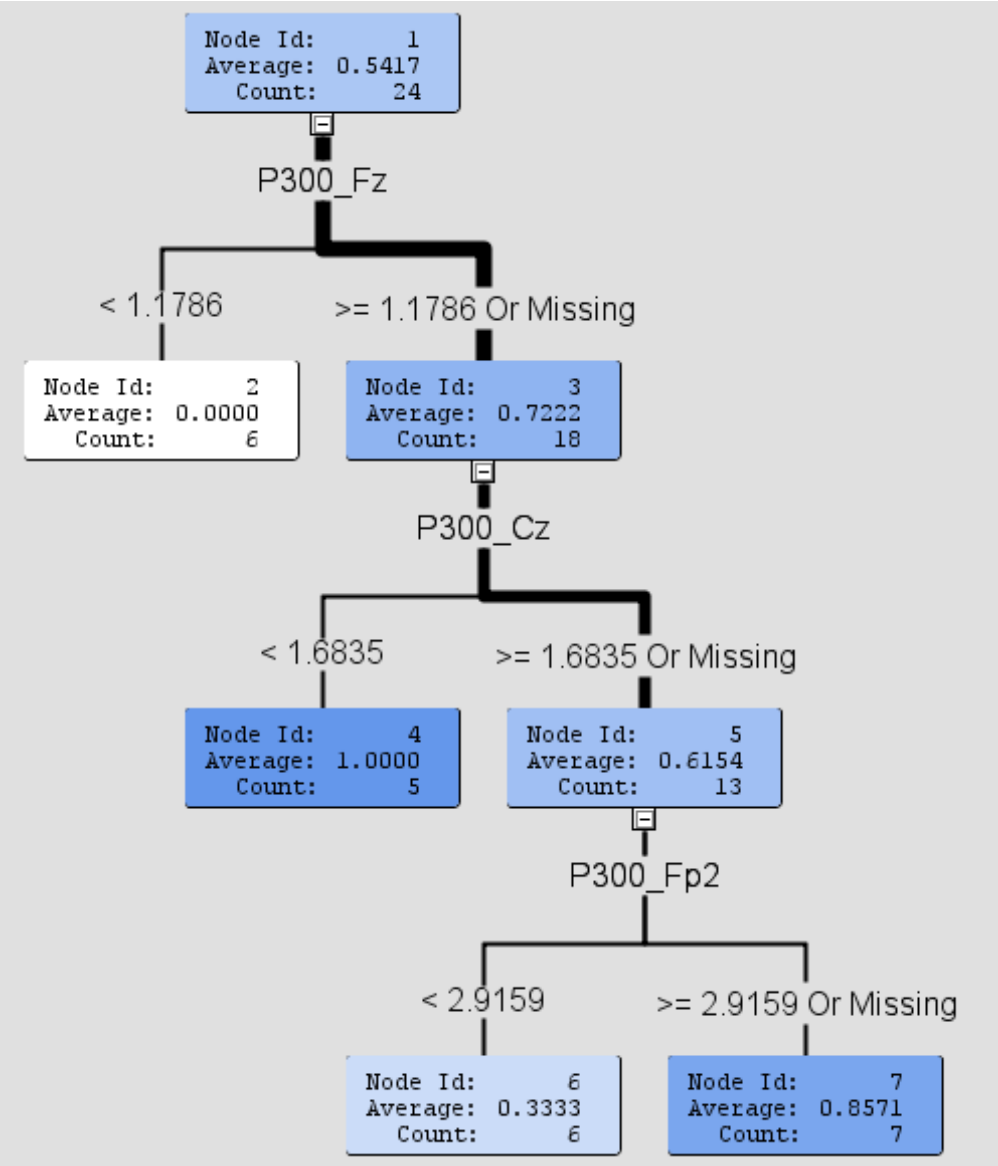


Figure 44: Decision tree for Crime II group

5.5.2 Logistic regression model

Lastly, a logistic regression, using maximum likelihood estimates, was performed. Using Enterprise Miner software (Dawson & Trapp, 2004), the following equation was derived to calculate the probability of a participant being part of the Crime II: Y group. The P300 peak amplitudes at electrode Fp1 and Fp2 were the only significant variables included in the model. These variables were used as input variables in Equation 6. Table 29 shows the estimates of the respective variables.

Table 29: Estimated parameters for logistic regression equation

Parameter	DF	Standard estimate	Error	t-value	p-value
Intercept	1	0.3390	0.1400	2.42	0.0246
$P300_{Fp1}$	1	-0.4487	0.2091	-2.15	0.0437
$P300_{Fp2}$	1	0.5547	0.2091	2.65	0.0149

$$\hat{\pi} = [1 + e^{(-0.3390+0.4487*P300_{Fp1}-0.5547*P300_{Fp2})}]^{-1} \quad (6)$$

From Equation 6, it is possible to determine whether someone has a close relative who had been exposed to violent crime, assault or sexual assault based on the EEG P300 scalp potentials recorded at electrode Fp1 and Fp2. In other words, with the known peak amplitudes between 250 and 500 ms post button press at electrode Fp1 and Fp2, it can be predicted whether a person would fall into the Crime II: Y group with a 58% accuracy. If the value calculated in Equation 6 is greater than 0.5, participants fall into the Crime II: Y group and if the value is less than 0.5, participants fall into the Crime II: N group. This is a preliminary equation and the accuracy of the equation is wholly dependent on the size of the data sample from which it was derived. Since the sample size for the respective Crime II groups are small, the efficacy of the equation is limited by the inadequate sample size.

The purpose of conducting the multivariate data analyses, is to find the variables with the greatest statistical significance. These variables emphasise points of divergence within the data series, with regards to a specified target variable. In Figure 44, the target variable was chosen as the Crime II group. The decision tree is therefore indicative of significant points of divergence within the Crime II: Y and Crime II: N groups. Knowing where in this data series splits occur is practically relevant, because it quantifies the traumatic subjective experiences investigated in this study. P300 peak amplitudes can therefore be used as a measure to determine whether someone has a close relative who had been the victim of a violent crime. Similarly, the logistic regression model acts as a prediction tool to show the probability of someone being a part of the Crime II: Y group. This decision tree and regression model illustrate the link between the P300 brain potential and familial exposure to violent crime. These models are relevant in the context of responding to questions relating to violent crime. The predictive power of these models will be further investigated in future research.

6 Conclusion and recommendations

This chapter concludes the research report by summarising the findings discussed in Chapter 5 and providing future recommendations. Future recommendations are formulated by first revisiting the research questions, then reflecting on the measures used to minimise errors and finally discussing the possible limitations of this study.

6.1 Revisiting the research question

The aim of this study was to investigate the neural mechanisms underlying higher order decision-making. Since this study was based on an existing study, the project was initially guided by the neural potentials and scalp locations evaluated in the original study. As was the case with the precursor study, this study defined two distinct decision classes, namely arbitrary and deliberate decisions. The experimental design aimed to investigate the neurophysiological differences between making arbitrary choices and deliberate decisions. The study succeeded in proving that there were no neurophysiological differences between arbitrary and deliberate decisions, as they were defined in this study. It was also proven that there were no neurophysiological differences between the convict and acquit trials or the left- and right-hand button presses. Contrary to the findings of the original experiment, there was a clear RP build-up prior to the button press events for both arbitrary and deliberate decisions. Furthermore, the choices presented in this research were more representative of real-world choices than the choices presented in the original study. This research therefore provides concrete evidence of the definitive presence of the RP for both deliberate and arbitrary decisions. Moreover, since the presented questions comprised of a moral component, the emotional context of participants' responses could be evaluated. There were observable differences between participants who had been exposed to violent crime, assault or sexual assault and participants who had not. The RP peaks at electrode Fz, Fp1 and Fp2 were more pronounced for participants who had been exposed to violent crime, assault or sexual assault, while the P300 peaks were attenuated for the same group. Moreover, there were also observable differences between participants with close relatives who had been exposed to violent crime, assault or sexual assault and participants without. The RP and P300 peaks at electrode Fz, Fp1 and Fp2 were more pronounced for this group of participants. This served to establish a clear correlation between the peak amplitudes exhibited in scalp potentials and certain emotional triggers. It was interesting to find that the P300 peaks were greatly increased at electrode Fz, which is the electrode that records from the intentional and motivational centres of the brain. This confirmed that the amplitude of the P300 potential resembles the emotional valence of a response. However, this same trend emerged for the RP amplitudes, suggesting that the RP too is influenced by response content. It

was clearly shown that personal experiences, specifically traumatic personal experiences, significantly influence the neurophysiological responses of the decision-making process. Lastly, multivariate analyses produced preliminary models that provide some quantification of the emotional content underlying higher order decision-making.

The link between the RP and free will, as well as the role of free will in the deliberate decision-making process, is still unclear. However, the findings of this study may suggest that Libet's original argument has merit, since the RP is present in higher order deliberate decisions. Although inconclusive with regards to the role of conscious free will, the study provided a glimpse into the delicate architecture underlying higher order and emotional decision-making.

6.2 Measures used to minimize errors

The validity of this study was contingent upon the quality of the recorded EEG data. In order to ensure the best quality raw data, electrode impedances were strictly lowered to 25 kΩ. Participants were also told to keep as still as possible while performing the decision task, to produce data that was mostly artefact free. Participants were fitted for the proper EEG cap sizes, since a cap that is too large or too tight might compromise the EEG recordings. Other measures taken to ensure reliable data capture related to the experimental setup: participants were seated in a dimly lit, quiet room with little to no distractions. All cell phones and smart watches were removed prior to testing.

6.3 Discussion of the possible limitations

Recording EEG data is a tedious and time-consuming process and because of this, most EEG studies consist of very small sample sizes. Still, it is possible to observe statistically significant trends with smaller sample sizes, the statistical power of the findings from the bivariate analyses confirms this. However, it is not possible to produce reliable multivariate statistical models with such small sample sizes. This restriction was observed in the Crime I group. Since the Crime I: Y sample size was too small to have relevant statistical power, participants who fell into both the Crime I and Crime II groups could not be eliminated from consideration for either of the two group analyses. Therefore, in order to investigate the effect of personal exposure to violent crime on neurophysiological data properly, a larger group of participants with such an exposure need to be studied.

Even though 64 data channels were recorded, only four electrode sites were evaluated during this study. It might be apposite to investigate whether the same trends, or possible alternative trends, arise at different electrodes that measure the neurophysiological activity of other brain centres.

6.4 Recommendations

Even though the bivariate findings discussed in this research report were conclusive, the multivariate results need to be validated with a larger sample. The accuracy of the preliminary predictive statistical models may be improved with larger sample sizes, as well as by incorporating model validation within the modelling process. It would also produce more conclusive results with regards to the effects of trauma on decision-making, if there was no overlap between participants categorised for the Crime I and Crime II groups. With an increased sample size, more evident dissimilarities between the two groups may be discovered. This could inform to what extent different degrees of emotional valence influence higher order decision-making. Moreover, it may be prudent to repeat the study using alternative modes of data capture, such as fMRI or functional near-infrared spectroscopy (fNIRS). These alternative methods may demonstrate the effect of trauma on neurophysiological activity recorded from deeper brain structures.

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Appendix A

A.1 Ethics approval notice

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

Health Research Ethics Committee (HREC)

Approval Notice

New Application

Ethics Reference #:0733

Title: EEG Investigation into the neural mechanisms involved in free moral decision making

HREC Reference # : S17/08/150

Dear Ms J Blignaut

The **New Application** received on 16/08/2017 06:17 was reviewed by members of **Health Research Ethics Committee** via **expedited** review procedures on 16/01/2018 and was approved.

Please note the following information about your approved research protocol:

Protocol Approval Period: **16-Jan-2018 – 15-Jan-2019**

Please remember to use your protocol number Project Id on any documents or correspondence with the HREC concerning your research protocol.

Please note that the HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

If you have any questions or need further assistance, please contact the HREC office at 021 938 9677

Yours sincerely,

Franklin Weber

HREC Coordinator

Health Research Ethics Committee 1 (HREC 1)

A.2 Informed consent form

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT:

EEG Investigation into neural responses during simulated legal trials as an effective measure to compile a jury.

REFERENCE NUMBER: SU-0733

PRINCIPAL INVESTIGATOR: Julianne Blignaut

ADDRESS: Room 625, Mechanical Engineering Building
Corner of Banghoek and Joubert Streets
Stellenbosch

CONTACT NUMBER: 072 902 2134

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

- *This study will be conducted at the Neuromechanics Unit located at the Department of Sport Science in Stellenbosch.*
- *A maximum total of 35 participants will be recruited.*

- *The study aims to determine whether there is any merit in utilising EEG to select a jury for a legal trial.*
- *The study will be divided into three parts. The first part will be completing a short written questionnaire. The second part requires you to perform a written psychometric test. The third part relates to the collection of EEG data.*
- *An EEG cap will be placed on your scalp. It might be necessary to add conducting gel to the electrodes placed across your scalp. The cap is hooked up to the EEG-system that records the neural activity related to your choices as you acquit/convict criminal offenders in hypothetical legal trials. This procedure is not harmful in any way.*
- *You will sit in front of a computer screen and perform a specific mental task as prompted by the computer. The task will be to acquit criminals when presented with certain legal case studies. Each trial will give you the chance to acquit/convict one out of two criminal offenders with different criminal charges.*
- *The expected duration of the entire procedure is 5 hours: 1 hour for Part 1 & 2 of the study and 4 hours for Part 3. Part 1 & 2 will be completed on a separate day, one week before Part 3. The 4 hours required to complete Part 3 include short breaks in between tests. The tests will take place during the week, i.e. from Monday to Friday – and not over weekends.*
- *Afterwards the EEG cap will be removed, and you can go home.*
- *If the psychometric test results reveal psychological abnormalities, you may be excluded from Part 3 of the study.*
- *If the EEG measurements contain too much noise or are in anyway not usable, your data may be excluded from the study.*

Why have you been invited to participate?

- *You are 21 years of age or older, you have no history of epilepsy or brain damage and your psychometric test results reveal that you have normal psychological mental health.*

What will your responsibilities be?

- *Your responsibilities include (1) completing the two paper based assessments and (2) sitting still for the EEG data collection period while performing the required mental tasks as prompted by a computer screen.*

Will you benefit from taking part in this research?

- *Although there are no personal benefits for taking part in this study, this research aims to understand how neuroscience may be implemented to improve our current legal systems. This can greatly impact the accuracy of conviction and acquittal rates.*

Are there any risks involved in your taking part in this research?

- *Apart from mild discomfort as a result of wearing the EEG cap, there are no real risks associated with this study.*
- *Execution of the study may result in mild mental and physical fatigue following the 4 hours of participation.*

If you do not agree to take part, what alternatives do you have?

- *Not applicable.*

Who will have access to your medical records?

- *The collected data will be treated as confidential. The identities of all participants will remain anonymous should the results of the study be published. Only the principal research investigator and her supervisor will have access to the information.*

What will happen in the unlikely event of some form of injury occurring as a direct result of your taking part in this research study?

- *This study is registered with Stellenbosch University's insurance brokers. In the unlikely event of injury occurring as a direct result of the study, you will immediately be attended to. The appropriate emergency response procedures are in place should an emergency occur. In case of serious injury and need of hospitalisation, your normal medical aid will cover any injury incurred.*

Will you be paid to take part in this study and are there any costs involved?

Yes, you will be paid R100 for your participation in this study. Water and snacks will also be available to you for the entire duration of the study. There will be no costs involved for you, if you do take part. You are expected to arrive at the facility using your own means of transportation, but you will be reimbursed for any travel costs incurred.

Is there anything else that you should know or do?

- You can contact *Julianne Blignaut* or *Dr Dawie van den Heever* at *072-902 2134* or *083-556 8311* if you have any further queries or encounter any problems.
- You can contact the Health Research Ethics Committee at *021-938 9207* if you have any concerns or complaints that have not been adequately addressed by your research assistants.
- You will receive a copy of this information and consent form for your own records.
- You can withdraw from this study without jeopardising this study.

Declaration by participant

By signing below, I …….…….. agree to take part in a research study entitled an *EEG investigation into neural responses during simulated legal trials as an effective measure to compile a jury*.

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.

- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ..... on (*date*) ……..…….. 2018.

....
Signature of participant **Signature of witness**

Declaration by investigator

I *(name)* …… declare that:

- I explained the information in this document to ……
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.*

Signed at (*place*) .....…….. on (*date*) ……..….. 2018.

....
Signature of investigator **Signature of witness**

Declaration by interpreter

I *(name)* …… declare that:

- I assisted the investigator (*name*) …… to explain the information in this document to (*name of participant*) ……. using the language medium of Afrikaans/Xhosa/Zulu/other.

- We encouraged him/her to ask questions and took adequate time to answer them.
- I conveyed a factually correct version of what was related to me.
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered.

Signed at (*place*) .....…….. on (*date*) ……...……..2018.

....

Signature of interpreter **Signature of witness**

A.3 Recruitment email

TO WHOM IT MAY CONCERN

Re: Recruitment for EEG Study

I, Julianne Blignaut, am conducting an experiment as part of my Masters Research project and I want to invite you to participate in this research. The aim of this study is to compile a jury for a mock legal trial. Jury selection will be done by means of EEG data collection, while participants complete several trials of judging criminal offenders. The study will require a total of 5 hours of availability from participants, spanning over two separate days. On the first day, participants will be required to fill out a short questionnaire and take a standard psychometric test (1 hour). The results from this test will determine if participants proceed to the second day of testing, one or two weeks later. This day will consist of participants completing the aforementioned legal trials for the jury selection process (4 hours). For these choice trials, electrodes will be attached to each participant's head in order to collect the EEG responses.

Tests are conducted in front of a computer screen in the form of written scenarios and there will be no exposure to graphic material or harmful persons. The EEG data collection procedure is non-invasive and safe. This research has been approved by Stellenbosch University's Health Research Ethics Committee (reference number 0733) and institutional permission has been granted for this subject recruitment process.

All participants will be rewarded R100 for participation and will be reimbursed for transport costs. Snacks and drinks will also be available throughout. The study will be conducted at the Neuromechanics Unit in Stellenbosch (main campus). All tests will take place during the week, and not over weekends. I require 35 volunteers, 21 years of age or older. If you meet this criterion, I encourage you to take part in this very exciting study!

If you are interested, please contact me at jblignaut@sun.ac.za so that I may provide you with further details.

Kind regards,

Julianne Blignaut

A.4 Participant questionnaire

PARTICIPANT QUESTIONNAIRE

PLEASE ANSWER THE FOLLOWING QUESTIONS AS TRUTHFULLY AS POSSIBLE. THERE ARE NO WRONG OR RIGHT ANSWERS. ALL ANSWERS WILL BE KEPT CONFIDENTIAL.

Personal Details

Participant number:_____

Age (21+): _____

Sex: Male | Female | Other

Race: Black | Coloured | White | Asian | Indian | Other

Nationality: _____

Education/Training (highest level): _____

Occupation (e.g. doctor, full-time student, unemployed): _____

NOTE THAT YOU ARE NOT OBLIGATED TO ANSWER THE QUESTIONS LISTED IN THE FOLLOWING SECTION IF DOING SO MAKES YOU FEEL UNCOMFORTABLE. YOU ARE FREE TO LEAVE THIS SECTION BLANK SHOULD YOU CHOOSE TO DO SO.

Personal History

1. Do you have any history of mental illness? Yes | No
2. Have you ever been the victim of a crime? Yes | No
3. Have you ever been the victim of a violent crime? Yes | No
4. Have you ever been a victim of assault? Yes | No
5. Have you ever been a victim of sexual assault? Yes | No
6. Do you know someone who has been the victim of a crime? Yes | No
   If yes, underline: **close relative/friend** or **acquaintance.**
7. Do you know someone who has been the victim of a violent crime? Yes | No
   If yes, underline: **close relative/friend** or **acquaintance.**
8. Do you know someone who has been a victim of assault? Yes | No
   If yes, underline: **close relative/friend** or **acquaintance.**
9. Do you know someone who has been a victim of sexual assault? Yes | No
   If yes, underline: **close relative/friend** or **acquaintance.**

10. Have you ever perpetrated a crime? Yes / No

11. Do you know someone who has perpetrated a crime? Yes / No

    If yes, underline: **close relative/friend** or **acquaintance.**

12. Are you a convicted felon? Yes / No

    If yes, specify degree: Theft / Arson / Assault / Rape / Manslaughter

13. Do you know someone who is a convicted felon? Yes / No

    If yes, underline: **close relative/friend** or **acquaintance.**

    If yes, specify degree: Theft / Arson / Assault / Rape / Manslaughter

Legal Bias

14. In your opinion, specify the gender of the most likely perpetrator of a misdemeanour:

    Male / Female / Both

15. In your opinion, specify the gender of the most likely perpetrator of a serious criminal offence:

    Male / Female / Both

16. In your opinion, specify the gender of the most likely perpetrator of a violent crime:

    Male / Female / Both

17. In your opinion, specify the gender of the most likely perpetrator of assault:

    Male / Female / Both

18. In your opinion, specify the gender of the most likely perpetrator of sexual assault:

    Male / Female / Both

19. In your opinion, specify the gender of the most likely perpetrator of murder:

    Male / Female / Both

20. In your opinion, specify the race of the most likely perpetrator of a misdemeanour:

    Black / Coloured / White / Asian / Indian / All

21. In your opinion, specify the race of the most likely perpetrator of a serious criminal offence:

    Black / Coloured / White / Asian / Indian / All

22. In your opinion, specify the race of the most likely perpetrator of a violent crime:

    Black / Coloured / White / Asian / Indian / All

23. In your opinion, specify the race of the most likely perpetrator of assault:

    Black / Coloured / White / Asian / Indian / All

24. In your opinion, specify the race of the most likely perpetrator of sexual assault:

Black	Coloured	White	Asian	Indian	All

25. In your opinion, specify the race of the most likely perpetrator of murder:

Black	Coloured	White	Asian	Indian	All

26. Are you or have you ever been a legal professional?

If yes, specify: _____

27. Do you trust the legal system to carry out justice in South Africa?

Why/why not? _____

_____

_____

28. Do you trust other legal systems to carry out justice in countries other than South Africa?

Why/why not? _____

_____

_____

29. Do you consider yourself of outstanding moral character to judge the offences and offenders in the following trials?

_____

_____

I hereby consent to the anonymous use of the information provided for research purposes, as well as to the use of my MMPI-2 test scores and EEG-trial results.

Signature: _____ Yes

☐ Please indicate here if answering these questions made you confront thoughts and feelings that you would like to discuss with a qualified professional. This will enable us to put you in touch with someone who can help you.

Appendix B

B.1 Legal terminology sheet

Legal Terminology

Prosecute : conduct legal proceedings against a person or organization
Convict : declare someone to be guilty of a criminal offence by a verdict of guilty
Acquit : free someone from a criminal charge by a verdict of not guilty

Perpetrator : a person who carries out a harmful, illegal or immoral act
Offender : a person who commits an illegal act

Premeditated : to plan something beforehand
In cold blood : to commit a ruthless act without feeling or mercy
Attempted : to try

Euthanasia : merciful killing of a patient suffering from an incurable disease
Self-defence: the defence of one's person or interests, using physical force

Homicide : the killing of one person by another
Manslaughter : the crime of killing another person without malicious intent
Murder : the unlawful premeditated killing of another person
Mass murder : the murder of a large number of people

Stalking : to harass someone with unwanted and obsessive attention
Assault : to make a physical attack on another person
Harassment : aggressive pressure or intimidation of a person (can be sexual)
Rape : to force someone to have sex with you against their will
Gang rape : the rape of one person by a group of other people

Kidnapping : an act of abducting someone and holding them captive
Abuse : to regularly or repeatedly treat someone with cruelty or violence
Mutilation : action of inflicting serious damage on someone or something

Theft : action or crime of stealing
Arson : criminal act of deliberately setting fire to a property

Forgery : act of forging a copy of a document, signature or work of art
Slander : making a false statement damaging another person's reputation
Negligence : failure to take proper care over something
Treason : the crime of betraying one's country

B.2 Legal cases*

Block 1 & Block 4
Employee responsible for stealing co-worker's personal belongings
Mother responsible for shaking baby to death due to postpartum depression
Arsonist responsible for setting school with children inside on fire
Arsonist arrested for setting house of known racist on fire
Employee accused of the attempted rape of a co-worker
Men arrested for the gang rape of a female student
Caretaker arrested for the attempted rape of a child
Student group responsible for the accidental death of peer as result of satanic ritual
Woman arrested for premeditated murder of spouse
Woman accused of sexual harassment of co-worker
Man arrested for treason after attempting to murder the president
Man arrested for the attempted murder of an elderly man
Gunman responsible for the death of 20 co-workers
Drunk driver responsible for killing a pedestrian
Man accused of slander of adversary in political campaign
Perpetrators arrested for killing hostage during break in gone wrong
Man arrested for double homicide
Man accused of stalking female victim with intent to harm
Young woman accused of manslaughter in self defence
Assault with a deadly weapon for cell phone and cash

Block 2 & Block 5
Home owner who shot intruder dead as he was breaking in
Man arrested for killing known rapist of his wife
Woman arrested for sending death threats to ex lover
Man arrested for euthanizing his dying mother
Man who killed attacker in self-defence
Bus driver who crashed school bus killing 7 children
Woman who accidentally set fire to building killing another resident
Woman who killed attacker in self-defence
Pilot arrested for negligence while flying after killing 60 passengers
Baby kidnapper that claims child was hers first
Perpetrator responsible for murder and mutilation of young attorney
Policeman violently assaulted known sex offender
Gang member arrested for rape of elderly lady
Site manager held accountable for accidental death of civilian passing construction site
Woman arrested for stealing food from Checkers to feed her family
Policeman accused of raping someone he had taken into custody
Shopkeeper accused of setting fire to a competitor's shop
Man arrested for exposing himself in public
Domestic worker who stole from employers who physically abuse her
Group of men accused of kidnapping a male university student

Block 3 & Block 6
Group of men arrested for stealing a car
Father responsible for accidental deaths of his two children
Woman arrested for killing a man while defending her children
Man arrested for brutally assaulting a female student
A gunman who shot and killed 13 people in a shopping mall
Man arrested for mass murder
Group of men arrested for raping a child
Man arrested for brutally assaulting a male student
Man arrested for stealing a television screen
Two friends planned and executed the murder of another friend
Man accused of murdering wife in cold blood
Woman guilty of violently abusing infant son
Woman accused of hiring someone to murder her husband
Student accused of theft of roommate's personal property
Woman arrested for breaking and entering
Man arrested for raping domestic worker
A father who admitted to raping his twelve-year-old stepdaughter
Man arrested for forging counterfeit currency
Grandparents arrested for exposing grandchildren to cocaine
Man arrested for killing a man while defending his children

**full list of case combinations for choice tasks can be obtained from author*

Appendix C

C.1 Artefact rejection rates

ICA	Participant	Block Type	Reference	Voltage (>100 uV)			Bad Channels (Kurtosis; Z-score = 5)		Keep/ Reject
				Right	Left	Total	Nr.	Name	
Yes	9	Arb	P7P8	0	1,1	0,6	5	TP10 = 9.09; T8 = 15.66; AF7 = 5.05; P5 = 6.83; P2 = 14.66	KEEP
Yes	9	Delib	P7P8	0	0	0	3	TP10 = 10.73; T8 = 13.73; P5 = 7.39	KEEP
Yes	10	Arb	P7P8	0	0	0	4	TP9 = 10.50; TP10 = 10.33; Fp2 = 17.09; TP8 = 6.50	KEEP
Yes	10	Delib	P7P8	0	0	0	6	TP9 = 21.48; Oz = 22.61; TP10 = 14.25; P1 = 9.92; P6 = 7.81; F2 = 5.59	KEEP
Yes	11	Arb	P7P8	0	1,1	0,6	3	Fp1 = 5.18; F7 = 9.05; P2 = 6.84	KEEP
Yes	11	Delib	P7P8	2,2	1,1	1,7	3	TP10 = 26.08; FC3 = 9.89; FC4 = 8.52	KEEP
Yes	13	Arb	P7P8	0	1,1	0,6	4	TP9 = 10.99; FC6 = 9.03; C6 = 9.66; FT8 = 5.92	KEEP
Yes	2	Arb	P7P8	1	3,7	2,2	0	-	KEEP
Yes	2	Delib	P7P8	0	0	0	0	-	KEEP
Yes	13	Delib	P7P8	0	0	0	0	-	KEEP
Yes	3	Arb	P7P8	0	0	0	4	TP9 = 14.07; Oz = 5.89; P4 = 7.64; P6 = 5.57	KEEP
Yes	3	Delib	P7P8	0	0	0	3	FT9 = 8.37; T7 = 5.01; FT7 = 5.73	KEEP
Yes	15	Arb	P7P8	0	0	0	4	C4 = 20.55; CP4 = 5.98; C6 = 9.01; FC4 = 8.61	KEEP
Yes	15	Delib	P7P8	0	0	0	4	FT9 = 6.03; TP9 = 14.27; FT10 = 6.69; FT8 = 10.90	KEEP
Yes	4	Arb	P7P8	0	0	0	4	T7 = 6.49; TP10 = 10.32; Fp2 = 9.92; FC3 = 7.15	KEEP
Yes	16	Arb	P7P8	1,1	4,3	2,8	3	AF7 = 13.18; F5 = 11.50; FT7 = 56.12	KEEP
Yes	16	Delib	P7P8	28,3	22,7	25,6	5	Fp1 = 10.10; FT9 = 11.77; F8 = 15.01; AFz = 29.05; AF8 = 13.26	REJECT
Yes	4	Delib	P7P8	0	0	0	4	T7 = 7.57; TP9 = 16.99; TP10 = 11.04; AF7 = 9.83	KEEP
Yes	7	Arb	P7P8	0	0	0	6	CP1 = 9.98; P4 = 7.24; PO8 = 12.75; P6 = 16.66; P2 = 10.38; Cz = 8.15	KEEP
Yes	17	Arb	P7P8	0	0	0	5	C3 = 6.26; TP9 = 12.24; CP5 = 5.97; C5 = 10.63; P6 = 13.49	KEEP
Yes	7	Delib	P7P8	0	0	0	0	-	KEEP
Yes	17	Delib	P7P8	0	1,3	0,6	6	TP9 = 11.65; P3 = 9.21; TP7 = 20.53; P1 = 8.48; P5 = 11.16; PO3 = 9.94	KEEP
Yes	18	Arb	P7P8	0	0	0	4	Oz = 12.23; O2 = 8.88; PO3 = 9.21; PO8 = 6.48	KEEP
Yes	8	Arb	P7P8	1	0	0,6	0	-	KEEP
Yes	18	Delib	P7P8	1	0	0,6	3	TP9 = 8.87; PO4 = 5.42; P6 = 5.19	KEEP
Yes	8	Delib	P7P8	0	0	0	2	TP9 = 20.20; C2 = 9.27	KEEP
Yes	19	Arb	P7P8	0	0	0	1	AF4 = 11.93	KEEP
Yes	20	Arb	P7P8	4,8	3,5	4,2	1	TP7 = 5.36	KEEP
Yes	19	Delib	P7P8	0	0	0	6	Fp1 = 5.31; TP9 = 13.98; Oz = 31.51; Fp2 = 7.23; AF7 = 8.76; AF8 = 6.94	KEEP
Yes	20	Delib	P7P8	2,4	3,2	2,8	2	Fp1 = 6.43; FC3 = 5.75	KEEP
Yes	23	Arb	P7P8	0	0	0	6	Oz = 5.61; TP10 = 5.54; FT10 = 22.09; PO3 = 10.48; PO8 = 5.29; P6 = 5.45	KEEP
Yes	22	Arb	P7P8	1,1	9,4	5	4	FT9 = 13.37; T7 = 5.46; TP9 = 22.90; TP10 = 33.61	KEEP
Yes	23	Delib	P7P8	0	0	0	5	Fp1 = 9.26; TP10 = 151.11; FT10 = 58.87; AF7 = 11.58; AF8 = 13.65	KEEP
Yes	22	Delib	P7P8	5,6	1,1	3,3	1	C6 = 5.74	KEEP
Yes	24	Arb	P7P8	1,2	1	1,1	1	T7 = 30.51	KEEP
Yes	29	Arb	P7P8	0	0	0	1	FT7 = 5.14	KEEP
Yes	24	Delib	P7P8	0	0	0	2	T7 = 7.20; T8 = 5.22	KEEP
Yes	29	Delib	P7P8	0	0	0	0	-	KEEP
Yes	30	Arb	P7P8	2,1	3,5	2,8	6	TP9 = 7.95; O2 = 29.93; TP10 = 10.82; FT10 = 85.71; CPz = 223.83; C6 = 43.14	KEEP
Yes	25	Arb	P7P8	1,1	1,1	1,1	4	TP9 = 24.74; Oz = 7.99; FT10 = 5.57; PO7 = 6.14	KEEP
Yes	25	Delib	P7P8	0	0	0	5	F7 = 6.43; T8 = 6.74; FT10 = 8.60; F6 = 5.14; AF8 = 5.56	KEEP
Yes	30	Delib	P7P8	0	0	0	2	TP9 = 57.57; AF7 = 5.30	KEEP
Yes	27	Arb	P7P8	0	0	0	5	TP9 = 51.22; TP10 = 60.34; C1 = 35.91; TP7 = 59.70; AF8 = 8.81	KEEP
Yes	31	Arb	P7P8	5,3	3,5	4,4	7	TP9 = 7.30; TP10 = 6.77; FT10 = 14.98; PO3 = 21.60; PO8 = 21.89; P6 = 5.80; AF8 = 9.26	KEEP
Yes	31	Delib	P7P8	2,3	1,1	1,7	3	F7 = 5.17; PO4 = 5.52; PO8 = 5.04	KEEP
Yes	27	Delib	P7P8	1	0	0,6	6	TP9 = 57.27; TP10 = 16.46; T8 = 7.88; FT7 = 7.80; TP7 = 45.42; PO7 = 5.27	KEEP
Yes	32	Arb	P7P8	0	0	0	5	FT10 = 42.37; P5 = 8.50; PO7 = 6.63; PO4 = 6.91; CP4 = 9.64	KEEP
Yes	36	Arb	P7P8	0	0	0	1	P2 = 11.07	KEEP
Yes	36	Delib	P7P8	0	1,1	0,6	4	TP9 = 323.40; CP5 = 6.52; AF7 = 33.40; C5 = 10.24	KEEP
Yes	32	Delib	P7P8	0	0	0	5	Fp1 = 5.07; FC5 = 5.03; T8 = 14.28; FT10 = 51.38; C5 = 7.32	KEEP
Yes	37	Arb	P7P8	0	0	0	6	Fp1 = 10.17; T7 = 7.09; TP9 = 5.65; AF7 = 8.21; FCz = 5.04; AF8 = 5.17	KEEP
Yes	33	Arb	P7P8	0	1,2	0,6	1	TP9 = 7.01	KEEP
Yes	33	Delib	P7P8	0	0	0	0	-	KEEP
Yes	34	Arb	P7P8	14,7	19,2	16,7	2	FT9 = 6.72; FT10 = 15.48	KEEP
Yes	37	Delib	P7P8	0	0	0	6	TP9 = 6.79; TP10 = 11.91; CP6 = 23.58; Fp2 = 8.74; PO7 = 13.47; AF8 = 152.72	KEEP
Yes	34	Delib	P7P8	76,7	81,1	78,9	5	Fp1 = 7.38; F7 = 6.28; FT10 = 6.04; AF7 = 6.51; F5 = 6.70	REJECT
Yes	35	Arb	P7P8	1	0	0,6	0	-	KEEP
Yes	35	Delib	P7P8	0	0	0	0	-	KEEP

Table C.1.1: Artefact rejection rates

Appendix D

D.1 Confidence intervals for left/right responses

Table D.1.1: 95% CI of the mean RP and P300 peaks for left and right button press responses at Fz

Variable	Left CI (µV)		Right CI (µV)	
	Lower 95%	Upper 95%	Lower 95%	Upper 95%
RP_Fz_arb	-4.41	-2.72	-4.54	-2.56
RP_Fz_delib	-3.78	-2.44	-3.77	-2.43
P300_Fz_arb	1.00	2.91	1.15	3.10
P300_Fz_delib	1.75	3.52	2.18	3.95

Table D.1.2: 95% CI of the mean RP and P300 peaks for left and right button press responses at Fp1

Variable	Left CI (µV)		Right CI (µV)	
	Lower 95%	Upper 95%	Lower 95%	Upper 95%
RP_Fp1_arb	-3.43	-1.96	-3.63	-1.80
RP_Fp1_delib	-2.54	-1.34	-3.22	-1.58
P300_Fp1_arb	1.24	2.98	1.59	3.45
P300_Fp1_delib	1.55	3.45	1.82	3.61

Table D.1.3: 95% CI of the mean RP and P300 peaks for left and right button press responses at Fp2

Variable	Left CI (µV)		Right CI (µV)	
	Lower 95%	Upper 95%	Lower 95%	Upper 95%
RP_Fp2_arb	-3.84	-2.23	-3.52	-1.96
RP_Fp2_delib	-3.11	-1.91	-2.82	-1.62
P300_Fp2_arb	1.02	2.72	1.25	3.16
P300_Fp2_delib	1.35	3.26	2.11	3.98

D.2 Average RP and P300 peak values for arbitrary and deliberate blocks

Table D.2.1: Average RP and P300 peak values for arbitrary and deliberate blocks at electrode Fz

Decision block	RP peak (µV)	P300 peak (µV)
Arbitrary	-3.736	2.244
Deliberate	-3.235	2.654

Table D.2.2: Average RP and P300 peak values for arbitrary and deliberate blocks at electrode Fp1

Decision block	RP peak (µV)	P300 peak (µV)
Arbitrary	-2.763	2.715
Deliberate	-2.295	2.532

Table D.2.3: Average RP and P300 peak values for arbitrary and deliberate blocks at electrode Fp2

Decision block	RP peak (µV)	P300 peak (µV)
Arbitrary	-2.947	2.567
Deliberate	-2.506	2.799

D.3 Crime II comparisons

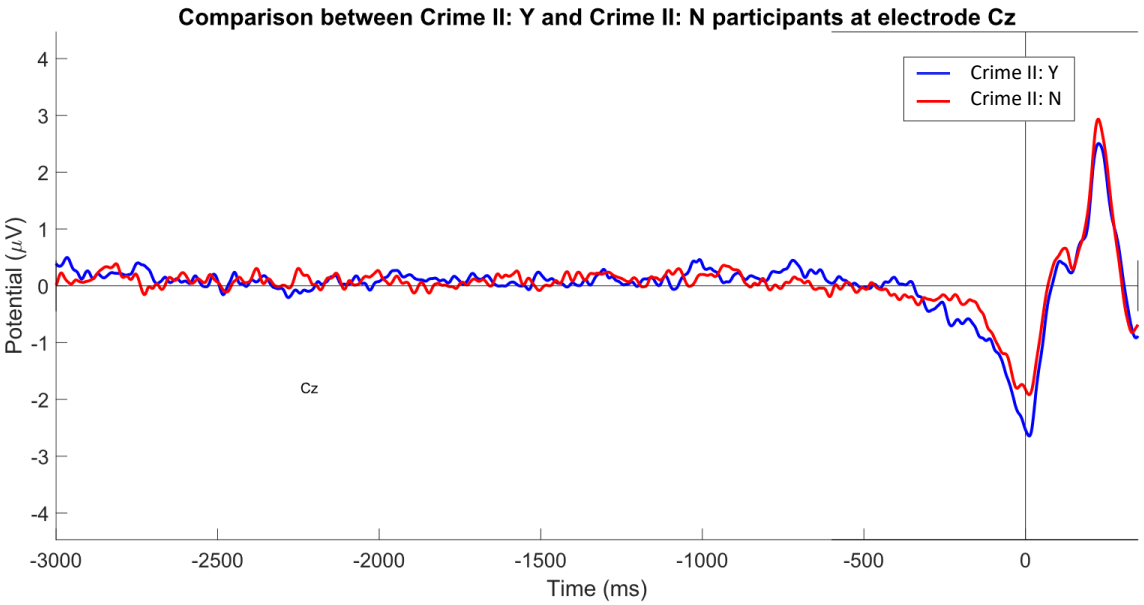

Figure D.3.1: Crime II comparisons at electrode Cz

D.4 Crime I comparisons

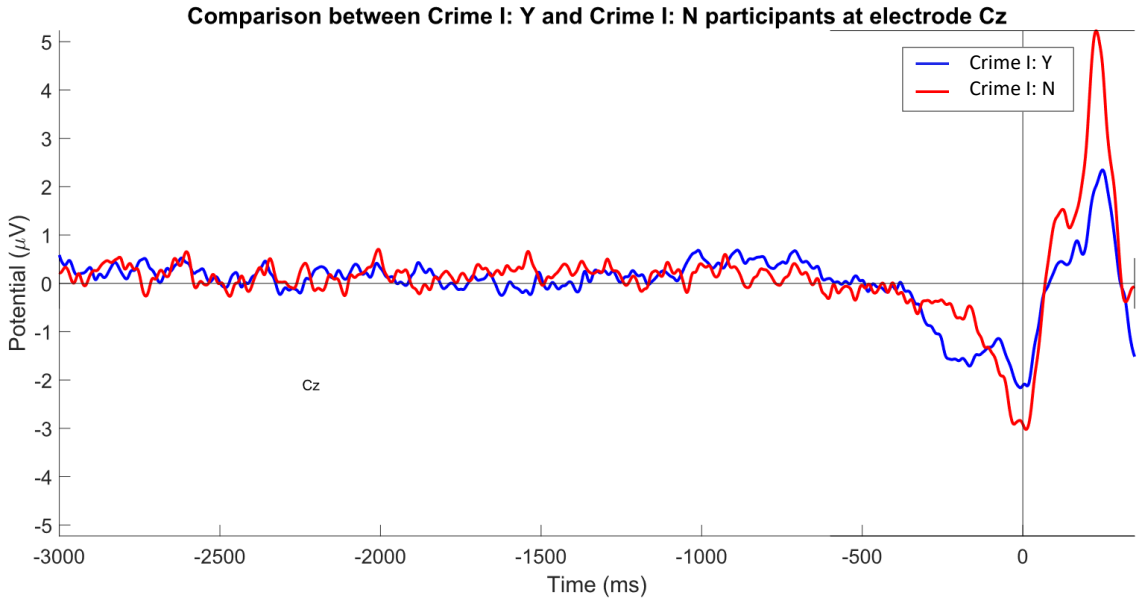

Figure D.4.1: Crime I comparisons at electrode Cz

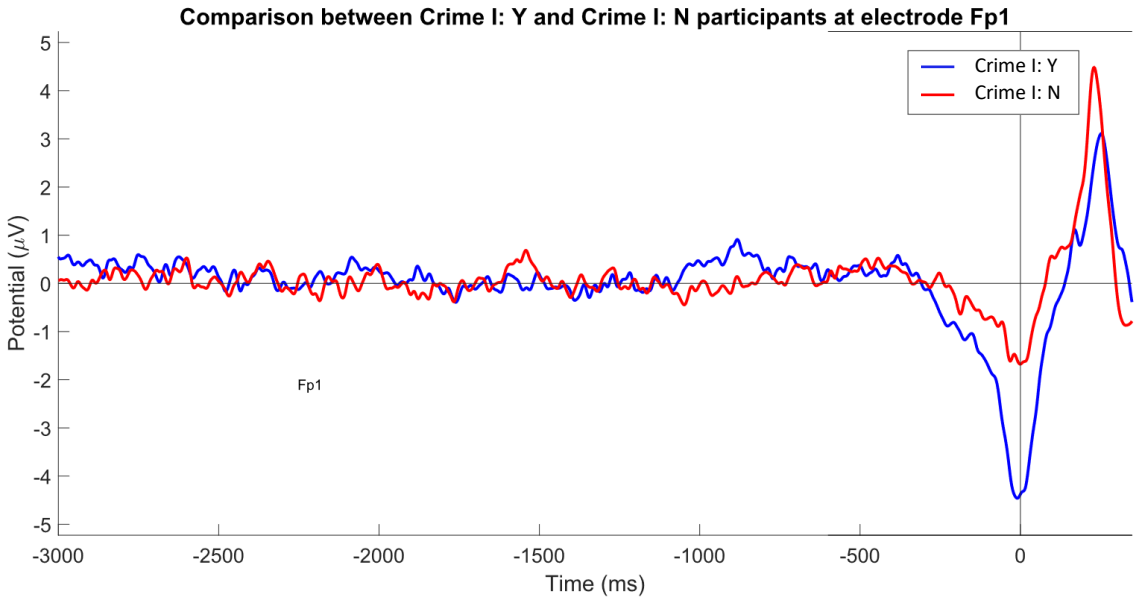

Figure D.4.2: Crime I comparisons at electrode Fp1

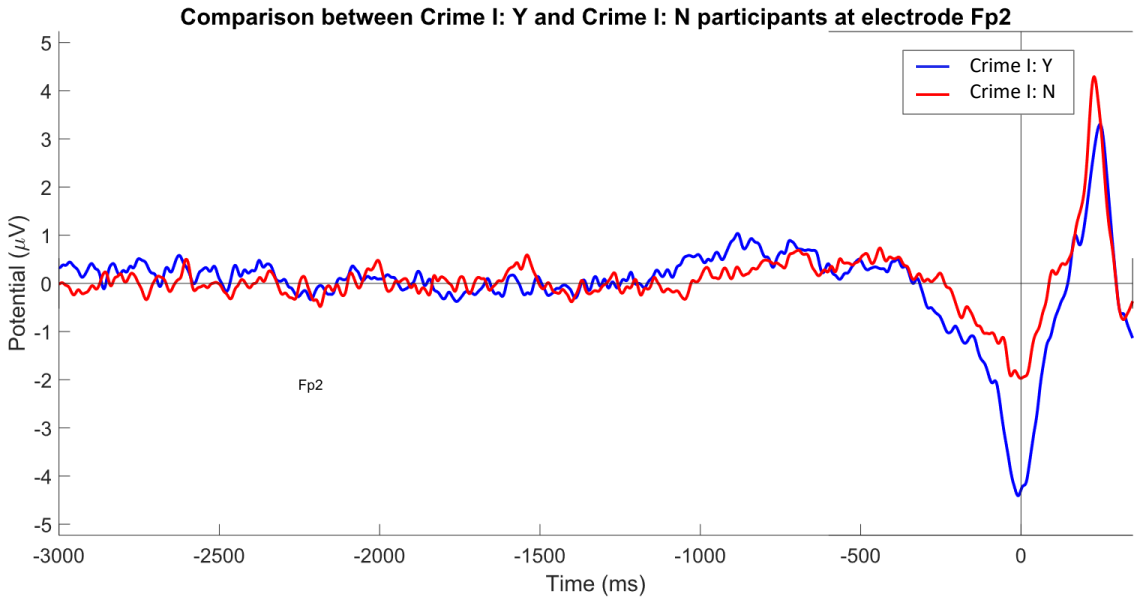

Figure D.4.3: Crime II comparisons at electrode Fp2

D.5 Crime I and II comparisons

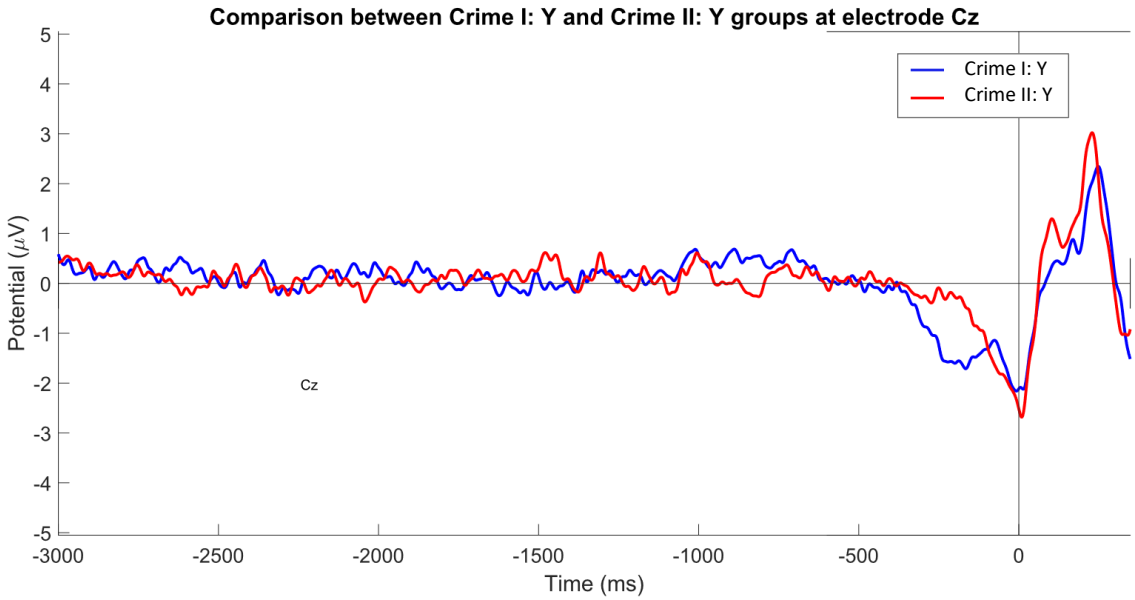

Figure D.5.1: Crime I and Crime II comparisons at electrode Cz

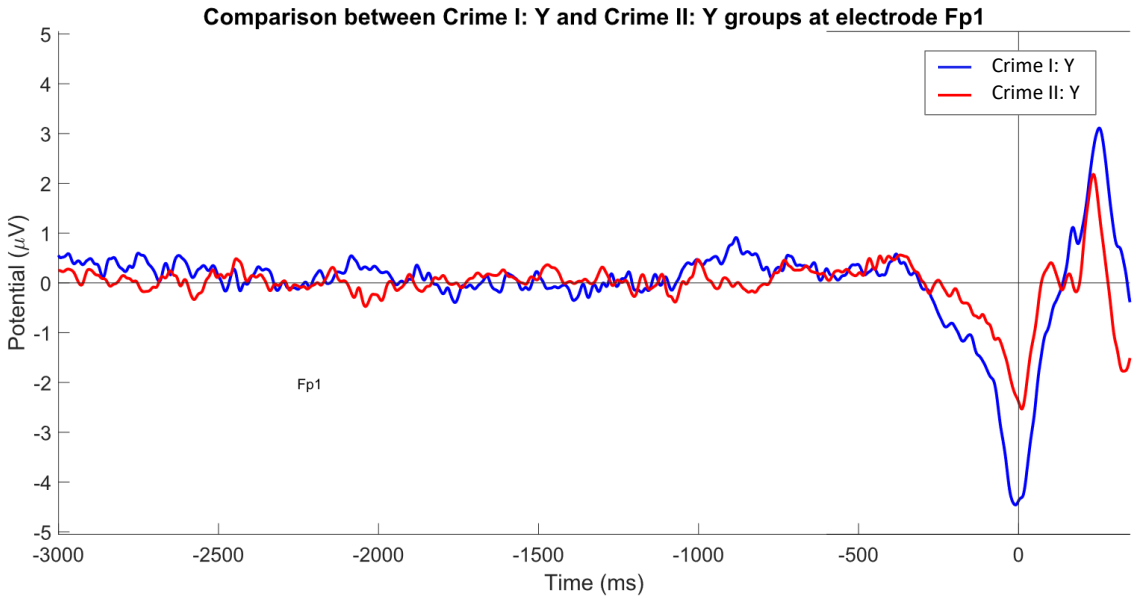

Figure D.5.2: Crime I and Crime II comparisons at electrode Fp1

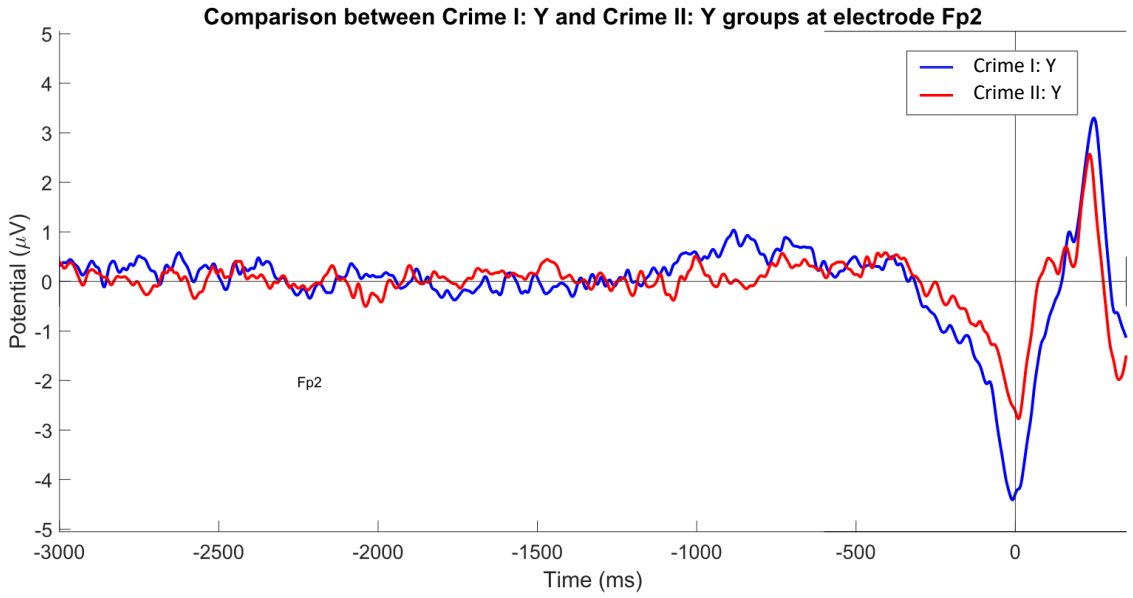

Figure D.5.3: Crime I and Crime II comparisons at electrode Fp2