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TESTING THE COGNITIVE IMPLICATIONS OF SYMBIOTIC HUNTING TECHNOLOGIES: 
A PILOT NEUROLOGICAL APPROACH

by

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Summary of the study

Thus far, the earliest convincing evidence for the production and use of bow-and-arrow technology has been associated with *Homo sapiens* who lived ~64 ka in southern Africa. In contrast to a single-component wooden spear or a composite stone-tipped spear, bow-and-arrow utilisation – where one composite tool is required to effectively use another – could signify higher levels of cognitive complexity and behavioural flexibility. Lombard and Haidle (2012) postulate that a novel cognitive component is evident in technological symbiosis, i.e., the ability to focus simultaneously and actively on manipulating a complementary set of tools that are independent from one another, but are used as an effective unit to obtain a single goal. For example, when a bow is used to fire an arrow to obtain meat. In the current pilot study, I investigated the validity of Lombard and Haidle’s (2012) hypothesis of technological symbiosis from a neurological perspective. Electroencephalography (EEG) equipment recorded cortical activity (within the parietal, frontal midline and orbitofrontal cortices), when each of the participants \(n. = 4\) engaged in three non-symbiotic and symbiotic tasks. The purpose of the pilot experiment was to measure levels of cortical activity with non-symbiotic and symbiotic tool use in an attempt to assess whether greater ‘neural effort’ was needed for the symbiotic tasks. These results suggest that executive functions (attention, active-inhibition, context updating, reinforcement learning and memory rehearsal) were enhanced when the participants engaged in the symbiotic bow-and-arrow task, as opposed to the non-symbiotic spear task. Furthermore, an increase in white matter (found within the prefrontal cortex), as opposed to changes in brain structure size, might be responsible for the complex executive functions that are identified in our species. Future research on the effects that task practice has on cortical dynamics (patterns of cortical activity) might be beneficial – for instance, it might help us understand the ways in which neural pathways are restructured, rewired or altered with repeated exposure to cognitively demanding activities.
CHAPTER ONE: INTRODUCTION
1.1. Background to developments in archaeological theory and method 2
1.2. Bow-and-arrow technology as proxy for technological symbiosis 4
1.3. Problem statement 5
1.3.1. The resting conditions hypothesis 6
1.3.2. The cognitive activation conditions hypothesis 7
CHAPTER TWO: NEUROLOGICAL COMPONENTS AND BEHAVIOURAL PROXIES FOR COMPLEX COGNITION IN THE MIDDLE STONE AGE CONTEXTS OF SOUTHERN AFRICA
2.1. Introduction 9
2.2. Theories on complex cognition 9
2.3. Neurological components involved in complex cognition 10
2.4. Symbolically mediated behaviour as proxy for complex cognition 11
2.4.1. Shell beads 12
2.4.2. Engravings 14
2.4.3. Critique of symbolically mediated behaviour as proxy for complex cognition 17
2.5. Domestic behaviour as proxy for complex cognition 18
2.5.1. Plant bedding 18
2.5.2. Critique of domestic behaviour as proxy for complex cognition 19
2.6. Technologically complex behaviour as proxy for complex cognition 20
2.6.1. Heat treatment of rocks for knapping 20
2.6.2. Composite tools 22
2.6.3. Compound-adhesive manufacture 23
2.6.4. Snares 23
4.5.1. The experimental conditions 52
4.5.2. The experimental setting 53
4.5.3. Pre-trial runs 53
4.5.4. The actual experiment 54
4.6. Data analysis 57
4.6.1. Preparing data for further analysis 57
4.6.2. Transforming the data 58
4.6.3. Extracting mean power values 59
4.6.4. Statistical analysis 59
4.7. Ethical Considerations 60
4.8. Conclusion 60
CHAPTER FIVE: RESULTS 61
5.1. Introduction 61
5.2. Descriptive statistics 61
5.2.1. Cortical activity across the parietal site 62
5.2.2. Cortical activity across the frontal midline site 70
5.2.3. Cortical activity across the orbitofrontal site 78
5.3. Inferential statistics 86
5.3.1. The resting or control tasks 86
5.3.2. The cognitive activation tasks 86
5.4. Conclusion 88
CHAPTER SIX: DISCUSSION AND CONCLUDING REMARKS 89
6.1. Introduction 89
6.2. The resting conditions 89
6.2.1. Analysing the eyes-closed task and the eyes-open task 91
6.3. The cognitive activation conditions 92
6.3.1. The chisel task versus the chisel-and-hammer task 93
6.3.1.1. The chisel task (non-symbiotic) 93
6.3.1.2. The chisel-and-hammer task (symbiotic) 94
6.3.1.3. Analysing the task set results 96
6.3.2. The plucking task versus the stroking task 96
6.3.2.1. The plucking task (non-symbiotic) 96
6.3.2.2. The stroking task (symbiotic) 97
6.3.2.3. Analysing the task set results 98
6.3.3. The spear task versus the bow-and-arrow task

6.3.3.1. The spear task (non-symbiotic) 98

6.3.3.2. The bow-and-arrow task (symbiotic) 99

6.3.3.3. Analysing the task set results 101

6.4. Symbiotic hunting technologies from the Middle Stone Age contexts of southern Africa and their neurological implications 101

6.5. Limitations of the study 105

6.5.1. The artificiality of the laboratory setting 105

6.5.2. Participant sample size 106

6.5.3. Procedural factors 106

6.5.4. Methodological factors 106

6.5.5. Summary of limitations 107

6.6. Concluding remarks 107

6.7. Future research 109

REFERENCES 110

List of tables

Table 2.1: Engraved artefacts from Middle Stone Age contexts in southern Africa 15

Table 5.1: Absolute mean power (μV²) for the 3 epochs during the eyes-closed task 62

Table 5.2: Absolute mean power (μV²) for the 3 epochs during the eyes-open task 63

Table 5.3: Absolute mean power (μV²) for the 3 epochs during the chisel task 64

Table 5.4: Absolute mean power (μV²) for the 3 epochs during the chisel-and-hammer task 65

Table 5.5: Absolute mean power (μV²) for the 3 epochs during the plucking task 66

Table 5.6: Absolute mean power (μV²) for the 3 epochs during the stroking task 67

Table 5.7: Absolute mean power (μV²) for the 3 epochs during the spear task 68

Table 5.8: Absolute mean power (μV²) for the 3 epochs during the bow-and-arrow task 69

Table 5.9: Absolute mean power (μV²) for the 3 epochs during the eyes-closed task 70
Table 5.10: Absolute mean power ($\mu V^2$) for the 3 epochs during the eyes-open task 71

Table 5.11: Absolute mean power ($\mu V^2$) for the 3 epochs during the chisel task 72

Table 5.12: Absolute mean power ($\mu V^2$) for the 3 epochs during the chisel-and-hammer task 73

Table 5.13: Absolute mean power ($\mu V^2$) for the 3 epochs during the plucking task 74

Table 5.14: Absolute mean power ($\mu V^2$) for the 3 epochs during the stroking task 75

Table 5.15: Absolute mean power ($\mu V^2$) for the 3 epochs during the spear task 76

Table 5.16: Absolute mean power ($\mu V^2$) for the 3 epochs during the bow-and-arrow task 77

Table 5.17: Absolute mean power ($\mu V^2$) for the 3 epochs during the eyes-closed task 78

Table 5.18: Absolute mean power ($\mu V^2$) for the 3 epochs during the eyes-open task 79

Table 5.19: Absolute mean power ($\mu V^2$) for the 3 epochs during the chisel task 80

Table 5.20: Absolute mean power ($\mu V^2$) for the 3 epochs during the chisel-and-hammer task 81

Table 5.21: Absolute mean power ($\mu V^2$) for the 3 epochs during the plucking task 82

Table 5.22: Absolute mean power ($\mu V^2$) for the 3 epochs during the stroking task 83

Table 5.23: Absolute mean power ($\mu V^2$) for the 3 epochs during the spear task 84

Table 5.24: Absolute mean power ($\mu V^2$) for the 3 epochs during the bow-and-arrow task 85

Table 5.25: Absolute mean power ($\mu V^2$) statistical differences between the eyes-closed task and the eyes-open task at the various sites 86

Table 5.26: Absolute mean power ($\mu V^2$) statistical differences between the chisel task and the chisel-and-hammer task at the various sites 86

Table 5.27: Absolute mean power ($\mu V^2$) statistical differences between the plucking task and the stroking task at the various sites 87
Table 5.28: Absolute mean power ($\mu V^2$) statistical differences between the spear task and the bow-and-arrow task at the various sites

List of figures

Figure 2.1: Geographic locations of the southern African Middle Stone Age sites mentioned in Section 2.4 12

Figure 2.2: Geographic locations of the southern African Middle Stone Age sites mentioned in Section 2.5 18

Figure 2.3: Geographic locations of the southern African Middle Stone Age sites mentioned in Section 2.6 21

Figure 3.1: Baddeley’s Working Memory Model (modified by Coolidge & Wynn 2009) 30

Figure 3.2: Brain areas mentioned in the revised version of the Working Memory Model 30

Figure 3.3: Brain areas that were recorded in the current EEG study 33

Figure 3.4: Brain areas involved in the working memory processes mentioned in Section 3.4.3 37

Figure 3.5: Brain areas involved in processing visual stimuli from Section 3.4.3.1 38

Figure 3.6: Brain areas involved in the praxis movements mentioned in Section 3.4.3.4 41

Figure 3.7: Brain areas involved in reward processing from Section 3.4.3.12 45

Figure 4.1: The electro-cap 49

Figure 4.2: The 10-20 system of electrode placement 50

Figure 4.3: The progression of the experiment 52

Figure 4.4: The chisel task 55

Figure 4.5: The chisel-and-hammer task 55

Figure 4.6: The plucking task 56
Figure 4.7: The stroking task 56
Figure 4.8: The spear task 56
Figure 4.9: The bow-and-arrow task 57

Figure 5.1: Graph representing variation in the mean power ($\mu V^2$) during the eyes-closed task 62
Figure 5.2: Graph representing variation in the mean power ($\mu V^2$) during the eyes-open task 63
Figure 5.3: Graph representing variation in the mean power ($\mu V^2$) during the chisel task 64
Figure 5.4: Graph representing variation in the mean power ($\mu V^2$) during the chisel-and-hammer task 65
Figure 5.5: Graph representing variation in the mean power ($\mu V^2$) during the plucking task 66
Figure 5.6: Graph representing variation in the mean power ($\mu V^2$) during the stroking task 67
Figure 5.7: Graph representing variation in the mean power ($\mu V^2$) during the spear task 68
Figure 5.8: Graph representing variation in the mean power ($\mu V^2$) during the bow-and-arrow task 69
Figure 5.9: Graph representing variation in the mean power ($\mu V^2$) during the eyes-closed task 70
Figure 5.10: Graph representing variation in the mean power ($\mu V^2$) during the eyes-open task 71
Figure 5.11: Graph representing variation in the mean power ($\mu V^2$) during the chisel task 72
Figure 5.12: Graph representing variation in the mean power ($\mu V^2$) during the chisel-
Figure 5.13: Graph representing variation in the mean power ($\mu V^2$) during the plucking task.

Figure 5.14: Graph representing variation in the mean power ($\mu V^2$) during the stroking task.

Figure 5.15: Graph representing variation in the mean power ($\mu V^2$) during the spear task.

Figure 5.16: Graph representing variation in the mean power ($\mu V^2$) during the bow-and-arrow task.

Figure 5.17: Graph representing variation in the mean power ($\mu V^2$) during the eyes-closed task.

Figure 5.18: Graph representing variation in the mean power ($\mu V^2$) during the eyes-open task.

Figure 5.19: Graph representing variation in the mean power ($\mu V^2$) during the chisel task.

Figure 5.20: Graph representing variation in the mean power ($\mu V^2$) during the chisel-and-hammer task.

Figure 5.21: Graph representing variation in the mean power ($\mu V^2$) during the plucking task.

Figure 5.22: Graph representing variation in the mean power ($\mu V^2$) during the stroking task.

Figure 5.23: Graph representing variation in the mean power ($\mu V^2$) during the spear task.

Figure 5.24: Graph representing variation in the mean power ($\mu V^2$) during the bow-and-arrow task.
CHAPTER ONE: INTRODUCTION

Two types of Stone Age hunting technologies are defined by Lombard and Phillipson (2010), namely hand-delivered weaponry and mechanically-projected weaponry. Hand-delivered weaponry, such as thrusting spears, does not require intermediate technology (Lombard & Phillipson 2010; Wadley 2010a). However, mechanically-projected weaponry requires exosomatic energy (stored in a bow or a spearthrower) to propel the projectile (Lombard & Phillipson 2010; Wadley 2010a). According to Lombard and Haidle (2012) mechanically-projected weaponry, such as the bow and arrow – where one composite tool is required to effectively use another – could signify higher levels of cognitive complexity and behavioural flexibility in comparison to hand-delivered weaponry. These researchers postulate that a novel cognitive component is evident in technological symbiosis, i.e., the ability to use a complementary set of tools that are separate from one another, yet interdependent (Lombard & Haidle 2012). For example, when a bow is used to fire an arrow to obtain meat (Lombard & Haidle 2012). I will attempt to investigate the validity of Lombard and Haidle’s (2012) hypothesis of technological symbiosis from a neurological perspective.

Electroencephalography (EEG) equipment will be used to record levels of cortical activity with non-symbiotic and symbiotic tool use as defined by Lombard & Haidle (2012) (Refer to Section 1.3 for more on this). The research question is: ‘does the use of symbiotic technologies indicate an increase or change in cortical activity in comparison to non-symbiotic tool use?’ The current pilot study is the first attempt at applying neurological research methods to this particular question.

The primary objective is to establish a method that can record differences (if any) in cortical activity during two tasks: 1) using tools non-symbiotically, and 2) with symbiotic tool use. Within a larger framework, the study aims to explore the potential uniqueness of Homo sapiens in their level of cognitive complexity. For example, bow-and-arrow technology (representing the concept of symbiotic technologies) has thus far only been identified in our species (Shea & Sisk 2010; Villa & Soriano 2010), and current evidence suggests that arrows (tipped with either stone and/or bone), and by inferences bows, were used from ~64 ka at South African sites, such as Sibudu Cave and Umhlatuzana (Backwell et al. 2008; Bradfield & Lombard 2011; Lombard 2011; Lombard & Phillipson 2010; Wadley & Mohapi 2008). Bow-and-arrow technology serves as proxy for the concept of technological symbiosis, which can vary in complexity, for example, using a simple chisel-and-hammer set or a complicated harpooning system (Lombard & Haidle 2012). Using the EEG method, it is predicted that I
should be able to assess whether using tools symbiotically requires more advanced cognitive functions than non-symbiotic technologies, and perhaps whether specific symbiotic tasks are more cognitively complex than others. Prior to discussing the theoretical and methodological framework of the current study, I present some theoretical developments in the field of archaeology that led to the cognitive approach to archaeology.

1.1. Background to developments in archaeological theory and method

Developments in archaeological theory and practice have influenced the ways in which archaeologists interpret behaviours from the evolutionary past. The emergence of cognitive archaeology is a direct product of this trend – it represents enriched ways of interpreting the archaeological record from a cognitive perspective. In the last decade, there has been further progress in this field of study. For example, archaeologists, who focus on the Middle Stone Age contexts of southern Africa, have expanded knowledge on the evolutionary development of the human mind and/or on the theoretical frameworks concerning human cognition (refer to Henshilwood et al. 2009; Henshilwood & Dubreuil 2011; Lombard 2012; Lombard & Haidle 2012; Wadley 2010a, 2013; Wadley et al. 2009; Wurz 2012 for examples).

The culture history paradigm was dominant in American archaeology from 1910 to 1960 (Binford 1964; Browman & Givens 1996; Caldwell 1959; Flannery 1967). Pioneers of the culture history paradigm established the first body of methods that were used by American archaeologists to derive meaning from the archaeological record (Dunnell 1978; Lyman et al. 1997). Archaeologists at the time were interested in reconstructing the ‘culture history’ of the past and used stratigraphic analysis to assign relative dates to the strata and its cultural contents – generating a timeline of the remains (Lyman & O’Brein1998). The founders of the culture history approach were able to identify variations in cultural remains over time, but they did not attempt to explain the underlying reasons for these changes. In contrast to conventional thought, Childe (1950) applied social and economic models to interpret trends, changes and/or variations in material culture across archaeological sites. He used a Marxist approach as an analytical tool to reconstruct social environments from the evolutionary past (Trigger 1989).

Binford (1964) argued that using social theories, such as Marxism, to explain variations in material culture results in circular, and thus, subjective reasoning. He decided to adopt a
hypothetico-deductive model, in which supportable hypotheses were used to explain the archaeological record. A number of Binford’s theories became central to the theoretical development of the processual approach. The processual school of thought incorporates a cultural evolutionist framework – for instance, it excludes phenomena such as beliefs and experiences, and instead suggests that culture is a consequence of adaptations to external catalysts (see White 1959). For example, environmental events contribute towards changes in subsistence strategies, paleodemographics and diets (White 1959). The processual paradigm, however, has been criticised for studying behavioural stimuli and not the minds responsible for eliciting these responses (Whitley 1992).

In the late 1970s, the post-processual movement emerged in response to the traditional processual approach. The processual approach was criticised by post-processualists for discouraging ‘paleopsychology’ and for incorporating a positivist view of science (Whitley 1992). In contrast, post-processualists use hermeneutic interpretation to understand the beliefs, motives and intents of people who lived in the past (Hodder 1987). Post-processualists, however, have been criticised for using an interpretative approach to explain the archaeological record, i.e., they rely on their own subjective experiences to situate themselves within the physical and social contexts of the distant past (Whitley 1992).

A new theoretical approach emerged in the 1980s, known as cognitive archaeology. Cognitive archaeology refers to the evolutionary development of cognition (the mental processing of information by which understanding and knowledge is developed). The pioneers of cognitive archaeology argued that post-processualism represents ‘personal likes’ and thus inferences were based on individual opinions (Bell 1987). During the late 1980s, however, a number of mind-related studies started including aspects of the processual and post-processual approaches to assist with scientific method and heuristic research method (refer to Whitley 1992). As a result, theories and methods are often applied from a number of academic domains (i.e., linguistics, cognitive psychology, philosophy of mind, neuropsychology and/or archaeology) to generate evidence of human cognitive evolution (see Wynn 2002 for an example).

The theoretical and methodological differences within and between disciplines has led to the emergence of several frameworks (Garofoli & Haidle 2013; Wynn 2002). Cognitive neuroscience, for example, is used by Coolidge and Wynn (2005) as the foundation of interpretative concepts, such as working memory, to explain the features of human cognition.
(see Wynn & Coolidge 2011; Wynn et al. 2009). Other frameworks range from evolutionary psychology (Mithen 1996) to computational theory (Barnard 2010; Barnard et al. 2007). Only a handful of studies, however, have integrated evolutionary archaeology and/or neuroscientific approaches in an attempt to understand aspects of the evolution of cognition in the human lineage (for examples see Stout & Chaminade 2007; Stout et al. 2008; Stout et al. 2000; Uomini & Meyer 2013). Thus far, neurological studies have not tested Lombard and Haidle’s (2012) premise of technological symbiosis and/or the neurological components that might be involved in using symbiotic hunting technologies, such as the bow and arrow that could date from ~64 ka at South African sites, such as Sibudu Cave and Umhlatuzana (Backwell et al. 2008; Bradfield & Lombard 2011; Lombard 2011; Lombard & Phillipson 2010; Wadley & Mohapi 2008).

1.2. Bow-and-arrow technology as proxy for technological symbiosis

Cognigrams are used by Lombard and Haidle (2012) to reconstruct the effective chains for the production-and-use sequences of a simple wooden spear, a composite stone-tipped spear, and a bow-and-arrow set. In the study, the Stone Age hunting technologies were distinguished from each other in terms of simple, advanced and amplified modularisation (Lombard & Haidle 2012). Here, modularity focuses on conceptualisation, perceptions, planning and the resulting actions, without attempting to provide a link with theories that expand on the neurological structure of the mind (Lombard & Haidle 2012).

An example of simple modularisation is the single-unit or unhafted wooden spear (Lombard & Haidle 2012), that could have been produced by Homo Heidelbergensis ~400 ka (Thieme 1997). Advanced conceptual and technological modularisation is represented by composite tool technology (Lombard & Haidle 2012), which includes stone-tipped spears that were knapped and hafted onto handles of wood or bone with plant gum, cords and sinews at ~285 ka in sub-Saharan Africa (e.g., McBrearty & Tryon 2005). Knapping a simple stone tool could be taught by demonstration (e.g., Wadley 2010a), but the complete composite tool represents an innovative concept – independent components are combined together and their qualities go beyond those of the original materials (Lombard & Haidle 2012). Composite tools thus reflect a development towards advanced technological, behavioural and cognitive flexibility and an expansion in problem-solution distance (Lombard 2012; Lombard & Haidle 2012). Amplified conceptual, technological and behavioural modularisation, however, is
evident in the manufacture and utilisation of a bow-and-arrow set. In comparison to the production-and-use sequence of a single or a composite spear (representing non-symbiotic technologies), the bow and arrow’s problem-solution distance and operational sequence is extended in both duration and complexity (Lombard 2012; Lombard & Haidle 2012).

It is neither the production nor the utilisation of an individual bow or arrow that is cognitively more demanding, but rather the thought-and-action processes involved in conceptualising, producing and using two tools as an effective unit (Lombard 2012; Lombard & Haidle 2012). In the study, Lombard and Haidle (2012) postulate that a novel cognitive component is evident in technological symbiosis – where the mind must focus simultaneously and actively on the manipulation of a set of separate yet interdependent tools that are used together for a single purpose – for instance, when a bow is used to fire an arrow to obtain meat. Based on the results obtained from Lombard and Haidle’s (2012) study, I tentatively suggest that Homo sapiens, who lived in southern Africa ~64 ka, possessed advanced planning and problem solving capabilities. Planning and problem-solving are two traits that Wynn and Coolidge (2011) describe as prerequisites for ‘modern’ human thinking.

The research methods that are used by Lombard and Haidle (2012) allow us to evaluate the cognitive and behavioural capabilities of tool manufacture and use from an unbiased perspective. They do not, however, attempt to assess the cognitive or behavioural implications of symbiotic tool use from a neurological perspective (Lombard & Haidle 2012). Furthermore, Ambrose (2001) and Wynn (2002) mention that brain expansion and technological elaboration are defining features of cognitive evolution, yet their relationship remains controversial and poorly understood due to a lack of experimental work that incorporates neurological research methods.

1.3. Problem statement

From a neurological perspective, I will attempt to investigate the validity of Lombard and Haidle’s (2012) hypothesis of technological symbiosis using an electroencephalography (EEG). The participants will engage in two resting conditions (an eyes-closed task and an eyes-open task), and six cognitive activation conditions (three sets of non-symbiotic and symbiotic tasks) for a duration of one minute per task. The first non-symbiotic and symbiotic set includes using a chisel non-symbiotically versus a chisel and hammer being used as an
effective unit. The second set entails plucking a bow non-symbiotically and stroking the bow symbiotically with an arrow. Finally, the participants will throw a spear non-symbiotically and use a bow-and-arrow symbiotically. EEG equipment will be used to measure voltage fluctuations in the brain during the above conditions and tasks, making it possible to deduce the rate at which neurons fire (mathematically expressed as power) with non-symbiotic and symbiotic task execution.

To assess potential differences in cognitive complexity, activity in the parietal, frontal midline and the orbitofrontal cortex will be recorded concurrently. The primary reason for choosing each of these brain areas is because of their mechanistic role, i.e., these cortices are activated during tasks that necessitate visual working memory processes. The parietal cortex is involved in selecting and maintaining perceptual information into working memory (Corbetta & Shulman 2002; Xu & Chun 2009), the frontal midline cortex is needed for sustained and internal attention (Aftanas & Golochekine 2001), and the orbitofrontal cortex plays an important role in decision-making (Rolls & Grabenhorst 2008; Schoenbaum et al. 2006), processing emotional information (Wallis 2007), and working memory processes (Barbey et al. 2011). From a neurodevelopmental perspective, the brain might have evolved in the following sequence: 1) the parietal cortex, 2) the frontal midline cortex, and 3) the orbitofrontal cortex. Therefore, more complex cognitive functions might be attributed to the more evolutionary advanced areas of the brain, such as the orbitofrontal cortex (Leisman et al. 2012).

1.3.1. The resting conditions hypothesis

Switching from the eyes-closed to the eyes-open task might lead to changes in cortical activity, because of the differences in task requirements (see Marx et al. 2004) (see Section 3.2 for more on delta, theta, alpha and beta activity). Based on previous EEG research (refer to Section 3.4.2), the following hypothesis are put forward: when the participants switch from the eyes-closed task to the eyes-open task, there might be an increase in parietal delta activity (needed for focused attention on visual stimuli), frontal midline delta activity (internal attention could be needed to process incoming sensory information), parietal theta activity (to process visual input), parietal alpha activity (involved in perceptual and attentional processes), parietal beta activity (associated with attention-related modulation of visual processing), and frontal midline beta activity (might be necessary for attention and/or sensory awareness). In addition, there is little to no research on orbitofrontal cortical activity during
the eyes-closed and the eyes-open task. Based on the mechanistic function of the orbitofrontal cortex (i.e., a number of neurons fire when visual information is processed), orbitofrontal brain waves might increase when participants switch from the eyes-closed task to the eyes-open task. When switching from the eyes-closed task to the eyes-open task, there could either be an increase or decrease in frontal midline theta activity (dependent on the participant’s mental state). Finally, frontal midline alpha activity might be inhibited when the participants open their eyes, i.e., to assist with cortical inhibition (e.g., Schürmann & Basar 2001), but further research is needed on this. I aim to generate further data regarding the resting conditions hypothesis with this study.

1.3.2. The cognitive activation conditions hypothesis

Switching from the non-symbiotic tasks to the symbiotic tasks could result in an increase in parietal, frontal midline and orbitofrontal cortical activity. If cortical activity is enhanced with symbiotic tool use (as opposed with non-symbiotic use), it might imply that greater ‘neural effort’ was needed. For example, an increase in neural activation indicates that task complexity correlates with the recruitment of additional neural mechanisms (see Rietschel et al. 2012). Neural mechanisms refer to structures (i.e., neurons, neural circuits, cortical areas of the brain, neurotransmitters and hormones) that regulate behaviour. In contrast to other non-symbiotic and symbiotic tasks, each of the participants might need to remember additional action sequences for the bow-and-arrow task. According to Seo and colleagues (2012), for example, archery necessitates the integration of working memory components to process visuo-spatial information. Thus, engaging in the bow-and-arrow task might result in greater frequency power in the more evolutionary advanced areas of the brain, such as the orbitofrontal cortex, I aim to assess this suggestion using EEG.

Furthermore, because more than one cortical area will be measured concurrently, I will be able to assess the spread of activity across the brain. The symbiotic tasks might be distinguished from the non-symbiotic tasks by a spread of synchronous activity across the fronto-parietal networks. For example, an increase in communication within and between cortical areas is needed for cognitively complex task execution (Rietschel et al. 2012). With short-term practice of the non-symbiotic tasks and the symbiotic tasks, there might be an increase or decrease in cortical activity within the parietal, frontal midline and orbitofrontal sites recorded. It has been proposed that a decline in cortical activity signifies an improvement in information-processing efficiency (Deeny et al. 2003), and/or that an
increase in cortical activity reflects the recruitment of additional neural mechanisms or the strengthening of synaptic connectivity within a specific area of the brain (Poldrack 2000). In the chapter that follows, I will provide examples of behaviours in the Middle Stone Age contexts of southern Africa that currently serve as proxies for complex cognition and their neurological implications.
CHAPTER TWO: NEUROLOGICAL COMPONENTS AND BEHAVIOURAL PROXIES FOR COMPLEX COGNITION IN THE MIDDLE STONE AGE CONTEXTS OF SOUTHERN AFRICA

2.1. Introduction

The material culture from the archaeological record of southern Africa has received much attention as it seems to reflect a capacity for complex cognition – implying that Middle Stone Age people who lived in the region, between ~100 ka and 60 ka, had cognitive, behavioural and technological capabilities that are comparable to those of current humans. Here I will touch on the neurological components that might be involved in complex cognition, and provide examples of behaviours that could serve as proxies for such cognition in the Middle Stone Age contexts of southern Africa.

2.2. Theories on complex cognition

Until recently, Palaeolithic archaeologists argued that only two cognitive components should be attributed to ‘modern human behaviour’, i.e., symbolic culture and language (Wynn & Coolidge 2011). Symbolic culture became the focal point in Palaeolithic research with the discovery of European Upper Palaeolithic art (including cave paintings, personal ornaments and figurines), that dates between ~40 ka and 14 ka (Wurz 2012). The presence of art implied the existence of meaning and/or modern symbolic sensibilities – thus, European modern anatomy and symbolism became interlinked (Wynn & Coolidge 2011). In addition, theoretical paradigms in the 1970s influenced the ways in which archaeologists interpreted the archaeological record. For example, Chomsky’s structuralist approach to language played an influential role – a number of archaeologists considered language the sine qua non of humanness (Wynn & Coolidge 2011).

Some Palaeolithic archaeologists use the term ‘behavioural modernity’ to distinguish Homo sapiens from their ancestors on a cultural basis. More recently, a number of archaeologists assert that this term should be abandoned as an analytical concept (Clark 1999; Shea 2011). The traits that are attributed to ‘modern’ human behaviour are biased – they have been extrapolated from Upper Palaeolithic archaeological assemblages, and do not take the African archaeological record into account (Shea 2011). A solution, however, has been proposed – incorporating methods that assess levels of behavioural, technological or cognitive
complexity, as well as potential variability (see Haidle 2010; Wadley 2010a; Wadley et al. 2009).

To assess levels of behavioural, technological or cognitive complexity, it is important to elaborate on complex cognition and/or cognitive components that could be unique to *Homo sapiens*. Complex cognition includes the mental ability to engage in abstract thought, multitasking, analogical reasoning, algorithmic capacity, ‘higher’ theory of mind, anticipatory planning and ‘cognitive fluidity’ (Amati & Shallice 2007; Henshilwood & Dubreuil 2011; Mithen 1996; Wadley 2013). The term ‘cognitive fluidity’ implies that modern humans were able to generate and engage in innovative thoughts and employ continuous multilevel operations (Mithen 1996). In addition, Wynn and Coolidge (2003, 2007, 2011) suggest that *Homo sapiens* might be distinguished from their ancestors by an enhancement in executive functions or working memory processes. One of the defining features of enhanced working memory is the enlargement of general working memory capacity (see Coolidge & Wynn 2005). For example, an individual is able to process, store, and temporarily maintain a larger amount of information in the mind, despite interference (Wynn & Coolidge 2003). An enhancement in working memory capacity assists with decision-making, complex goal-directed actions, focused attention, response-inhibition, and flexibility in problem-solving and advanced planning capabilities (Wynn & Coolidge 2003).

2.3. Neurological components involved in complex cognition

From an evolutionary perspective, there is an interest in identifying the neurological mechanisms (neurons, neural circuits, brain areas, or neurotransmitters) that might be needed for complex cognition. Some scholars propose that an increase in brain size, specifically in the prefrontal cortex, might be responsible for human cognition (e.g., Toro et al. 2008). Mesulam (2000), however, argues that an increase in brain size is not the only factor that contributes towards cognitive ability – for instance, the evolution of cerebral reorganisation and connectivity might be important for human cognition. For example, Schoenemann and colleagues (2005) argue that humans have a larger volume of white matter found within the prefrontal cortex than other primates, which improves neural connectivity and thus encourages communication within and between cortices. According to Ardilla (2008) improvements in neural interconnectivity could have led to the complex executive functions that are identified in our species. In humans, for example, fronto-parietal networks are
amplified during tasks that require eye-hand coordination and controlled movements (Battaglia-Mayer et al. 2003) (refer to Section 2.6 for examples), and with tasks that necessitate abstract thought (Koenig et al. 1998) (see Section 2.4 for more on this). From a neurological perspective, repeated exposure to cognitively demanding tasks can lead to changes in synaptic connectivity within the fronto-parietal circuits, known as synaptic or brain plasticity (Kolb et al. 2012).

2.4. Symbolically mediated behaviour as proxy for complex cognition

Some archaeologists consider geometric or iconographic representations, personal ornaments and elaborate burials as indicators of symbolically mediated behaviour (d’Errico et al. 2005; Henshilwood et al. 2009; Knight et al. 1995; McBrearty & Brooks 2000). A key characteristic of all symbols is that their meaning is attributed to arbitrary and socially constructed conventions (e.g., Chase & Dibble 1987), and perhaps reflect the external thought processes of Homo sapiens who lived more than 70 ka (d’Errico et al. 2005; Hovers et al. 2003; Wadley 2001). In other words, evidence of early symbolically mediated behaviour could “signal the emergence of the first societies in which social conventions, beliefs and knowledge about the world are coded, stored and transmitted using conventional signs” (d’Errico et al. 2012: 942-943).

In search of early traces of complex human cognition, some researchers evaluate the mental architecture and/or the cognitive components that might be needed for symbolic thought. For example, Henshilwood and Dubreuil (2011) argue that advances in the cognitive component, theory of mind, perhaps led to the emergence of symbol use in human cognitive evolution. Theory of mind refers to the cognitive ability to attribute mental states to others (Fletcher et al. 1995; Saxe & Powell 2006). On a neurological level, mental state reasoning activates brain areas, such as the medial prefrontal cortex and the superior temporal sulcus (see Gallagher & Frith 2003). Higher theory of mind might have encouraged humans to solve technological problems and maintain social bonds (Dunbar 1993, 2003). Furthermore, evolutionary biology and neuroscientific studies reveal that hominin symbolic communicative capacities might have co-evolved with certain areas of the brain (see Deacon 1997). For example, an expansion of the prefrontal cortex possibly improved neuronal interconnectivity – resulting in the mental ability to engage in abstract symbolic concepts and advanced planning capabilities (Wurz 2012). This premise is supported by Malafouris (2010)
who argues that symbolic behaviour might be a consequence of brain or synaptic plasticity. The plasticity of the brain implies that it is a dynamic organ that is capable of transformation. For example, neural pathways can be restructured or rewired when one engages in cognitively, socially, and/or technically advanced behaviours (Malafouris 2010). Below I highlight some material examples that have been used to infer cognitive complexity during the Middle Stone Age in southern Africa.

2.4.1. Shell beads

Forty-one intentionally perforated tick shell (Nassarius kraussianus) beads were recovered from Blombos Cave, with an age estimation of ~72 ka (d’Errico et al. 2005; Henshilwood et al. 2004) (see Figure 2.1 for locations of sites mentioned in this section). Three of the six Afrolittorina africana shells from Sibudu also seem to be perforated, and date to ~71 ka (d’Errico et al. 2008). Border Cave is another South African site that might reflect early evidence of shell bead utilisation. Here, a perforated Conus shell was found with an infant burial, potentially dating to ~76 ka (Beaumont 1980; Beaumont et al. 1978; Cooke et al. 1945; de Villiers 1973). The Middle Stone Age context of this find is, however, questioned (see d’Errico et al. 2008). In addition, a perforated Patella oculus specimen has been excavated from Klasies River (Voigt 1982; Watts 1998), and dates between ~22 ka and 58 ka (Deacon 1995; Jacobs et al. 2008).

Figure 2.1: Geographic locations of the southern African Middle Stone Age sites mentioned in section 2.4.
The Blombos shells were perhaps intentionally transported from the species’ natural habitat to the site. For example, the *Nassarius kraussianus* shells do not derive from the geological structure in which the cave is situated, and they were not brought to the site by natural events (see d’Errico et al. 2005). *Homo sapiens*, who lived more than 70 ka, might have deliberately transported the shells to the cave for consumption purposes (see d’Errico et al. 2005; Henshilwood & Dubreuil 2011). For example, shellfish provides a valuable source of fatty acids that is important for brain development (see Broadhurst et al. 2002). The shells, however, were too small to have any food value. Alternatively, the shells may have been carefully chosen for perforation purposes (see d’Errico et al. 2005 for more on this). The selection and transportation of the shells could have been a time-consuming activity that required a considerable amount of planning. According to Wynn and Coolidge (2011) long-range planning capabilities necessitate ‘modern’ or enhanced executive functions of the brain. From a neurological perspective, the prefrontal cortex is responsible for enhanced executive functions in the human brain, such as planning an action in advance (Koechlin et al. 2000).

The perforated marine shell beads found at Blombos ~72 ka, provide us with valuable information about the technical skills that may have been needed at this time. All 41 beads appear to be deliberately pierced with a bone awl, which could imply that careful, controlled motions and/or visuo-spatial attention were necessary (d’Errico et al. 2005). Motor and procedural skills would also have been needed for skilled object manipulation (Gibson 2011). From a neurological perspective, skilled object manipulation activates a large network of brain regions, such as the primary motor, premotor and parietal cortex (Binkofski et al. 1999). In addition, the ‘plasticity of the brain’ makes it possible for an individual to absorb previous technical advances, and build upon them when they engage in cognitively demanding activities (Malafouris & Renfrew 2010).

The perforated marine shells found at Blombos (d’Errico et al. 2005), Sibudu (d’Errico et al. 2008), Klasies River (e.g., Jacobs et al. 2008), and Border Cave (e.g., Beaumont 1980), dating between ~76 ka and 22 ka, could have been worn as beads. If they functioned as personal ornaments, then they may have been used for symbolic purposes – representing a symbol of social status for clan membership (e.g., d’Errico et al. 2005; Henshilwood & Dubreuil 2011). Unlike young children (aged two to three), adults are able to create symbolic artefacts that have collectively shared meanings (Henshilwood & Dubreuil 2011). Symbolically mediated behaviour also requires a person to infer mental states to others by inhibiting self-perspective, and the capacity to ‘hold in mind’ opposing points of view,
known as theory of mind (Gallagher & Frith 2003; Wadley 2011). Apes can engage in some aspects of theory of mind (Heyes 1998), but only humans have the capacity for higher theory of mind (Burns 2006). Higher theory of mind refers to the mental ability to understand false beliefs and/or other abstract mental states, such as higher-order desires (Henshilwood & Dubreuil 2011). For example, bead wearing or personal ornament use might represent the capacity for higher theory of mind – the latter could be a consequence of the expansion of late-maturing regions in the prefrontal cortex and the temporo-parietal areas (Henshilwood & Dubreuil 2011). In contrast, Burns (2006) argues that higher theory of mind represents an important component of social cognition, which could have occurred in our species between ~150 ka and 40 ka. He speculates that it might be a result of an increase in white matter that improved brain connectivity in the prefrontal and temporo-parietal cortices.

Whereas it is reasonable to associate Middle Stone Age shell beads with personal ornament use, it is not the only possibility. The marine shell beads perhaps functioned as a tallying device, i.e., the stringed beads could have been used to keep track of quantities (Coolidge & Overmann 2012). If so, the cognitive functions and/or processes involved would differ from those of personal ornament use. For example, the core system of numerosity (the mental ability to think and/or reason in numbers) might serve as an evolutionary basis for abstract and higher-level symbolic thinking, i.e., analogical reasoning and the mental ability to use metaphors in language (Coolidge & Overmann 2012). Some researchers argue that algorithmic capacity might reflect ‘modern’ thinking, as it is the basis of logical operations, arithmetic, geometry and mathematics (Amati & Shallice 2007; Bonatti 1994). From a neurological perspective, engaging in arithmetic tasks activates sub-regions within the prefrontal and parietal cortices – for instance, the dorsolateral prefrontal cortex, left superior prefrontal gyrus, and the bilateral inferior parietal lobule (Dehaene et al. 1999). Mathematical thinking thus requires communication within and between cortices, which further validates the premise that improvements in neural connectivity (by means of an increase in white matter) might be important for complex cognition.

2.4.2. Engravings

Engravings refer to a design that has been intentionally cut into a material, such as a chunk of ochre, with the aid of an implement. According to d'Errico and colleagues (2012: 943) “painted, engraved, and carved abstract and depictional representations are generally considered key to assessing the modern character of human cultures.”
Table 2.1: Engraved artefacts from Middle Stone Age contexts in southern Africa

<table>
<thead>
<tr>
<th>Site</th>
<th>Description</th>
<th>Age estimate</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Two rib pieces with 26 notches</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>An ochre pebble with sub-parallel lines</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A slab of sandstone with an engraved lattice pattern</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blombos Cave</td>
<td>Engraved ochre plaques (including complex geometric patterns, cross-hatched designs, right-angled juxtapositions, parallel lines and dendritic forms)</td>
<td>~100 ka to 72 ka</td>
<td>(Henshilwood et al. 2009; Henshilwood &amp; Sealy 1997; Jacobs et al. 2006).</td>
</tr>
<tr>
<td></td>
<td>A bone fragment with sub-parallel incised lines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pinnacle Point</td>
<td>Engraved ochre nodules</td>
<td>~100 ka</td>
<td>(Watts 2010).</td>
</tr>
<tr>
<td>Sibudu Cave</td>
<td>Notches displayed on bone fragments</td>
<td>~77 ka to 50 ka</td>
<td>(e.g., Hodgskiss 2010, 2013).</td>
</tr>
<tr>
<td>Border Cave</td>
<td>Broken rib fragment with 12 notches displayed on the edge</td>
<td>~69 ka to 55 ka</td>
<td>(Beaumont et al. 1978; Bird et al. 2003; Grün &amp; Beaumont 2001; Miller et al. 1999).</td>
</tr>
<tr>
<td>Klein Kliphuis</td>
<td>A piece of ochre with cross-hatched incised lines</td>
<td>~66 ka to 55 ka</td>
<td>(Mackay 2006, 2010; Mackay &amp; Welz 2008).</td>
</tr>
<tr>
<td>Diepkloof Cave</td>
<td>More than 270 pieces of ostrich eggshell beads include repetitive patterns, i.e., hatched motifs</td>
<td>~75 ka to 55 ka</td>
<td>(Jacobs et al. 2008; Rigaud et al. 2006; Texier et al. 2010).</td>
</tr>
<tr>
<td>Palmenhorst</td>
<td>A cobble with a cross-hatched design</td>
<td>Not dated</td>
<td>(Wendt 1976).</td>
</tr>
<tr>
<td>Bushman Rock Shelter</td>
<td>Ochre and bone fragments with parallel lines</td>
<td>Not dated</td>
<td>(d’Errico &amp; Henshilwood 2007; Watts 1998).</td>
</tr>
</tbody>
</table>

In the archaeological record, some of the earliest evidence of engraved artefacts has been recovered from southern African Middle Stone Age deposits from ~126 ka to 50 ka (Table 2.1). Microscopic analysis of engraved ‘designs’ (specifically, the Blombos ochre pieces with complex geometric patterns from ~100 ka), allows us to evaluate the intentions, technical competence, and the techniques employed by people at the time (d’Errico et al. 2012). Prior to cutting an incision, the engraver must intentionally plan where to place each of the markings, which reflects the capacity for forethought and short-term goal attainment. Functional magnetic resonance imaging studies indicate that the lateral occipito-parietal junction assists with action planning (Culham & Valyear 2006). To make a simple geometric
pattern also necessitates fine motor control and visuo-spatial skills, but it does not require enhanced working memory (Gibson 2011). From a neuropsychological perspective, the dorsolateral prefrontal cortex is activated during visuo-spatial tasks (see Pochon et al. 2001). In addition, neurons within the parietal cortex might have fired in response to cutting the incised lines and/or the complex geometric patterns onto the material’s surface. The parietal lobe, for example, is involved in visuo-spatial and/or manual guidance, which encourages an individual to move their body across space with greater control and accuracy (Goodale & Milner 1992).

Some of the ‘engraved designs’ on worked ochre pieces from southern African sites (Table 2.1), might have been produced during powder production, and may thus not represent intentional engraving (e.g., Hodgskiss 2010, 2013; Wadley 2010b). A wide-range of functions has been proposed for ochre utilisation: protection against insect bites, protection against the cold and/or the sun (Henshilwood et al. 2009; Wadley 2001), medicinal purposes (Velo 1984), a dietary iron supplement (e.g., Wadley 2001), and to assist with preparing or softening a hide (e.g., Wadley et al. 2003). Currently the best documented and experimentally supported use of ochre powder is that of it being included as a key ingredient for compound-adhesive production (e.g., Lombard 2005; 2006a, 2007; Wadley 2005, 2010a). However, bright-red ochre seems to be preferred over other colours, which could imply that ochre powder was not only used for functional purposes (Henshilwood et al. 2009). ‘Blood-red’ ochre, for example, could have been used to paint abstract designs onto ritual performers’ bodies (Watts 2002). From a neurological perspective, ritual performance requires enhanced working memory, and activates the dorsolateral prefrontal and the anterior cingulate cortex (Rossano 2010). Indeed, the symbolic use of colour could be an indicator of complex behaviour, but these finds, on their own, make it difficult for archaeologists to infer cognitive or behavioural conclusions about how ochre was used in the past (Hodgskiss 2013).

Some of the chunks of ochre recovered from Blombos, dating between ~100 ka and 70 ka, might not have been ‘engraved’ for powder production purposes, but perhaps are early indicators of artistic representation and, and by implication, symbolic human behaviour (see d’Errico et al 2001; Henshilwood et al. 2002). For example, the following engraved patterns are inconsistent with powder production – cross-hatched designs, sinuous lines, incised lines displayed on small pieces of ochre, and juxtaposed incisions (see Henshilwood et al. 2009). Other examples of engraved motifs include the engraved ostrich eggshell fragments recovered from Diepkloof ~65 ka (Rigaud et al. 2006; Texier et al. 2010), and the engraved
bone found at Blombos and Klasies River, the latter at ~101 ka (d’Errico et al. 2001) (see Table 2.1 for other examples).

The initial reasons for creating ‘engraved designs’ might be a consequence of an undefined sense of arousal that intrigued the minds of Homo sapiens (Hodgson 2006). For example, when an individual sees simple shapes, such as lines or dots, it increases attention or arousal levels and thus places greater demands on their visual system (Hodgson 2006). From a neurological perspective, the primary and secondary visual cortex is activated during tasks that require visual acuity and attention to fine detail (Rees et al. 2002). Neuronal sensitivity within the primary and secondary visual cortex increases even further with repeated exposure to stimulating material (Schoups et al. 2001). Hodgson (2006) speculates that complex geometric designs, such as those found on the Blombos ochre plaques, might be a by-product of the perceptual, cognitive and motivational skills that evolved in the human lineage. Taking all of the above into consideration, I tentatively suggest that the evolutionary development of the visual system could have been an evolutionary advantage. For example, Hodgson and Helvenston (2006) mention that it would have improved visuo-spatial skills when hunting.

2.4.3. Critique of symbolically mediated behaviour as proxy for complex cognition

Recovered shell beads and engraved material remains from Middle Stone Age contexts in southern Africa could represent symbolically mediated behaviour, but this interpretation is still subject to debate (see Hodgson 2006; Wadley 2013). There has also been much debate over the ways in which symbolism has been interpreted. For example, Wadley (2013) argues that symbolism is interpreted in a biased manner, i.e., some archaeologists imply that Homo sapiens might be the only hominin capable of engaging in symbolic thought (e.g., Knight et al. 1995; McBrearty & Brooks 2000). Current archaeological findings, however, suggest that symbolism is not solely attributed to a certain hominin taxa (see d’Errico & Stringer 2011). Thus, ‘cultural modernity’ should be replaced with the term ‘complex cognition’ (see Wadley 2013). In addition, Wadley (2011) argues that the initial appearance of theory of mind is unable to be calibrated chronologically, and even if this faculty could be linked to the evolutionary development of the temporo-parietal, it is impossible to securely connect it to recent changes in the brain.
2.5. Domestic behaviour as proxy for complex cognition

From a cognitive perspective, to construct, maintain and deliberately organise a domestic space might require advanced planning capabilities and reflect aspects of ‘modern’ human behaviour. Currently, the oldest evidence for plant bedding is found at Sibudu from ~77 ka, which is 50 ka older than the patches of packed grass recovered from Strathalan Cave B (Opperman 1996) (See Figure 2.2 for locations of sites mentioned in this section). Hearths (consisting of ash dumps and burnt bedding) have also been found at Diepkloof Rock Shelter from Middle Stone Age contexts (Goldberg et al. 2009).

Figure 2.2: Geographic locations of the southern African Middle Stone Age sites mentioned in section 2.5.

2.5.1. Plant bedding

Plant bedding refers to a type of floor preparation that has been constructed out of plant materials (Goldberg et al. 2009). At Sibudu, plant bedding, that dates to ~77 ka, could have been used for sleeping purposes and/or as a comfortable surface to work on (Goldberg et al. 2009; Wadley et al. 2011). To produce the thin-layered, fibrous charcoal and phytolith layers requires a large volume of plant material, and a considerable amount of time and energy must have been spent collecting the plants to prepare the living space (Miller & Sievers 2012). The plant bedding at Sibudu was repeatedly burnt from ~73 ka (Wadley et al. 2011), perhaps to remove pests, and/or to eliminate garbage (see Crucifix 2006). Micromorphological research
indicates that other activities could have been executed for site maintenance, including hearth construction, sweeping or dumping of ashes, and trampling of combusted material (e.g., Goldberg & Berna 2010; Goldberg et al. 2009). The amount of preparation that would have been needed to produce and preserve domestic space implies that forethought was essential. In humans, the dorsolateral prefrontal cortex is activated when one contemplates future actions or scenarios (Hoshi & Tanji 2004).

At Sibudu, the plant material that was used to construct the sedge-covered areas or bedding consisted of insecticidal properties (Wadley et al. 2011). According to Wadley and colleagues (2011) the Cryptocarya woodii leaves could have been intentionally selected to protect people against insect bites and stings. If the plant materials were carefully chosen for their insecticidal properties, then the people who inhabited Sibudu during the Middle Stone Age were experienced botanists who relied on procedural knowledge.

The layout of the bedding heaps or the organisation of living space also represents an important trait for culturally ‘modern’ behaviour (e.g., Deacon 1995; Wadley 2001). For example, the faculties involved in intentionally organising a living space signifies complex social organisation (e.g., Deacon 1995; Wadley 2001), which could be a consequence of the evolutionary development of ‘social’ circuits, such as the amygdala, and the ventromedial prefrontal cortex (Insel & Fernald 2004). According to Rossano (2010) a secure and/or stable domestic environment also has a positive effect on cognitive development, i.e., it can improve working memory capacity.

2.5.2. Critique of domestic behaviour as proxy for complex cognition

One of the problems with investigating current evidence for domestic behaviour is that plant material is not well-preserved in the archaeological record (Lombard 2012). In situations where plant material has been preserved, such as Sibudu, the micromorphology and seed remains provide direct evidence for the construction and maintenance of plant bedding (see Goldberg et al. 2009). Goldberg and colleagues (2009), however, argue that interpreting the plant materials in behavioural terms is a challenge. For example, the cognitive functions or the neurological components involved in conceptualising, planning and organising a domestic space are not always easy to identify and/or interpret.
2.6. Technologically complex behaviour as proxy for complex cognition

In the archaeological record of southern Africa, innovative technologies, dating from ~ 100 ka to 60 ka, might serve as proxies for complex cognition (see Wadley 2013 for examples). Behavioural attributes that reflect complex cognition and/or enhanced executive functions of the brain include: goal-oriented actions, response-inhibition, abstract thought, analogical reasoning, flexibility in problem-solving and long-range planning capabilities (Wynn & Coolidge 2003). In humans, an increase in white gyral matter has improved neural connectivity between cortical areas (Schenker et al. 2005), which might assist with higher-order executive functions (Ardilla 2008). Some archaeologists suggest that a neural mutation might be responsible for strengthened neural connections within higher-order areas of the brain (Klein & Edgar 2002; Mithen 1996). More recently, Coolidge and Wynn (2005; Wynn & Coolidge 2003, 2007) mention that a neural mutation could have improved memory and/or cognitive capabilities. An improvement in cognitive capacity is collectively referred to as ‘executive functions’, and perhaps reached modern capacity by an enhancement in working memory (Coolidge & Wynn 2005). Thus, Homo sapiens might be distinguished from their ancestors by the mental ability to engage in enhanced executive functions and/or working memory processes (see Wynn & Coolidge 2011). In the section that follows, I will touch on the executive functions or the cognitive components that might be needed for technologically complex behaviours inferred from the Middle Stone Age contexts in southern Africa.

2.6.1. Heat treatment of rocks for knapping

Heat treatment refers to the controlled transformation of a rock’s properties with the assistance of heat (Schmidt et al. 2013), which ultimately improves the flaking quality of some rock types (Brown et al. 2009). For example, heat treatment allows the tool knapper to have a high degree of control when detaching a flake from its core – assisting with tool production (Mourre et al. 2010; Villa et al. 2009). Some of the earliest evidence of heat treatment might be found at Pinnacle Point 13b, by ~164 ka (Brown et al. 2009) (see Figure 2.3 for locations of sites mentioned in this section). At Diepkloof Rock Shelter, thermally transformed silcrete was recovered with an age estimation of ~100 ka (Porraz et al. 2013), but it is unclear whether the heating was accidental or intentional (Miller et al. 2013). In addition, heat treated silcrete was excavated at Blombos and Pinnacle Point 5 and 6, with age estimates of ~75 to 72 ka (Brown et al. 2009; Mourre et al. 2010). In the Middle Stone Age context of southern Africa, heat treating some of the rocks to produce the foliate bifacial
points, associated with the Still Bay techno-complex (~77 ka to 70 ka), led to their thinner, sharper and narrower qualities (Mourre et al. 2010; Villa et al. 2009). Functional studies indicate that the Still Bay bifacial pieces could have functioned as tips for hunting spears (Villa et al. 2009), (butchery) knives (Minichillo 2005), or based on use-trace evidence, it is most probably both (Lombard 2006b).

Figure 2.3: Geographic locations of the southern African Middle Stone Age sites mentioned in section 2.6.

Lithic heat treating strategies also requires procedural knowledge similar to that mentioned in the previous section on plant bedding manufacture. For example, the artisan must remember the correct temperature for heating and/or the thermal responses to the heat treated rock (Mercieca & Hiscock 2008). To prevent rock damage or destruction during heat treatment, underground heating strategies might have been used (see Wadley 2013). If the latter is true, analogical reasoning would be important, because the heat treated rock is out-of-sight, i.e., the artisan must devise a mental algorithm (based on the above-ground performance of fire) to determine underground temperatures (Wadley 2013). Cognitive neuroscientists mention that executive functions, such as response inhibition, assist with analogical reasoning – activating the inferior frontal gyrus (Morrison et al. 2004). Amongst young children, there is also a correlation between improvements in analogical reasoning and developmental changes in the rostrolateral prefrontal cortex (Kroger et al. 2002; Wendelken et al. 2008). In addition, lesions in the prefrontal cortex can impair performance during analogy tasks (Morrison et al.
2004). Thus, current research implies that analogical reasoning represents a critical component of human cognition.

2.6.2. Composite tools

In contrast to knapping a simple stone tool that could be taught by demonstration (Wadley 2010a), hafted stone tools represent the innovative concept of composition (Ambrose 2010; Lombard & Haidle 2012). The term composition refers to independent components that are combined together, which extends the properties of a tool beyond its original materials (Lombard 2012; Lombard & Haidle 2012). For example, multiple components (including stone segments, a handle or shaft, and binding material or adhesive) are combined together to produce a composite tool. According to Ambrose (2001, 2010), composition reflects an increase in cognitive capacity because it places substantially greater demands on working, prospective and constructive memory than single-unit tools. Most current interpretations of the archaeological record suggest that composite tool manufacture appears ~300 ka (Ambrose 2010), with the inception of Mode 3 technologies (see Foley & Lahr 1997; McBrearty & Tryon 2005). Composite tool production has been suggested for points at Kathu Pan that could be ~500 ka (Wilkins et al. 2012), but the age and context of these artefacts need verification and replication at other sites. Composite spear production is not exclusive to our species (Lombard & Haidle 2012). At Campitello, Italy, for example, evidence of hafting has been associated with Neanderthals, at ~195 to 130 ka (Mazza et al. 2006), so some aspects or levels of complex cognition are not only attributed to Homo sapiens (Wadley 2013).

To gain a better understanding of the mental processes involved in composite tool manufacture and use, Lombard and Haidle (2012) use cognigrams to code the associated thought-and-action sequences. In comparison to the single-unit, non-composite wooden spears from Schöningen, Germany, at ~400 ka (Thieme 1997), composition represents a development towards advanced technological, behavioural and cognitive flexibility and an expansion in the problem-solution distance (Lombard & Haidle 2012). The advanced problem solving and/or planning capabilities that are associated with composite tool production could have played an important role in the evolutionary development of the frontal lobe (Ambrose 2010). For example, the ‘plastic brain’ is capable of being transformed by technologically advanced behaviours or in situations where an individual engages in cognitively demanding activities. A sequence of motor actions or fine motor control is also needed when each of the techno units (the stone segments, handle or shaft, and binding
material or adhesive) are combined together to produce a composite tool (Ambrose 2010; Reuland 2010). Neuroscientific studies indicate that the adjacent areas of the inferior left frontal lobe are activated to assist with fine motor control (Hugdahl 2005).

2.6.3. Compound-adhesive manufacture

Thus far, the earliest direct evidence for ochre-loaded compounded adhesives was found on stone points recovered from Sibudu Cave dating to ~70 ka, and the technology continues to ~35 ka at the site (e.g., Lombard 2005, 2006a, 2006b). In addition, backed tools were hafted with ochre-enriched adhesives at Sibudu, Rose Cottage and Umhlatuzana between ~65 ka and 59 ka (Gibson et al. 2004; Lombard 2007). According to Wadley (2010a), complex cognition was needed to bind the tools onto their shaft using compound adhesives. She argues, for example, that a high level of imagination and abstraction is needed to conceptualise using ingredients, such as plant gum or ochre, to manufacture the compound adhesives (Wadley et al. 2009). Current studies in neurobiology suggest that abstract thought (a basic executive function of the brain) activates the dorsolateral prefrontal cortex (Goel & Dolan 2001).

The glue-makers must also switch their attention between actions and/or operations in the production process, which reflects the ability to multitask (Wadley et al. 2009). The capacity for multilevel cognitive operations could be a consequence of improvements in neural connectivity within the prefrontal cortex (Amati & Shallice 2007). For example, the prefrontal cortex directs inhibitory and excitatory signals to a broad network of neural circuits, which assists with multitasking (e.g., Thoma et al. 2008). Neurological patients, who have prefrontal damage, are unable to inhibit task-irrelevant information and thus cannot execute cognitively demanding activities that require them to multitask (Dux et al. 2009).

2.6.4. Snares

At Sibudu, snares might have been used as an innovative meat procurement strategy from ~70 ka (Wadley 2010c). Circumstantial evidence for traps or snare use includes: the mortality profiles, the taxonomic diversity and/or the high frequency of blue duiker and small carnivores that are found at Sibudu at this time (see Clark & Plug 2008). A set trap or snare is designed to function in the future without human involvement and thus requires the hunter to conceptualise and integrate actions through time and across space (Wynn & Coolidge 2003). To produce a snare necessitates ‘modern’ executive functions of the brain (representing
enhanced working memory capacity and complex cognition), as remote capture integrates a number of sophisticated cognitive concepts (Wadley 2013; Wynn & Coolidge 2003). The hunter, for example, must use contingency planning to ‘hold in mind’ actions that are out-of-sight (Wadley 2010c, 2013). Another important executive function might have been focused attention (Wadley 2013), which prevents extraneous thoughts and allows an individual to concentrate on the task at present (Wynn & Coolidge 2007). The prefrontal cortex assists with executive functions, such as focused attention, planning and decision-making (Curtis & D’Esposito 2003).

To improve the hunter’s chances of capturing an animal with a snare, procedural knowledge of prey ecology and behaviour would have been important (Wadley 2010c). Snare users were thus capable of observing and memorising animal behaviour, which may have been needed when choosing the best location for the snare (Wadley 2010c). From an evolutionary perspective, early Homo sapiens were biologically predisposed to specific kinds of learning, i.e., certain brain systems may have become specialised at detecting natural categories, such as animals and their behaviour (Caramazza & Mahon 2003), but further neurological research is needed on this topic.

2.6.5. Bow-and-arrow technology

Previous archaeological research suggests that bow-and-arrow technology is a recent invention in Eurasia and the Americas, as it has been linked to the Late-Upper Palaeolithic (Shea 2009). More recent archaeological findings suggest that it was invented in Africa earlier than previously thought – at least by ~44 ka at Border Cave (Villa et al. 2010), or perhaps as early as ~100 ka elsewhere in sub-Saharan Africa (Brooks et al. 2006). Multistranded evidence indicates that arrows (tipped with either stone and/or bone), and by inference bows, could have been used at Sibudu and Umhlautuzana from ~64 ka (Backwell et al. 2008; Bradfield & Lombard 2011; Lombard 2011; Lombard & Phillipson 2010; Wadley & Mohapi 2008). In addition, circumstantial evidence for traps and snare use has been found at Sibudu ~70 ka, which implies that people at this time understood the concept of ‘latent energy’ stored in a bent branch and were capable of making cords with the necessary strength for bow production (Lombard & Phillipson 2010).

In contrast to a single-component wooden spear or a composite stone-tipped spear, the thought-and-action sequences associated with the production and use of a bow-and-arrow set reflects amplified conceptual, technological and behavioural modularisation, and an
extension in the problem-solution distance (Lombard & Haidle 2012). It can thus be suggested that by ~64 ka people possessed advanced problem-solving and planning capabilities. From a cognitive perspective, planning an action in advance requires imagination – one must construct a mental representation that deviates from ways in which the world is perceived in ‘reality’ (Reuland 2010). It also requires retrospective, episodic and/or autobiographical memory (referring to personal events or experiences), declarative memory (general knowledge), and procedural knowledge (learned actions) (Ambrose 2010). As soon as the imagined future is put into action, the individual needs to construct a set of objectives or a ‘to-do list’ to assist with goal-oriented behaviour (requiring procedural memory) (Ambrose 2010).

To produce and/or use individual technological components, such as the bow or the arrow, is not more cognitively demanding than that of composite tool manufacture or utilisation (Lombard & Haidle 2012). The mental ability to conceptualise, manufacture and use a bow-and-arrow set as an effective unit, however, represents a novel cognitive component, known as technological symbiosis (Lombard 2012; Lombard & Haidle 2012). Technological symbiosis requires an individual to focus simultaneously and actively on manipulating a complementary set of tools that are independent from one another, but are used as an effective unit to obtain a single goal – for instance, when a bow is used to fire an arrow to obtain meat (Lombard & Haidle 2012). In contrast to non-symbiotic tool use, two separate tools that are utilised for a single purpose requires an individual to ‘hold in mind’ an additional visual item and its properties – thus focused attention and greater memory load would be needed. For example, Seo and colleagues (2012) mention that archery experts perform better at visuo-spatial working memory tasks than novices. This might be explained by the cognitive requirements of archery – for instance, archery experts must integrate working memory components to process visuo-spatial information during task execution (Seo et al. 2012). From a neurological perspective, the middle frontal cortex, the dorsolateral prefrontal cortex and the supplemental motor area play an important role in visuo-spatial attention, and/or working memory processes (Seo et al. 2012).

2.6.6. Critique of technologically complex behaviour as proxy for complex cognition

In humans, the evolved capacities for complex or advanced technological action might be associated with improvements in neural connectivity (Holloway 1966), and/or a consequence of the evolutionary development of neurological structures within the brain (Ambrose 2010;
Stout et al. 2008). There is, however, a lack of research on the neurological components that might be needed for complex tool-manufacture and use (refer to Johnson-Frey 2003 for its importance). Below, I summarise some of the research methods that are used by archaeologists to assess the cognitive demands of technologically complex behaviours inferred from the southern African archaeological record.

2.6.7. Overview of methods used to assess technologically complex behaviours

To assist with interpreting aspects of complex cognition, a number of archaeologists use the working memory model as bridging theory (see Wadley 2010a). The working memory model is a theoretical framework adopted by Wynn and Coolidge (2003, 2007, 2011), and it elaborates on the cognitive components that might be needed for ‘modern’ human thinking. The working memory model suggests that *Homo sapiens* could be distinguished from their ancestors by an enhancement in working memory capacity, which encourages an individual to process and temporarily store and/or maintain a number of items in the mind (Wynn & Coolidge 2003).

In another approach, cognigrams are used by Lombard and Haidle (2012) to code the thought-and-action sequences involved in Middle Stone Age bow-and-arrow manufacture and use. Cognigrams are a useful because tool behaviour can be compared between all types of animals (including hominins) in an unbiased manner (Haidle 2010). Also, the method does not evaluate other species’ cognitive capacities from a ‘modern’ human perspective (Haidle 2010). Unlike spear hunting, the ability to manufacture and use bow-and-arrow technology has, thus far, only been identified in our species (Shea & Sisk 2010; Villa & Soriano 2010), and therefore might be of value when researching human cognitive evolution (Lombard 2012; Lombard & Haidle 2012). The bow and arrow, for example, could serve as a proxy for the novel cognitive component represented in technological symbiosis (Lombard 2012; Lombard & Haidle 2012).

Neuroimaging techniques are another method that is used to study human cognitive evolution. Yet, from a global archaeological perspective, only a handful of studies have used neuroimaging techniques to assess activations in the brain (for examples see Stout & Chaminade 2007; Stout et al. 2008; Stout et al. 2000; Uomini & Meyer 2013). With one of the studies, a Positron Emission Tomography (PET) scan was used to measure the areas of the brain that were activated when tool-makers knapped (Stout et al. 2008). In comparison to knapping Oldowan flakes (of more than 1.5 Ma), visuo-motor coordination and/or
hierarchical action orientation was amplified with the more technologically advanced Acheulean assemblages that date from ~1.5 Ma to 300 ka (Stout et al. 2008). In another study, functional transcranial Doppler ultrasonography (ftCD) was used to compare the neurological substrates involved in Acheulean tool-making and a language task (Uomini and Meyer 2013). The results of this study support the premise that the capacity for language and manual-praxis might have co-evolved in the human lineage (Uomini and Meyer 2013). Thus far, no neurological studies have tested more recent cognitive theories on complex cognition in direct relation with Middle Stone Age material from southern Africa. As a pilot project, I will use an EEG scan to evaluate the amount of ‘neural effort’ that is required for non-symbiotic and symbiotic tool use, as defined by Lombard and Haidle (2012), and I will attempt to interpret the results in the context of the working memory model and a broader neurological framework.

2.7. Conclusion

Cognitive archaeologists aim to construct hypotheses that can be used to explain important phases in human cognitive and behavioural evolution. For example, they evaluate the thought processes involved, and/or the cognitive components that might be needed for tool manufacture and use. But, there are only a handful of studies that test cognitive theories on complex cognition from a neurological perspective. To contribute towards current research in the field of human evolution, I will use EEG equipment to measure the rate at which neurons fire with non-symbiotic and symbiotic tool use. In the chapter that follows, I elaborate on current neuropsychological research that uses EEG equipment to assess cognitively complex behaviours.
3.1. Introduction

Prior to discussing the primary role of cortical activity found within the parietal, frontal midline and orbitofrontal cortex, it is necessary to elaborate on the basics. Within the brain, electrical activity is divided into bands by its frequency. The reader will be introduced to the four frequency bands that are used in EEG research and the influence that learning a novel task has on cortical dynamics. Here, the bands discussed, differ in frequency range, i.e., delta (1-4Hz), theta (4-8Hz), alpha (8-14Hz), and beta (14-20Hz). In comparison to a simple motor task, learning a cognitively demanding activity will often result in greater ‘neural effort’ and/or working memory processes. In addition, levels of cortical activity are influenced by the individual’s mental state and the cortical area recorded (viz. the parietal, frontal midline, or orbitofrontal cortex). Once an individual has practiced the activity, synaptic or neural plasticity will occur. The brain is thus a dynamic organ that is capable of changing, even with short-term practice.

3.2. The four frequency bands

As mentioned, there are four frequency bands used in EEG research, delta (1-4Hz), theta (4-8Hz), alpha (8-14Hz) and beta (14-20Hz). Delta activity is often associated with a resting state (Lu et al. 2007). Delta activity might be needed during tasks that require decision making (Basar et al. 1999). The delta band is also involved in motivational processes that are triggered by biological rewards and dangers, for example, hunger and sexual arousal (Knyazev 2012). In the cognitive domain, delta activity constantly screens internal and external stimuli, in order to search for motivationally salient cues that signal potential threats or rewards (Knyazev 2012).

Theta activity plays an important role in a number of cognitive functions, including: retaining information in short-term memory (e.g., Tesche & Karhu 2000), declarative memory processing (Fell et al. 2003), episodic memory processing (Klimesch et al. 2001), memory encoding (Klimesch et al. 1996), retrieving information from memory (Ward 2003), and focused attention (Basar et al. 1999). The theta frequency band is also involved in sensorimotor processing (Bland & Oddie 2001). The sensorimotor integration hypothesis indicates that theta oscillations and neural synchrony (coordinated theta activity across brain
areas) assists with constantly updating feedback (e.g., from sensory to voluntary motor regions) in an attempt to correct motor output and/or performance of a task (Bland & Oddie 2001).

The alpha band is involved in highly specific attentional (Worden et al. 2000), perceptual (e.g., Thut et al. 2006), and memory-related processes (Klimesch et al. 2005) – for instance, it plays an active role in suppressing irrelevant information (Palva & Palva 2007). Neurological studies show that the alpha wave inhibits unnecessary cognitive processes and/or suppresses distractions when a number of items need to be encoded, stored, and retrieved in short-term memory (Jensen et al. 2002; Obleser et al. 2012).

Low amplitude beta waves are associated with a strongly engaged mind where active attention is required (e.g., Gross et al. 2004). Beta waves are needed during mental activities that require higher-order cognitive functions (refer to Ray & Cole 1985). Thus, beta waves signify alertness and a wakeful state (Lanlan et al. 2009).

Current EEG research provides us with some insight into the mechanistic role associated with each frequency band recorded. In general, however, both the occurrence and amplitudes of frequency oscillations vary within and between individuals, even for identical tasks. In addition, communicative signals in each frequency band can consist of multiple functions; depending on the area of the brain recorded, the task condition and whether the individual has practiced the activity or not.

3.3. Effects of task practice

When a novice is learning a motor task, higher-order cognitive engagement is needed. Participants, for example, might have to establish innovative performance strategies in an attempt to become accustomed to the task procedure and/or to produce accurate motor responses (Landau et al. 2004; Staines et al. 2002). Thus, a substantial amount of executive control (Shiffrin & Schneider 1984) and/or working memory processing are required (Landau et al. 2004) (Figure 3.1). The working memory system consists of temporary memory stores and mechanisms to rehearse information (Engle 2002). A mechanism of central executive is required to coordinate working memory processes, for example, to manipulate information in active memory and to allocate attentional resources (e.g., Cocchini et al. 2002; Engle 2002) (Figure 3.1).
Figure 3.1: Baddeley’s Working Memory Model (modified by Coolidge & Wynn 2005).

Figure 3.2: Brain areas mentioned in the revised version of the Working Memory Model.
The visuospatial sketchpad (inner eye) processes, stores and manipulates visual and/or spatial information in working memory (referred to as visual-spatial working memory or visual working memory) (Baddeley 2003) (see Figure 3.1 and 3.2). When learning a complex cognitive motor task, visual working memory is often needed. Visual working memory is defined as the cognitive ability to hold visual information in the mind – usually for just a few seconds at a time (Luck & Vogel 1997). From a cognitive perspective, visual working memory processes are involved in: the selection and storage of sensory information, visual attention, and the temporary maintenance of visual material (Baddeley 2003; Fukuda et al. 2010; Sauseng et al. 2011). In theory, visual working memory is restricted to three or four items, but storage capacity is limited even further when complex features or objects need to be encoded as a cohesive unit (representing high memory load) (Song & Jiang 2005). This premise is substantiated by Seo and colleagues (2012), who argue that archery, as opposed to other motor tasks, necessitates the integration of working memory components in order to process visuo-spatial information.

3.3.1. Cortical activation during simple and complex motor task engagement

A number of studies use the EEG method in an attempt to understand the impact that cognitive-motor task difficulty has on cerebral cortical dynamics. Previous neuroimaging studies, much like mine (refer to Section 4.4.1 in this dissertation), have constrained their analyses to observing cortical activation in a restricted number of cortical regions (e.g., Mizuki et al. 1982; Sauseng et al. 2007; Sterman & Mann 1995). To have a better understanding of the correlation between cortical dynamics and a complex motor task, Rietschel and colleagues (2012) examined cortical activation (EEG spectral power) and cerebral cortical networking (EEG coherence). Participants were confronted with easy and difficult motor tasks. When the participants switched from the easy to the cognitively complex motor tasks, neuronal activations were amplified, which validates the psychomotor efficiency hypothesis – for instance, an increase in task difficulty places greater demands on ‘neural effort’ (Rietschel et al. 2012). In addition, communication within and between cortical networks was amplified with the more complex tasks, as opposed to the simpler tasks (Rietschel et al. 2012).

EEG research refers to ‘phase synchronisation’ as the integration of neuronal oscillations in the same frequency range, within and between cortical areas (Nolte et al. 2004). In contrast, ‘cross-frequency phase synchronisation’ is defined as synchronised neuronal interactions that
Cortical communication or synchronised cortical activity assists with attention (Plankar et al. 2013), decision making (Miller & Cohen 2001), maintaining information in working memory (the latter is important when an individual is learning a novel task) (Fell & Axmacher 2011; Sauseng et al. 2010), and motor activity or sensori-motor integration (Andres & Gerloff 1999; Pfurtscheller & Andrew 1999). Repeated exposure to cognitively complex tasks, and thus synchronous neuronal activations, plays an important role during brain development (Sporns et al. 2004). For example, it leads to synaptic strengthening or refinements in cortical networking, which is referred to as neural or synaptic plasticity (Plankar et al. 2013).

3.3.2. Task practice and synaptic plasticity

Once a motor task has been learnt or is no longer a novelty (referred to as habituation), motor skill acquisition occurs, whereby movements (produced individually or in sequence) are performed effortlessly (Akinlofa et al. 2012). Unlike unskilled marksmen, for example, skilled performers display less networking in motor regions of the brain (Deeny et al. 2003). Thus, task practice leads to refinements in networking or a decline in cortical activity, which is referred to as information-processing efficiency or neural efficiency. Other experimental results revealed that cortical activation increased within certain brain regions with task practice (Elbert et al. 1995; Hund-Georgiadis & von Cramon 1999; Karni et al. 1995; Munte et al. 2002). An increase in cortical activity might reflect the recruitment of additional neural mechanisms or the strengthening of synaptic connectivity within a specific area of the brain (Poldrack 2000).

Inconsistencies in results could be attributed to differences in task requirements and/or cognitive demands (Jolles et al. 2010; Kelly & Garavan 2005; Landau et al. 2004). For example, tasks range from motor learning (Peterson et al. 1998; Tracy et al. 2001), verb generation (Peterson et al. 1998), artificial grammar learning (Fletcher et al. 1999), passive visual perception (Rainer & Miller 2000) to categorical and probabilistic learning (Seger et al. 2000). Patterns of cortical activity might also be influenced by the amount of time spent practicing an activity (short-term within-session learning versus long-term task learning) (Landau et al. 2004). In one such study, frontal midline theta rhythms were amplified when experienced pistol shooters, as opposed to novices, focused their attention on shot preparation (Doppelmayr et al. 2008). The findings could imply that certain cortical areas are important for skilled task performance.
3.4. Cortical activation within the brain areas investigated

My study will investigate cortical activity found within the parietal, frontal midline and orbitofrontal cortices (Figure 3.3). Each of these cortical areas plays an important role during resting (eyes-closed and eyes-opened) tasks and cognitive activation states (including visuo-spatial tasks or motor tasks). Thus, the following will be discussed: 1) each brain region and its mechanistic role, and 2) activity recorded within each area, i.e., responses to resting conditions and more cognitively demanding tasks. However, the four frequency bands represent non-unitary phenomena, i.e., there is considerable variation identified in each brain wave. Patterns of cortical activity can also be affected by an individual’s mental state and the task at hand. In the current study, the aim is to eliminate the confounding effects of variability by comparing the results that are obtained from the pilot study to those of former studies wherever possible. Here, the focus will be on discussing specific functions of the parietal, frontal midline and orbitofrontal cortices, i.e., the cognitive components mentioned are directly linked to the thought processes involved in motor task execution (see Petzschner & Krüger 2012; Itthipuripat et al. 2013 for examples).

Figure 3.3: Brain areas that were recorded in the current EEG study. A) The parietal cortex, B) the frontal midline cortex, C) the orbitofrontal cortex.
3.4.1. The function of each cortical area

Functional magnetic resonance imaging (fMRI) studies tend to elaborate on individual sub-regions located within the parietal lobe. The EEG method, however, records overall parietal cortical activity. To understand the mechanistic function of the parietal cortex, it is pertinent to discuss how individual sub-regions work together as a cohesive unit. Current research shows that parietal sub-regions are activated when visuo-spatial information is processed in the mind (Rushworth & Taylor 2006; Sack et al. 2002), and thus it is needed for visual working memory processes (Berryhill & Olson 2008). In addition, the parietal cortex (Figure 3.3A) might be involved in selecting and maintaining perceptual information in working memory (Corbetta & Shulman 2002; Xu & Chun 2009).

The frontal midline (Figure 3.3B) is also associated with working memory processes (Jensen & Tesche 2002; Onton et al. 2005) and/or when an individual is learning a novel task (Laukka et al. 1995). In addition, the frontal midline is activated during tasks that require concentration (Koji & Haruhiko 1993), and/or sustained and internalised attention (Aftanas & Golocheikine 2001). The findings imply that it has a multi-functional role, as it is needed for a variety of cognitive functions or tasks.

The precise function of the orbitofrontal cortex (Figure 3.3C) is still unknown. The wide range of deficits caused by orbitofrontal lesions implies that it has a variety of functions (see Ongür & Price 2000). A number of neuroimaging studies show, however, that the orbitofrontal cortex coordinates and integrates perceptual and emotional activity (e.g., Kringelbach 2005). For example, the orbitofrontal cortex receives continuous feedback from cortical areas that are involved in perceptual or sensory processing, such as the inferior parietal lobule (e.g., Griffiths et al. 1998). Previous fMRI and intracranial EEG studies mention that the orbitofrontal cortex is activated when people are exposed to emotional stimuli (see Kringelbach 2005; O’Doherty et al. 2003), and in situations where decision-making is required (Schoenbaum et al. 2006; Wallis 2007).

3.4.2. The cognitive energetic model

To understand cortical dynamics, EEG researchers use the Cognitive Energetic Model (CEM) to measure a wider bandwidth of cortical activity patterns. Arousal is defined as the current energetic state of the individual (Barry et al. 2007). Activation refers to changes in cortical arousal when an individual switches between tasks. Cortical activation changes from the
eyes-closed to the eyes-open resting condition (as the participant is subjected to visual stimulation), and again from the resting state to the cognitive activation task (Barry et al. 2007). During the baseline assessment, the eyes-closed task activates visual, somatosensory, auditory and vestibular systems (Marx et al. 2004). The eyes-open task, however, activates the attentional and ocular-motor systems (the latter is involved in controlling eye movements) (Marx et al. 2004). Changes in cortical activity imply that there are two states of mental activity. An interospective state is associated with imagination and multisensory stimulation, and occurs during the eyes-closed task (Marx et al. 2004). An exteroceptive state, however, is characterised by attention and ocular motor activity, and it is attributed to the eyes-open task (Marx et al. 2004). I will now elaborate on previous EEG research that discusses fluctuations in cortical dynamics when participants switch from the eyes-closed task to the eyes-open task.

There is very little research on the role of the orbitofrontal cortex during resting conditions. In one study, it is mentioned that the orbitofrontal cortex is activated when a person’s eyes are closed (Schoenbaum & Setlow 2001). The results are surprising, as a number of neurons fire in the orbitofrontal cortex when visual input is being processed. For example, visual input in the ventral, temporal cortex, and the visual stream is concerned with ‘what’ objects are seen, and the orbitofrontal cortex determines the function of the objects in view, depending on the rewards that are associated with it (see Rolls et al. 1996 for more on this; Rolls & Deco 2002; Rolls & Grabenhorst 2008). Further research is needed to determine the role of the orbitofrontal cortex during the baseline assessment.

Further studies on parietal and frontal midline cortical activity are also necessary. Parietal delta activity might be important for focused attention on visual stimuli (see Section 3.4.3.1). In comparison to the eyes-closed task, opening one’s eyes might result in visual stimulation (representing the exteroceptive state) (Marx et al. 2004), which could lead to an increase in parietal delta activity. Unfortunately, there is little to no research on frontal midline delta activity during resting conditions. It is tentatively suggested that when an individual opens their eyes, frontal midline delta activity might increase. For example, internal attention is necessary when a person processes incoming visual stimuli (see Section 3.4.3.5).

Parietal theta activity is involved in processing visual input (Romei et al. 2011), which implies that it might increase when participants switch from the eyes-closed task to the eyes-open task. In contrast, frontal midline theta activity monitors internal processes, and it is also
associated with daydreaming, deep meditation and a flow of ideas (Aftanas & Golochekine 2001; Ishii et al. 1999). The multi-functional role of frontal midline theta activity suggests that it is either activated during the eyes-closed task or the eyes-open task – depending on the participant’s psychological state. During the eyes-closed task, for example, the participant might daydream or meditate, because there is a lack of cognitive engagement. I suggest that this could lead to an increase in frontal midline theta activity. The participants, however, could contaminate the baseline assessment by focusing their attention on internal thoughts, i.e., anticipating the experimental conditions.

EEG research indicates that alpha activity is amplified during the eyes-closed task and blocked with the eyes-open task (e.g., Schürmann & Basar 2001). Previous research associates the alpha frequency band with relaxation and disengagement, implying that alpha enhancement represents ‘cortical idling’ (Pfurtscheller et al. 1996; Schürmann & Basar 2001). However, parietal alpha activity appears to be enhanced during the eyes-open task (e.g., Westphal et al. 1993), which substantiates the theory that parietal alpha activity is needed for perceptual (e.g., Thut et al. 2006), and attentional processes (Worden et al. 2000). In comparison, frontal midline alpha activity might be inhibited when the participants open their eyes – assisting with cortical inhibition (e.g., Schürmann & Basar 2001), but further research is needed on this topic.

Parietal beta activity might be associated with attention-related modulation of visual processing. Previous research indicates that stimulation of the visual pathway evokes bursts of beta activity that spreads to visual centres, such as the lateral posterior cortical areas (Wróbel 2000). This theory implies that parietal beta activity is propagated by incoming sensory information that needs to be processed in the mind. Frontal midline beta activity appears to increase with the eyes-open condition (Barry et al. 2007), which could be a result of attention and/or sensory awareness.

3.4.3. The cognitive activation tasks

In contrast to resting conditions, cognitive activation conditions tend to require greater ‘neural effort’ and/or working memory processes (unless the results have been contaminated). It is unsurprising, due to the imperative role of working memory in visual cognition, that visual working memory requires communication within and between a large network of cortical sites (Linden et al. 2003; Munk et al. 2002; Sala et al. 2003). Executive functions, such as attentional selection and the control or manipulation of information in working
memory, are often associated with the prefrontal cortex (Bor et al. 2003; Curtis & D’Esposito 2003) (Figure 3.4A). The parietal cortex is responsible for temporarily storing sensory information in visual short-term memory (Smith & Jonides 1998; Rowe & Passingham 2001) (Figure 3.4B). In addition, the posterior parietal lobe (Figure 3.4C) and the inferior temporal region (Figure 3.4D) might be involved in the retention of visual information (Munk et al. 2002; Todd & Marois 2004). Indeed, visual short-term memory appears to recruit a vast network of brain regions (Linden et al. 2003; Munk et al. 2002), but the extent to which different nodes of the fronto-parietal network process distinct components of visual short-term memory is still unresolved (Pessoa et al. 2002).

![Figure 3.4: Brain areas involved in the working memory processes mentioned in Section 3.4.3. A) The prefrontal cortex, B) the parietal cortex, C) the posterior region, D) the inferior temporal region.](image)

3.4.3.1. Parietal delta

Attention is necessary, because at any given time, the environment presents more perceptual information than one can process in the mind (Chun et al. 2011). A consequence of the limited processing capacity problem has been the evolutionary development of attentional mechanisms (Chun et al. 2011), which allows a person to focus attentively on task-relevant information. For example, it encourages an individual to select, modulate and focus their
attention on task-relevant stimuli that is necessary for goal obtainment (Chun et al. 2011; Pashler et al. 2001). There are two types of attention; referred to as internal and external attention (Section 3.4.3.5. discusses internal attention). External attention requires an individual to select and modulate sensory information that needs to be processed in the brain, which includes modality-specific representations (vision, taste, hearing, etc.), and/or episodic tags (points in time and spatial locations) (Chun et al. 2011).

Attention to visual stimuli activates relevant topographic areas within the retinotopic visual cortex (Tootell et al. 1998) (Figure 3.5A). Thus, the observer can detect fine details that are found on features or objects. Tactile improvement of vision is a result of multimodal parietal areas (Figure 3.5B) projecting attentional signals to enhance the unimodal visual cortex (Macaluso et al. 2000) (Figure 3.5C). Based on the mechanistic function of the parietal cortex (Macaluso et al. 2000), and the delta band (Lakatos et al. 2008), parietal delta activity might be needed for visual or external attention. External attention is important for processing important sensory information, i.e., spatial locations, features and objects (Chun et al. 2011).

![Figure 3.5: Brain areas involved in processing visual stimuli from Section 3.4.3.1. A) The retinotopic visual cortex, B) the parietal cortex, C) the unimodal visual cortex.](image)

Spatial attention is important, i.e., a person can focus their attention on spatial locations in their environment (Chun et al. 2011). Mechanisms associated with attention to spatial
locations evolved in order to guide and control eye movement (Rayner 2009; Schall & Thompson 1999). For example, it is necessary during target shooting (see Buys 2002). External attention is also used to detect whole objects and features (Scholl 2001). Once an object has been selected, so are all of its features (O’Craven et al. 1999), which includes the objects’ characteristics as it moves or changes through time and over space (Kahneman et al. 1992). Selecting two features from the same object is less demanding than the selection of two features from separate objects (Chun et al. 2011). Using two tools as an effective unit, for example, might thus require higher levels of parietal delta activity than simply using a single tool unit.

3.4.3.2. Parietal theta

During motor task execution, there might be a correlation between parietal theta power and the memory updating process that underlies the P300 (Klimesch et al. 1994; Makeig et al. 2004), which implies that parietal theta activity is involved in context updating. Context updating allows a person to integrate current perceptual information with memory-associated visuo-spatial cue information (e.g., Lenartowicz et al. 2010; Thompson et al. 2012). In this framework, context updating relies on the P300 (an electrophysiological response), which responds to infrequent, unexpected or motivationally relevant stimuli (Knyazev 2007). For example, the P300 indexes cortical activities that are involved in the re-evaluation or revision of mental representations that are induced by incoming stimuli (e.g., Donchin 1981). After the initial stages of sensory processing have occurred, attention driven processes actively evaluate and compare the information with representations of previous events in working memory (Heslenfeld 2003). If there are no changes detected, then the current mental model (‘schema’) is maintained (Donchin & Coles 1988). If a new stimulus is identified, attentional processes either change or ‘update’ the stimulus that is associated with the P300 (Donchin & Coles 1988). An increase in parietal theta activity could be associated with changes in the environment, or in response to earlier movement changes. Thus, parietal theta activity might be necessary for coordinating and/or integrating visual and sensory motor-information (Bland & Oddie 2001; Caplan et al. 2003), and perhaps works in conjunction with frontal midline theta activity (refer to Section 3.4.3.6).

3.4.3.3. Parietal alpha

The cognitive demands of a task can be determined by alpha oscillations across cortical sites. For example, during perceptual and working memory processes, fronto-parietal alpha
rhythms work together to select and maintain information in the mind (Kawasaki et al. 2010). Parietal alpha power increases when information needs to be encoded or retained, and/or with complex tasks that require a number of items to be remembered (Jensen et al. 2002; Obleser et al. 2012). Archery, for example, requires the tool user to remember a number of task-specific items, such as eye-hand coordination and visuo-guided movements.

When storing visual items in short-term memory, synchronised alpha activity suppresses distracting information that could affect memory capacity (Jensen et al. 2002; Klimesch et al. 2007). Inhibiting irrelevant information, therefore, allows an individual to focus their attention on the task at hand. In other words, alpha oscillations assist with working memory performance by filtering out irrelevant information and preventing interferences from conflicting stimuli (Klimesch et al. 2007). Once a task has been learnt, alpha activity might fluctuate or change. For example, experienced pistol shooters are distinguished from novices by the rate at which parietal alpha activity fires during task execution (Del Percio et al. 2011), which could reflect neural efficiency and/or skilled cognitive-motor task performance (see Janelle et al. 2000; Kerick et al. 2004; Landers et al. 1994; Loze et al. 2001; Salazar et al. 1990; Shaw 1996).

3.4.3.4. Parietal beta

Praxis refers to the ability to plan and coordinate motor movements (May-Benson & Cermak 2007.). The sensory integration theory suggests that praxis is a uniquely human skill that requires: 1) ideation (conceptualising ‘what’ is required to carry out the task), 2) motor planning (directing and organising the specific movement), and 3) task execution (Ayres 1985). Distributed fronto-parietal networks might be needed for praxis movements. For example, coupled communication between the parietal (Figure 3.6A) and the premotor regions (Figure 3.6B) is needed for tool manipulation, grasping and other tasks that require motor control (see Binkofski et al. 1999). Beta coupling within the parietal (Figure 3.6A), premotor (Figure 3.6B) and motor networks (Figure 3.6C) has also been observed when participants prepare and/or execute praxis movements (Wheaton et al. 2009; Wheaton et al. 2005). The studies indicate that beta coupling might be necessary for integrating preparatory and motor-related activity.
3.4.3.5. Frontal midline delta

Working memory processes allow attentional mechanisms to be selected from relevant perceptual information in the external world (Chun et al. 2011). Information is then actively maintained as internal representations in the mind (Chun et al. 2011). Delta activity is amplified when participants engage in cognitively complex tasks, as opposed to easy conditions, and might be associated with working memory load (Harmony et al. 1996). According to Harmony and colleagues (1996), an enhancement in delta activity could be associated with internal processing during the performance of a cognitively demanding task. In addition, the frontal midline is activated when internal attention is required (Aftanas & Golocheikine 2001). Thus, frontal midline delta activity might assist with internal attention or concentration. Internal attention refers to the selection, modulation and maintenance of internal information in working memory and/or long-term memory (Chun et al. 2011).

3.4.3.6. Frontal midline theta

A number of studies indicate that frontal-midline theta activity is needed for cognitively demanding tasks that require focused attentional processing (e.g., Ishii et al. 1999). A study
conducted by Gevins and colleagues (1997) shows that theta power was amplified with tasks that required the highest level of sustained attention and/or with an increase in memory load. In another study, Sauseng and colleagues (2007) analysed local frontal-midline theta power and interregional theta phase coherence. The results of the study reveal that local frontal midline theta activity is associated with sustained attention, whereas interregional theta coherence correlates with memory load (Sauseng et al. 2007).

During the initial stages of task performance, long-range interactions in the theta frequency band could be needed in situations where large amounts of visual information need to be processed to execute a motor response (Sauseng et al. 2007). Once learnt, frontal midline theta activity could play an important role in context updating (Makeig et al. 2004), possibly working in conjunction with parietal theta activity. Updating familiar sensorimotor representations in the mind allows the performer to execute memorised action sequences (Makeig et al. 2004). If a task comprises a number of action sequences, the individual would have to retain more information in working memory.

3.4.3.7. Frontal midline alpha

Frontal midline alpha activity is needed during tasks that require internal attention, imagination and mental imagery (Cooper et al. 2003, 2006). Prior to the commencement of an experimental task, irrelevant cognitive processes are inhibited, which allows a person to focus their attention on task-relevant information (Cooper et al. 2003).

3.4.3.8. Frontal midline beta

Frontal midline beta activity might be involved in memory rehearsal, i.e., rehearsing object representations that are found in short-term memory (Tallon-Baudry et al. 1999). Previous research has shown that frontal midline beta activity is enhanced after movement onset (Pfurtscheller et al. 1994), which implies that the beta band plays an active role in motor imagery. Motor imagery refers to the internal rehearsal of simple or complex motor acts without accompanying body movement (Jeannerod 1995; Porro et al. 1996). A participant, for example, might feel themselves performing the action (known as kinaesthetic or internal imagination), or they may construct a mental image of the movement in their mind (Munzert et al. 2009; Porro et al. 1996). Motor imagery plays an imperative role in motor skill learning (Brouziyne & Molinaro 2005). With motor imagery, short-term activations in beta rhythms occur to improve task performance (Neuper et al. 2005). Prior to launching an arrow with a
bow, for example, an individual might mentally rehearse the shot – allowing the tool user to suppress non-relevant task-related thoughts. Motor imagery, however, does not assist with feedback of the actual shot.

3.4.3.9. Orbitofrontal delta

An important finding in cognitive research is the correlation between P300 amplitude and an increase in delta power (Basar-Eroglu et al. 1992; Roschke & Fell 1997). The P300 is enhanced with salient cues or with motivationally relevant stimuli (Knyazev 2007), which implies that it is linked to reinforcement learning and/or when emotional stimuli must be processed (Carretie et al. 2001). Thus, delta oscillations could be associated with basic motivational processes (Knyazev 2012), specifically in the orbitofrontal and the anterior cingulate cortices (Knyazev 2011). Based on the aforementioned findings, orbitofrontal delta activity might be needed for salience detection and/or in situations in which motivational urges are triggered by biological rewards and dangers. This premise is substantiated by Knyazev (2012) who mentions that the delta band is involved in screening internal and external stimuli in order to search for motivationally salient cues that signal either a threat or a reward. Therefore, orbitofrontal delta activity could be pertinent during cognitively demanding task execution, as it allows an individual to focus their attention on selective external and internal stimuli. Based on its mechanistic role, orbitofrontal delta activity could work in conjunction with parietal and frontal midline delta activity.

3.4.3.10. Orbitofrontal theta

Along with delta activity, theta activity could contribute towards the P300 response. According to van Wingerden and colleagues (2010), reward anticipation (amongst rats, in the orbitofrontal cortex) results in an increase in theta phase locking. In humans, reward motivation is associated with successful memory encoding (Wittmann et al. 2005). In addition, the orbitofrontal cortex plays an influential role in processing, storing and retrieving motivationally rewarding information or non-neutral, emotionally driven stimuli (Gottfried et al. 2003; Schoenbaum et al. 1998). Based on the above, orbitofrontal theta activity could represent an essential frontal component for processing novel stimuli. For example, it might assist with working memory tasks that are cognitively demanding. This premise is validated further by experimental results that show a correlation between an increase in frontal theta activity and working memory load (Jensen et al. 2002; Jensen & Tesche 2002). Furthermore, Kawasaki and Yamaguchi (2012) mention that an enhancement in frontal theta amplitudes
could assist with increasing visual working memory capacity, i.e., reward-related brain waves facilitate the visual working memory systems.

3.4.3.11. Orbitofrontal alpha

Orbitofrontal alpha activity has been associated with the inhibition of specific processes (such as motor programs and neuronal mechanisms) that are involved in working memory processes (Knyazev 2007). There are, for example, some studies that show enhanced prefrontal alpha amplitude during the execution of a short-term memory task (Goldman-Rakic 1996). In addition, orbitofrontal alpha activity could work in conjunction with parietal and frontal midline alpha activity. An increase in orbitofrontal alpha activity might contribute towards focused attention (on salient stimuli) and the inhibition of unnecessary processing to assist with motivational control and goal-directed behaviour.

3.4.3.12. Orbitofrontal beta

In humans, reward processing is possible because of our extensive fronto-subcortical network, which includes the amygdala (Figure 3.7A), the striatum (Figure 3.7B), the insular cortex (Figure 3.7C), and the orbitofrontal cortex (Camara et al. 2009; Koob & Volkow 2010) (Figure 3.7D). The fronto-subcortical network requires brain oscillations to coordinate information that occurs in each of the cortical areas involved (Buzsáki & Draguhn 2004; Varela et al. 2001). High frequency beta and gamma activity is necessary for synchronising these different components, thereby contributing towards the integration of information across cortical sites (Colgin et al. 2009; Steriade 2006).
EEG research shows that the beta frequency band is involved in reward processing (i.e., selectively signalling positive events that can result in improvements in task performance) (Cunillera et al. 2012; HajiHosseini et al. 2012; Schutter & Van Honk 2005; Snyder & Hall 2006). When performing a novel task, for example, I tentatively suggest that reward-related stimuli might be needed to process salient stimuli during a cognitively complex task (resulting in future behavioural adjustments). After the initial stages of performance, with the possible reward in mind, the individual might use positive feedback or reinforcement learning to become more skilled at the task (see Cunillera et al. 2012; Yeung et al. 2005; Young & Schmidt 1992). Based on the mechanistic function of the orbitofrontal cortex (Gottfried et al. 2003; Tremblay & Schultz 1999) and the beta band (Cunillera et al. 2012; HajiHosseini et al. 2012; Schutter & Van Honk 2005; Snyder & Hall 2006), orbitofrontal beta activity might be needed for reinforcement learning and/or positive feedback.

3.5. Conclusion

Executing a novel motor task often requires visual working memory. For example, it is necessary for the selection and maintenance of object representations. Maintaining
information in visual short-term memory requires a vast network of intra-cortical communication – for instance, cortical activations in the fronto-parietal networks work together to assist with working memory processing. Once a task has been practiced, synaptic plasticity occurs. Cortical changes, however, are not always predictable. EEG research results indicate that cortical activity is influenced by the task, the cortical area recorded, the mental state of the participant and whether the task has been practiced for a short or long period of time. The brain is thus a complex organ that is subject to change. To better understand cerebral-cortical dynamics, I will discuss EEG methodology in more detail.
CHAPTER FOUR: RESEARCH METHODS

4.1. Introduction

In previous chapters I have indicated that I will attempt to assess the cognitive implications of using non-symbiotic and symbiotic technologies. There is a particular interest in measuring differences (if any) in cortical dynamics when a tool is used non-symbiotically, and when two tools are utilised as an effective unit. EEG equipment is needed to record patterns of cortical activity (elevation or suppression) for the four frequency bands: delta, theta, alpha and beta. In this pilot study, I will assess levels of cortical activity found within the parietal, frontal midline and the orbitofrontal sites in an attempt to address the proposed research question, and the hypothesis and/or problem statements that are put forward in chapter one for the cognitive activation conditions. For example, when the participants switch from the non-symbiotic tasks to the symbiotic tasks it could result in an increase in parietal, frontal midline and orbitofrontal cortical activity. If cortical activity is enhanced with symbiotic tool use (as opposed with non-symbiotic use), it might imply that greater ‘neural effort’ was needed (see Rietschel et al. 2012). In addition, the raw data obtained per epoch (time segment), task, and cortical area recorded must be prepared for further analysis. Thus, the following stages of data analysis were necessary: removal of confounding noise and/or artefacts from the waveforms, transformation of the data, extraction of mean power values and, finally, the implementation of statistical research methods. Prior to mentioning the experimental procedures, I discuss the research design in more detail.

4.2. Research design

The EEG method is a medical imaging technique that records electrical movement found within selected areas of the brain. I will use the method to record levels of cortical activity while the participants engage in non-symbiotic tasks and symbiotic tasks. Thus, a positivist approach is appropriate, as cortical activations within the parietal, frontal midline and orbitofrontal sites will be objectively measured and empirically tested. Due to factors such as time, cost and, thus far, limited application of the method in cognitive archaeology, the study is contained and exploratory. If the approach yields useful results, it can be built upon. Future research may refine the technique, enlarge the sample and database, or explore other thought-and-action sequences. With the current pilot study, a within-subjects design and a between-
subjects design will be used. The intention is to try control most variables, but there may be too many. For this reason, a quasi-experimental, repeated measures design will be applied. The research design mentioned is used by scholars to encourage internal validity of the research findings and to ensure that the experimental conditions are equivalent (for an example see Funderburg *et al.* 2010). It is thus appropriate for the current study, because differences between conditions (and the independent variables thereof) need to be controlled.

**4.3. Participants**

Approximately twenty participants took part in the experiment, but only four were included for data analysis purposes (see Sections 4.5.2 and 4.6.2). In an attempt to recruit participants, announcements were made at the end of first- and second-year lectures at the University of Johannesburg. The experiment included participants of a similar age, because age differences might result in a partially confounding experiment – influencing the results of the clinical trial. For example, myelination and synaptic pruning are age dependent variables that could affect patterns of cortical activity during an EEG recording (see Anokhin *et al.* 1996; Clarke *et al.* 2001; Klimesch 1999; Michels *et al.* 2012).

**4.4. Measuring Instruments**

The research question is concerned with investigating the potential differences (if any) in cortical activity when each of the participant’s engage in non-symbiotic tasks and symbiotic tasks (refer to Section 1.3). An EEG is appropriate as the technique records activity of the cortical nerve cells in the brain (Fisch 1999), whereby a number of brain functions can be assessed. Previous research validates that the EEG method is useful for detecting mental disorders and/or mental illnesses, such as Alzheimer’s disease (e.g., Dauwels *et al.* 2010), and attention-deficit hyperactivity disorder (e.g., Loo & Barkley 2005). The EEG method is also utilised to assess the influence that emotions has on task performance (e.g., Hart *et al.* 2010). In addition, the approach provides researchers with information about electrical processing that occurs when a participant engages in cognitive activation tasks (Ferreria 2011; Gevins *et al.* 1998; Hatfield *et al.* 2004; Teplan 2002).
The technical aspects that are associated with using EEG equipment needs to be discussed further. Cortical activity is presented in waveforms, which are measured by amplitude and frequency (Teplan 2002). In terms of the wave theory, neurons form connections with other neurons, and the electrical impulse of one neuron results in the firing of several others (e.g., Goldstein 2008; Musall et al. 2012), where cortical activity spreads to different regions of the brain like a wave (pers. comm. Professor Alban Burke, May 2012). Amplitude can be expressed in microvolts (μV) and EEG power is defined by amplitude squared (μV²) (Thatcher et al. 2005). Frequency is the rate at which neurons are fired and it is measured in cycles per seconds, referred to as hertz (Hz) (Loo & Barkley 2005).

4.4.1. The EEG Biopac MP Systems Hardware

I will use EEG Biopac MP Systems Hardware ® to assess patterns of cortical activity found within the parietal, frontal midline and orbitofrontal sites for each of the tasks performed. The equipment consists of surface electrodes that are embedded in the electro-cap (Figure 4.1.), which records delta, theta, alpha and beta activity (Loo & Makeig 2012; Teplan 2002). The EEG amplifiers, obtained via the EEG Biopac MP Systems Hardware ®, are used to measure a very weak signal that is attained by two types of electrodes, known as ‘active’ (+) and ‘baseline’(-). The ‘active’ and ‘baseline’ electrodes are placed around the scalp (recording the same noise), but they measure different EEG signals. The amplifier subtracts these two signals, which cancels out the noise (Pivik et al. 1993). EEG activity, therefore, reflects the potential differences that exist between these two inputs (Pivik et al. 1993). The recording techniques that were used for this system have been ethically approved and represent a non-invasive, safe and painless procedure (Babiloni et al. 2007; Teplan 2002).

Figure 4.1: The electro-cap.
Multiple electrodes are used to record cortical activity patterns across the scalp. According to Loo and Makeig (2012), EEG recordings and their subsequent interpretation, depend on the positioning of the recording sites. To ensure standardised reproducibility, the current study included the International 10-20 system – a reputable method for electrode placement (Herwig et al. 2003). The 10-20 system is based on the identification of anatomical landmarks, such as the naison (located above the bridge of the nose) and the inion (the lowest point of the skull, evident by a prominent bump) (Figure 4.2). To adhere to the 10-20 system, an electro-cap was used (Figure 4.1). The electro-cap consists of electrodes that are intentionally placed underneath the cap at a distance between 10 and 20% from electrode to electrode (Figure 4.2).

Figure 4.2: The 10-20 system of electrode placement. Each of the electrodes have individually subscribed letters to identify the location of a lobe and either a number or a letter to recognise the locality within the lobe (e.g., Teplan 2002). The letters represent the following: F (frontal), T (temporal), C (central – used solely for identification purposes), P (parietal) and O (occipital) cortical sites (Teplan 2002). Even numbers signify electrode positions found on the right hemisphere, while odd numbers refer to those located on the left hemisphere. The electrodes that were used in the current study are highlighted in different colours. The orbitofrontal (Fp1 and Fp3) is red; the frontal midline (Fz) is blue; and the parietal (P3 and P4) is green.

The electro-cap is frequently used in clinical and scientific research as well as a number of peer-reviewed EEG studies (e.g., Mizuki et al. 1982; Sauseng et al. 2007; Sterman & Mann
The cap provides a standardised reference for electrode positioning, and prevents individual measurement errors and inter-investigator differences (Herwig et al. 2003). New developments of high resolution EEG have resulted in an extended version, known as the 10-10 system (Koessler et al. 2009; Oostenveld & Praamstra 2001). In contrast to the 10-20 system, some researchers argue that the 10-10 system is a more effective way of assessing cranio-cerebral correlations due to the high number of EEG electrodes placed on the scalp. For example, the 10-20 system consists of 21 to 74 electrodes (Chatrian et al. 1985), whereas the 10-10 system ranges between 64 and 256 electrodes (Koessler et al. 2009). On the other hand, the 10-20 system has been used for nearly five decades and represents a more conventional transcranial method than the 10-10 system (Jurcak et al. 2005). In addition, the 10-20 system is flexible in applicability. Although optimal for EEG studies, the 10-20 system can also be used for newly-developing transcranial neuroimaging techniques, such as transcranial magnetic stimulation and near-infrared spectroscopy (Jurcak et al. 2005).

A number of EEG researchers record only a limited number of cortical sites (Mizuki et al. 1982; Sauseng et al. 2007; Sterman & Mann 1995). A small number of cortical sites are often recorded because it provides the analyst with ample quantitative data, which is scientifically valid (Clarke et al. 2001). For example, researchers are able to assess cortical communication within and between different areas of the brain, i.e., when participants engage in perceptual or attentional tasks (Gross et al. 2004; Kujala et al. 2007; Kveraga et al. 2011; Lou et al. 2010; Siegel et al. 2008). The EEG method is thus useful as it records patterns of cortical activity, which contributes towards our understanding of the areas of the brain that are involved when we engage in cognitively complex tasks (Lachaud 2013).

Furthermore, the EEG method shows high test-retest reliability. Previous research suggests that its performance is reasonably constant during resting states or cognitively simple tasks, such as oddball stimulus detection (see Burgess & Gruzelier 1993; Salinsky et al. 1991). The oddball task consists of stimuli that are presented in a continuous stream, whereby participants are expected to detect an oddball stimulus (Squires et al. 1975). The oddball stimulus is distinguished from the other stimuli by distinct characteristics, i.e., a tone that differs from other auditory stimuli (Squires et al. 1975). The EEG method also appears to be stable despite variability in task conditions and complexity (McEvoy et al. 2000). In some cases, however, the results of an EEG apparatus can be influenced by the mental state of the participant. For example, anxiety can influence levels of cortical activity (Aftanas et al. 1995).
For this reason, EEG examiners must ensure that the participants are relaxed, but sober, to prevent a partially confounded experiment.

4.5. The experimental procedure

4.5.1. The experimental conditions

The participants engaged in two resting tasks (representing a baseline assessment). For the resting conditions, they were asked to keep their eyes-closed, followed by the eyes-open task (Figure 4.3). EEG researchers use a baseline assessment to gauge whether there is a change in cortical activity from the resting conditions to the cognitive activation conditions. This is referred to as the cognitive-energetic model (Goldstein 2008; Helps et al. 2008). To assess potential differences in cortical activity during non-symbiotic and symbiotic tool use, participants were required to perform six cognitive activation tasks. In total, there were three activity sets (consisting of a non-symbiotic task and a symbiotic task). The first set, for example, includes using a chisel non-symbiotically versus a chisel-and-hammer being used as an effective unit. The second set entails plucking a bow non-symbiotically and stroking the bow symbiotically with an arrow (replicating a musical instrument, a one-string guitar or a violin). Finally, participants were asked to throw a spear non-symbiotically (in this instance we simply used an arrow to replicate the task) and to use a bow and arrow symbiotically. The tasks were each conducted for a minute, resulting in EEG recordings of eight minutes per participant. An eight minute EEG scan equates to 420 epochs of data. Thus, each recording had sufficient amounts of data for analysis and subsequent interpretation. To compensate for the small participant sample size in the pilot study, non-parametric statistical procedures were used (e.g., Greene & D’Oliveira 2009) (see Section 4.6.4).

Figure 4.3: The progression of the experiment. The abbreviations in the figure represent the
following tasks: eyes closed (EC), eyes open (EO), chisel (chi), chisel and hammer (CH), plucking (plu), stroking (ST), spear (sp), and bow and arrow (BA). *Each 1 minute in length

4.5.2. The experimental setting

The experiments commenced in the morning and attempted to finish in the afternoon. Current research shows that mental fatigue or tiredness can influence cognitive performance (Boksem et al. 2005; Cook et al. 2007; Lorist et al. 2000). To prevent other confounding variables, such as external noise and disruptions during the experiment, students and staff were verbally notified of the experiment and a sign was placed outside of the door. Prior to the commencement of the experiment, some of the blinds were closed, as bright light might influence alpha readings (Barry et al. 2007).

4.5.3. Pre-trial runs

To prevent anxiety-related escalations in cortical activity, the consent form was explained to each of the participants as they entered the room. The EEG equipment that was used to record cortical activity, such as the EEG electro-cap (refer to Figures 4.1 and 4.2), was described as a safe, non-invasive and painless procedure. The participants were then asked to sit in the chair provided. I applied the electro-conductive gel into each of the electrodes using a blunt-ended syringe. The gel is used to minimise impedance of electrical connection by conducting electrical activity between the scalp and the electrodes (Light et al. 2010). Similar to the instructions issued by Light and colleagues (2010), the participants were asked to hold the cap in place, while I pulled it over the scalp. To ensure that it was correctly positioned, the cap was aligned between the participants’ nasion and the inion. The Fz electrode, for example, must be placed in the middle of the forehead (Figure 4.2). If the cap is correctly positioned, the Fp1 and the Fp2 electrodes will be located directly above the eyebrows (Light et al. 2010) (see Figure 4.2).

Next, the participants were asked to relax and make themselves comfortable, followed by the commencement of the experiment. For the resting conditions, the participants were asked to keep their eyes-closed, followed by the eyes-open task – both a minute in duration. During the eyes-open task, the participants were instructed to focus their attention on a blank computer screen. This was to prevent a partially confounded experiment, as visual stimulation could result in a further increase in cortical activity. For example, stimulation of
the visual pathway evokes bursts of beta activity that spreads to visual centres, such as the lateral posterior cortical areas (Wróbel 2000).

The cognitive activation conditions during this pre-trial were also each a minute in duration, and resulted, as mentioned below, in a partially confounded experiment. Participants were required to use a pencil and a piece of cardboard (a proxy for a chisel and a piece of wood) and cut a shape into the cardboard provided. For the chisel-and-hammer task, they used a second pencil to tap the ‘chisel’. Both of these tasks were not successful as a number of participants laughed during the task (perhaps a consequence of the experimental conditions), which resulted in a partially confounded experiment. In addition, participants had to pretend to hold a violin (the bow) and pluck it non-symbiotically, followed by playing it symbiotically with an arrow (as a violin bow). When I observed these two tasks, it was apparent, as soon as the participants visualised plucking and/or stroking an actual violin string, they began ‘thinking in music’ – by the manner in which they moved their fingers. There were also problems with the spear task. During the EEG recording, participants threw the arrow (spears) before the end of the task. I had to stop the EEG recording to retrieve the arrow (spears) so that they could be used for subsequent use. Not only did this prevent the experiment from running smoothly, but it also distracted the participants from the task at hand – affecting cortical arousal levels. Finally, the bow-and-arrow task did not include the actual firing of the arrow, as I was concerned that the results would be contaminated by muscle noise. Thus, the participants were instructed to place the arrow in the bow and attempt to do the action without actually firing the arrow. Upon further testing, I noticed that the actual firing of the arrow did not contaminate the results, as there was little to no change in levels of cortical arousal.

4.5.4. The actual experiment

Based on the results of the abovementioned trial-runs, experiments running from the 31st of July to the 1st of August 2012 have been excluded from my formal results. The cognitive activation conditions were modified for the experiments that commenced on the 2nd and 6th of August 2012 (Figures 4.4, 4.5, 4.6, 4.7, 4.8, and 4.9). The experiment also required a more standard procedure. Each of the cognitive activation tasks, for example, was explained to the participants by a set of instructions that were issued on a piece of paper. To prevent a contaminated experiment, the participants were given a vague overview of the experimental procedures. Then, the EEG recording commenced.
The participants were given a chisel to use on a piece of wood. To keep the task standardised, they were asked to cut out a straight line (Figure 4.4). The chisel-and-hammer task entailed using a hammer to tap the chisel into the wood provided (Figure 4.5). The participants were then issued with a bow and asked to pluck it, representing the plucking task (Figure 4.6). Using the bow’s string for plucking purposes prevented the individuals from ‘thinking in music’. The stroking task followed, where the participants were asked to stroke the arrow on the bow (Figure 4.7). For the spear task, additional arrows (spears) were provided to avoid the previous problem associated with retrieval (Figure 4.8). The participants were then instructed to fire the bow and arrow, unlike the previous set of experiments (Figure 4.9).
Figure 4.6: The plucking task


Participant performing the plucking task.

Figure 4.7: The stroking task

(www.fotopedia.com/wiki/Bow_and_arrow, consulted November 2012).

Participant performing the stroking task.

Figure 4.8: The spear task


Participant performing the spear task.
4.6. Data analysis

Once the experiments were completed, the data was analysed. The data analysis phase is necessary for EEG research, as it removes artefacts and confounding noise from the waves. Data analysis is also important for extracting numerical values for subsequent analysis. The following stages of data analysis prevailed: 1) preparation of the data, 2) transformation of the data, 3) extracting the mean power values, and 4) applying statistical methods.

4.6.1. Preparing data for further analysis

EEG recordings contain parasitic artefact signals that can easily contaminate the data (Delorme et al. 2007; Teplan 2002). Ocular artefacts are created from mechanical movement of the eyes or eyelids, which contaminates delta activity found within the frontal and temporal regions (Boudet et al. 2012). In contrast, electrode artefacts are created by electrode or wire movements, heart beats and skin galvanic resistance variation (Boudet et al. 2012), the latter refers to physiological responses to emotional states. Similar to ocular movements, electrode artefacts affect the delta waves that are found within the frontal and temporal areas (Boudet et al. 2012). Finally, muscular artefacts correspond to electro-myographic potentials that are generated by the muscles (Boudet et al. 2012). For example, muscular artefacts are mostly a consequence of jaw and forehead movement (e.g., Safieddine 2012). Muscular artefacts are recorded in the beta band and are generally found within the frontal and the temporal areas (Boudet et al. 2012).

The current study might be particularly at risk of muscle noise, as each of the participants engaged in six motor tasks. To prevent a confounded experiment, all traces of artefact signal...
needed to be removed. In an attempt to cleanse the data, AcqKnowledge Software® was used to filter the waveforms. The EEG data (i.e., the individual channels and cortical areas recorded), had the band-pass filter set at 0.001Hz and 25Hz. The digital filter was applied to retain the frequency components of interest and remove other data, such as physiological signals that were outside the range of interest. Digital filtering is useful for reducing almost all artefact types and preserving brain signals (Teplan 2002). According to Pivik and colleagues (1993), filters are used to control contamination, but sometimes artefacts remain. Thus, the researcher must also visually screen the raw data (Pivik et al. 1993). For this reason, the data was visually reviewed – normal waveforms were selected for further analysis, whereas abnormally high-voltage, sharp spikes were excluded. For example, researchers often eliminate high-frequency changes in spike amplitude when it occurs sporadically, and/or when the spikes are of an unusual wave pattern. This preventative measure is taken to eradicate artefactual segments that might contaminate the results obtained. Visual inspection is, however, not always feasible in situations where there is an ample amount of data (Juozapavicius et al. 2011). In addition, sometimes it is difficult to identify the specific types of noise (Repovš 2010).

4.6.2. Transforming the data

After the EEG data was prepared, the data transformation phase commenced. The first step included the careful selection of individual epochs, also known as time segments. For each of the recordings per task, three epochs were extracted. The resting conditions (the eyes-closed and eyes-open tasks) epochs were extracted at a fixed time of twenty seconds. For the cognitive activation conditions (the non-symbiotic and symbiotic tasks), epochs were extracted according to changes in wave amplitudes across task performance. For example, I wanted to assess whether task practice resulted in changes in cortical activity. To ensure scientific validity, changes in waveforms were repeatedly analysed. Then, each of the cognitive activation tasks had a specific epoch selected to ensure standardised research procedures (see Clarke et al. 2002; Piantoni et al. in press for examples).

Thereafter, the epochs were transformed. A logarithmic transformation (the natural log of mean magnitude) was used to approximate the normal distribution of the data, as it renders right-skewed data normal. Log transformations can be applied in situations when there are concerns about the data’s normality. For example, time-frequency averages found over a small number of frequency components, referred to as bins (Kiebel et al. 2005). According to
Davidson and colleagues (1990), logarithmic transformations are necessary for obtaining results – contributing towards quality distributional properties found for each frequency band. Unfortunately, four participants had to be excluded from the study because there were difficulties in converting the EEG data. This indicates that the mean and variance could not be evenly distributed, possibly due to a large quantity of independent variables.

In addition, the EEG signal consists of several spectral components, which ranges from 10 to 100 μV (see Gevins & Smith 2000 for example). The frequency range includes a fuzzy lower and upper limit, with the most important frequencies occurring in the range of 0.1 and 30 Hz (Gevins & Smith 2000). For example, delta, theta, alpha and beta frequency bands are found within this range (Gevins & Smith 2000). In the current study, the original signal was separated into sub-spectral frequency components, referred to as sinusoids (see Shaker 2005). To convert EEG signals into fragments requires the assistance of a mathematical equation, known as the Fast Fourier Transform (or FFT). In the current study, the data was transformed via the AcqKnowledge Software ®, as it includes the Fast Fourier Transform algorithm.

4.6.3. Extracting mean power values

The frequency components were then clustered into delta, theta, alpha and beta frequency bands. The following frequency parameters were set: delta (1-4 Hz), theta (4-8Hz), alpha (8-14 Hz), and beta (14-20Hz). This is the most suitable clustering approach for either preliminary investigations or hypothesis testing. The quantification process included the selection of three epochs (or time segments) per task, which was clustered using the AcqKnowledge Software ® at the frequencies mentioned. Each of the four bandwidths had the rootmean-square average amplitude (V²) value extracted. After the extraction of mean power values (per participant, epoch, task and cortical area under investigation), they were tabulated into an excel document. Statistical analysis ensued once all of the mean scores were included.

4.6.4. Statistical analysis

The sample size did not meet the strict requirements for parametric analysis. Thus, non-parametric statistical procedures were applied with SPSS software. Non-parametric tests are needed to assess wider applicability for a small sample size, for instance, when the number is five or less. The statistical methods include the Mann-Whitney U-test for differences between participants and the Kruskal Wallis test for differences between tasks for each of the
participants (Greene & D’Oliveira 2009). The data are statistically analysed in an attempt to measure whether statistically significant trends (differences or similarities) exist within and between the non-symbiotic and symbiotic tasks.

4.7. Ethical Considerations

A consent form was issued to each of the participants. The participants were informed that there would not be any direct benefits or risks. For example, the participants were notified that the experiment was voluntary and that they could withdraw at any time during the experiment. Similar to Edge’s (2010) study, the participants’ research results were anonymous. The data, for example, was captured in codes and each of these codes was only meaningful to the researcher. Permission was needed to photograph individuals and each participant indicated on the consent form whether they would allow photos to be taken or not. Finally, participants were notified of the results.

4.8. Conclusion

The aim of the research is to test whether using two tools symbiotically results in changes in cortical activity. To address the research question, hypothesis and/or problem statements, the EEG method was used. A positivist approach was employed because the activated cortical areas were objectively measured and empirically tested. Measures were taken to control potential confounding variables. The non-symbiotic tasks and symbiotic tasks were, for example, adapted after pre-trial experiments in order to increase scientific rigour. Digital filtering was applied to prevent ocular, electrical and muscular artefacts from interfering with the results. Once all of the information was tabulated, statistical analysis prevailed. In the section that follows, I will discuss the results of the experiments and the statistical trends identified.
CHAPTER FIVE: RESULTS

5.1. Introduction

Here I report on the EEG recordings that produced ample data for the resting tasks and the cognitive activation tasks. Statistical methods were used to observe the trends identified in the data, and to interpret the results. Each of the brain waves was set at the following frequency parameters: delta (1-4 Hz), theta (4-8 Hz), alpha (8-14Hz), and beta (14-20 Hz). Descriptive statistics were used to measure each of the brain waves’ absolute mean power ($\mu V^2$) per task and cortical area. The results are presented in tables and graphs – both the tables and the graphs display the trends identified in the data. The graphs include self-drawn pictures of the brain. Each cortical area is highlighted in a specific colour: the parietal is represented in green, the frontal midline in blue, and orbitofrontal cortex in red. In addition, inferential statistics were applied to assess whether statistical trends ($p < 0.10$) were identified between the tasks. Although 5% significance levels are typically used in social research, it was deemed appropriate in the current study, due to the small sample size, to extend this to a 10% significance level. Here, inferential statistics were used to compare the data values obtained amongst the resting conditions (from the eyes-closed task to the eyes-open task), and the cognitive activation conditions (from the non-symbiotic task to the symbiotic task).

5.2. Descriptive statistics

Descriptive statistics are used by researchers to provide summaries of a data set, which are usually presented in a table or a graph (Greene & D’Oliveira 2009). The current study includes tables and graphs to show the trends identified in the data. The tables include structured, numerical summaries of the data set (tabulated in epochs or time segments). In contrast, the graphs consist of graphical summaries that allow the reader to visually compare patterns of cortical activity across the task. Each table and graph represents the absolute mean power ($\mu V^2$) for each brain wave, cortical area and task – displaying changes in cortical activity as a task progresses through time. The absolute power ($V^2$) per brain wave shows the amount of cortical activity that was needed to perform a task – for instance, greater ‘neural effort’ might correlate with an increase in absolute power ($V^2$). With the graphs that follow, the scale of activation is set at 0.060 for the resting conditions, and at 0.030 for the cognitive
activation conditions. The primary focus, however, will be on differences in levels of cortical arousal between non-symbiotic and symbiotic tasks, i.e., the cognitive activation conditions.

5.2.1. Cortical activity across the parietal site

Table 5.1: Absolute mean power ($\mu V^2$) for the 3 epochs during the eyes-closed task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.007</td>
<td>0.011</td>
<td>0.002</td>
</tr>
<tr>
<td>Theta</td>
<td>0.016</td>
<td>0.020</td>
<td>0.005</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.009</td>
<td>0.009</td>
<td>0.004</td>
</tr>
<tr>
<td>Beta</td>
<td>0.003</td>
<td>0.003</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Figure 5.1: Graph representing variation in the mean power ($\mu V^2$) during the eyes-closed task.

Delta activity across the task: from epoch 1 to 2, there is a gradual increase (0.007 - 0.011), followed by a rapid decline (0.011 - 0.002) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a gradual increase (0.016 - 0.020), followed by a rapid decline (0.020 - 0.005) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is no change (remains at 0.009), followed by a gradual decline (0.009 - 0.004) from epoch 2 to 3.
Beta activity across the task: from epoch 1 to 2, there is no change (remains at 0.003), followed by a slight decline (0.003 - 0.002) from epoch 2 to 3.

Table 5.2: Absolute mean power ($\mu V^2$) for the 3 epochs during the eyes-open task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.011</td>
<td>0.005</td>
<td>0.002</td>
</tr>
<tr>
<td>Theta</td>
<td>0.016</td>
<td>0.011</td>
<td>0.005</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.008</td>
<td>0.005</td>
<td>0.002</td>
</tr>
<tr>
<td>Beta</td>
<td>0.004</td>
<td>0.002</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Figure 5.2: Graph representing variation in the mean power ($\mu V^2$) during the eyes-open task.

Delta activity across the task: from epoch 1 to 2, there is a gradual decrease (0.011 - 0.005), followed by a further decline (0.005 - 0.002) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a gradual decrease (0.016 - 0.011), followed by a further decline (0.011 - 0.005) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a gradual decrease (0.008 - 0.005), followed by a further decline (0.005 - 0.002) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is a gradual decrease (0.004 - 0.002), followed by a slight decline (0.002 - 0.001) from epoch 2 to 3.
Table 5.3: Absolute mean power (μV^2) for the 3 epochs during the chisel task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.003</td>
<td>0.001</td>
<td>0.005</td>
</tr>
<tr>
<td>Theta</td>
<td>0.004</td>
<td>0.002</td>
<td>0.009</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.002</td>
<td>0.001</td>
<td>0.005</td>
</tr>
<tr>
<td>Beta</td>
<td>0.001</td>
<td>0.000</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Figure 5.3: Graph representing variation in the mean power (μV^2) during the chisel task.

Delta activity across the task: from epoch 1 to 2, there is a slight decrease (0.003 - 0.001), followed by a gradual increase (0.001 - 0.005) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a slight decrease (0.004 - 0.002), followed by a rapid increase (0.002 - 0.009) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a slight decrease (0.002 - 0.001), followed by a gradual increase (0.001 - 0.005) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is a slight decrease (0.001 - 0.000), followed by a gradual increase (0.000 - 0.003) from epoch 2 to 3.
Table 5.4: Absolute mean power ($\mu V^2$) for the 3 epochs during the chisel-and-hammer task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.006</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>Theta</td>
<td>0.010</td>
<td>0.005</td>
<td>0.012</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.004</td>
<td>0.002</td>
<td>0.008</td>
</tr>
<tr>
<td>Beta</td>
<td>0.001</td>
<td>0.001</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Figure 5.4: Graph representing variation in the mean power ($\mu V^2$) during the chisel-and-hammer task.

Delta activity across the task: from epoch 1 to 2, there is a gradual decrease (0.006 - 0.003), followed by a gradual increase (0.003 - 0.006) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a gradual decrease (0.010 - 0.005), followed by a rapid increase (0.005 - 0.012) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a slight decrease (0.004 - 0.002), followed by a gradual increase (0.002 - 0.008) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is no change in cortical activity (remains at 0.001), followed by a slight increase (0.001 - 0.003) from epoch 2 to 3.
Table 5.5: Absolute mean power ($\mu V^2$) for the 3 epochs during the plucking task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.002</td>
<td>0.003</td>
<td>0.005</td>
</tr>
<tr>
<td>Theta</td>
<td>0.004</td>
<td>0.005</td>
<td>0.007</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.002</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Beta</td>
<td>0.001</td>
<td>0.002</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Figure 5.5: Graph representing variation in the mean power ($\mu V^2$) during the plucking task.

Delta activity across the task: from epoch 1 to 2, there is a slight increase (0.002 - 0.003), followed by a gradual increase (0.003 - 0.005) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a slight increase (0.004 - 0.005), followed by a gradual increase (0.005 - 0.007) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is no change in cortical activity (remains at 0.002), followed by a gradual increase (0.002 - 0.004) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is a slight increase (0.001 - 0.002), followed by a slight decrease (0.002 - 0.001) from epoch 2 to 3.
Table 5.6: Absolute mean power ($\mu V^2$) for the 3 epochs during the stroking task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.012</td>
<td>0.008</td>
<td>0.011</td>
</tr>
<tr>
<td>Theta</td>
<td>0.015</td>
<td>0.013</td>
<td>0.020</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.007</td>
<td>0.007</td>
<td>0.010</td>
</tr>
<tr>
<td>Beta</td>
<td>0.003</td>
<td>0.003</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Figure 5.6: Graph representing variation in the mean power ($\mu V^2$) during the stroking task.

Delta activity across the task: from epoch 1 to 2, there is a gradual decrease (0.012 - 0.008), followed by a slight increase (0.008 - 0.011) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a slight decrease (0.015 - 0.013), followed by a rapid increase (0.013 - 0.020) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is no change in cortical activity (remains at 0.007), followed by a slight increase (0.007 - 0.010) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2 there is no change in cortical activity (remains at 0.003), followed by a slight increase (0.003 - 0.005) from epoch 2 to 3.
Table 5.7: Absolute mean power ($\mu V^2$) for the 3 epochs during the spear task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.001</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Theta</td>
<td>0.001</td>
<td>0.002</td>
<td>0.003</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Beta</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Figure 5.7: Graph representing variation in the mean power ($\mu V^2$) during the spear task. (Note beta activity is not represented on the graph as it remains at 0).

Delta activity across the task: from epoch 1 to 2, there is no change in cortical activity (remains at 0.001), followed by a gradual increase (0.001 - 0.002) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a gradual increase (0.001 - 0.002), followed by a further increase (0.002 - 0.003) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2 and 2 to 3, there is no change in cortical activity (remains at 0.001).

Beta activity across the task: from epoch 1 to 2 and 2 to 3, there is no change in cortical activity (remains at 0.000).
Table 5.8: Absolute mean power ($\mu V^2$) for the 3 epochs during the bow-and-arrow task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.002</td>
<td>0.002</td>
<td>0.003</td>
</tr>
<tr>
<td>Theta</td>
<td>0.003</td>
<td>0.005</td>
<td>0.006</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Beta</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Figure 5.8: Graph representing variation in the mean power ($\mu V^2$) during the bow-and-arrow task.

Delta activity across the task: from epoch 1 to 2, there is no change in cortical activity (remains at 0.002), followed by a slight increase (0.002 - 0.003) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a slight increase (0.003 - 0.005), followed by a further increase (0.005 - 0.006) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2 and 2 to 3, there is no change (remains at 0.002).

Beta activity across the task: from epoch 1 to 2 and 2 to 3, there is no change (remains at 0.001).
5.2.2. **Cortical activity across the frontal midline site**

Table 5.9: Absolute mean power ($\mu V^2$) for the 3 epochs during the eyes-closed task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.005</td>
<td>0.006</td>
<td>0.008</td>
</tr>
<tr>
<td>Theta</td>
<td>0.015</td>
<td>0.015</td>
<td>0.020</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.008</td>
<td>0.008</td>
<td>0.013</td>
</tr>
<tr>
<td>Beta</td>
<td>0.003</td>
<td>0.003</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Figure 5.9: Graph representing variation in the mean power ($\mu V^2$) during the eyes-closed task.

Delta activity across the task: from epoch 1 to 2, there is a slight increase (0.005 - 0.006), followed by a further increase (0.006 - 0.008) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is no change (remains at 0.015), followed by a gradual increase (0.015 - 0.020) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is no change (remains at 0.008), followed by a gradual increase (0.008 - 0.013) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is no change in cortical activity (remains at 0.003), followed by a slight increase (0.003 - 0.005).
Table 5.10: Absolute mean power ($\mu V^2$) for the 3 epochs during the eyes-open task.

<table>
<thead>
<tr>
<th>Wave:</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.009</td>
<td>0.009</td>
<td>0.016</td>
</tr>
<tr>
<td>Theta</td>
<td>0.013</td>
<td>0.020</td>
<td>0.032</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.007</td>
<td>0.010</td>
<td>0.019</td>
</tr>
<tr>
<td>Beta</td>
<td>0.004</td>
<td>0.003</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Figure 5.10: Graph representing variation in the mean power ($\mu V^2$) during the eyes-open task.

Delta activity across the task: from epoch 1 to 2, there is no change (remains at 0.009), followed by a gradual increase (0.009 - 0.016) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a gradual increase (0.013 - 0.020), followed by a rapid increase (0.020 - 0.032) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a slight increase (0.007 - 0.010), followed by a gradual increase (0.010 - 0.019) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is a slight decrease (0.004 - 0.003), followed by a slight increase (0.003 - 0.007) from epoch 2 to 3.
Table 5.11: Absolute mean power ($\mu V^2$) for the 3 epochs during the chisel task:

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.001</td>
<td>0.001</td>
<td>0.003</td>
</tr>
<tr>
<td>Theta</td>
<td>0.002</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.001</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Beta</td>
<td>0.000</td>
<td>0.000</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Figure 5.11: Graph representing variation in the mean power ($\mu V^2$) during the chisel task.

Delta activity across the task: from epoch 1 to 2, there is no change (remains at 0.001), followed by a rapid increase (0.001 - 0.003) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is no change (remains at 0.002), followed by a rapid increase (0.002 - 0.004) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is no change (remains at 0.001), followed by a gradual increase (0.001 - 0.002) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is no change (remains at 0.000), followed by a gradual increase (0.000 - 0.001) from epoch 2 to 3.
Table 5.12: Absolute mean power ($\mu V^2$) for the 3 epochs during the chisel-and-hammer task.

<table>
<thead>
<tr>
<th>The chisel-and-hammer task</th>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.004</td>
<td>0.004</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td>Theta</td>
<td>0.006</td>
<td>0.007</td>
<td>0.013</td>
<td></td>
</tr>
<tr>
<td>Alpha</td>
<td>0.003</td>
<td>0.004</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td>Beta</td>
<td>0.001</td>
<td>0.003</td>
<td>0.002</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.12: Graph representing variation in the mean power ($\mu V^2$) during the chisel-and-hammer task.

Delta activity across the task: from epoch 1 to 2, there is no change (remains at 0.004), followed by a slight increase (0.004 - 0.007) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2 there is a slight increase (0.006 - 0.007), followed by a gradual increase (0.007 - 0.013) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2 there is a slight increase (0.003 - 0.004), followed by a gradual increase (0.004 - 0.009) from epoch 2 to 3

Beta activity across the task: from epoch 1 to 2, there is a slight increase (0.001 - 0.003), followed by a slight decline (0.003 - 0.002) from epoch 2 to 3.
Table 5.13: Absolute mean power (μV²) for the 3 epochs during the plucking task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.003</td>
<td>0.005</td>
<td>0.004</td>
</tr>
<tr>
<td>Theta</td>
<td>0.005</td>
<td>0.006</td>
<td>0.007</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.003</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Beta</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Figure 5.13: Graph representing variation in the mean power (μV²) during the plucking task.

Delta activity across the task: from epoch 1 to 2, there is a slight increase (0.003 - 0.005), followed by a slight decline (0.005 - 0.004) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2 there is a slight increase (0.005 - 0.006), followed by a further increase (0.006 - 0.007) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a slight decrease (0.003 - 0.002), followed by a slight increase (0.002 - 0.004) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2 and 2 to 3, there is no change in cortical activity (remains at 0.002).
Table 5.14: Absolute mean power (μV²) for the 3 epochs during the stroking task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.005</td>
<td>0.008</td>
<td>0.005</td>
</tr>
<tr>
<td>Theta</td>
<td>0.008</td>
<td>0.011</td>
<td>0.009</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.004</td>
<td>0.005</td>
<td>0.006</td>
</tr>
<tr>
<td>Beta</td>
<td>0.002</td>
<td>0.001</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Figure 5.14: Graph representing variation in the mean power (μV²) during the stroking task.

Delta activity across the task: from epoch 1 to 2, there is a slight increase (0.005 - 0.008), followed by a slight decline (0.008 - 0.005) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a slight increase (0.008 - 0.011), followed by a slight decline (0.011 - 0.009) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a slight increase (0.004 - 0.005), followed by a further increase (0.005 - 0.006) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is a slight decrease (0.002 - 0.001), followed by a slight increase (0.001 - 0.002) from epoch 2 to 3.
Table 5.15: Absolute mean power ($\mu V^2$) for the 3 epochs during the spear task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.001</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Theta</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Beta</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Figure 5.15: Graph representing variation in the mean power ($\mu V^2$) during the spear task. (Note beta activity is not represented on the graph as it remains at 0).

Delta activity across the task: from epoch 1 to 2, there is no change (remains at 0.001), followed by a gradual increase (0.001 - 0.002) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2 and 2 to 3, there is no change (remains at 0.002).

Alpha activity across the task: from epoch 1 to 2 and 2 to 3, there is no change (remains at 0.001).

Beta activity across the task: from epoch 1 to 2 and 2 to 3, there is no change (remains at 0.000).
Table 5.16: Absolute mean power ($\mu V^2$) for the 3 epochs during the bow-and-arrow task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.004</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Theta</td>
<td>0.006</td>
<td>0.004</td>
<td>0.007</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.002</td>
<td>0.002</td>
<td>0.003</td>
</tr>
<tr>
<td>Beta</td>
<td>0.001</td>
<td>0.001</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Figure 5.16: Graph representing variation in the mean power ($\mu V^2$) during the bow-and-arrow task.

Delta activity across the task: from epoch 1 to 2, there is a gradual decrease (0.004 - 0.002), followed by a gradual increase (0.002 - 0.004) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a gradual decrease (0.006 - 0.004), followed by a gradual increase (0.004 - 0.007) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is no change (remains at 0.002), followed by a slight increase (0.002 - 0.003) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is no change (remains at 0.001), followed by a slight increase (0.001 - 0.002) from epoch 2 to 3.
5.2.3. Cortical activity across the orbitofrontal site

Table 5.17: Absolute mean power ($\mu V^2$) for the 3 epochs during the eyes-closed task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.011</td>
<td>0.025</td>
<td>0.017</td>
</tr>
<tr>
<td>Theta</td>
<td>0.026</td>
<td>0.049</td>
<td>0.045</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.015</td>
<td>0.022</td>
<td>0.025</td>
</tr>
<tr>
<td>Beta</td>
<td>0.005</td>
<td>0.008</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Figure 5.17: Graph representing variation in the mean power ($\mu V^2$) during the eyes-closed task.

Delta activity across the task: from epoch 1 to 2, there is a rapid increase (0.011 - 0.025), followed by a gradual decline (0.025 - 0.017) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a rapid increase (0.026 - 0.049), followed by a gradual decline (0.049 - 0.045) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a gradual increase (0.015 - 0.022), followed by a slight increase (0.022 - 0.025) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is a slight increase (0.005 - 0.008), followed by a slight decline (0.008 - 0.007) from epoch 2 to 3.
Table 5.18: Absolute mean power ($\mu V^2$) for the 3 epochs during the eyes-open task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.015</td>
<td>0.039</td>
<td>0.013</td>
</tr>
<tr>
<td>Theta</td>
<td>0.032</td>
<td>0.062</td>
<td>0.027</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.022</td>
<td>0.024</td>
<td>0.018</td>
</tr>
<tr>
<td>Beta</td>
<td>0.012</td>
<td>0.009</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Figure 5.18: Graph representing variation in the mean power ($\mu V^2$) during the eyes-open task.

Delta activity across the task: from epoch 1 to 2, there is a rapid increase (0.015 - 0.039), followed by a rapid decline (0.039 - 0.013) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a rapid increase (0.032 - 0.062), followed by a rapid decline (0.062 - 0.027) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a slight increase (0.022 - 0.024), followed by a gradual decrease (0.024 - 0.018) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is a slight decrease (0.012 - 0.009), followed by a further decline (0.009 - 0.008) from epoch 2 to 3.
Table 5.19: Absolute mean power ($\mu V^2$) for the 3 epochs during the chisel task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.008</td>
<td>0.006</td>
<td>0.012</td>
</tr>
<tr>
<td>Theta</td>
<td>0.011</td>
<td>0.012</td>
<td>0.018</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.005</td>
<td>0.006</td>
<td>0.008</td>
</tr>
<tr>
<td>Beta</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Figure 5.19: Graph representing variation in the mean power ($\mu V^2$) during the chisel task.

Delta activity across the task: from epoch 1 to 2, there is a slight decrease (0.008 - 0.006), followed by a gradual increase (0.006 - 0.012) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a slight increase (0.011 - 0.012), followed by a gradual increase (0.012 - 0.018) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a slight increase (0.005 - 0.006), followed by a further increase (0.006 - 0.008) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2 and 2 to 3, there is no change in cortical activity (remains at 0.003).
Table 5.20. Absolute mean power ($\mu V^2$) for the 3 epochs during the chisel-and-hammer task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.010</td>
<td>0.009</td>
<td>0.006</td>
</tr>
<tr>
<td>Theta</td>
<td>0.015</td>
<td>0.020</td>
<td>0.015</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.007</td>
<td>0.015</td>
<td>0.010</td>
</tr>
<tr>
<td>Beta</td>
<td>0.003</td>
<td>0.006</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Figure 5.20: Graph representing variation in the mean power ($\mu V^2$) during the chisel-and-hammer task.

Delta activity across the task: from epoch 1 to 2, there is only a slight decrease (0.010 - 0.009), followed by a gradual decline (0.009 - 0.006) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a gradual increase (0.015 - 0.020), followed by a gradual decline (0.020 - 0.015) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a gradual increase (0. 007 - 0.015), followed by a gradual decline (0.015 - 0.010) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is a slight increase (0.003 - 0.006), followed by a slight decline (0.006 - 0.004) from epoch 2 to 3.
Table 5.21: Absolute mean power ($\mu V^2$) for the 3 epochs during the plucking task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.011</td>
<td>0.010</td>
<td>0.006</td>
</tr>
<tr>
<td>Theta</td>
<td>0.017</td>
<td>0.013</td>
<td>0.013</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.007</td>
<td>0.006</td>
<td>0.007</td>
</tr>
<tr>
<td>Beta</td>
<td>0.002</td>
<td>0.003</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Figure 5.21: Graph representing variation in the mean power ($\mu V^2$) during the plucking task.

Delta activity across the task: from epoch 1 to 2, there is a slight decrease (0.011 - 0.010), followed by a gradual decline (0.010 - 0.006) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a gradual decrease (0.017 - 0.013), followed by no change (remains at 0.013) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a slight decrease (0.007 - 0.006), followed by a slight increase (0.006 - 0.007) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is a slight increase (0.002 - 0.003), followed by no change (remains at 0.003) from epoch 2 to 3.
Table 5.22: Absolute mean power ($\mu V^2$) for the 3 epochs during the stroking task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.010</td>
<td>0.010</td>
<td>0.012</td>
</tr>
<tr>
<td>Theta</td>
<td>0.015</td>
<td>0.016</td>
<td>0.021</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.008</td>
<td>0.009</td>
<td>0.010</td>
</tr>
<tr>
<td>Beta</td>
<td>0.004</td>
<td>0.004</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Figure 5.22: Graph representing variation in the mean power ($\mu V^2$) during the stroking task.

Delta activity across the task: from epoch 1 to 2, there is no change (remains at 0.010), followed by a slight increase (0.010 - 0.012) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a slight increase (0.015 - 0.016), followed by a gradual increase (0.016 - 0.021) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a slight increase (0.008 - 0.009), followed by a further increase (0.009 - 0.010) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is no change (remains at 0.004), followed by slight decline (0.004 - 0.003) from epoch 2 to 3.
Table 5.23: Absolute mean power (μV^2) for the 3 epochs during the spear task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.005</td>
<td>0.012</td>
<td>0.007</td>
</tr>
<tr>
<td>Theta</td>
<td>0.011</td>
<td>0.017</td>
<td>0.013</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.005</td>
<td>0.006</td>
<td>0.006</td>
</tr>
<tr>
<td>Beta</td>
<td>0.002</td>
<td>0.002</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Figure 5.23: Graph representing variation in the mean power (μV^2) during the spear task.

Delta activity across the task: from epoch 1 to 2, there is a gradual increase (0.005 - 0.012), followed by a gradual decline (0.012 - 0.007) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a gradual increase (0.011 - 0.017), followed by a gradual decline (0.017 - 0.013) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a slight increase (0.005 - 0.006), followed by no change (remains at 0.006) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is no change (remains at 0.002), followed by a slight increase (0.002 - 0.003) from epoch 2 to 3.
Table 5.24: Absolute mean power ($\mu V^2$) for the 3 epochs during the bow-and-arrow task.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>0.013</td>
<td>0.014</td>
<td>0.012</td>
</tr>
<tr>
<td>Theta</td>
<td>0.022</td>
<td>0.027</td>
<td>0.026</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.010</td>
<td>0.012</td>
<td>0.019</td>
</tr>
<tr>
<td>Beta</td>
<td>0.003</td>
<td>0.004</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Figure 5.24: Graph representing variation in the mean power ($\mu V^2$) during the bow-and-arrow task.

Delta activity across the task: from epoch 1 to 2, there is a slight increase (0.013 - 0.014), followed by a slight decline (0.014 - 0.012) from epoch 2 to 3.

Theta activity across the task: from epoch 1 to 2, there is a gradual increase (0.022 - 0.027), followed by a slight decline (0.027 - 0.026) from epoch 2 to 3.

Alpha activity across the task: from epoch 1 to 2, there is a slight increase (0.010 - 0.012), followed by a gradual increase (0.012 - 0.019) from epoch 2 to 3.

Beta activity across the task: from epoch 1 to 2, there is a slight increase (0.003 - 0.004), followed by a gradual increase (0.004 - 0.008) from epoch 2 to 3.
5.3. Inferential statistics

In the previous section, the data trends were identified per task. Inferential statistics were used to interpret or infer meaning to the data presented. Inferential statistics are procedures used by researchers to infer meaning from the sample to the larger population in which they were intended. To make these inferences, non-parametric statistical procedures were applied. This included the Mann-Whitney U-test for differences between participants and the Kruskal Wallis test for differences between tasks for each of the individuals involved (Kranzler 2003; Greene & D’Oliveira 2009). In the tables below, ‘z’ represents ‘z-scores’ (equal to the participants’ score, minus the mean, and then divided by the standard deviation). In addition, ‘p’ signifies the ‘p-value’, i.e., the level of significance – indicating whether the null hypothesis can be accepted or rejected.

5.3.1. The resting or control tasks

Table 5.25: Absolute mean power ($\mu V^2$) statistical differences between the eyes-closed task and the eyes-open task at the various sites.

<table>
<thead>
<tr>
<th>Wave:</th>
<th>Parietal</th>
<th>Frontal midline</th>
<th>Orbitofrontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$Z$-scores</td>
<td>Z</td>
<td>P</td>
</tr>
<tr>
<td>Delta</td>
<td>-0.365</td>
<td>-0.73</td>
<td>0.465</td>
</tr>
<tr>
<td>Theta</td>
<td>-1.461</td>
<td>-0.365</td>
<td>0.715</td>
</tr>
<tr>
<td>Alpha</td>
<td>-1.461</td>
<td>-0.365</td>
<td>0.715</td>
</tr>
<tr>
<td>Beta</td>
<td>-1.461</td>
<td>-0.73</td>
<td>0.465</td>
</tr>
</tbody>
</table>

When the participants switched from the eyes-closed task to the eyes-open task, there were no significant changes in cortical activity (either elevation or suppression) within the parietal, frontal midline or orbitofrontal sites.

5.3.2. The cognitive activation tasks

Table 5.26: Absolute mean power ($\mu V^2$) statistical differences between the chisel task and the chisel and hammer task at the various sites.
When the participants switched from the non-symbiotic chisel task to the symbiotic chisel- and- hammer task, there was a significant increase ($p < 0.10$) in absolute delta, theta, alpha and beta power in the frontal midline site. The results indicate that the chisel-and-hammer task required synchronous cortical activity within the frontal midline cortex. The statistical trends show that the symbiotic chisel-and-hammer task was cognitively demanding. For example, cortical activations within the frontal lobes are often associated with cognitively complex task engagement.

Table 5.27: Absolute mean power ($\mu V^2$) statistical differences between the plucking task and the stroking task at the various sites.

<table>
<thead>
<tr>
<th>Wave:</th>
<th>Parietal</th>
<th></th>
<th>Frontal midline</th>
<th></th>
<th>Orbitofrontal</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>$-0.73$</td>
<td>$0.465$</td>
<td>$-1.826$</td>
<td>$0.068^*$</td>
<td>$0$</td>
<td>$1$</td>
</tr>
<tr>
<td>Theta</td>
<td>$-1.095$</td>
<td>$0.273$</td>
<td>$-1.826$</td>
<td>$0.068^*$</td>
<td>$-0.365$</td>
<td>$0.715$</td>
</tr>
<tr>
<td>Alpha</td>
<td>$-1.461$</td>
<td>$0.144$</td>
<td>$-1.826$</td>
<td>$0.068^*$</td>
<td>$-0.73$</td>
<td>$0.465$</td>
</tr>
<tr>
<td>Beta</td>
<td>$-0.73$</td>
<td>$0.465$</td>
<td>$-1.826$</td>
<td>$0.068^*$</td>
<td>$-0.73$</td>
<td>$0.465$</td>
</tr>
</tbody>
</table>

Statistically significant $p < 0.10^*$

In contrast to the plucking task, the stroking task required a significant increase ($p < 0.10$) in absolute parietal theta and alpha as well as orbitofrontal alpha power. There were no significant differences identified in the frontal midline site. The stroking task required increased cortical activation within the parietal and orbitofrontal cortices to assist with attention, and basic memory processing – indicating that cortico-cortical communication was needed when the participants performed the stroking task. The stroking task, however, did not require complex cognitive engagement, as statistical trends were mostly found in the parietal cortex.

Table 5.28: Absolute mean power ($\mu V^2$) statistical differences between the spear task and the bow-and-arrow task at the various sites.
<table>
<thead>
<tr>
<th>Wave</th>
<th>Parietal Z</th>
<th>Parietal P</th>
<th>Frontal midline Z</th>
<th>Frontal midline P</th>
<th>Orbitofrontal Z</th>
<th>Orbitofrontal P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>-1.826</td>
<td>0.068*</td>
<td>-1.826</td>
<td>0.068*</td>
<td>-1.826</td>
<td>0.068*</td>
</tr>
<tr>
<td>Theta</td>
<td>-1.826</td>
<td>0.068*</td>
<td>-1.826</td>
<td>0.068*</td>
<td>-1.826</td>
<td>0.068*</td>
</tr>
<tr>
<td>Alpha</td>
<td>-1.826</td>
<td>0.068*</td>
<td>-1.826</td>
<td>0.068*</td>
<td>-1.826</td>
<td>0.068*</td>
</tr>
<tr>
<td>Beta</td>
<td>-1.841</td>
<td>0.066*</td>
<td>-1.826</td>
<td>0.068*</td>
<td>-1.826</td>
<td>0.068*</td>
</tr>
</tbody>
</table>

Statistically significant $p < 0.10^*$

There were statistical trends identified across cortical sites when the participants switched from the spear task to the bow-and-arrow task. There was a significant increase ($p < 0.10$) in absolute delta, theta, alpha and beta power at the parietal site. In the frontal lobe, a significant increase ($p < 0.10$) in absolute delta, theta, alpha and beta power was also evident at the frontal midline and orbitofrontal sites. The statistical analysis indicates that communication within and between the fronto-parietal networks was needed for the bow-and-arrow task. An increase in synchronous cortical activity implies that the bow-and-arrow task was cognitively complex.

5.4. Conclusion

Here I reported on the results obtained from the EEG recordings. Descriptive statistics were included to represent the absolute mean power ($\mu V^2$) per task and cortical area – showing the trends identified in the data. In the descriptive statistics section, both the tables and graphs reveal: 1) the rate at which the neurons fired, 2) the ways in which brain waves interacted with one another to process information, 3) the cognitively complex tasks required enhanced brain wave power, and 4) the effects that task practice has on synaptic plasticity. In addition, inferential statistics assist us with identifying statistical trends between tasks. For example, comparisons between the non-symbiotic tasks and the symbiotic tasks indicate that using two tools symbiotically required greater ‘neural effort’. In addition, cognitively complex symbiotic tasks required an enhancement in synchronous cortical activity within and between cortical sites to effectively process information. In the next chapter I will elaborate on the neurological or cognitive implications of using two tools as an effective unit, as opposed to non-symbiotic tool use.
CHAPTER SIX: DISCUSSION AND CONCLUDING REMARKS

6.1. Introduction

In this current study, I used EEG equipment to record cortical activity found within the parietal, frontal midline and orbitofrontal sites. These brain areas were selected in an attempt to test for differences in levels of cognitive complexity between non-symbiotic and symbiotic tool use as defined by Lombard and Haidle (2012). In the current chapter I discuss the action sequences for the resting conditions (the eyes-closed task and eyes-open task) and the cognitive activation conditions (the non-symbiotic tasks and symbiotic tasks). The action sequences are mentioned for two reasons: 1) to assess the cognitive or thought processes needed to engage in the various tasks, and 2) to gain better understanding of the function of each brain wave per cortical area. Finally, the results of the study will be related to aspects of the Middle Stone Age context. Can *Homo sapiens* be distinguished from their ancestors by the cognitive ability to manufacture and use symbiotic tools? If so, what could be the neurological implications?

6.2. The resting conditions

A baseline assessment is necessary for interpreting cortical activation changes when participants switch between resting conditions (from the eyes-closed task to the eyes-open task) (Gusnard & Raichle 2001). The experimental results indicate that switching between resting conditions resulted in stimulus induced cortical activation changes (Tables 5.1, 5.2, 5.9, 5.10, 5.17 and 5.18 and Figures 5.1, 5.2, 5.9, 5.10, 5.17 and 5.18), but the differences between these activities are not statistically significant ($p < 0.10$) (Table 5.25 and Figure 5.25). There could be a correlation between fluctuations in cortical activity and differences in task requirements. The eyes-closed task, for example, represents an interoceptive state (Marx *et al.* 2004). Interoception refers to an individual’s awareness of their body’s internal physical condition, i.e., coolness, warmth, a full bladder, pain etc. (Craig 2003). In contrast, the eyes-open task signifies an exteroceptive state (Marx *et al.* 2004). Exteroceptive refers to the ways in which the eyes respond to visual stimulation or external stimuli (Lee & Aronson 1974). Unlike the eyes-closed task, the eyes-open task requires increased activations within brain areas involved in ocular, motor and attentional systems (Marx *et al.* 2004).
Once the participants switched from the eyes-closed task to the eyes-open task, there was an increase in parietal delta activity (Tables 5.1 and 5.2 and Figures 5.1 and 5.2), which implies that the participants were focusing their attention on incoming sensory information or visual stimuli. These findings are unsurprising – opening one’s eyes results in visual stimulation and thus bursts of cortical activation (representing the exteroceptive state) (Marx et al. 2004). As the eyes-open task prevailed, there was a decline in parietal delta activity (Table 5.2 and Figure 5.2). A decline in parietal delta activity indicates that attention to visual stimuli was no longer needed. When each of the participants switched from the eyes-closed task to the eyes-open task, frontal midline delta activity increased (Tables 5.9 and 5.10 and Figures 5.9 and 5.10), which could be involved in processing incoming sensory information (see Section 3.4.3.5). A gradual increase in frontal midline delta activity was shown as the eyes-open task prevailed – perhaps the participants were distracted by the posters that were placed directly above the computer screen (Table 5.10 and Figure 5.10). During the eyes-open task, there were changes in orbitofrontal delta, theta and alpha activity, i.e., first gradual adjustment, followed by an increase, and then a decline in activity (the latter implies that habituation occurred) (Tables 5.17 and 5.18 and Figures 5.17 and 5.18). The gradual increase in orbitofrontal cortical activity is unsurprising. For example, a number of neurons fire in the orbitofrontal cortex when people process visual input or sensory information (Rolls et al. 1996). However, further research is needed on the mechanistic function of orbitofrontal delta, theta and alpha activity during resting states.

There is little information on parietal theta activity during resting states. Some researchers, nonetheless, argue that parietal theta activity is involved in processing incoming sensory information (Morgan et al. 2010), which could imply that it is needed during the eyes-open task. This premise is validated by the results obtained in the current study, i.e., there was an increase in parietal theta activity, followed by a gradual decline – the latter suggests that habituation occurred (Tables 5.1 and 5.2 and Figures 5.1 and 5.2). When the participants switched from the eyes-closed task to the eyes-open task, there was a decline in frontal midline theta activity (Tables 5.9 and 5.10 and Figures 5.9 and 5.10). As the task prevailed, there was a rapid increase in frontal midline theta activity (Table 5.10 and Figure 5.10). Frontal midline theta activity could have increased because of the visual stimuli in the room – resulting in a flow of ideas or thoughts.

Once the participants opened their eyes, parietal alpha activity increased, and it declined as the task prevailed (Tables 5.1 and 5.2 and Figures 5.1 and 5.2). Parietal alpha activity is
needed during the initial stages of an eyes-open task to assist with perceptual (Thut et al. 2006), and attentional processes (Worden et al. 2000). In contrast, there was a decrease, followed by a gradual increase in frontal midline alpha activity (Tables 6.9 and 6.10 and Figures 6.9 and 6.10), which may have inhibited unnecessary information during the eyes-open task.

During the initial stages of the eyes-open task, there was an increase in parietal beta activity (Tables 6.1 and 6.2 and Figures 6.1 and 6.2). Parietal beta activity might be involved in attention-related modulation of visual processing. For example, some researchers suggest that stimulation of the visual pathway results in bursts of beta activity that spreads across cortical areas, including the parietal lobe (see Wröbel 2000). In the current study, the experimental results, therefore, validate the premise that parietal beta activity is propagated by attentive visual behaviour. As the eyes-open task progressed, there was gradual decline in parietal beta activity, i.e., the participants’ eyes might have adjusted to the visual stimulation in the room (Table 5.2 and Figure 5.2). Frontal midline beta activity also increased, and it was followed by a gradual decline (Tables 5.9 and 5.10 and Figures 5.9 and 5.10). The fluctuations in frontal midline beta activity could imply that focused attention was only needed during the initial stages of the eyes-open task. In addition, orbitofrontal beta activity increased, and then declined (Tables 5.17 and 5.18 and Figures 5.17 and 5.18). Further research is needed on the mechanistic function of orbitofrontal beta activity during the eyes-open task.

6.2.1. Analysing the eyes-closed task and the eyes-open task

Switching from the eyes-closed task to the eyes-open task led to dynamic changes in cortical activity. Fluctuations in cortical dynamics could be a consequence of differences in task requirements. In contrast to the eyes-closed task (representing an interoceptive state), opening the eyes required: 1) the participants to respond to visual stimulation, and 2) to process incoming sensory information. The parietal cortex is involved in processing incoming sensory information (Rushworth & Taylor 2006; Sack et al. 2002), which could explain why there was an increase in cortical activity within the parietal site during the initial stages of the eyes-open task (Table 5.2 and Figure 5.2). There was also an increase in beta activity across the parietal, frontal midline and orbitofrontal sites – implying that higher-order cognitive processes were needed during the initial stages of the eyes-open task (Tables 5.2, 5.10 and 5.18 and Figures 5.2, 5.10 and 5.18). As the task progressed, there was an increase in frontal...
midline and orbitofrontal delta, theta and alpha activity (Tables 5.2 and 5.10 and Figures 5.2 and 5.10), which implies that incoming information still needed to be processed.

However, the high levels of cortical activity suggest that the results were partially confounded. The following variables may have contributed towards a partially confounded experiment: 1) the visual stimuli in the room, 2) the tasks were not recorded for a minimum of two minutes, and 3) because of the small sample size. Despite the limitations, the results of the current study clearly demonstrate that cortical activity within and between brain regions interacted with one another to assist with a specific task. For example, synchronous cortical activity within the parietal lobe was apparent during the eyes-open task (as shown by an increase, and then decrease in parietal delta, theta, alpha and beta activity) (Table 5.2 and Figure 5.2). In addition, patterns of beta activity (within the parietal, frontal midline and orbitofrontal sites) were in synchrony during the eyes-open task, which reflects fronto-parietal communication (Tables 5.2, 5.10 and 5.18 and Figures 5.2, 5.10 and 5.18).

6.3. The cognitive activation conditions

To assess levels of cognitive complexity, each non-symbiotic and symbiotic set was compared (refer to Sections 6.3.1, 6.3.2 and 6.3.3 for examples). When the participants switched from the non-symbiotic task to the symbiotic task, for example, a further increase in parietal, frontal midline and orbitofrontal delta, theta, alpha and beta activity was needed (see Table 5.28 for an example). The symbiotic tasks, as opposed to the non-symbiotic tasks, thus required greater ‘neural effort’ and high-coherence of cortico-cortical communication across cortical sites – indicating higher levels of cognitive complexity. Previous studies have shown that cortico-cortical communication was amplified to assist with the following cognitive functions: learning, memory, decision-making, attention, perception, and sensorimotor integration (refer to Rietschel et al. 2012 for an example). These cognitive functions are necessary in certain circumstances – for instance, when an individual is learning a novel task.

For the symbiotic tasks, as opposed to the non-symbiotic tasks, the participants needed to learn and/or remember more complex action sequences. For example, there was greater power in memory-related frequency bands, such as parietal and frontal midline theta as well as frontal midline and orbitofrontal beta (Tables 5.3, 5.4, 5.11, 5.12, 5.19 and 5.20 and Figures 5.3, 5.4, 5.11, 5.12, 5.19 and 5.20). The results imply that there was an increase in
memory load, i.e., the symbiotic tasks represent high memory load, whereas the non-symbiotic tasks signify low memory load. Unlike non-symbiotic tool use, using two tools symbiotically thus contributed towards the reduction in visual working memory capacity. For example, each of the participants needed to process, store and/or retain additional visual items in working memory for the symbiotic tasks, as opposed to the non-symbiotic tasks.

Task practice resulted in the functional reorganisation of activations across brain regions. Functional reorganisation refers to increases and decreases in cortical activity (Kelly & Garavan 2005). When the participants engaged in the non-symbiotic tasks and symbiotic tasks, there was a decline in certain brain waves as the tasks prevailed. For example, orbitofrontal delta and theta activity decreased with bow-and-arrow task practice (Table 5.24 and Figure 5.24). Activation decreases indicate ‘synaptic pruning’. ‘Synaptic pruning’ improves neural efficiency – for instance, it allows an individual to become more efficient at performing a task (see Kelly & Garavan 2005). There were also increases in cortical activity. For example, parietal delta and theta activity, frontal midline delta, theta, alpha and beta activity as well as orbitofrontal alpha and beta activity increased near the final stages of the bow-and-arrow task (Tables 5.8, 5.16 and 5.24 and Figures 5.8, 5.16 and 5.24). This could imply that task-relevant brain waves were amplified to assist with motor skill acquisition – improving the participants’ performance on the task.

6.3.1. The chisel task versus the chisel-and-hammer task

6.3.1.1. The chisel task (non-symbiotic)

Each of the participants was instructed to use the chisel to carve a straight line into the wood (Figure 4.4). The participants started chiselling from the one side of the plank to the other. The hand was used to guide the tool – resulting in controlled hand movement (refer to Kadiallah et al. 2011). To cut a straight line, the participants needed to focus their attention on the visual items involved (i.e., the chisel and the piece of wood), as well as spatial location. Spatial location was important, because each of the participants had to concentrate on where the chisel was positioned on the plank of wood – preventing displacement. Parietal delta activity increased in epoch 1, decreased in epoch 2, and gradually increased in epoch 3 (Table 5.3 and Figure 5.3). Parietal delta activity may have increased to assist with external attention – allowing the participants to concentrate on the visual items involved and spatial location. Orbitofrontal delta activity continued to increase throughout the chisel task (Table 5.19 and Figure 5.19). From a cognitive perspective, orbitofrontal delta activity might be
needed to reinforce the participants’ attention on salient or task-relevant stimuli (see Section 3.4.3.9). As the participants progressed with the chisel task, there was a further increase in parietal, frontal midline and orbitofrontal alpha activity (Tables 5.3, 5.11 and 5.19 and Figures 5.3, 5.11 and 5.19). The alpha bands could have been amplified to inhibit irrelevant information – allowing the participants to focus their attention on task-relevant stimuli.

Furthermore, frontal midline delta activity remained the same from epoch 1 to 2, but from epoch 2 to 3 there was a rapid increase in frontal midline delta activity (Table 5.3 and Figure 5.3). An enhancement in frontal midline delta activity could have been needed for internal attention, i.e., to assist participants with processing, storing and retrieving information in the mind. Throughout the chisel task, there was a gradual increase in orbitofrontal theta activity (Table 5.19 and Figure 5.19), which perhaps motivated the participants to process, store and retrieve information from memory. There was also a gradual increase in parietal beta activity (Table 5.3 and Figure 5.3), which implies that task practice resulted in motor skill acquisition. For example, as the task prevailed, an increase in parietal beta activity may have been needed once each of the participants adjusted their grip force (see Baber 2000 for more on grip force-adjustments during tool use). Improvements in precision gripping would have encouraged each of the participants to exert more pressure on the fairly blunt chisel – resulting in deeper engravings. The chisel task also required context updating, i.e., parietal and frontal midline theta activity was amplified in epoch 3 (Tables 5.3 and 5.11 and Figures 5.3 and 5.11). In addition, motor imagery was needed, as frontal midline beta activity increased near the end of the chisel task (Table 5.11 and Figure 5.11). There was, however, no change in orbitofrontal beta activity (Table 5.19 and Figure 5.19). No change in orbitofrontal beta activity implies that positive feedback or reinforcement learning was not needed, i.e., complex action sequences did not need to be remembered.

6.3.1.2. The chisel-and-hammer task (symbiotic)

The participants were required to use a chisel and hammer on a plank of wood (Figure 4.5). Similar to the non-symbiotic chisel task, participants were instructed to carve a straight line as they chiselled from one side to the other. The chisel-and-hammer task appears to be more cognitively complex than the previous non-symbiotic hammer task. For example, using a chisel-and-hammer set as an effective unit led to an increase in most of the brain waves found within the parietal, frontal midline and the orbitofrontal sites (as shown in Tables 5.3, 5.4, 5.11, 5.12, 5.19 and 5.20 and Figures 5.3, 5.4, 5.11, 5.12, 5.19 and 5.20). One of the reasons
the chisel-and-hammer task could have been more cognitively demanding than the chisel task – each of the participants had to focus their attention on an additional visual item, i.e., the hammer. They also needed to concentrate on the hammer’s location in space (i.e., the hammer’s spatial proximity from the chisel) and ensure that the hammer was hit directly in the middle of the chisel – allowing the force to be evenly distributed. During the initial stages of the chisel-and-hammer task, parietal delta activity increased, and continued to increase to the end – possibly assisting participants with using the chisel-and-hammer set as a cohesive unit (refer to Tables 5.3 and 5.4 and Figures 5.3 and 5.4 for differences between tasks). An increase in parietal delta activity, for example, could have improved the participants’ performance on the chisel-and-hammer task, i.e., by providing each of the volunteers with focused attention on the visual items involved and/or assisting with controlled object manipulation. There was a gradual increase in orbitofrontal alpha activity, followed by a decline (Table 5.20 and Figure 5.20). Orbitofrontal alpha activity might have been needed for focused attention on salient or task-relevant stimuli.

In contrast to the chisel task, the chisel-and-hammer task required eye-hand coordination. Not only were the participants expected to monitor the properties of the chisel (the state of the chisel blades), but also the properties of the hammer (including solidity, mass, size and shape). Integrating all of this sensory information in the mind would have been essential when each of the participants used the chisel and hammer symbiotically. There was a gradual increase in orbitofrontal theta activity, followed by a gradual decline (Table 5.20 and Figure 5.20). There may have been an enhancement in orbitofrontal theta activity to motivate the participants to encode all of the sensory information into memory. To improve task performance, there was a gradual increase in parietal and frontal midline alpha activity from epoch 1 to 3 (Table 5.12 and Figure 5.12). These two frequency bands could be involved in inhibiting irrelevant information (see Sections 3.4.3.3 and 3.4.3.7), which perhaps allowed the participants to focus their attention on the chisel, hammer, the wood and their properties. For example, when swinging a hammer, the tool user must coordinate movement, monitor force and/or the changes that are made to the variable properties (Baber 2006).

A number of grip force adjustments would have been necessary throughout the task (see Baber 2006). During the initial stages of task engagement, most of the participants grasped the hammer too low on the handle, and the weight of the hammer pulled the hand forward. Once the chisel-and-hammer task prevailed, the participants changed the position of their hand. I also observed that task practice resulted in the chisel being tightly grasped. When the
participants tightly grasped onto the chisel it encouraged controlled movement – for instance, it prevented the chisel from moving while it was being hit with the hammer. To assist the participants with grip force adjustments, there was an increase in parietal beta activity shown near the final stages of the task (Table 5.4 and Figure 5.4). There was also an increase in orbitofrontal beta activity (Table 5.20 and Figure 5.20), which might reflect improvements in the learning strategies adopted. Near the final stages of the chisel-and-hammer task, there was a slight increase in frontal midline delta activity to assist with internal attention (Table 5.12 and Figure 5.12). Finally, frontal midline beta activity increased throughout the task (Table 5.12 and Figure 5.12), which implies that motor imagery was needed.

6.3.1.3. Analysing the task set results

When the participants switched from the chisel task to the chisel-and-hammer task, there were no statistical trends identified across the parietal and orbitofrontal sites (Table 5.26). However, there was a statistically significant increase ($p < 0.10$) in absolute delta, theta, alpha and beta power at the frontal midline site (Table 5.26). With the symbiotic use of the chisel-and-hammer set, frontal midline delta activity was amplified to assist with internal attention. Internal attention refers to the selection, modulation and maintenance of incoming information in the mind (Chun et al. 2011). For example, the participants needed to process additional sensory information in the mind when they used the chisel-and-hammer set as an effective unit. Frontal midline theta activity would also have been useful for working memory processes. According to Jensen and Tesche (2002) frontal theta activity is enhanced when working memory load increases. Once the task had been practiced, frontal midline theta activity was involved in context updating – allowing the participant to update familiar sensorimotor representations in the mind (refer to Makeig et al. 2004). To assist with memorising the action sequences, frontal midline beta activity may have encouraged each of the participants to rehearse the information in the mind (could be involved in positive feedback and/or reinforcement learning) (refer to Section 3.4.3.12), whereas frontal midline alpha activity may have inhibited unnecessary information during task execution (see Section 3.4.3.7).

6.3.2. The plucking task versus the stroking task

6.3.2.1. The plucking task (non-symbiotic)
For the plucking task, participants were required to pick up the bow and hold it in the one hand (Figure 4.6). The participants’ hand needed to tightly grasp onto the bow to prevent movement while plucking. For example, a slight increase in parietal beta activity occurred from epoch 1 to 2, followed by a slight decline in epoch 3 (Table 5.5 and Figure 5.5), which implies that the participants were tightly grasping onto the bow. The participants used their index finger (on the other hand) to pluck the stringed bow. When the participants plucked the string, a gradual increase in parietal delta activity occurred as the task progressed (Table 5.5 and Figure 5.5). Parietal delta activity might have been needed to focus the participants’ attention on the visual stimulus involved, for example, the bow string while plucking. Concentration did not need to be reinforced, as orbitofrontal delta activity continued to decline as the task prevailed (Table 5.21 and Figure 5.21). A continuous decline in orbitofrontal delta activity might be explained by the gradual increase in parietal, frontal midline and orbitofrontal alpha activity as the task prevailed (Tables 5.5, 5.13 and 5.21 and Figures 5.5, 5.13 and 5.21). Parietal, frontal midline and orbitofrontal alpha bands could have increased to assist with focused attention – allowing the participants to perform the task skilfully.

The plucking task might have required basic memory processing, as there was a slight increase in frontal midline delta activity, followed by a decline (Table 5.13 and Figure 5.13). A slight increase in frontal delta activity could have been needed for internal attention (processing incoming sensory information). There was a gradual decrease, followed by no change in orbitofrontal theta activity (Table 5.21 and Figure 5.21), which implies that the participants did not need to encode information into memory. As the task prevailed, parietal and frontal midline theta activity continued to increase (Tables 5.5 and 5.13 and Figures 5.5 and 5.13), which may have been involved in context updating. There was no change in frontal midline beta activity, i.e., the task did not require the participants to rehearse complex action sequences in their mind (Table 5.13 and Figure 5.13). In addition, there was no change in orbitofrontal beta activity (Table 5.21 and Figure 5.21), which suggests that the plucking task did not necessitate positive feedback or reinforcement learning.

6.3.2.2. The stroking task (symbiotic)

Similar to the plucking task, participants grasped the bow with the one hand. With the other hand, the participants used select fingers to stroke the arrow against the bow’s string, resulting in hand movement (Figure 4.7). The participants, therefore, had to concentrate on
using the bow and the arrow as a complementary tool set. Focused attention led to a further increase parietal, frontal midline and orbitofrontal alpha power from epoch 1 to 3 (Tables 5.6, 5.14 and 5.22 and figures 5.6, 5.14 and 5.22). To assist with processing all of the incoming sensory information, there was a slight increase in frontal midline delta activity, followed by a slight decline as the task progressed (Table 5.14 and Figure 5.14).

The stroking task might have required basic eye-hand coordination. For example, there was a slight increase in parietal beta activity shown near the final stages of the stroking task (Table 5.6 and Figure 5.6), which could have been involved in coordinating both vision and hand movement (refer to Buchholz et al. 2013; Dean et al. 2012). There was no change in orbitofrontal delta activity, followed by a slight increase (Table 5.22 and Figure 5.22). Perhaps the participants had to reinforce their attention on task-relevant stimuli, i.e., to assist with eye-hand coordination. In addition, orbitofrontal theta activity increased throughout the task (Table 5.22 and Figure 5.22), which may have motivated each of the participants to encode information into memory (see Witmann et al. 2005). Once the action sequences were memorised, parietal and frontal midline theta activity increased even further to assist with context updating (Tables 5.6 and 5.14 and Figures 5.6 and 5.14). The stroking task did not require reinforcement learning or positive feedback, as there was little to no change in orbitofrontal beta activity (Table 5.22 and Figure 5.22).

6.3.2.3. Analysing the task set results

In contrast to the plucking task, the stroking task required a statistically significant increase ($p < 0.10$) in absolute parietal theta and alpha power as well as orbitofrontal alpha power (Table 5.27). The statistical trends imply that additional action sequences needed to be remembered and that attention was enhanced.

6.3.3. The spear task versus the bow-and-arrow task

6.3.3.1. The spear task (non-symbiotic)

Participants were instructed to pick up a spear and throw it at a target (Figure 4.8). Prior to throwing the spear, attention to spatial location would have been needed for distance judgment. The participants also needed to focus their attention on the visual items involved – for instance, the object’s properties, i.e., the mass of the spear to determine the force in which it should be thrown. There was a gradual increase in orbitofrontal delta and alpha activity, followed by a decline (Table 5.23 and Figure 5.23). An increase in orbitofrontal delta activity
might have been necessary to reinforce the participants’ attention on visual stimuli, whereas an increase in orbitofrontal alpha activity perhaps allowed the participants to concentrate on task-relevant stimuli and inhibit irrelevant information. There was a gradual increase in orbitofrontal theta activity, followed by a decline (Table 5.23 and Figure 5.23). An increase in orbitofrontal theta activity might have motivated the participants to encode the information into memory (see Section 3.4.3.10). During the initial stages of the task, there were no changes in parietal delta activity, followed by a gradual increase (Table 5.7 and Figure 5.7). Parietal delta activity might have only increased during the final stages of the task, because it was only needed once orbitofrontal delta and alpha activity declined. An increase in parietal delta activity could have been involved in external attention – allowing the participants to focus their attention on the visual stimuli involved (refer to Section 3.4.3.1).

As the task prevailed, there was a further increase in parietal theta activity (Table 5.7 and Figure 5.7). Parietal theta activity is involved in context updating (Klimesch et al. 1994). During the final stages of the spear task, frontal midline delta activity increased (Table 5.16 and Figure 5.16). Frontal midline delta activity might have increased to assist with internal attention. There were no changes in orbitofrontal beta activity, followed by a slight increase (Table 5.23 and Figure 5.23). Orbitofrontal beta activity was perhaps involved in positive feedback or reinforcement learning (refer to Section 3.4.3.12). I tentatively suggest that parietal theta and orbitofrontal beta activity increased to improve task performance (Tables 5.7 and 5.23 and figures 5.7 and 5.23). For example, once the participants had practiced the spear task, they might have exhibited a locked wrist to ensure that the spear would successfully reach the target.

6.3.3.2. The bow-and-arrow task (symbiotic)

The spear task required relatively limited cognitive engagement, but using the bow-and-arrow set as an effective unit was more cognitively complex. To fire an arrow with a bow, for example, requires a sequence of movements. The arrow needs to be inserted onto the bowstring with the aid of the index finger and thumb, and the bow is held in place (Hennessy & Parker 1990). Then, the tool user stands in a fixed position, and centres pressure on the ground to assist with stability (Hennessy & Parker 1990). Finally, the individual continues to draw the bowstring back in order to reach to the full-draw, followed by aiming the arrow at the target, and its subsequent release (Leroyer et al. 1993). Prior to its release, however, the
person must avoid gripping too much onto the bow handle – it can result in a sideways deflecting torque, both on the bow and on the arrow (Leroyer et al. 1993).

Thus, the bow-and-arrow task required the participants to focus their attention on a number of task-relevant visual items. During the initial stages of the task, there was a slight increase in orbitofrontal delta activity, followed by a decline (Table 5.24 and Figure 5.24). Orbitofrontal delta activity might be useful for screening internal and external stimuli, and increasing attention to task-relevant stimuli (see Section 3.4.3.9). There was no change in parietal delta activity, followed by a slight increase (Table 5.8 and Figure 5.8). Parietal delta activity might have increased to assist with visual attention. For example, the participant would have needed to focus their attention on spatial location. In addition, both clarity and detail are essential for target shooting (Abernethy & Neal 1999).

Furthermore, a number of action sequences needed to be remembered for the bow-and-arrow task. There was an increase in frontal midline delta activity in epoch 1, followed by a decline in epoch 2, and a slight increase in epoch 3 (Table 5.16 and Figure 5.16). An increase in frontal midline delta activity could have been important for internal attention, i.e., it allowed the participants to process incoming sensory information. To assist participants with encoding the sensory and perceptual information into memory, there was a gradual increase in orbitofrontal theta activity, followed by a slight decline (Table 5.24 and Figure 5.24). Orbitofrontal theta activity might be needed in situations where a number of action sequences need to be remembered. For example, frontal theta is enhanced with an increase in working memory load (Jensen & Tesche 2002).

To motivate each of the participants to focus their attention on the bow-and-arrow task, orbitofrontal alpha activity might have been important. As the task progressed, orbitofrontal alpha activity continued to increase (Table 5.24 and Figure 5.24), and possibly worked in conjunction with frontal midline alpha activity. The latter does not change from epoch 1 to 2, but there was a slight increase in epoch 3 (Table 5.16 and Figure 5.16). Both of these frequency bands might have been involved in inhibiting irrelevant information and encouraging sustained alertness on task-relevant stimuli. For example, once each of the participants practiced using the bow-and-arrow set as an effective unit, sustained alertness might have encouraged them to perform the task skilfully.

Task practice resulted in a further increase in memory-related brain waves. For example, parietal and frontal midline theta activity increased as the bow-and-arrow task prevailed.
(Tables 5.8 and 5.16 and Figures 5.8 and 5.16). Both parietal and frontal midline theta activity play an important role in updating familiar sensorimotor representations, which allows an individual to execute memorised action sequences (Makeig et al. 2004). Context updating is useful in situations where an individual must engage in cognitively complex tasks that require additional information to be processed (Makeig et al. 2004). With the bow-and-arrow task, for example, the participants had to update complicated action sequences in the mind. To assist with task performance, participants might have mentally rehearsed the action sequences (see Cisek & Kalaska 2004). For example, a slight increase in frontal midline beta activity was shown at the final stages of the bow-and-arrow task (Table 5.16 and Figure 5.16). In addition, kinaesthetic sensations might have been needed – providing each of the participants with sensory feedback on the motor actions performed. To improve task performance, the participants might have used positive feedback or reinforcement learning to actively recall the ‘correct’ actions from memory. For example, orbitofrontal beta activity increased as the task progressed (Table 5.24 and Figure 5.24).

6.3.3.3. Analysing the task set results

There are statistical trends identified across cortical sites when the participants switched from the spear task to the bow-and-arrow task. There was a statistically significant increase \((p < 0.10)\) in absolute delta, theta, alpha and beta power across the parietal, frontal midline and orbitofrontal sites (Table 5.28). For the bow-and-arrow task, higher-order cognitive processes were needed. Such processes are associated with the frontal lobes, specifically the orbitofrontal cortex, and are substantiated in this instance by the high levels of orbitofrontal cortical activity (Table 6.24 and Figure 6.24). I tentatively suggest that the bow-and-arrow task required more ‘motivation’ than any of the other tasks. For example, the participants might have been motivated to perform the task properly, because a number of action sequences needed to be remembered – proving to themselves or the examiner that they were cognitively capable.

6.4. Symbiotic hunting technologies from the Middle Stone Age contexts of southern Africa and their neurological implications

Lombard and Haidle (2012) use cognigrams to reconstruct the effective chains for the production-and-use sequences of a simple wooden spear, a composite stone-tipped spear, and
a bow-and-arrow set. In contrast to the thought-and-action processes involved in producing or using a single-component wooden spear, or a composite stone-tipped spear, they suggest that the bow and arrow’s problem-solution distance and operational sequence is extended in both duration and cognitive complexity, and reflects amplified conceptual, technological and behavioural modularisation. Neither the production nor the use of individual components of the bow or the arrow is perceived to be cognitively more complex than that of a composite spear (Lombard & Haidle 2012). Rather, it is postulated that a novel cognitive component is evident in technological symbiosis – where the mind focuses simultaneously and actively on manipulating a complementary set of tools that are independent from one another, but are used as an effective unit to obtain a single goal (Lombard & Haidle 2012). For example, when a bow is used to fire an arrow to obtain meat (Lombard & Haidle 2012).

The results obtained from my study, using EEG to interpret changes in brain-wave activity, supports Lombard and Haidle’s (2012) hypothesis – that using tools symbiotically might be cognitively more demanding than non-symbiotic tool use. For each non-symbiotic and symbiotic tool set (refer to Sections 6.3.1, 6.3.2 and 6.3.3), cortical activity was enhanced when the participants switched from the non-symbiotic task to the symbiotic task (Tables 5.26, 5.27 and 5.28). Thus, *Homo sapiens*’ mental ability to use a bow-and-arrow set symbiotically might have required the recruitment of additional or more advanced neurological mechanisms than the simple or composite non-symbiotic spears that were used by *Homo heidelbergensis* and/or *Homo neanderthalensis*.

There is an increasing trend to date the capacity for complex culture, and by implication high levels of cognitive complexity, back to before the *Homo sapiens*-Neanderthal split (e.g.; Wadley 2013). Very little explicit neurological work has, however, been completed on the topic. And it has been said that, although Neanderthals possibly had some advanced working memory capabilities, *Homo sapiens* might have been able to engage more effectively in enhanced working memory processes (Wynn & Coolidge 2003, 2007, 2011). The term ‘enhanced working memory’ is used by Wynn and Coolidge (2003, 2007, 2011) to describe ‘modern’ human thinking. One the defining features of enhanced working memory is the enlargement of general working memory capacity (see Coolidge & Wynn 2005). For example, an individual is able to process, store and temporarily maintain a larger amount of information in the mind, despite interference (see Wynn & Coolidge 2003). In theory, visual working memory is restricted to only three or four items, but storage capacity is limited even further when complex features or objects need to be encoded as a cohesive unit (representing
high memory load) (see Song & Jiang 2005). Unlike the non-symbiotic tasks, the participants had to actively and simultaneously manipulate two tools as an effective unit for the symbiotic tasks, which implies that additional visual items and action sequences needed to be remembered (representing higher memory load) (refer to Section 6.3 for more on this). When the participants switched from the non-symbiotic spear task to the symbiotic bow-and-arrow task, for example, the following executive functions were enhanced to assist with working memory processes: attention, active-inhibition, context updating, reinforcement learning, and memory rehearsal (refer to Section 6.3.3.2). Based on the results obtained from the current study, I tentatively suggest that *Homo sapiens*’ ability to use tools (such as a bow and arrow) symbiotically, might reflect the capacity for enhanced working memory. For example, Wadley (2013) mentions that innovative technologies require enhanced executive functions of the brain. According to Coolidge and Wynn (2007) enhanced working memory, by way of recursion, might have allowed *Homo sapiens* to ‘hold in mind’ a number of options – resulting in a greater range of creativity and behavioural flexibility.

The question remains – what neurological mechanisms might be responsible for enhanced working memory processes? In comparison to other primates, humans have a larger volume of white matter found within the prefrontal cortex, which improves neural connectivity (and thus communication) within and between cortices (Schenker et al. 2005). According to Ardilla (2008) an improvement in neural connectivity might be responsible for the complex executive functions that are identified in our species. For example, greater intra-hemispheric communication across the fronto-parietal networks was needed for the symbiotic bow-and-arrow task, as opposed to the non-symbiotic spear task (Table 5.28). In addition, the current study clearly demonstrates that cortical activity within the orbitofrontal cortex (a sub-region found within the prefrontal cortex) was amplified when the participants performed the bow-and-arrow task (refer to Tables 5.23 and 5.24 and Figures 5.23 and 5.24 to compare differences in cortical arousal with the spear task and the bow-and-arrow task). The orbitofrontal cortex is an important substrate for working memory, i.e., it is involved in manipulating and monitoring information in working memory (Barbey et al. 2011). This brain area is also involved in ‘top-down processes’ – for instance, the orbitofrontal cortex directs attention to task-relevant sensory stimuli that is found in posterior areas of the brain during cognitively complex task execution (see Rolls & Grabenhorst 2008 for more on this). From a neurological perspective, *Homo sapiens*, therefore, might be capable of learning and executing more cognitively complex tasks than their ancestors, such as those that necessitate
enhanced working memory processes, because of an increase in white matter found within the prefrontal cortex (improving neural connectivity within and between the fronto-parietal networks).

Initially, *Homo sapiens* might have relied on enhanced working memory processes for symbiotic tool use. For example, greater ‘neural effort’ and/or amplified communication within and between the parietal, frontal midline and orbitofrontal cortices were shown during the initial stages of the bow-and-arrow task (Tables 5.8, 5.16 and 5.24 and Figures 5.8, 5.16 and 5.24). During the Middle Stone Age – the period associated with the appearance of *Homo sapiens* in sub-Saharan Africa based on palaeoanthropological, genetic and archaeological evidence – repeated use of symbiotic tools could have led to increased activations within memory-related brain waves and the ‘synaptic pruning’ of functional activations that are not needed for skilled task performance. This premise is based on the results obtained in my current study (refer to Tables 5.8, 5.16 and 5.24 and Figures 5.8, 5.16 and 5.24 for examples), and previous EEG research on the effects that task practice has on synaptic plasticity (see Kelly & Garavan 2005). In other words, there might have been increasingly less reliance on working memory processes and more dependence on the memory-related frequency bands that are associated with long-term memory. For example, task practice might have led to an increase in high-frequency bands, such as orbitofrontal beta activity, to assist with motor skill acquisition (as shown in Table 5.24 and Figure 5.24), but further research is needed on this aspect (see Section 6.7). Thus, I tentatively suggest that continuous use of symbiotic technologies could have led to the reconstruction and re-wiring of neural circuitry, known as synaptic plasticity.

Current research on synaptic plasticity changes our perceptions of the brain from a fixed entity, to a dynamic system that is subject to transformation (Malafouris 2010). This theory implies that changes in the neural structure and function of the frontal lobe are not solely or originally genetic as sometimes argued (Klein & Edgar 2002; Mithen 1996; Wynn & Coolidge 2003). Previous research, for example, suggests that a neural mutation occurred, which could be responsible for ‘modern’ thinking (Klein & Edgar 2002; Mithen 1996). More recently, Wynn and Coolidge (2003) mention that a neural mutation perhaps improved memory capacity, i.e., reaching modern capacity by an enhancement in working memory. However, the manner in which the brain develops can also be a result of epigenetic (environmental, social or cultural) factors (refer to Malafouris 2010). Thus, the functional and anatomical features of the brain can be transformed and remodelled by behaviourally
important experiences (Malafouris 2010). In the Middle Stone Age contexts of southern Africa, continuous use of symbiotic hunting technologies, for example, could have resulted in long-lasting functional changes in neural circuitry (within and between the fronto-parietal networks), which could have improved processing efficiency and/or cognitive performance during cognitively complex task execution.

6.5. Limitations of the study:

With any experimental design, there are a number of variables that might confound the results of a study. In the current study, methodological factors, the artificiality of the experimental setting, the small sample size and procedural factors could have contributed towards a partially confounded experiment. I will discuss the limitations of the study, and its possible implications on the results obtained, as well as preventative measures that were taken in an attempt to limit potentially confounding variables.

6.5.1. The artificiality of the laboratory setting

Unlike natural situations, laboratory experiments are usually more ‘artificial’ in nature, because the participants are aware that their behaviour is being observed (Henshel 1980). The participants, for example, might attempt to ‘work out’ the researcher’s hypothesis and act accordingly. There is also the danger that dynamic interactions between individual and situation have been omitted. In the current study, for example, the experimental room did not include environmental stimuli that may have been found in the Middle Stone Age context. In the past, Homo sapiens would have encountered environmental variables (such as wind, foliage, distance and moving animals) that perhaps made using symbiotic tools more cognitively demanding than it was for the participants in the experimental setting. For example, focused attention is needed when an individual fixates on a moving target (e.g., Culham et al. 1998).

Although functional imaging studies conducted with modern humans, as I have attempted in this study, may not directly reveal the mental capacities of our ancestors, they can shed some light on the relative demands of evolutionary significant tasks. For example, the results obtained from the study indicate that the symbiotic use of a bow-and-arrow set might require complex perceptual, cognitive and motor skills, and/or enhanced working memory processes (refer to Section 6.3.3.2).
6.5.2. Participant sample size

Approximately twenty participants took part in the experiment, but only four were included for data analysis purposes (see Sections 4.5.2 and 4.6.2). Due to the small sample size, it is difficult to infer the results obtained from the sample to a large population in which it was intended. In the human brain, for example, fluctuations in cortical dynamics are highly variable across individuals, but they are relatively constant within individuals. In other words, there is greater sampling variability with a small sample. Thus, a larger sample would have been beneficial, as it reflects a more accurate representation of a population. Non-parametric statistical procedures were applied to make inferences from the sample to the larger population in which it was intended (refer to Section 4.6.4). Despite the limitations of a small sized sample, the results obtained in the experiment are validated by previous EEG research on fluctuations in cortical dynamics during cognitively demanding tasks (see Rietschel et al. 2012).

6.5.3. Procedural factors

In this study, the resting conditions (the eye-closed and eyes-open tasks) were used as a baseline assessment. For the resting conditions, the participants were asked to relax, but the high levels of cortical activity could imply that the results were partially confounded (Tables 5.1, 5.2, 5.9, 5.10, 5.17 and 5.18 and Figures 5.1, 5.2, 5.9, 5.10, 5.17 and 5.18). For example, it is unlikely that the participants ‘cleared their minds’ completely. As mentioned previously, patterns of cortical activity may have been contaminated by procedural factors – for instance, the participants were perhaps contemplating future scenarios, i.e., the experimental procedures or the tasks that would follow, and/or focusing their attention on the visual stimuli in the room. Despite the limitations, the results obtained from the current study clearly demonstrates that cortical activations within and between brain regions interact with one another to assist with a specific task (see Section 6.3.2).

6.5.4. Methodological factors

Three epochs (time segments) were extracted for each task, frequency-band and brain area recorded. For the resting conditions (i.e., the eyes-closed task and eyes-open task) epochs were extracted at a fixed time of twenty seconds. For the cognitive activation conditions (i.e., the non-symbiotic task and symbiotic task) epochs were extracted according to changes in wave amplitudes across task performance. For example, I wanted to assess whether task
practice resulted in changes in cortical dynamics. With every EEG recording, however, there is second to second variability (Pivik et al. 1993). For example, the small number of epochs selected per condition might not represent the full range of variability for each of the conditions. To ensure scientific rigour and/or standardised research procedures, changes in waveforms were repeatedly analysed, and a specific epoch was selected for each of the cognitive activation conditions.

6.5.5. Summary of limitations

In the current study, several factors may have compromised the results obtained, which limits its generalisability (see Sections 6.5.1, 6.5.2, 6.5.3 and 6.5.4). Also, despite all of the measures taken, confounding variables cannot always be predicted or controlled during the experimental situation. The results obtained in the current study, however, are comparable to other EEG research results (e.g., Sauseng et al. 2002). In addition, the findings are validated further by the action sequences that were needed for each of the cognitive activation conditions. There was, for example, a correlation between ‘brain power’, cognitive complexity and the number of action sequences involved (refer to Sections 6.3.3.1 and 6.3.3.2 for differences between tasks).

6.6. Concluding remarks

Despite the limitations of the current study, the EEG was an effective method to use. I was able to measure fluctuations in cortical dynamics when the participants switched between tasks (refer to Sections 5.2.1, 5.2.2 and 5.2.3 for examples). Cortical activations found within the parietal, frontal midline and orbitofrontal sites were recorded concurrently, which means that synchronised neuronal interactions across brain regions could be observed, and/or the ways in which individual neurological components work together as a cohesive unit during information processing. In addition, the rate at which neurons fired or the amount of ‘brain power’ that was needed for each of the tasks could be measured.

In the current study, the results obtained from the EEG recording clearly demonstrate that additional neurological mechanisms were needed when each of the participants switched from the non-symbiotic tasks to the symbiotic tasks (Tables 5.26, 5.27 and 5.28). Here, the symbiotic tasks serve as a proxy for the concept of technological symbiosis, i.e., the ability to use a set of separate, yet interdependent tools as an effective unit (Lombard & Haidle 2012).
The research findings thus support Lombard and Haidle’s (2012) hypothesis – unlike the non-symbiotic spears that were used by archaic Homo, Homo sapiens’ ability to use two independent, but interdependent tools as a complementary tool set is cognitively more complex. With the EEG recording, as soon as the participants switched from the non-symbiotic spear task to the symbiotic bow-and-arrow task, there was a further increase in absolute delta, theta, alpha and beta power across the parietal, frontal midline and orbitofrontal sites (Table 5.28). These findings are substantiated further by the premise that an increase in task difficulty places greater demands on ‘neural effort’ (see Rietschel et al. 2012). In addition, cortical activity within and between frequency bands fired in synchrony across the fronto-parietal networks during the symbiotic bow-and-arrow task (Table 5.28).

From a neurological perspective, interregional brain activations are important for cognitively demanding tasks, as it assists with learning a novel motor task and/or with higher-order information processing (Rietschel et al. 2012). During the initial stages of the bow-and-arrow task, for example, frequency-bands (involved in working memory processes) were amplified, which could have been important for manipulating information in active memory and/or allocating attentional resources (refer to Section 6.3.3.2). These findings thus support Wynn and Coolidge’s (2003) premise that an enlargement in general working memory capacity might be the defining feature of ‘modern’ human thinking.

Based on the results obtained from the current study and brain-related research within the field of evolutionary cognitive neuroscience, I tentatively suggest that the most plausible explanation for current human cognition could be associated with the evolutionary development of neural connectivity (due to an increase in white matter), and not just an increase in brain size as mentioned in chapter one. In other words, brain size alone is unable to explain the faculties present in our species. For example, researchers suggest that an improvement in neural connectivity (between the fronto-parietal networks) encourages cortico-cortical communication within and between brain regions, which assists with cognitively demanding tasks (e.g., Burns 2006). If Homo sapiens are distinguished from their ancestors by an increase in white matter, it may have provided our species with an evolutionary advantage, i.e., enhancing our capacity to process, store and retain information in working memory, which might have encouraged behavioural flexibility.

The current study thus contributes towards scientific research in the field of cognitive archaeology – for instance, only a handful of studies have integrated evolutionary, archaeological, and/or neuroscientific approaches in an attempt to understand aspects of the
evolution of brain development in the human lineage (e.g., Stout & Chaminade 2007; Uomini & Meyer 2013). Unlike previous studies, I discuss the effects that repeated exposure to a specific task has on cortical dynamics. Although changes in cortical dynamics were observed at the final stages of task execution, further research is needed.

6.7. Future research

The pilot experiment presented here focused on the cognitive requirements of non-symbiotic and symbiotic tool use only. Further tests can be developed to assess the more complex processes involved in tool development and manufacture (see Meyer et al. 2013 for an example). Researchers could also test cognitive theories of complex cognition through time and across space, as current research on synaptic plasticity indicates that multiple experiences shape or change the neural pathways in the brain, which may have been essential for the evolution of human cognition. In addition, the effects that task practice has on brain development could provide us with a better understanding of the influence that continuous task engagement has on the neurological components found within the brain.

Finally the EEG is a useful method to use to measure fluctuations in cortical dynamics (i.e., it allows researcher to assess the ways in which individual neurological components in the brain work together as a cohesive unit). Future research, however, might benefit from incorporating the EEG method with other neuroimaging techniques. For example, the fMRI method records individual sub-regions located within a specific brain region, whereas the EEG method covers a wide surface of the scalp. The benefits of including more than one method – we could measure neuronal interactions more effectively during higher-order cognitive processing (see Babiloni et al. 2005). However, unlike the fMRI, EEG equipment is feasible, user-friendly, and it can be used in a variety of experimental settings.
CHAPTER SEVEN: REFERENCES


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