**EXPLORING EVENT-RELATED POTENTIAL PATTERNS IN A**

**CHESS ENVIRONMENT**

**Proposal**

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**September 2018**

**ABSTRACT**

While decision making may have external manifestations, its roots lie in the intricate interaction of millions of neuronal networks in the brain. Electroencephalography (EEG) can record the electrical impulses (in the form of waves) emitted by these neural networks. When linked to specific events or stimuli, these waves are called event-related potentials (ERPs). Research in the medical field has highlighted the value of determining patterns related to specific time-locked events when analysing ERPs. However, the research into non-medical, value-based neural decision-making is limited. The proposed study will strive to identify patterns in a complex and sequential value-based decision-making process using a ‘blitz chess’ scenario. A purposive sample of 24 chess players from three different skill levels from the population of FIDE ranked blitz-chess players will be selected. They will be asked to play multiple blitz chess games against a computer and their decisions, namely time-locked chess moves, will be recorded. Using a mixed-methods approach, this study will attempt to determine ERP patterns linked to each move and also to investigate any ERP patterns occurring between moves. Qualitative input from the players will help interpret the events that created the ERPs while computational neuroscience and algorithmic models will point to the patterns underlying the quantitative data. In consequence, this novel pattern-seeking approach to complex, value-based decision making, using mixed-methods, will hopefully contribute to the broader neural decision-making field. The insight gained may ultimately have application in brain-computer interface studies, artificial intelligence and even in diagnosing abnormalities in decision making.

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*“**Everything we do, every thought we've ever had, is produced by the human brain. But exactly how it operates remains one of the biggest unsolved mysteries, and it seems the more we probe its secrets, the more surprises we find.”* Neil deGrasse Tyson (deGrasse Tyson, n.d.)

#  INTRODUCTION

Since time immemorial, humans have been occupied with trying to explain the workings of the brain. From Aristotle who claimed that the brain was a cooling mechanism for the blood and that the heart was the seat of intelligence (Kochanek & Jackson, 2017) to Descartes who proposed a duality of mind and body known as Cartesian dualism (Damasio, 1994), the brain has fascinated researchers, philosophers and psychologists alike. Despite many advances in understanding the components of the brain with its neurons and networks communicating in milliseconds[[1]](#footnote-1), the brain still remains a mystery that relinquishes a bit of that mystery with any new information that can throw light on its workings. The history of neuroscience is that of building blocks of information which add, bit by bit to a greater understanding of the workings of the brain.

With the accumulated knowledge we have of the brain so far, thanks to the concerted efforts of a myriad of researchers, we are able to use this knowledge for the good of humankind through improved decision making, brain computer interfaces (BCI), and a better understanding of mental health issues. It is in this context that this study will attempt to add a piece to the puzzle by exploring the concept of neural decision making in a complex and sequential, value-based decision-making environment, an environment that emulates the complexity of natural decision making. To this end, the proposed study will be applying the game of chess as the context of choice[[2]](#footnote-2). This research will attempt to explore whether patterns can be obtained from waveform analyses and temporal segmentation of ERP with the events being a sequence of decisions in the context of chess. Unlike many studies based in neuroscience that favour computational and quantitative methods, this research will apply a mixed-methods design using a pragmatic paradigm. This mixed-method design will be implemented both at the data capture and analysis stages. By doing this, not only will the researcher be able to capture precise numerical measurements, but the interpretation of these measurements will involve not only the researcher, but also the participants whose opinions about their own realities are important in understanding the implications of any patterns that may be found. By integrating the quantitative results with qualitative insights from participants, experts and the researcher’s own reflexive input, the proposed study can be legitimised and deeper and richer data can be obtained.

# NEURAL DECISION MAKING

In the introduction, it was highlighted that this proposed study is about neural decision making, particularly in the context of a complex, sequential, value-based decision-making environment. The academic literature is replete with articles on how the brain makes decisions. A search on Scopus (“Scopus,” n.d.), the world’s largest academic bibliography, identifies over 15,471 sources[[3]](#footnote-3) containing the terms “decision making” and “neural”. The research proposed in this study plans to utilise the electroencephalogram (EEG) as the instrument of choice and by adding the keyword “EEG” to the search brings the list down to just under 436 sources, still quite considerable. Other databases searched such as Proquest (“Proquest,” n.d.) and Google Scholar (Google, n.d.), resulted in equally high results. Notwithstanding the many articles in the field of neural decision making, researchers acknowledge that neuroscientists are only beginning to understand how the brain works and that considerable further research is still required (Seigfried, 2017). The broad purpose of this proposed study is therefore to contribute to the research on neural decision making and the aim of this section is to outline the current literature on this topic.

As a point of departure a definition of neural decision making as understood in this study is provided below.

## 2.1 Defining neural decision making

Neural decision making as used in the context of this study, can be defined as processes endogenous to the brain which result in manifest decision-making behaviour. Incorporated in this definition is the importance of the neurobiological basis of human behaviour. In addition, classic definitions of decision making include the importance of choice among competing courses of action that have relative values based on their consequences (Balleine, 2007). Research into neural decision-making addresses this complexity by way of understanding how such diverse concepts such as value, memory and ambiguity are processed in the brain and what the resulting actions are.

It is worth noting that the activity of ‘decision making’ has popularly been considered from a different, non-neural perspective, namely from an exogenous or external perspective in which decisions are considered in interaction with the world surrounding the decision maker. This view of decision making can be placed on a continuum from normative theories which predicate how decisions should be made to obtain the optimum results for the decision maker, to descriptive theories which attempt to understand how decisions are made. Neural decision making could be placed on this continuum at the opposite end from normative decision making and in the realm of descriptive decision making.

The broad field of decision making – not restricted to neural decision making – encompasses a wider reach as far as research is concerned, with more than 650 000 published articles on Scopus[[4]](#footnote-4). In this instance, often little consideration is taken of what happens in the brain with the focus more on the nature and effectiveness and ensuing behaviour of the decision in the external context in which the decision is made rather than decision making as it happens in the brain, namely the neural perspective.

## 2.2 How decisions are made in the brain

The brain is part of the Central Nervous System (CNS) and is made of billions of cells including specialised cells for information processing called neurons (Freberg, 2016). A neuron comprises a cell body (also called a soma) with a nucleus, together with branch-like dendrites and leash-like axons (which also have a branch-like structure called axon terminals at their far end). The neuron generates the electric signal (called an action potential[[5]](#footnote-5)), while the dendrites and axons essentially facilitate the transmission of the signal either inward or outward – a neuron’s dendrites receive electrical signals from upstream neurons, while axons carry an electrical signal from the current cell to one or more other neurons. Essentially the dendrite acts as a receiver of signals from the axons of neighbouring cells, while the axon acts as a transmitter of signals to the dendrites of neighbouring cells.

The ‘signal’ or action potential is in the form of electrical impulses that travel along the dendrites (inwards from a neighbouring neuron) and axons (outwards to a neighbouring neuron). A neuron may establish many connections to different neighbouring neurons. In the initiating neuron, a chemical reaction takes place that 44generates a differential in electrical potential between the inside and outside of the neuron. The chemicals that are inside and outside of the neuron, are all electrically charged. When the differential in electrical charge is large enough between the inside and outside of the neuron, a differential potential threshold is reached and the electrical charges move between the inside and outside of the cell as impulses of electrical energy. They are carried upstream by the dendrite to the next neuron, or they are received from the downstream neuron to the current neuron. Where the dendrite and axon meet is called a synapse and this is where the electrical charge is passed between neurons.

Thus, in a normally functioning brain, electric signals – essentially thoughts, motor instructions and related information – are generated within the neuron and these are passed from neuron to neuron via the dendrites, axons and synapses that link the neurons together.

Researchers do not have a clear understanding how decision making can occur from this complex array of processes, but there are suggestions that intricate networks or systems of neurons – also called populations by some researchers (Pitkow & Angelaki, 2017) – work together to produce an action in the form of a decision in response to particular stimuli, namely information from the senses and memory (Duan et al., 2012; Seigfried, 2017). This systems approach has been referred to as brain modularity (Brocas & Carrillo, 2014). Other researchers have also suggested that the brain is a network that interacts to produce a decision outcome but have included concepts of memory and emotions (which are also neural-based) as playing an important part in the activities of these networks (Damasio, 1994). A decision evolves from a state where alternatives are presented to a state of commitment to an overt action subsequent to the state of commitment (Schall, 2001, p. 34). In addition, decisions which involve choices, take time – a fact that lends itself to categorisation of a decision and possible patterned activities on a neuronal level.

Neurons function on a continuous basis – 24 hours a day and every millisecond of every day – constantly generating and processing thoughts, stimuli, emotions, memories, motor instructions and sharing information. While not every electrical activity in the brain depicts a decision (the activity could be associated with the processing of autonomous motor responses, memory, emotion, language, learning) decision making is arguably one of the many complex activities of the brain resulting from electrical activity in the brain (Pearson & Platt, 2008).

The brain thus comprises a huge mass of hundreds of billions of these interconnected neurons. This is a living mass that changes form constantly, creating new dendrites and axons and even new cells (a process called ‘plasticity’), to facilitate intra-neural communication and processing, depending on processing needs. Intra-neural communication occurs through events called action potentials[[6]](#footnote-6) (Spruston, 2008) and it is possible to measure the action potentials being generated by neurons using equipment such as EEG.

## 2.3 Defining the action potential

In neurons, information is represented as charged molecules called ions that are carried in chemical solutions of either calcium (positively charged), chlorine (negatively charged), potassium (positively charged) or sodium (positively charged). Because ions have either a positive or negative charge – and depending on the size of the charge and the difference in charge between the ions on the inside and outside of the neuron – a difference potential threshold is reached and the ions move from the place of high charge to low charge. However, the neuron cell membrane is impermeable to ions and for this reason, microscopic ‘devices’ exist called ion channels that are mostly closed, but when a difference potential threshold is reached, the ion channels open up to allow the ions to move in the desired direction. When this happens, an action potential is created and, in the case of EEG, is represented by a small electrical spike on the EEG graph.

## 2.4 Measuring brain activity

There are various ways in which the electrical impulses generated in the brain can be measured. These range from needle-thin microscopic sensors that can be surgically implanted in the brain to receive and record the signals being generated in close proximity to the actual neurons (also called single cell recording) (Banich & Compton, 2011, p. 68) to functional magnetic resonance imaging (fMRI) which measures changes in blood flow and metabolism in active areas of the brain (Banich & Compton, 2011, p. 65), functional near infrared spectroscopy (fNIRS) which, like fMRI, measures blood flow in shallower areas of the brain to produce a spatial map (Pfeifer, Scholkmann, & Labruyère, 2018), magnetoencephalography (MEG) which records the magnetic fields (also called neuronal oscillations) generated by electrical currents (Proudfoot, Woolrich, Nobre, & Turner, 2014), and electroencephalography (EEG) which provides a graphical representation of the minute electrical currents, measured in milliseconds and created by synchronous neuron populations when synaptic activity occurs (De Kock, 2014). In addition, EEG does provide some spatial information, albeit on the large scale (in neural terms) of centimetres (Mangalathu-Arumana, Liebenthal, & Beardsley, 2018).

In conjunction with EEG, measuring psychophysiological responses using galvanic skin response (GSR), heart rate variability (HRV), pupillometry and eye tracking can add information about emotion, valence, stress, attention and anxiety. These other measures can provide a wealth of additional data with respect to specific ‘point-in-time’ events.

### 2.4.1 Electroencephalography

This proposed study will focus on EEG as the technology to be used to measure brain activity. The reason for this is manifold. Most importantly EEG is affordable. Whereas fMRI, MEG and fNIRS are technologies that cost millions of Rands and require special environments within which to install the respective technologies, acceptable EEG devices are available for under R30 000. What is more, the University of South Africa’s (UNISA) Bureau for Market Research (BMR) has an EEG device available for research purposes. Furthermore, EEG provides excellent temporal results down to millisecond intervals (which fMRI, MEG and fNIRS, their prices notwithstanding, cannot do). EEG also provides broad spatial perspectives on where the brain activity is occurring; it is relatively easy to use; it is not very restrictive it has a wide variety of hardware and software options; there are many analysis options available using EEG data; the EEG data is rich in information, there is considerable research already published on EEG research; EEG is non-invasive and EEG holds little danger for the participant. In addition, as suggested by Larsen and O’Doherty (2014), EEG can provide “insights into the temporal dynamics of decision-making” (Larsen & O’Doherty, 2014, p. 1). These details are arguably compelling reasons to adopt EEG as the technology of choice for this proposed study.

EEG comprises a head-worn device – a skull cap – with receptors or receivers (also referred to as electrodes) built into the device that can measure very small electrical impulses ranging from 1 to 100 Hertz (Hz – a Hz represents a cycle per second) that are being produced at the surface of the skull (actually at the surface of the brain within the skull). The receptors that are built into an EEG head cap are positioned according to a well-researched and recognised reference system referred to as the international 10/20 system – see figure 1.



Figure 1: Schematic of the 10-20 System. Electrode placement (AdafruitIndustries, n.d.)

EEG devices also differ according to the number of receptors they have. Some have only a few (one or two) and others may have 64, 128 or 256 receptors or even more. EEG caps are also classified according to whether they are clinical – which means that they have been certified by an authority such as the United States Food and Drug Administration as sufficiently accurate to measure neurological signals for clinical or medical purposes – or they are non-clinical or research-grade (also known as consumer grade), which means that they can be used for research purposes. The clinical devices are usually more accurate but also much more expensive. The literature does suggest that the non-clinical devices, especially those with greater number of receptors, are relatively accurate and compete well with clinical devices (Ratti, Waninger, Berka, Ruffini, & Verma, 2017).

EEG caps can be tethered or wired, or wireless. Wired devices are usually faster and more accurate, while wireless devices provide for more freedom of movement and can be used in a mobile context. This proposed study will use a wireless research grade EEG device to track brain activity.

# 3. **THE EVENT RELATED POTENTIAL**

In section 2.3, the action potential was described and defined. When an action potential ‘fires’ in response to a stimulus or some event (which could be internal to the brain, internal within the body, or external to the body), this action potential is called an event-related potential (ERP). The EEG measures this as an overall voltage change in a population of neurons in response to a specific stimulus. The challenge is that while researchers can generate some or other experimental stimulus (also called an event), many ERPs are associated with endogenous cognitive events (memories, motor reactions, emotions, etc.)[[7]](#footnote-7), that are not known to the researcher. Thus, all the bumps, spikes and cycles that one sees when measuring neural activity are reactions to some or other unknown event – they are uncontrolled (also known as unsupervised) ERPs. When this raw data is distinguished from surrounding extraneous activity by using algorithmic computations in an activity called feature extraction, the resulting waveforms are called components.

In the literature on ERPs, certain common waveforms – the components – have been isolated as belonging to certain psychological operations in response to stimulus (Kropotov, 2016). These components can be isolated according to temporal and spatial distributions (Blankertz, Lemm, Treder, Haufe, & Müller, 2011, p. 4). The components are named according to whether the wave peak produced is positive or negative and according to temporal distance from the onset of the stimulus. The sequence of ERP peaks indicates a flow of information through the brain and the voltage change during the ERP reflects brain activity at that precise moment (Luck, 2014, p. 8). To date, the majority of neural research has been focused on controlled ERPs that are repeatedly recorded in response to an experimental stimulus – this is referred to as between-trial ERPs (Gu, Zhang, Luo, Wang, & Broster, 2018). In the next section, an overview of the literature will capture the main areas of focus on current research into ERPs.

## 3.1 Research using ERPs

In this section, the focus is on outlining in broad terms, the research so far on neural decision making using an ERP design. Examples of research using an ERP approach are discussed and the value of ERP research is highlighted.

Since EEG was first invented by Hans Berger in 1924, researchers have been trying to make sense of the cacophony of waves presented graphically by the EEG. In the 1930s the first ERPs were recorded but it was only in the 1960s that ERP research came to the fore and it was also in the 1960s that the well-researched ERP component P3[[8]](#footnote-8) was discovered (Sutton, Braren, Zubin, & John, 1965).

It has been suggested that using ERPs can provide benefits over other measuring tools such as fMRI. As recently proposed by Kappenman and Luck: “The fact that ERPs provide an instantaneous, continuous, millisecond-resolution measure of processing means that they can be used to isolate the dozens of individual sensory, cognitive, affective, and motor processes that occur between a stimulus and a response, making it possible to unpack the many different factors that contribute to overt behaviour” (Kappenman & Luck, 2017, p. 2).

There have been numerous examples of ERP-designed research subsequent to the ERP’s discovery in the 1930s, particularly with the advent of computers and the greater calculating power that computers provide. Clinical studies are plentiful. One study that investigated cognitive decline in Parkinson’s Disease, investigated the P3 component of ERP and concluded that cognitive impairment could be shown through electrophysiological indicators. Bridwell et al. (2018) focuses on EEG analyses methods which help explain brain-behaviour relationships and cognitive function. Cognitive deficits in bipolar disorder were reviewed and evaluated by using ERPs and it was found that ERP differences occur at different stages during cognitive processing in bipolar disorder (Morsel, Morrens, Dhar, & Sabbe, 2018).

Other fields that have successfully used ERP in their research include, for example, consumer marketing (Kaneko, Toet, Brouwer, Kallen, & van Erp, 2018), neuromarketing (C. Wang et al., 2018), cognitive fatigue (Haubert et al., 2018), neurolinguistics (Van de Meerendonk, Kolk, Vissers, & Chwilla, 2018), sport (Muraskin, Sherwin, & Sajda, 2015) and studies of memory (Hering, Kliegel, Bisiacchi, & Cona, 2018).

Decision making studies have not been neglected and a study by Niu, Li and Cao (2018) that specifically looked at sequential decision making using ERPs and response times concluded that ERP components showed that response times and temporal processes are important during choice. San Martín (2012) examined previous research related to two ERP components, the P3 and feedback-related negativity (FRN) in terms of outcome processing post-choice and how these ERP components are affected by outcome valence, magnitude, probability and behavioural adjustment. In 2018 Li, Wang, Du, and Cao (2018) conducted a study along similar lines where they measured the ERPs in response to informative feedback and were able to identify the ERP components that are associated with informative feedback. Decision making in children was studied using ERPs and it was suggested, based on the results obtained, that neurophysiological responses (as indicated by ERPs) could be an indication of a child’s level of decision-making skills in affective-motivational situations (Carlson, Zayas, & Guthormsen, 2009).

## 3.2 Sequential ERPs

In the above section, the focus has been to highlight the research around ERPs. As was previously mentioned, ERPs are studied in reaction to an experimental stimulus and numerous trials are conducted usually with a repeated stimulus that has (usually) only two possible responses and then the participant’s choice of response to the stimulus is recorded over several hundred trials (also referred to as ‘epochs’). The resultant ERP for each epoch is summated and the many wave forms associated with each epoch are averaged out to generate a clear conspicuous single waveform – the typical ERP waveform referred to in most academic articles and that has been extensively studied in the literature (see section 2.5 above). This is referred to as between trial studies.

What is less common in the literature are experiments that take a longitudinal approach to neural decision making where, a number of related, sequential decisions are taken over a given period of time, and the EEG wave patterns associated with the series of decisions are studied to learn what insight can be extracted from these EEG waves. This is referred to as within-trial studies (Gu et al., 2018). The sequence and moment of decision in the series of decisions should at least be known, in order to support the experiment under consideration. The challenge is that the EEG waveforms associated with a temporal sequence of known decisions is likely to contain many ERPs mostly associated with uncontrolled and unknown events or stimuli, but interspersed with occasional controlled or at least known (also referred to as time-locked) decision events.

The question arises as to what insight can be extracted from the EEG waveforms prior to, as well as following a known event, more specifically a series of known events, but where the events driving the ERPs in-between the known events, are not known. In section 2.5 the ERP immediately following a known event was discussed and it was posited that much research has been done on this topic and that this type of ERP is reasonably well understood. It is not clear whether the ERP associated with a repeated, similar dichotomous event will have significant commonality with the ERP associated with a sequential, albeit related decision event (as is proposed in this study). However, as the circumstances are different when doing a repeated experiment with only two outcomes, compared to an experiment comprising a series of decision events each of which have no clear immediate outcome, but which together may contribute to an eventual success or failure situation (which it can be argued, is more representative of real-world situations), it is more likely that the ERP immediately following the decision event may differ from event to event based on other variables (such as stress, memory, learning, emotion, cognitive load, focus, personality type, etc.). It is thus proposed that the differences and similarities of the ERPs following a sequence of events, need to be explored.

At the same time, the ERPs preceding a decision event (especially one of many related decision events) also arguably require investigation. However, as the events underpinning each of the ERPs preceding a decision event are unknown, whatever could be extracted from the ERP itself is of little value unless what is causing it is known. Nevertheless, if the ERP waveforms have patterns that repeat themselves across the time space of the sequential experiment, these patterns may prove revealing. If these patterns are combined with some understanding of what the participant was feeling, thinking and experiencing at the time of the experiment (solicited through interviews), then the patterns may become more useful and can be possibly be unpacked in terms of neural correlates such as cognitive load, stress, emotion, memory, insight, attention and learning among other constructs.

## 3.3 Patterns in EEG data

In terms of a pattern in EEG data, ‘pattern’ can be defined as a temporally recurrent series of waveforms in terms of amplitude, shape and intensity. EEG patterns[[9]](#footnote-9) are well-known in clinical circles and are known for being associated with various medical conditions, epilepsy being an example (Andraus, Andraus, & Alves-leon, 2011) as well as encephalopathy (Kaplan & Rossetti, 2011). EEG patterns used in medical settings are well-documented (Gholami Doborjeh, Kasabov, Gholami Doborjeh, & Sumich, 2018; Khanmohammadi, Laurido-Soto, Eisenman, Kummer, & Ching, 2018; Weisdorf, Gangstad, Dunn-Henrikson, Mosholt, & Kjaer, 2018).

However, the use of EEG patterns can not only be found in medical literature. A further search of the literature reveals numerous articles on pattern research within EEG and ERP data (Singer, 2018; Wang, Wang, & Yu, 2018). Brockmeier (2014) for example, notes that analysis of neural data is often based on general pattern recognition methods and he presents a model for pattern recognition of neural data. Blankertz, Lemm, Treder, Haufe, and Müller, (2011) suggest that spatio-temporal patterns and filters can be applied to single-trial[[10]](#footnote-10) ERPs. As indicated by Gu et al. (2018); “Linking brain activation patterns with behavioral choices provides invaluable knowledge about the nature of human decision-making” (Gu et al., 2018, p. 99). Brockmeier, (2014) suggests that by using the methodological approach of averaging time-locked neural responses when calculating ERPs, much of the underlying responses are lost and if any patterns exist, these will be lost by averaging. He further concludes “The signal itself may be the result of multiple unobserved sources impinging on each recording sensor. Averaging does not provide a means to separate the contribution of the other sources, and cannot be used to separate multiple sources for an individual trial” (Brockmeier, 2014, p. 22). This supports the use of a within-trial study and methods such as Fourier Transform or Independent Component Analysis (ICA) analysis rather than a between-trial study.

Patterns can be acquired from between-trial and within-trial sources – the latter also being referred to as single-trial studies. However, much research is focused on latitudinal research where an experiment is repeated across a set number of independent trials to understand the averaged response which, as was mentioned earlier, can be referred to as between-trials design. Within-trial design has been used less often and consists of a series of related trials where one trial could serve as both the result of a stimulus and a precursor to a stimulus which is related to the previous stimulus. In a study by Scherbaum, Fischer, Dshemuchadse and Goschke (2011), within-trial cognitive adjustments by participants were revealed (called sequential conflict adaptation effects [Scherbaum et al., 2011, p. 591]) which would not have produced the same results if an averaging of between-trial had been undertaken.

# USING CHESS AS THE DECISION-MAKING CONTEXT

Chess has had an impact on the field cognitive psychology because of the “experimental and theoretical tools it has provided” (Charness, 1992, p. 4). It has many benefits. It provides a complex, sequential decision-making environment, offering a number of distinct, time-locked, decision-events that can be attached to event-related potentials. As with many such games, chess, by its very nature, involves a dyadic relationship[[11]](#footnote-11). Although not describing the game of chess, the description of the ‘Ultimatum Game’ used in a study by Shaw et al. (2018) gives a description that can be applied to the game of chess “…each individual’s behaviour is simultaneously a consequence of and antecedent to that of their partner’s” (Shaw et al., 2018, p. 1). Shaw et al’s study involved fMRI and found that reciprocal behaviour is associated with neural alignment. The view that there are consequent and antecedent actions suggests the presence of patterns within these actions. This is illustrated in figure 2.

RM = Respondent’s move

CM = Computer’s move



Figure 2: Schematic of chess decisions and where a pattern is expected to occur

Another important advantage of using chess as the context for this study is that there is an internationally acknowledged system of ranking, allowing for heterogenous groups to be obtained – in the case of this study low ranking, middle ranking and high ranking players will be used. There are several rating systems in use, but it is envisioned that this study will make use of the internationally recognised competitive ranking, the *Fédération Internationale des Échecs* ([FIDE](https://en.wikipedia.org/wiki/FIDE)) ranking (“FIDE – World Chess Federation,” n.d.). This is based on the ELO system (“Chess Rating System – the Elo Rating,” n.d.). Games can be played on computer, with games adjusted to the ranking of the player. In addition, there is an acknowledged form of chess called “Blitz chess or “fast” chess which consists of any game less than 10 minutes per player (Chess SA Ratings Bureau, 2018) which is ideally suited to an experimental, computer-based setting.

Chess has been used in numerous neural research studies. The game of chess is an acknowledged environment for studying complex cognitive activities (Silva Junior, Cesar, Rocha, & Thomaz, 2017). A study by Mayeli, Rahmani and Aarabi (2018) investigated the topic of the neural underpinnings of chess expertise using MRI and concluded that in chess, expertise resulted in structural changes in the brain. Parallels with Kahneman’s (2002) intuitive and rational thinking (systems 1 and 2 respectively) in the context of chess, has been made (“Thinking and looking,” 2018). ERPs have been used to study the components related to expertise in chess (Wright, Gobet, Chassy, & Ramchandani, 2013). Additionally, Stepien, Klonowski and Suvorov (2015) investigated EEG analysis models within the game of chess. The validity of using EEG in a chess environment was further shown in a study that used the EEG signal, in conjunction with LORETA software to create spatial cognitive brain mappings for individuals with different proficiency in chess (Rocha, Silva, Cesar, Giraldi, & Thomaz, 2017). A paper written by the same authors and presented at the 6th International Conference on Pattern Recognition Applications and Methods in the same year, included the use of EEG and eye tracking to map neural and eye-tracking patterns when comparing chess proficiency among participants. Chess also has the advantage of providing a series of value-based decisions.

## 4.1 Value-based decision making

A final perspective on the proposed study is that it will take a value-based decision-making approach. This is in contrast to a perceptual decision-making approach, which is where much neural research has been focused (for example, there are three times as many articles on perceptual decision making, than on value-based decision making – both with a neural slant – on the Scopus bibliography). For the sake of the proposed study, value-based decision making can be defined as the decisions based on the subjective analysis of the value in terms of needs that a particular choice will result in for the decision maker, while perceptual decision making can be defined as decision making based on information obtained from the senses. Value-based decision making employs more cognitive load in that a number of abstract principles such as memory, perception of value and morality may come into play.

Recent research into value-based decision making includes the work of Hiser and Koenigs (2018) and Pushkarskaya et al. (2017). The experimental environment proposed for this study – blitz chess (discussed in the next section) – provides a useful environment for testing both value-based decisions (weighing up options between alternatives), as well as perceptual decision making (responding to visual stimuli on screen). However, the study will focus on value-based decisions as the aim of the study is to create a demanding mental challenge (choosing between options under time constraint), to see how the brain responds to these challenges

# INFORMATION GAP

From the above discussion, it is clear that while the literature on the ERP associated with a known, repeated event has been extensively studied, the ERPs preceding and following a sequence of known events has been less extensively studied. An examination of the literature on sequential value-based decisions reveals a relative dearth of articles on the neural activity between events in a sequence of related events, the specific ERPs directly related to the events in question notwithstanding. This lack of research is the information gap that the proposed study will address.

While much neural activity is associated with events that a researcher cannot be aware of or that are uncontrolled, it is arguably feasible to create an experimental environment where a sequence of decisions are (a) related, (b) they are known and can be clearly time-locked, (c) they occur within a very short period of time that contributes to reducing the influence of other exogenous and even endogenous factors or variables that could play an influencing role in the decisions being made, and (d) a controllable laboratory context can be created that will enable the neural activity associated with the neural decision tasks to be explored to identify common and regular patterns should they be found to exist.

# RESEARCH QUESTION

Based on the information gap identified above, the following research question can be postulated: ***Do ERPs associated with a sequence of high-speed, high cognitive involvement, value-based decisions exhibit discernible pre- and post-event patterns?***

# RESEARCH OBJECTIVES

Given the above research question, the following research objectives are proposed.

These can be divided into both primary and secondary objectives and are as follows:

## 7.1 Primary objective

The primary objective for this proposed study can be stated as follows: *To explore the existence of ERP patterns, both spatially and temporally, as well as related physiological responses associated with the sequence of value-based decisions made in chess using EEG, related psychophysiological measurement methods and the subjective insights of the participants.*

The above primary objective can be dissected into several secondary objectives that are outlined below:

## 7.2 Secondary objectives

The following are the proposed secondary objectives for the study:

1. To explore the temporal ERP patterns that may exist in the chess context described above;
2. To explore the spatial ERP patterns that may exist in the chess context described above;
3. To explore the cognitive load correlates associated with the chess context described above;
4. To explore the emotions associated with the decision making linked to the chess context described above, incorporating both the participant’s subjective experience and the neural correlates linked with these emotions;
5. To attempt to identify a moment of realisation (an “AHA” moment) of success or failure associated with the chess context described above, both from a participant’s subjective experience and the neural correlates linked to the moment or realisation.
6. To explore if any found patterns differ between male and female participants
7. Based on the insight gained from the above secondary objectives a descriptive model of the patterns identified in the context above will be constructed.

# RESEARCH METHOD

This is first and foremost an exploratory study using the mixed-methods design of “sequential explanatory strategy” (Creswell, 2009, p. 211). It investigates (i.e. explores) an area of neural decision making that has arguably received limited attention so far, namely sequential, complex, value-based decision making. In exploring this topic, the study proposes to use a controlled laboratory environment (using blitz chess) that focuses attention on the neural patterns driving sequential decision making in a highly constrained experimental and manageable context. In this context it is acknowledged that considerable raw data will be generated and that sophisticated quantitative methods will be used to analyse the data, however the research approach also draws on qualitative input from the participants, expert chess players (discussed below) and the researcher’s own interpretation of the quantitative findings. The quantitative data combined with the qualitative input will be integrated to support the findings associated with the various secondary objectives, justifying the mixed-methods design being proposed.

In order to explore the presence of patterns in pre- and post-ERP as described in the research question, quantitative descriptive statistics and algorithmic computations related to pattern-recognition will be used. At the same time, the possible resultant patterns discovered will be explored and confirmed using qualitative interviews of chess experts and the participating chess players. Not only will qualitative data be obtained, but during the collection of ERP data, GSR and HRV will also be gathered to aid in interpretations. Eye tracking and pupillometry will further provide data underlying the decisions and possible emotions and reasoning associated with these decisions. The reason for combining both quantitative and qualitative data is to better understand the research problem by integrating both quantitative (broad numeric trends) and qualitative (subjective interpretations) data, resulting in a richness of data that could otherwise not be obtained. Although this approach is generally not used in a neurological study, it was felt that significant interpretation of the complex, quantitative results will be required. This interpretation cannot be undertaken in isolation from the participants it claims to study and their subjective experiences may throw additional light on the quantitative results obtained. As an important part of this study will rely on the integration of quantitative and qualitative methods at all levels of the research process (Barnes, 2012), it was felt that a mixed methods design can be justified as it will provide qualitative insights resulting in a more legitimate perspective and interpretation of the quantitative results.

## 8.1 A laboratory setting to test the research question

In order to investigate the research question given above and its related objectives, an experimental context needs to be identified. Chess, specifically ‘blitz’ or ‘fast’ chess, is proposed as the experimental context. Blitz chess involves a sequence of related, value-based decisions that require considerable cognitive engagement, and that together contribute to a clear outcome – that is, either winning or losing the game, analogous to the reward/punishment often associated with decision making in the literature. In addition, high-speed chess incorporates emotions, one or more moments of realisation (of a likely win or loss – the AHA moment alluded to earlier), different stages of engagement (opening game, middle game and end game, each likely requiring different cognitive involvement), as well as a number of clear time-locked events (namely the moves by both players). Blitz chess as an experimental environment also has several positive added features, namely that players interact online with a chess computer that is able to play at the same level of expertise as the participant and to do so algorithmically and emotionlessly, reducing variability in the experiment. Being online and laboratory based, also makes online chess a useful means of gathering psychophysiological data, to support the EEG data being gathered.

## 8.2 Paradigmatic approach

In keeping with the choice of a mixed methods design, a pragmatic paradigm will inform this study. The pragmatic paradigm approach suggests that truth is not based on a duality of reality which rejects either external or internal reality (Creswell, 2009). The emphasis of pragmatist researchers is on the research problem and the use of any methods that could bring understanding of the problem (Mackenzie & Knipe, 2006).

## 8.3 Research process

### 8.3.1 Expert input

The research begins with an extensive literature review that highlights the extent of knowledge around sequential decision making. With the key issues distilled from the literature, the study turns to an expert group comprising four to five top ranked chess players. The study will be explained to them and they will be asked to identify additional constructs that they think may come from this study. This qualitative input will be used to guide the gathering of data and the interpretation of results obtained from the EEG. They will also be asked to suggest areas of caution and to propose questions the eventual participants should be asked about their respective games.

### 8.3.2 Pre-test

Thereafter, the experiment will be planned and extensively tested in a pre-test study. It is believed that extensive testing will be crucial to the success of the study and the pretesting may prove to take longer and be more problematic than the actual experiment itself. Only once the experiment (together with the analysis of the data) is shown to be achievable, will the study move on to the actual experiment.

### 8.3.3 Sample selection

The population for this study consists of chess players with FIDE rankings. For the sample 24 voluntary participants will be recruited using purposive sampling. The criteria for the purposive sampling are indicated in Table 1. These participants will comprise eight top-ranked blitz chess players (four male and four female), eight middle-ranked players (four male and four female) and eight-low ranked players (four male and four female). The exact rankings will be determined after consultation with the expert group. The official FIDE rankings will be used to select players from a closely similar or same competency level. Final participants will be recruited from chess clubs in the vicinity of the university after obtaining permission from the relevant gate keepers. Participants will have the reason for the study explained to them and will be provided with the necessary ethical documentation that they will be requested to sign (see section 3). It is expected that each participant will spend about an hour and half in the lab.

Table 1: Purposive sampling criteria

|  |  |
| --- | --- |
| **Criteria** |  |
| FIDE rankings | This will be implemented to obtain equivalent experience levels.FIDE is an internationally accredited ranking system and will help ensure experiential equivalency within the groups. In addition, each participant will be matched according to the number of games they have played within a specific time frame, the exact time frame and ranking requirements will be decided on in collaboration with the expert group. |
| Male and female participants | In each of the three groups, there will be two male and two female players. There has been some research around the differences between male and female players in the past (Chabris & Glickman, 2006; Gerdes & Gränsmark, 2010; Studer, Scheibehenne, & Clark, 2016). As Howard suggests “Comparing modestly- and highly-practiced individuals can be misleading. Studies should control for differences in number of games played, either by equating males and females on this or by examining differences at the typical rating peak at around 750 games.” (Howard, 2014) |
| Age group | To remove the variable of age, one age-group will be used. This age group will be determined in consultation with the expert group. |
| Availability post-experiment | Participants will be asked if they would be available for further consultations during the analysis stage for the researcher to follow-up on any queries she may have. The requirement to be available is one of the purposive sampling criteria. |

### 8.3.4 Data collection

It is planned that the data collection will take place in a laboratory setting at UNISA’s BMR. The equipment used will consist of a computer on which chess software has been installed. This software is still to be determined but a number of possible programmes have already been sourced and are plentiful. In addition, *iMotions* synchronisation software, *Tobii* eye tracking tools, *Shimmer* galvanic skin response and *B-Alert* EEG hardware will be used. These devices generate the following forms of time-series data:

* EEG waves generated by the brain are measured in microvolts by the B-Alert EEG device, which has 10 channels/electrodes. The electrodes are positioned according to the 10/20 international system mentioned earlier in this proposal. Electromyography data and electrooculography data are also collected by the *B-Alert* and this data is used to remove the artefacts of muscular and ocular ‘noise’ from the EEG data.
* Focus and eye gaze data (X and Y coordinates and fixations [dwell time at various points on the screen]) are recorded via the eye tracking equipment.
* Pupillometry data, which measures the diameter of the pupil in fractions of a millimetre, is recorded together with the eye gaze and fixation data recorded by the eye tracker. Pupillometry data is useful for measuring emotional response and stress.
* Skin conductance data measured in micro Siemens is measured using the Shimmer GSR device. GSR data, as with pupillometry data and heart rate variability (HRV – see below), is useful for measuring emotional response and stress.
* HRV, available from the Shimmer device, measures both heart rate (in beats per minute) and HRV. HRV is the change over time that the heart beats (a more narrow function than heart rate).

All of these data sources are recorded simultaneously using the *iMotions* software platform which not only records these sources in real time, but attaches a millisecond time stamp to the data which enables the data to be accurately synchronised. The *iMotions* platform also records the onscreen activities of the chess game (overlaid with the eye tracking gaze and fixation data), as well as the webcam video that records the participant’s facial responses. The *iMotions* platform presents all of the data in graphic format against a millisecond time frame and makes the same data available in raw form for analysis in other software such as sLoreta, Fourier Transform, WinEEG, MatLab, etc.

The participant will be seated in front of a computer with the chess software loaded and the EEG will be attached to him/her. A pre-game baseline for each participant will be established against which subsequent measures can be measured on an individual basis. Participants will then, in random order, play two 1-minute, two 5-minute and two 10-minute blitz chess games. Between each game, a short, recorded interview will take place to establish their subjective view of the game they just played, whether an AHA moment occurred and whether there were any particular stages in the game where they had a particular awareness of their own thinking processes. The reason for undertaking this interview is to obtain as much insight as possible from the participant’s point-of-view.

During the games, data will be captured from the various psychophysiological tools and ERPs will be isolated according to the moves the participant (and the computer) make. As mentioned earlier, chess involves both consequent and antecedent actions, both of which could lead to ERPs.

A comprehensive analysis of each participant will proceed prior to each new participant being tested. Despite the additional time that will be required to undertake the study on a participant-by-participant basis, it was felt that proceeding in this manner would allow for follow-up questions of the participant while the games were still fresh in memory. By undertaking this immersion in the data at an early stage, this has the added benefit of making analysis more manageable (Green et al., 2007) and will hopefully help with acquiring analytical insight of both the quantitative and qualitative data that has been acquired.

Post-experimental interviews with experts on the participants’ games will be included in the analysis.

## 8.4 Proposed data analysis

The research objectives point to several sources of data. The main source of data is that of the EEG signals being recorded from the various EEG electrodes. There are 14 electrodes on the EEG device that will be used, and therefore 14 signals to consider, each approximately representing the area of the brain over which they are located.

EEG data (generated from each electrode) is time series data, but the data can also be described as a signal, so the field of signal processing has a role to play in the analysis of EEG data. EEG data conforms to a typical waveform and it therefore has an amplitude from the top of the wave to the bottom of the wave where the stronger the signal, the larger the amplitude. As EEG data represents electrical current, the data represents microvolts that are reflected on the Y-axis of the graph depicting the EEG data (the X-axis represents time, t). As the data is measured in microvolts[[12]](#footnote-12), which can either have a positive or a negative charge, the graph will typically have a zero position (representing ‘0’ microvolt or no charge) which can be considered to be the graph’s baseline. The EEG signal thus fluctuates between a positive value (P – the part above the baseline), through the baseline to a negative value (N – the part below the baseline), and back again, over time.

In the proposed study, the focus will be on three parts of the EEG signal. The first part is the one second before and after a decision has been made by the participant. The second part is the one second before and after the computer makes a move. The third part is all the time between these two events. These three parts are repeated from decision to decision (or move to move). The number of moves vary from game to game but the average chess game generally comprises 38 (David, Herik, Koppel, & Netanyahu, 2014, p. 2) to 40 moves (“Chess Statistics,” n.d.).

The first two parts are clearly time-locked to easily discernible events (the participant’s move and the computer’s move). The last part – the in-between part – is associated with a longer time range in which several ERPs may occur, which are not clearly linked to any obvious event. While the literature on pattern recognition in EEG data will be scrutinised for suitable algorithms to identify patterns, the typical patterns that will be sought will be where the wave *amplitude* for a single decision exceeds the average variance across all decisions, for both positive and negative oscillations. This points to the analysis of variance (ANOVA) as a method of analysis. The larger the amplitude, arguably the more intense the thought pattern. It may be appropriate to group the decisions according to opening game, middle game and closing game and see whether in these groups the difference in variance is the same across groups or whether they differ between groups (also an appropriate approach when comparing the genders).

Similarly, the analysis will examine the intensity of waveforms, namely the number of waves that occur per time segment. Intensity is analogous to hertz which represents one cycle per second, and, which in turn, is aligned to the various brain waveforms namely, delta, theta, alpha, beta and gamma. A further focus will be to determine the actual shape of the waveform – this is where pattern recognition and feature extraction algorithms will play a role (such as Fourier Transform, [Kaur & Sharma, 2019]). If a recurring waveform shape can be identified at the various event points, then this waveform shape can be unpacked to learn what it encompasses in terms of the neural decision process. This is where the qualitative data generated from the interviews with participants will come into play.

As far as the period in-between time-locked events is concerned (the part three referred to above), this segment of the EEG data is likely to produce a large number of ERPs that have no clear events associated with them. At the same time, the qualitative interviews may point to mental activities that the participants may identify that they were aware of (e.g. recalling from memory common opening moves, anticipating moves, strategising attacks or defences, mental anguish associated with an obviously bad move, emotional happiness or frustration, insight or inspiration experienced at points throughout the game, etc.) during the period in question. Thus, while it may not be possible to associate *specific* ERPs with *general* mental activity, the signal characteristics for certain relatively broad time periods, such as signal amplitude, signal intensity and even signal frequency (i.e. regularly occurring signal activity), might possibly be linked to mental activities such as cognitive load, emotional spikes, evoked memories, anticipation and other similar activities, as reflected on by the participants in question. This insight will enable further exploration to be undertaken, based on the findings (highlighting the value of combining qualitative and quantitative data as alluded to earlier in this proposal).

Not only will the data be analysed on a temporal basis, but spatial analysis will be used as well. sLoreta (Pascual-Marqui, n.d.) and Brainstorm (“Introduction – Brainstorm,” n.d.) are two well-known neuroimaging software applications that use triangulation of the EEG electrodes to determine approximately where in the brain the neural activity is being generated. Although not as accurate as fMRI, they do provide further insight to determine what part of the brain is involved in the decision making under consideration. This spatial insight brings together the part of the brain generating the EEG signal and the electrode recording the signal and has successfully been used in research mapping brain areas to activity in a chess context (Rocha et al., 2017). In addition to sLoreta and Brainstorm, ICA has successfully been used to provide “enhanced cm-scale resolution of its cortical sources” (Onton, Westerfield, Townsend, & Makeig, 2006, p. 808)

Various established EEG software programs will be used to analyse the data. These include WinEEG and MatLab. The use of these programs and their functioning are well documented in the literature. These programs also provide automated filtering of the EEG data to remove artefacts such as ocular, muscular and heart ‘noise’, which would otherwise corrupt the EEG data.

### 8.4.1 Incorporating and analysing other data

As has been mentioned earlier, other psychophysiological data will be used in this proposed study, namely eye tracking data, pupillometry data, GSR data and heart rate value (HRV) data. The analysis of this data is briefly discussed below:

* Pupillometry, GSR and HRV data (all time-series data, also measured in millisecond time slots), will be combined to provide an indication of the emotional valence underpinning the decision making of participants. This data will be analysed both separately in terms of variance and also correlated with the EEG data together with the qualitative feedback from the participants.
* The eye-tracking data is particularly useful in identifying the focus of attention of the participant. It provides a gaze pattern, broad areas of interest and specific focus areas (i.e. fixations) that can also be correlated with the other sources of data described above.
* Contextual data will be captured in that the entire onscreen interaction with the chess computer will be recorded and will serve as an underlay against which various psychophysiological and EEG responses can be positioned in time.
* Verbal protocols will be conducted with each participant and this qualitative data will be analysed to extract appropriate neural and decision-making themes such as memory/recall, emotion (e.g. frustration and excitement), insight (AHA), stress, strategy thinking, tactical responses, intuitive moving, anticipation etc.
* Observational data. The interactions, facial expressions, comments and other behavioural factors stemming from the participants involvement with the chess game will be captured on video (with permission) and this will serve as reference data to confirm/challenge the qualitative insights generated.

## 8.5 Findings, conclusions and recommendations

Once the data is analysed, the findings will be interpreted and presented. Based on the findings, conclusions and recommendations will be proposed. The sample of participants is relatively small and no inferences about the broad field or population will be able to be made from this study.

# EXPECTED CONTRIBUTION TO KNOWLEDGE

This research is basic research, attempting to investigate patterns in ERPs, triggered by decision making in a specific environment. Any contribution of this study can be seen in terms of the value of basic research.

## 9.1 Basic research

Basic research adds to knowledge, without which there can be no moving forward in science and no understanding of the complexities of human life. It feeds into the more practical ‘applied’ studies.

Basic research is also sometimes called curiosity-driven research (Geuna, 2001) or pure research (Davis, 2014, p. 73) and has been described as an attempt to elaborate on fundamental understanding (Nyeko, 2016, p. 27). It focuses on the testing of theories (Hale, 2011) and generating knowledge which may not always have an immediate practical value but can be used in future research to facilitate practical applications. Cherry (2018) argues that the main difference between basic and applied research is time and that the applicability of basic research is not always immediately evident.

With these definitions in mind, this proposed study incorporates research that can be described as falling in the basic research category. To add to the conundrum, this study spans several disciplines including neuroscience, cognitive psychology, neuroeconomics and specifically, decision-making. It could be argued that this research is examining the mind from the inside rather than traditional psychology which views external manifestation of behaviour and extrapolates that behaviour to an internal cause (Arbib, 2018, p. 116).

## 9.2 Expected contribution

The proposed study explores neural correlates associated with sequential decision making that are not yet clearly understood and hopes to uncover neural EEG patterns that will lead to further research as to how the identified patterns can be used to benefit human cognition and social well-being. Given that much is still not understood about the brain, the aim of the proposed study will be to investigate the neural EEG activity associated with a sequence of related decisions in a time constrained, value-based decision-making context, namely blitz chess.

Pattern recognition of neural activity has in the past proved to be a fruitful activity, leading to brain-computer interface design and resulting in a better understanding of various brain-related activities. Brockmeier, while discussing recurrent patterns in neural data, advocates the investigation of these patterns in order to create a generative model of behaviour over time. This study, in keeping with Brockmeier’s suggestions, is using a sequence of decisions over time which will elicit ERPs and explores the occurrence of patterns (or “recurrent waveform decompositions” [Brockmeier, 2014, p. 170]). Neural pattern recognition is also an important component of Artificial Intelligence (AI) and BCI development.

The importance of decision making was earlier emphasised. Taking a new approach to understanding decision making in terms of neural patterns will add to the discourse on understanding decision making and may eventually be used in understanding, diagnosing and treating mental disorders where decision making is compromised. As suggested by Pushkarskaya: “Systematic investigation of different aspects of decision making, under varying conditions, may shed new light on commonalities between and distinctions among clinical syndromes“ (Pushkarskaya et al., 2017, p. 305)

It should be noted, however, that this study is about chess and from a strict statistical perspective, the findings can only be applied to the context of chess. However, it is hoped that what is learnt from this basic research can influence research in other real-world, high-cognitive, time-constrained, value-based environments such as driving a car, dealing with a tense boardroom situation, trading on the share market, flying an aircraft or even reacting in a human disaster situation.

This study will hopefully be a building block for future studies and theories. As this proposed study falls within the field of psychology, the next section strives to justify the positioning of the study within psychology.

## 9.3 Why is this a psychology study?

Despite the stated contribution of this study, the Department of Psychology at UNISA, within which this study will be undertaken, has a strong social and community-driven focus, with a qualitative bent. Basic neuroscience research does not, at first glance, fit comfortably with the Department’s core research focus. However, it is argued that basic research is the foundation of all subsequent applied and context-driven research, as well as the bed rock of all eventual human, social and community research.

To support the focus on neural decision making, the view of Eagleman (2018) is outlined below:

*“Decision making lies at the heart of everything. … Without the ability to decide we would be stuck in limbo between conflicting desires. We wouldn’t be able to navigate the now or plan for the future. Neuroscience shows you are not an individual. You are made of multiple competing drives and by understanding how choices battle it out in the brain, we can learn to make better decisions for ourselves and for society.”*

The justification of this study within the field of psychology is argued on the grounds that decision making (which traditionally falls within the ambit of cognitive psychology) impacts on all of life’s decisions. It is an innately human activity and good or bad decision making permeates all of humankind’s social activities. Bad decision making can lead to abuse, suicide, violence, bias, failure, stress, and a host of other psychological maladies. Good decision making can lead to happiness, contentment, success, peace, cooperation and a better world. While it is acknowledged that external context as well as process and practice can influence good or bad decision making, decision making is first and foremost a brain activity. To ignore what is happening in the brain and to argue that psychology research begins ‘outside’ of the brain would be a mistake.

The mixed-methods approach taken in this study is one that is not often used in similar studies and suggests that the researcher is looking beyond the usual empirical data that neuroscience favours. To sum up, “empirical knowledge of neurophysiological, electrophysiological, and cognitive phenomena may be integrated in developing theories that link brain activity to psychological function and behaviour” (Nieuwenhuis, Aston-jones, & Cohen, 2005, p. 526).

# EXPECTED LIMITATIONS

There are several limitations that need to be considered, the first and foremost of these is the context that the study is situated in, as was mentioned earlier. Finding neural patterns in decisions made in a blitz chess environment may not necessarily be transferrable to other situations. Despite this, the presence of patterns may suggest that similar patterns can be found in other situations and this could be an area for future research. The ERP results could potentially be the result of other artefacts. To reduce the likelihood of this, qualitative and subjective information will be obtained from participants to understand what their insight was of the occurrences during different stages of the chess games.

Other limitations include:

* The fact that only one age-group is used. Other age groups, given their general life experience, may react and decide differently.
* A small sample size. While neural research often includes small samples, a larger sample could generate more inferable data.
* Dependance on technology. The technology used in neural studies is often temperamental. It is not uncommon for technology to fail because of the factors associated with human peculiarities (very long hair that produces poor EEG data, very sweaty individuals that confound the GSR device, individuals with very nervous dispositions that produce poor data, etc.).

# ETHICAL CONSIDERATIONS

In any study dealing with the human brain, the issue of neuroethics must be taken into account. The term “neuroethics” was first introduced at the beginning of the millennium by the journalist William Saﬁre (Glovin, 2017) who described neuroethics as being a philosophical approach dealing with the moral implications of treatment and research of the brain. In 2016, the Stanford Encyclopedia of Philosophy had this to say about neuroethics:

“*Neuroethics is an interdisciplinary research area that focuses on ethical issues raised by our increased and constantly improving understanding of the brain and our ability to monitor and influence it, as well as on ethical issues that emerge from our concomitant deepening understanding of the biological bases of agency and ethical decision-making.”* (Roskies, 2016, p. 1)

The subject of neuroethics is becoming increasingly important as brain imaging and tools for brain research are becoming more sophisticated and more readily available and the moral implications of this research needs to be addressed in neurological studies. Various organisations such as the International Neuroethics Society (“What is Neuroethics?,” n.d.), government commissioned reports (“Gray Matters: Topics at the Intersection of Neuroscience, Ethics, and Society,” n.d.) and the Human Brain Project lay great emphasis on the ethics of brain research (“Social Ethical Reflective,” n.d.). In particular, the ethical principles espoused in the Declaration of Helsinki, which can be applied to all research that uses human subjects (“World Medical Association Declaration of Helsinki,” 2013), will guide the ethical approach of the researcher in this study (Bošnjak, n.d.).

According to an editorial in the Lancet Neurology, these moral implications are related to several issues in particular: “…an individual’s autonomy (ie, their right to make informed decisions) and best interests, the fairness (or lack of it) in our societies regarding access to experimental diagnostic and treatment methods, and respect for human rights” (The Lancet Neurology, 2018, p. 1). This study will address these concerns in the following ways.

* All instruments that will be used are non-invasive – no signals are being sent to the participants and are not in any way harmful.
* Participants’ will be encouraged to make informed decisions by providing them with information about the purpose of the study and the methods involved in data collection prior to signing an informed consent form. Knowledge of the purpose of the study will not harm the integrity or validity in this research.
* Participants will be sent a follow-up report of the aggregated results of the study for their information should they be interested. Transparency in all matters to do with the research will be stressed and queries will be answered with honesty and integrity.
* The experiment should take no longer than 1½ hours (including verbal protocols). Participants will be informed of this.
* Participants will be required to complete and sign a consent form. See Appendix A.
* Participants will, at all stages, be in control by providing them the opportunity to withdraw from the study unconditionally at any time.
* No unusual ethical considerations are envisaged.
* Participants will at all times be treated with respect and the anonymity of their responses will be assured, both in the quantitative collection of the data and the qualitative collection of the data. The only person privy to the identities of the participants will be the researcher.
* The data will be anonymised from the start, to ensure that the subject’s name is not linked to their data. Only this anonymised data will be analysed.
* As this data may be used for various articles associated with this study, the data will be kept available in a secure form (on a secure, password protected drive) and stored away under lock and key for a period of not more than five years. After which the data will be permanently deleted.

# PROPOSED CHAPTER OUTLINE

The proposed study will comprise seven chapters as suggested below:

## 12.1 Chapter 1: Introduction

Chapter 1 will provide an introduction to the study. A background on neural decision making, ERPs and the research related to these topics will be provided. This chapter will provide the rationale for the study based on the preliminary literature review. The research question, research objectives and research methodology for the study will be discussed.

## 12.2 Chapter 2 Neural decision making

This chapter will provide an overview of neural decision making. Information on the structure of neural networks in the brain, action potentials and the presence of electrical signals in the brain will highlight the applicability of using EEG to measure electrical activity in the brain. Concepts such as Action Potentials and ERPs will be introduced.

## 12.3 Chapter 3: Neural correlates in sequential decision making

Chapter 3 will focus on the neural correlates in sequential decision making. Neural decision-making theories will be introduced such as the drift diffusion model and sequential models of decision making will be presented. The importance of these models to this study will be highlighted. The importance of ERPs to this study will be further established and their value to the exploration of sequential decision making will be underlined.

## 12.4 Chapter 4: Chess as experimental context

Chapter 4 will provide a short background on chess as the experimental context for this study. Previous neural research using chess as the context will be highlighted and the advantages and disadvantages of chess as an experimental context will be elaborated on.

## 12.5 Chapter 5: Research methodology

Chapter 5 will explain the research methodology that this study will follow. The research process followed will be described and the research paradigm, the research approach, the experimental method, the pretesting and the method of analysis will be offered.

## 12.6 Chapter 6: Findings

Chapter 6 will present the findings of the study. The data that is collected will be discussed and analysed.

## 12.7 Chapter 7: Conclusions and recommendations

Chapter 7 will provide the conclusion of the study and further recommendations for the study.

# SUMMARY

The proposed study as outlined above will use EEG and other psychophysiological tools to explore whether any ERPs patterns can be discerned related to decision making during blitz chess games. The value of neural pattern recognition was explained as was the popularity of using EEG as a means to determine underlying neural correlates to certain behaviours. The proposal outlined the information gap, the research question, the research objectives and the proposed research method. Several other issues were addressed, including the expected contribution to knowledge, the expected limitations of the study, ethical considerations and the proposed chapter outline.

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# APPENDIX A

**Participant information sheet and informed consent form**

Ethics clearance reference number: xxxx

31 October 2018

*Title: Exploring Event-Related Potential Patterns in a Chess Environment*

**Dear Prospective Participant**

My name is Christine Bothma and I am doing research with Professor P. Joubert, a Professor in the Bureau of Market Research towards a Master of Arts (Research Consultation) degree at the University of South Africa. We are inviting you to participate in a study entitled Exploring Event-Related Potential Patterns in a Chess Environment.

**WHAT IS THE PURPOSE OF THE STUDY?**

I am conducting this research to find out if patterns exist when making decisions while playing a game of chess. To access these patterns, I am looking at electroencephalogram (EEG) readings and other psychophysiological measurements that are visible when a decision in the form of a chess move has taken place. By undertaking this study, I hope to add to the body of knowledge around neural decision making.

**WHY AM I BEING INVITED TO PARTICIPATE?**

You are being invited to participate as you have a specific FIDE ranking in chess. In addition, as you are a member of a chess club, you are familiar with the game. You either contacted me directly (and thank you for showing interest) or your name was given to me by your Chess Club Master/Secretary as a player who possibly may be interested in taking part in our study. I will be inviting at least eleven other participants of varying FIDE rankings.

**WHAT IS THE NATURE OF MY PARTICIPATION IN THIS STUDY?**

Describe the participant’s actual role in the study.

The study involves playing three games of Blitz chess, twice… (1 minute, 5 minute and 10 minute games) against a computer while I measure the EEG from your scalp, skin response from your fingers and eye movements during the games. I will undertake short interviews after every game where your subjective experiences of the games will prove invaluable. I will require approximately 2 hours of your time with the possibility that there will be a follow-up interview of approximately an hour at a future date

**CAN I WITHDRAW FROM THIS STUDY EVEN AFTER HAVING AGREED TO PARTICIPATE?**

Participating in this study is voluntary and you are under no obligation to consent to participation. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a written consent form. You are free to withdraw at any time and without giving a reason. Unless you specifically request otherwise, all data collected is confidential and will be not be disseminated in such a way that you are linked to the data collected.

**ARE THEIR ANY NEGATIVE CONSEQUENCES FOR ME IF I PARTICIPATE IN THE RESEARCH PROJECT?**

All measurements are using non-invasive devices. In other words, I will be recording your reactions but at no stage am I sending signals to you through my devices.

**WILL THE INFORMATION THAT I CONVEY TO THE RESEARCHER AND MY IDENTITY BE KEPT CONFIDENTIAL?**

You have the right to insist that your name will not be recorded anywhere and that no one, apart from the researcher and identified members of the research team, will know about your involvement in this research. Your data will be given a code number or a pseudonym and you will be referred to in this way in the data, any publications, or other research reporting methods such as conference proceedings.

Your data may be reviewed by people responsible for making sure that research is done properly, including the transcriber, external coder, and members of the Research Ethics Review Committee. Nevertheless, records that identify you will be available only to people working on the study, unless you give permission for other people to see the records.

A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

**HOW WILL THE RESEARCHER(S) PROTECT THE SECURITY OF DATA?**

Hard copies of your answers will be stored by the researcher for a minimum period of five years in a locked cupboard/filing cabinet at the researcher’s premises for future research or academic purposes; electronic information will be stored on a password protected computer. Future use of the stored data will be subject to further Research Ethics Review and approval if applicable.

**WILL I RECEIVE PAYMENT OR ANY INCENTIVES FOR PARTICIPATING IN THIS STUDY?**

Unfortunately, no incentive to participate is being offered. Should any transport costs be involved in participating in this study, these will be addressed on an individual basis.

**HAS THE STUDY RECEIVED ETHICS APPROVAL**

This study has received written approval from the Research Ethics Review Committee of the *[identify the relevant ERC],* Unisa. A copy of the approval letter can be obtained from the researcher if you so wish.

**HOW WILL I BE INFORMED OF THE FINDINGS/RESULTS OF THE RESEARCH?**

If you would like to be informed of the final research findings, please contact Christine Bothma on 0836765637 or email chris@ireality.co.za. The findings are accessible for 1 year after the study is completed.

Should you require any further information or want to contact the researcher about any aspect of this study, please contact Christine Bothma, 0836765637 or chris@ireality.co.za.

Should you have concerns about the way in which the research has been conducted, you may contact Professor Joubert, joubejpr@unisa.ac.za, (012) 4298086. Contact the research ethics chairperson of the College of Human Sciences Research Ethics Committee, Professor P Kruger (012) 429 6235, krugep@unisa.ac.za if you have any ethical concerns.

Thank you for taking time to read this information sheet and for participating in this study.

Thank you.



Christine Bothma

**CONSENT TO PARTICIPATE IN THIS STUDY**

I, \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (participant name), confirm that the person asking my consent to take part in this research has told me about the nature, procedure, potential benefits and anticipated inconvenience of participation.

I have read (or had explained to me) and understood the study as explained in the information sheet.

I have had sufficient opportunity to ask questions and am prepared to participate in the study.

I understand that my participation is voluntary and that I am free to withdraw at any time without penalty (if applicable).

I am aware that the findings of this study will be processed into a research report, journal publications and/or conference proceedings, but that my participation will be kept confidential unless otherwise specified.

I agree to the recording of the chess game and interviews.

I have received a signed copy of the informed consent agreement.

Participant Name & Surname………………………………………… (please print)

Participant Signature……………………………………………..Date…………………

Researcher’s Name & Surname………………………………………(please print)

Researcher’s signature…………………………………………..Date…………………

1. A millisecond is one-thousandth of a second [↑](#footnote-ref-1)
2. Justification for the use of chess is provided later in this proposal [↑](#footnote-ref-2)
3. As at 28 July 2018 [↑](#footnote-ref-3)
4. As at 31 July 2018 [↑](#footnote-ref-4)
5. An action potential is a sufficient rise or fall created when a difference potential threshold is reached across a cellular membrane. See section 2.4 for more detail. [↑](#footnote-ref-5)
6. See section 2.3 for more detail. [↑](#footnote-ref-6)
7. It has been argued that when a researcher introduces a sensory rather than a cognitive stimulus, then the researcher is accessing an evoked potential (Hruby & Marsalek, 2003) rather than an ERP. Evoked potentials are often used in clinical settings. [↑](#footnote-ref-7)
8. This is also sometimes called the P300. This component and others will be discussed in a later chapter [↑](#footnote-ref-8)
9. The most common type are called “periodic patterns” [↑](#footnote-ref-9)
10. Single-trial ERPs do not use an averaging paradigm over a large number of trials. Instead, variance within participants (Pernet, Sajda, & Rousselet, 2011) and spatio-temporal patterns (Blankertz et al., 2011) are considered. [↑](#footnote-ref-10)
11. The fact that in this study, one of the participants in this relationship is a computer could be relevant from a social relationship viewpoint. [↑](#footnote-ref-11)
12. A microvolt is one millionth of a volt. [↑](#footnote-ref-12)