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EXPLORING TIME PERCEPTION AND RELATED NEURAL ACTIVITY IN ADHD AND NON-ADHD YOUNG ADULTS

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Abstract

Attention-Deficit Hyperactivity Disorder (ADHD) is one of the most prevalent disorders diagnosed in children. However, less is known about the clinical manifestation of the disorder in adults and the impact thereof on for instance social and occupational functioning. With respect to temporal perception deficits in both child and adult ADHD, contemporary findings have produced mixed results. In line with this, the current investigation aimed to identify whether young adults who possess significant ADHD symptomology have pure time perception deficits and/or differences in self-reported habitual time perception.

Stratification of the ADHD and non-ADHD group was achieved using the Adult ADHD Self-report Scale (ASRS V1.1). Between group differences in self-reported temporal orientation was investigated using the Zimbardo Time Perspective Inventory (ZTPI). These outcome scores were compared using an ANOVA. The investigation into pure psychophysical time perception was conducted on a sub sample of that used in the self-report investigation. The ADHD group consisted of 12 participants whereas the non-ADHD group consisted of 10 participants. These two groups conducted temporal estimation and temporal discrimination tasks. Between groups, performances on these tasks were compared using an ANOVA.

In addition to this, electroencephalography (EEG) recordings of frontal, frontal midline and parietal activity during resting states and task performance were conducted. This allowed for between group comparisons in absolute and relative power scores at four different frequency bands (delta, theta, alpha and beta) to be made. A non-parametric Mann-Whitney-U test was used in this regard. The same statistical technique was used to compare the theta/beta ratios elicited by the resting state and temporal perception conditions. Results showed that those with significant ADHD symptomology have a characteristically different self-reported habitual time perception. This is illustrated by negative thoughts towards past and present life events, and an absence of future orientated behaviour.

In terms of the objective psychophysical measures, the current investigation found no group differences in estimation or discrimination task performance. Despite this absence of difference, the group with significant ADHD symptomology showed significantly different EEG recorded neural activity, during resting states and during task performance. The nature of this activity was in line with a generalised cortical under arousal hypothesis of ADHD. Taken together, these findings indicate that individuals with significant ADHD symptomology do not only consciously perceive time differently to those who do not have significant symptomology, but also show different neuro-physiological processes when performing tasks that require the utilisation of temporal processing mechanisms. In this way, the findings provide insight into possible objective measures that could be utilised in ADHD diagnosis.

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Chapter 1: Introduction

1.1 Introduction and Background to the Study

Given the attention that it regularly receives in the popular media, Attention-Deficit Hyperactivity Disorder (ADHD) is probably one of the most prevalent disorders diagnosed in children. This is understandable when looking at the current worldwide prevalence rate of the disorder in children below the age of 17 years, which according to Chandler (2011) is estimated to range from 5% to 9%. However, less is known about the occurrence of the disorder in adults, as well as the consequences to those living with it, which is concerning when considering that the prevalence rate is estimated to be 3.4% in the adult population (Chandler, 2011). Compared to the worldwide prevalence of bipolar disorder (0.9%), psychotic disorders (0.8%) and alcohol dependence (2.4%), it is clear that adult ADHD is vaster (Chandler, 2011).

From the literature, it is well known that ADHD causes deficits in social interaction, academic achievement and work performance through the core symptoms of hyperactivity, impulsivity and inattentiveness, as well as through the secondary or related symptoms, including social clumsiness, disorganisation and low self-esteem (Brown, 2002; Vorster, 2012). Poor time management is also a symptom that is consistently associated with ADHD (Goldstein & Ellison, 2002). Despite the fundamental symptoms related to inattention and hyperactivity/impulsivity, which tend to be amended or adapted throughout development; poor time management has a profound effect on adult life when one considers the demands of holding an occupation within a competitive economic environment (Wasserstein, 2005). The current investigation aimed to elucidate the exact nature of this deficit in time management by exploring both the self-reported and psychophysical aspects of time perception amongst adults with ADHD.

1.2 Rationale

Through the use of various temporal measurement tasks such as time estimation, time production/reproduction and temporal discrimination, a number of studies have demonstrated time perception deficits in individuals with ADHD. Significant differences have been found between ADHD and control groups on time production/reproduction tasks (Smith, Taylor, Rogers, Newman, & Rubia 2002; Meaux & Chelonis, 2003; Mullins, Bellgrove, Gill, & Robertson, 2005; Rommelse, Oosterlaan, Buitelaar, Faraone & Sergeant 2007; Valko et al., 2010), as well as estimation and discrimination tasks (Smith et al., 2002; Radonovich & Mostofsky 2004; Toplak & Tannock, 2005; Toplak, Dockstader & Tannock, 2006). In addition to these psychophysical measures, Carelli and Wiberg (2012) have confirmed that adults with ADHD have a significantly different self-reported habitual time perception. As a result of the diversity in measurement and task nature, replication is essential in confirming the hypothesis that individuals who show signs of ADHD symptomology do indeed have impaired timing mechanisms.

The present study aimed to confirm whether young adults, who present with significant ADHD symptomology, from both the inattentive and hyperactive subcategories, do in fact have impaired temporal

perception mechanisms, in addition to a dissimilar self-reported concept of time. This postulation was investigated through the use of discrimination and verbal estimation tasks. Although the discrimination task utilised was only confirmatory in nature; the estimation task was novel in that it cantered on an actual cognitive task. Estimating how long an actual task takes/took provides more ecological validity because it represents the manner by which an adult with ADHD would approach the temporal dynamics of a task faced within a work or study environment, rather than estimating the passage of time devoid of an actual task.

In terms of the neural derivatives of time perception, the present study aimed to explore the differences in electroencephalography (EEG) recorded brain activity between ADHD and non-ADHD individuals. Differences in structural activity, as well as task performance would be an unwavering indication of impaired timing mechanisms in those individuals who present with significant ADHD symptomology, as indicated by the Diagnostic and Statistical Manual of Mental Disorders – Fifth Edition (DSM-5) (American Psychiatric Association, 2013) criteria.

Along with this, results that show a clear link between EEG activity and poor temporal task performance may contribute to ADHD screening and diagnostic techniques. The DSM-5 criteria (American Psychiatric Association, 2013), which stipulates that a person with ADHD regularly experiences difficulty in organizing work-related tasks, is too vague to specify a pure time perception deficit that acts in the range of milliseconds to hours.

Perhaps this criterion should be elaborated upon through the specification of simple temporal measurement tasks that could be performed by clinicians in order to gain an objective measure of a time perception deficits. This would provide a more accurate measurement regarding the presence or absence of this criterion. In this way, the current investigation aimed to add to the body of literature that proposes the introduction of objective techniques in ADHD diagnosis, and more specifically adult diagnosis.

Along with diagnosis and screening, the present study might contribute to ADHD management. For example, if a pure structural and cognitive time perception deficit is found amongst individuals with ADHD, then failing to finish work on time, or consistently being late, should be attributed less to the individual's own conscious behaviour but rather to the presence of ADHD. In this case, school and work environments may aid these individuals by providing more information with regard to how a task can be temporally divided. Alternatively clinicians may teach ADHD diagnosed individuals coping skills that emphasize the accurate temporal breakdown of a task before its initiation.

1.3 Aim

Taking the above into consideration, this study aimed to investigate the manner in which young adults between the ages of 18 to 38 years with significant ADHD symptomology perform on time perception tasks when compared to their counterparts who do not have significant ADHD symptomology. Along with this, the

study aimed to identify whether there is a difference between the two groups in EEG recorded brain activity when performing temporal perception tasks.

1.4 Research Questions

- Do young adults who present with significant ADHD symptomology have a different self-reported habitual perception of time when compared to controls who do not present with significant ADHD symptomology?
- Do young adults who present with significant ADHD symptomology have a different temporal discrimination threshold when compared to controls who do not present with significant ADHD symptomology?
- Are there any differences in the ability of young adults with significant ADHD symptomology to accurately estimate how long a given cognitive task will take to complete, when compared to controls who do not present with significant ADHD symptomology?
- Are there any differences in the ability of young adults with significant ADHD symptomology to accurately estimate how long a given cognitive task took to complete, when compared to controls who do not present with significant ADHD symptomology?
- In comparison to non-ADHD controls, do young adults who present with significant ADHD symptomology show any differences in electrical activity within the frontal lobe, frontal midline and parietal lobe, as measured on an EEG, during resting states?
- In comparison to non-ADHD controls, do young adults who present with significant ADHD symptomology show any differences in electrical activity within the frontal lobe, frontal midline and parietal lobe, as measured on an EEG, when performing temporal discrimination tasks?
- In comparison to non-ADHD controls, do young adults who present with significant ADHD symptomology show any differences in electrical activity within the frontal lobe, frontal midline and parietal lobe, as measured on an EEG, when estimating how long a given cognitive task will take/took to complete.

1.5 Hypothesis

- Young adults who present with significant ADHD symptomology have noteworthy differences in self-reported habitual time orientation as compared to controls who do not present with significant ADHD symptomology.
- Young adults who present with significant ADHD symptomology have a noteworthy higher threshold to time discrimination as compared to controls who do not present with significant ADHD symptomology.
- Young adults with significant ADHD symptomology show more inaccuracy when verbally estimating time as compared to controls who do not present with significant ADHD symptomology.

- In comparison to non-ADHD controls, young adults who present with significant ADHD symptomology have higher slow wave activity and lower fast wave activity within the frontal lobe, frontal midline and parietal lobe during resting states.
- In comparison to non-ADHD controls, young adults who present with significant ADHD symptomology have higher slow wave activity and lower fast wave activity within the frontal lobe, frontal midline and parietal lobe during temporal discrimination tasks.
- In comparison to non-ADHD controls, young adults who present with significant ADHD symptomology have higher slow wave activity and lower fast wave activity within the frontal lobe, frontal midline and parietal lobe during temporal estimation tasks.

1.6 Approach

1.6.1 Research Design

In order to test the above mentioned hypothesis, the current study utilised a quasi-experimental design. According to Jackson (2011), quasi experimental designs are utilised when the investigator does not have the ability to self-manipulate the independent variable in question. In the current investigation, the presence of ADHD could not be overtly manipulated by the researcher. In this way it was not possible to control which group the participants would form part of. Rather, it was the presence or absence of existing ADHD symptomology that determined this factor.

According to Jackson (2011), when an investigation tests the differences in a certain outcome factor amongst a population with pre-existing stratifications, the design can be classified further as being ex post facto. With relation to the current investigation, the pre-existing stratifications would be the presence, or lack of, ADHD symptomology. In addition to this, the design was cross sectional in nature. This means that all the tests that were used to measure the variables of interest were conducted once on each participant (Jackson, 2011). In this line of thought, the current design can be classified as a quasi-experimental, cross sectional, ex post facto design.

1.6.2 Analysis

In order to analyse whether there were significant differences in the outcome variables, both parametric and non-parametric statistical techniques were utilised. Although the ADHD symptomology variable was dichotomous in nature, the degree of symptomology was measured on an interval scale. This means that the magnitude of symptomology could be compared amongst participants (Rosenthal, 2011). Measuring symptomology in this manner also aided in stratifying both the ADHD and non-ADHD group into subgroups of high and low occurrence/absence of symptomology.

All of the outcome variables in question were of an interval scale. This included the self-report scale, the psychophysical time perception measures and the EEG recorded brain activity. As discussed, this allows for a comparison of the degree or magnitude of difference between these variables.

Parametric techniques were used to compare differences between the ADHD and non-ADHD group with regard to the self-report and psychophysical measures. These techniques were utilised because the data from the above outcome measures were found to be parametric in nature. According to Rosenthal (2011) parametric tests are used when the data of interest is normally distributed. This means that results are not skewed in a particular direction, but are rather distributed evenly around the mean outcome score for each group in question. An ANOVA was a suitable test to compare means in this regard (Rosenthal, 2011). The EEG recorded data was found to be skewed, or non-normally distributed, within each group, which necessitated the use of a non-parametric Mann–Whitney U test. According to Rosenthal (2011) the Mann–Whitney U test is suitable because it compares the median outcome of a non-normally distributed interval scale variable between two groups.

1.7 Concept Clarification

1.7.1 Self-Reported Habitual Time Perception

Self-reported time perception is an individual's behaviour towards, and the extension of his/her representation of the past, present and future (Zimbardo & Boyd, 2009). In this way self-reported time perception explains an individual's current behaviour and demeanour based on their outlook towards past experiences, current life events, and future opportunities and/or threats.

1.7.2 Psychophysical Time Perception

This concept can be defined as the quantitative relationship between the objective passage of time and the subsequent sensational and perception response it elicits (Grondin, 2008). In simple terms, psychophysical time perception aims to delineate the relationship between a temporal stimulus and the sensation/response it elicits within an individual.

1.7.3 Neural Substrate

Neural substrates are the biological mechanisms that underlie cognition (Fatemi & Clayton, 2008). In the current investigation there is a specific focus on the neurological processes (neural substrates) that are utilised in consciously perceiving time, and the behavioural manifestations that these processes result in. In this way, the question of how psychological/cognitive functions are produced by neural circuitry is addressed. More so, neural substrates are the processes utilised within the soma to connect an objective temporal experience with perceptual consciousness.

1.7.4 Discrimination Threshold

A discrimination threshold is the shortest time interval at which two stimuli are detected to be asynchronous (Grondin, 2008). In the current investigation, it is defined as the threshold at which two visually presented stimuli are perceived as clearly distinct in terms of the temporal duration they were presented for.

1.7.5 Temporal Estimation

In the current investigation, a temporal estimation refers to a verbal response that is given in minutes and/or seconds regarding a certain temporal epoch of time that has either passed or is about to begin (Zakay, 1993).

1.8 Chapter Outline

This study is divided into five chapters; chapter one serves as an overall introduction.

Chapter 2 contains the literature review. In this chapter, through the use of both long standing and contemporary explanations, the concept of ADHD and time perception is expanded upon. Theoretical models of both ADHD and time perception are discussed along with the foremost neural substrates that correspond to these models. In addition to ADHD and time perception, insights into EEG analysis and consequential contemporary findings are examined.

Chapter 3 expands on the methodology utilised in the current investigation. This is done by outlining specifics regarding the procedures, methods of investigation, analysis and ethical considerations.

Chapter 4 reports on the results from all the investigations that were conducted. These findings are presented in the form of tables and statements describing ether the absence or presence of statistically significant differences.

Chapter 5 discusses the results that were generated by the current investigation. This chapter aims to link these results to contemporary findings within the literature. Results are described as ether being congruent with, or opposed to, the majority of findings from similar studies. Along with this, an attempt is made to describe the results in line with contemporary models of ADHD and time perception.

Chapter 2: Literature Review

2.1 Introduction

This chapter aims to discuss theoretical concepts and report on contemporary findings that surround the topics of ADHD and time perception. This is done by firstly describing the clinical picture of ADHD. Insights into the clinical symptomology and diagnostic criteria are described. ADHD is recognised as a neuro-developmental disorder and in this way, both the neurobiological aetiology and corresponding theoretical models of the disorder are discussed.

In addition to this, EEG investigative techniques and characteristic findings within ADHD populations are assessed. The review then moves on to consider the concept of time perception. This concept is described with regard to theoretical models, neural substrates and investigative techniques. Finally, the topics of time perception and ADHD are merged. This section sheds light on contemporary findings that discuss whether there are significant differences in time perception, between ADHD and non-ADHD groups. Furthermore, the neurobiological origins of these differences, or non-differences, are discussed in line with contemporary literature.

2.2 Clinical Picture of ADHD

ADHD is a neuro-developmental disorder that affects children and adults. It is characterised by the presentation of impulsive, abnormally overactive and inattentive behaviours (Millichap, 2010). Reynolds and Fletcher-Janzen (2009) indicate that ADHD does not fit into the traditional disease model because its presence is not defined as either absent or existent; rather, it is assessed on a continuum, or a degree of manifestation. The symptoms associated with the disorder are multi-dimensionary rather than unitary. There is consensus in the literature that ADHD symptoms fall into two broad categories of inattentive and hyperactive-impulsive behaviours (Reynolds & Fletcher-Janzen, 2009). Reynolds & Fletcher-Janzen (2009) further indicate that the presence of ADHD should not only be based on the existence of inattentive or hyperactive-impulsive behaviours, but rather on how the resultant behaviours impact on everyday functioning.

2.2.1 DSM Criteria

In relation to the DSM-5 (Table 1), the diagnosis of ADHD requires an individual to present with at least six symptoms from either the inattentive or hyperactive-impulsive categories (American Psychiatric Association, 2013). Along with this, the symptoms need to persist for at least six months; the presence of symptoms must cause impairment in at least two settings (e.g. work and home); and the symptoms cannot be the result of any differential diagnosis. A diagnosis is made by categorising the form of ADHD into either the inattentive, hyperactive-impulsive, Inattentive Presentation (Restrictive) or combined subtypes,

depending on which behaviours predominantly constitute the disorder (American Psychiatric Association, 2013). In relation to the criteria regarding time management, the DSM-5 indicates that a person with ADHD regularly experiences difficulty in organizing work-related tasks (American Psychiatric Association, 2013).

2.2.2 Changes from the DSM-IV-TR to the DSM-5

Between 2007 and 2012 the American Psychiatric Association systematically took on the task of improving the former DSM-IV-TR and developing the new DSM-5. The changes that have been made from the DSM-IV-TR to the DSM-5 are reflected in the ADHD diagnostic criteria. The DSM-IV-TR stated that ADHD symptoms, along with impairment, must be present by the age of seven years.

However, contemporary research indicates otherwise. In their study of the age of onset criterion for ADHD, Barkley and Biederman (1997) found no support for the continued use of the 'below the age of seven' criterion for either research or diagnostic purposes. Research by Rohde et al. (2000) found similar results among a sample of learners aged 12 to 14 years. Both these studies concluded that until such time as an empirical justification can be clarified for a precise age of onset for ADHD, the below the age of seven criteria should be either abandoned or broadened to include onset of symptoms during the entire childhood years. These findings have lead DSM-5 developers to adjust the age of onset to below the age of twelve years (American Psychiatric Association, 2013).

Along with an unjustified age of onset, the previous DSM-IV-TR was criticised for requiring the presentation of too many symptoms in the diagnosis of adult ADHD. For Wasserstein (2005), adults with ADHD do not have the same degree of symptomology as that presented in childhood. Core childhood symptoms shift with development in such a way that hyperactivity often declines by adolescence, and although attentional problems appear to remain more constant, impulsivity may transform into more subtle difficulties in executive function (Wasserstein, 2005).

The authors attribute these findings to the fact that in adulthood, individuals tend to develop sufficient contingency strategies that mask many of the overt ADHD deficits present in childhood. In line with this, the American Psychiatric Association (2013) has decreased the number of symptoms required to make an adult diagnosis. Previously, the diagnosis of ADHD required at least 6 of the 9 listed symptoms of inattention and/or 6 of the 9 symptoms of hyperactivity/impulsivity. The DSM-5 only requires 5 symptoms from either category in the diagnosis of persons over the age of 17 years (American Psychiatric Association, 2013).

Another major change made to the ADHD criteria is that of comorbidity. The previous DSM-IV-TR noted that the condition could not be comorbid with autism spectrum disorders (ASD) (American Psychiatric Association, 2000). Contemporary research has criticised this imperative by noting that comorbidity between these disorders is relevant, and a frequent occurrence.

For example, Leyfer et al. (2006) found that children with ASD, who have been diagnosed in clinical settings, present with comorbid symptoms of ADHD at rates ranging between 37% and 85%. For Rao and Landa (2013), this has implications for clinical practice. The findings give evidence as to the need for ADHD screening at an early age in children diagnosed with ASD (Rao & Landa, 2013).

Along with this and in order to optimize clinical outcomes (Rao & Landa, 2013); further research is needed to determine efficacious interventions for children and adults who have comorbid ASD and ADHD. With respect to these contemporary findings, the DSM-5 allows a concurrent diagnosis of both disorders when criteria for both are met (American Psychiatric Association, 2013).

2.2.3 The DSM 5 and Adult ADHD

The DSM-5 has also included more examples of how adult ADHD symptomology may manifest. In describing the manifestation of criterion symptoms, the DSM-IV-TR provided examples that were out of context for an adult diagnosis. The examples given largely pertained to the 'school environment', 'homework', 'teachers', 'school assignments' and 'behaviour in class' (American Psychiatric Association, 2000).

Consequently, the DSM-V has included more appropriate examples such as behaviour in the 'office', 'workplace', 'restaurants' and 'meetings', and tasks such as 'preparing reports', 'completing forms', 'returning calls', 'paying bills' and 'keeping appointments' (American Psychiatric Association, 2013).

2.2.4 Manifestation of ADHD Symptomology

As noted, the DSM-5 indicates that the main functional impairments caused by ADHD involve deficits in attention, hyperactivity and impulse control. Brown (2002) elaborates on these characteristic symptoms by explaining the impact they have on an individual's executive functioning. For instance, deficits in attentional capacity result in difficulty sustaining focus and shifting focal attention from one task to another. It also relates to being easily distracted by one's surroundings and own thoughts (Brown, 2002).

Deficits involving processing speed and sustained effort are also considered major executive impairments. These problems will result in an individual failing to provide sustained effort on long term tasks, and a failure to complete tasks on time (Brown, 2002; Turkington & Harris, 2006). Difficulty modulating emotion is another impairment listed by Brown (2002). The result of an inability to modulate emotion is that task completion, and thus performance, is impeded by the existence of emotionally loaded information within the conscious.

This emotionally loaded material demands a large proportion of an individual's attention and cannot be suppressed in order to allow for more processing capacity to be used on the current task at hand (Brown, 2002). Another impairment associated with ADHD is that of working memory. According to Brown (2002),

deficits in working memory are described by the faulty retrieval of information that has recently entered short term memory.

This can be explained using the analogy of a faulty 'search engine' within the brain, that fails to retrieve all the desired information from short term storage and integrate it with current information. Activation has also been discussed as an executive impairment in individuals with ADHD. Defective activation results in difficulty organising tasks, prioritising tasks and estimating time (Brown, 2002).

These executive impairments are what may cause difficulty in an ADHD individual's ability to start tasks on time and decrease levels of procrastination; even when there is an important task at hand (Brown, 2002).

In addition to the above listed impairments, Vorster (2012) describes the secondary symptoms that are frequently found in people diagnosed with ADHD. The first of these is social clumsiness. Individuals with ADHD can be sensitive and caring; however in many contexts they misinterpret social cues and this results in actions that are inappropriate for the immediate setting (Vorster, 2012).

In some cases coordination deficits are present. These deficits affect fine and gross motor skills which may impede handwriting ability and larger muscle group coordination (Vorster, 2012). Secondary symptoms of disorganisation and poor self-esteem are related to each other. The result of disorganisation is a deficit in task completion and an inability to perform at an optimal level. This in turn results in poor self-esteem. Individuals with ADHD may feel as though they can do nothing right no matter how hard they work on the task (Vorster, 2012).

2.3 Theoretical Models of ADHD

Numerous theories as to the pathophysiology of ADHD exist in the contemporary literature. The most frequently cited of these theories are: the executive dysfunction theory, the state regulation hypothesis, the delay aversion theory, the dual pathway model and the dynamic development theory.

2.3.1 The Executive Dysfunction Theory

According to Willcutt, Doyle, Nigg, Faraone, and Pennington (2005), The Executive Dysfunction Theory (EDT) suggests that the symptoms of ADHD arise wholly as a result of a reduction in executive control. This reduction is proposed to be caused by abnormalities in the structure, function and neurotransmitter activity of the fronto-parietal and fronto-striatal neural networks (Willcutt et al., 2005).

As discussed above, imaging techniques that are sensitive to the workings of the executive function system (mainly the frontal cortex) have been used to confirm these deficits. The results of these investigations directly (via fMRI and EEG) and indirectly (via behavioural studies) implement physiological and anatomical abnormalities within the frontal cortex and specifically, the fronto-parietal and fronto-striatal circuits in individuals with ADHD.

For Willcutt et al. (2005), the predictive value of EDT is highlighted by the fact that it does not prescribe that ADHD be situated in one of four broad categories. Rather, EDT approaches each case as a unique set of executive dysfunction deficits that may implement working memory, planning and temporal processing, to name a few, rather than lumping cases into inattention and/or hyperactivity/impulsivity subcategories (Willcutt et al., 2005).

Despite its strength in individualising each case of ADHD impairment, EDT fails to account for the full complexity of ADHD symptomology. Along with this, executive dysfunction is not always found in all children with ADHD. Nigg, Willcutt, Doyle, and Sonuga-Barke (2005) provide evidence that 35% to 50% of individuals with an ADHD combined subtype diagnosis showed response inhibition deficits.

According to Passarotti, Sweeney, and Pavuluri (2010) response inhibition is a deficit that is most often related to subcortical malfunction. In this way EDT overlooks the presence and origins of deficits related to subcortical influences such as response inhibition. Another downfall of EDT is related to the fact that it is not possible to investigate the functions of individual executive system components without the influence of non-executive brain processes.

Neuropsychological tests of executive function are complex and involve the collaboration of different executive function processes thus making it difficult to resolve the exact locus of dysfunction (Willcutt et al., 2005). Additionally, poor performance by individuals with ADHD on neuropsychological tasks might be the result of a motivational or a state regulation deficit that causes a down regulation in the neural circuits associated with executive functioning (Willcutt et al., 2005). In this line of thinking, EDT will never have power in explaining the full ensemble of ADHD aetiology.

2.3.2 The State Regulation Hypothesis

The State Regulation Hypothesis (SRH) affirms that a non-optimal energetic state could explain performance deficits in children with ADHD. In this way, the SRH is based on a cognitive energetic model that describes the efficiency with which a task is performed as being the product of elementary cognitive stages (stimulus encoding, memory search, binary decision and motor preparation) and their energy distribution (Sanders, 1983).

According to Sanders (1983), an individual's performance in these elementary cognitive stages is based on arousal and activation levels. Arousal is defined as an immediate physiological response to a stimulus input; whereas activation refers to a long lasting voluntary readiness for action (Sanders, 1983). For Sanders (1983) effort is necessary to meet task demands, and to compensate for a suboptimal state of arousal and/or activation, by either up regulating or inhibiting the current levels of arousal and activation.

In a review by Van der Meere (2002), a sub optimal activation state was confirmed to exist in individuals with ADHD. The review pointed out that these individuals tend to have a rapid decline in efficiency when tasks have a slow presentation rate, and perform normally when tasks have faster presentation rates.

Taken together, these findings suggest that people with ADHD are easily under activated and have difficulty in adjusting their under activated state due to the insufficient allocation of extra effort (Van der Meere, 2002).

Despite providing a seemingly accurate explanation as to the pathological origin of ADHD, SRH has theoretical and investigative downfalls. As discussed, the state regulation model is based on research using the cognitive energetic model which prescribes a distinction to be made between arousal and activation. However, for Johnson, Wiersema, and Kuntsi (2009) psychophysiological evidence for this distinction is limited and more research is warranted.

Along with this, although Barry, Clarke, and Johnstone (2003) confirm that higher theta to beta ratios are found in the EEG recordings of individuals with ADHD, these findings cannot consistently confirm that this is an indication of cortical, and more importantly subcortical, under arousal (Johnson et al., 2009). Another downfall of the SRH is that it explains poor cognitive performance as the result of a neural under activation.

However, Sonuga-Barke (2002) found that people with ADHD experience time use problems on trials that have a short and long duration, while performance increased on trials with a medium duration. This gives evidence as to the fact that over activation may also be a source of cognitive deficits in ADHD.

2.3.3 The Delay Aversion Theory

According to Yates, Lund, Johnson, Mitchell, and McKee (2009) The Delay Aversion Theory (DAT) predicts that individuals with ADHD are not impulsive in the sense of always opting for an immediate reward at the expense of overall rewards, but that they do so only in circumstances where this leads to a shorter overall delay. It is a motivational account of ADHD that most often implements the functioning of subcortical reward systems, thus in contrast to theories focusing on higher order cognitive deficits.

In this way, DAT accounts for the finding that individuals with ADHD symptoms 'can wait but often don't want to'. The symptoms of inattentiveness and hyperactivity are considered to reflect attempts at reducing the subjective experience of delay in situations where delay cannot be avoided (Yates et al., 2009). This delay aversion behaviour was demonstrated by Sonuga-Barke, Taylor, Sembi, and Smith (1992) in a task that required participants to make a choice between a small immediate reward and a large delayed reward under two conditions.

In the experimental condition there was no additional delay after participants made their choice. The control condition had consistent delays after a choice was made, irrespective of the choice that was made. Sonuga-Barke et al. (1992) only found a group difference (ADHD vs. non-ADHD) in the ‘no post choice delay’ experimental condition, with the ADHD group choosing the small immediate reward more often than control children.

2.3.4 The Duel Pathway Theory

Although DAT provides an attractive explanation as to why individuals with ADHD possess symptoms of hyperactivity and inattentiveness, if fails to account for deficits in higher order cognition such as working memory, processing speed, regulating emotions and temporal perception. It is both the strengths and weaknesses of DAT and EDT that lead contemporary ADHD researchers to combine these accounts into a new model known as the Duel Pathway Theory (DPT) of ADHD.

This theory proposes the existence of two distinct subtypes (pathways) in the formation of ADHD symptomology; one characterised by executive function deficits and the other by delay aversion (Sonuga-Barke, 2003). In terms of neurobiology, the theory predicts that the pathway involving executive function deficits are linked to the mesocortical dopamine branches.

In contrast, the pathway involving delay aversion is linked to the mesolimbic dopamine branch and associated subcortical reward centres (Sonuga-Barke, 2003). Evidence for the DPT is provided by Solanto et al. (2001) in a study that compared the performance of ADHD individuals with controls on an executive function and a delay aversion task. Whereas poor performance on both tasks was associated with ADHD, there was a lack of a significant association between inhibition and delay aversion performance, leading to the conjecture of two independent pathways (Solanto et al., 2001; Sonuga-Barke, 2003).

As this model has power in describing all of the apparent ADHD symptomology, along with providing evidence as to the pathophysiological processes that precede the observed impairments, there are not many criticisms apart from those addressing the methodology of findings that support its development.

Johnson et al. (2009) highlight that the DPT is based on correlational data which has a multitude of interpretative passageways that is not causal in nature. Along with this, the same authors propose that the development of the model would benefit from a clear description of tasks and variables that measure the proposed constructs. In short, many of proposed links in the model are yet to be tested and, overall, replication of findings with independent samples is important for confirmatory purposes.

2.3.5 The Dynamic Developmental Theory

The Dynamic Developmental Theory (DDT) of ADHD, developed by Sagvolden, Russell, Aase, Johansen, and Farshbaf (2005) over the past 20 years, attempts to explain the behavioural manifestations of ADHD from a neurotransmitter through to a societal level. The theory suggests that there are two main behavioural mechanisms underpinning many of the symptoms associated with ADHD, namely, altered reinforcement of novel behaviour and reduced annihilation of incorrect behaviour (Sagvolden et al., 2005).

In classic behaviourism, the efficacy of a reinforcer is greater if the delay between the response and the reinforcement is smaller. When delivery of the reinforcer stops, extinction occurs and responses are subsequently not elicited. DDT hypothesises that in individuals with ADHD the critical ‘window of opportunity’ for the reinforcer to take effect is shorter than normal (Sagvolden et al., 2005).

In this way, socially desirable behaviours are not reinforced in time thus leading to many of the archetypal ADHD symptoms. In addition, Sagvolden et al. (2005) propose that altered levels of dopamine (specifically along the anterior cingulate-fronto-striatal circuit) results in the faulty extinction of undesired behaviours, along with causing a decrease in the reinforcement window.

By incorporating neurobiological factors (in the same way as the DPT), behavioural factors and environmental factors, DDT is able to address all downfalls of previously mentioned theories along with the addition of broader ranging explanations that encompass a diverse array of possible ADHD outcomes. Johnson et al. (2009) confirm DDT as being a rigorous theory that is both testable and falsifiable.

2.4 Aetiology and Neurobiology of ADHD

2.4.1 The Structural and Neurochemical Differences in Frontal Regions

Neurobiological influences and the study of brain structure are providing major contributions to the understanding of what causes ADHD. When comparing ADHD individuals with controls, Tannock (1998, as cited in DuPaul & Stoner, 2004), describe how studies using magnetic resonance imaging and positron emission tomography have discovered important structural differences and possible abnormalities in the fronto-striatal regions of the brain.

According to Toplak, Rucklidge, Hetherington, John, and Tannock (2006), individuals with ADHD show volumetric decreases in the posterior–inferior lobules of the cerebellar vermis, decreases in prefrontal volume, particularly the right PFC and increases in PFC metabolism. As the PFC is involved in inhibitory processes and higher order cognition, much research has focussed on linking cortical abnormalities with ADHD behaviour (DuPaul & Stoner, 2004).

Similarly, discoveries have been made describing the lack of dopamine and norepinephrine in the frontal cortex of patients diagnosed with ADHD (DuPaul & Stoner, 2004). Spencer, Biederman, Wilens, and Faraone (2002) concur with the observed dopamine and norepinephrine deficiency.

These authors also hypothesise that the abnormal functioning of dopamine circuits within PFC, responsible for working memory, alerting and response inhibition, cause unstable fluctuation in associative communication pathways between cortical areas (eg. the Hippocampus, premotor cortex and dorsolateral prefrontal associative area).

2.4.2 The Influence of Subcortical Regions on ADHD

Individuals with ADHD are also found to have structural abnormalities in subcortical regions. As most of the dopaminergic pathways originate in subcortical regions, the involvement of structures situated around the basal ganglia are rightfully implemented in the disorder.

For Zametkin and Rapoport (1987), deficient dopamine activity results in decreased feedback from frontal brain regions to subcortical structures such as the striatum, and dopamine releasing areas such as the ventral tegmental area and substantia nigra. The result of this 'miscommunication' is that there is less inhibitory control on the functioning of these subcortical regions.

With the idea of deficits in the communicative process between cortical and subcortical regions, Faraone and Biederman (2002) have denoted the term fronto-subcortical disorder. In line with this, prefrontal irregularities in ADHD may result from abnormalities in prefrontal cortex; however, they may also reflect the dysfunction of brain areas that have projections to the prefrontal cortex (Faraone & Biederman, 2002).

Given the known role of subcortical networks as modulators of prefrontal functioning (mainly in terms of dopamine release through mesocortical projections), the term frontosubcortical seems appropriate for ADHD (Faraone & Biederman, 2002). This term denotes a behavioural or cognitive dysfunction that appears as the result of deficits in frontal activity, but may be influenced by subcortical projections.

Along with communicative issues, Max et al. (2002) found that lesions of the basal ganglia, specifically the ventral putamen, corresponded to increased diagnosis of ADHD in children, particularly of the inattentive-subtype. In a similar line of investigation, Lee, Lee, Lombroso, and King (2004) showed that children with ADHD had metabolic increases in the striatum which decreased in the presence of methylphenidate.

This abnormal hyperactivity was hypothesised to result in decreased control of attention and motor response to irrelevant environmental stimuli (Lee et al., 2004). Taken together, these findings indicate that subcortical structures have the ability to produce ADHD symptomology through faulty reward and communicative processes.

Along with the inseparable influence of frontal and subcortical activity, Anderson, Polcari, Lowen, Renshaw, and Teicher (2002) proposed the cerebellum in ADHD aetiology. These authors indicate that there is a decreased steady state blood flow to the cerebellar midline of highly hyperactive children with ADHD, although, this deficiency does decrease with the administration of methylphenidate. Such a deficit could explain symptoms related to decreased motor coordination and less specifically, sustaining a productive daily routine.

2.4.3 A Multifaceted Syndrome

The multitude of proposed neurobiological causes of ADHD strengthens the fact that this syndrome cannot be attributed to a single factor. Along with this, the varieties of factors that are thought to have an influence in ADHD aetiology are not constant among those that have the disorder.

For example, within the neurobiological paradigm, Williams (2008) and Rastmanesh (2010) describe how disagreement exists as to how dopamine deficit results in the different manifestations of the disorder (inattentive and hyperactive/impulsive); along with arguments as to whether dopamine should be considered as the major biological contributor when abnormal serotonergic and norepinephrine

concentrations also exist in these individuals. Taken together, these findings indicate that ADHD should not be viewed as a disorder that can be resolved by means of one therapeutic pathway.

2.5 Investigating ADHD with Electroencephalography (EEG)

As discussed above, brain imaging studies have supported the fact that individuals with ADHD have a number of neuroanatomical and neurophysiological differences compared to those who do not have the disorder. EEG recording is one technique that has brought this fact to light. An EEG records the frequency (the rate of firing of groups of neurons in hertz (Hz)) and the electrical activity (Voltage (μV)) at desired cortical sites. EEG recordings can be dissected into different frequency bands namely: delta (0 – 3.4Hz), theta (3.5 – 7.4Hz), alpha (7.4 - 12.4Hz) and beta (12.5 – 24Hz) (Niedermeyer & Da Silva, 2005).

Each of these bands has a characteristic amplitude or degree of electrical activity produced by the firing of groups of neurons. There are a number of ways to quantify or measure this activity. According to Retz and Klein (2010), three such measures are absolute power, relative power and theta/beta ratios.

Absolute power is the actual power (mean electrical activity in microvolts squared) of a certain frequency band during a particular time epoch. Relative power is the percentage of electrical activity of a certain frequency band in relation to the summed power of all frequency bands at a particular cortical site, during a specific time epoch. The theta/beta ratio score represents the slow to fast wave relationship and is calculated by dividing the relative theta power by the relative beta power.

2.5.1 Normal EEG Activity

The dominant frequency band (band with the highest power) depends on an individual's activity state (Retz & Klein, 2010). EEG activity of healthy adults in a resting state (with their eyes closed) is usually characterised by higher fast wave (alpha) activity. When an individual transitions into a sleeping state, slower wave frequency (delta and theta) power begins to increase. In this way, the dominance of activity at different frequency bands can be related to the level of cortical arousal (Retz & Klein, 2010).

According to Sanei and Chambers (2008) delta waves are primarily associated with deep sleep and may be present in the waking state. It is important to note that delta wave activity is sensitive to the movement of muscles in the jaw and neck. Thus it is easy to confuse artefact signals induced by these muscles with genuine delta signals (Sanei & Chambers, 2008).

Theta wave activity, according to Sanei and Chambers (2008), has a presumed thalamic origin. Increased activity in this frequency is associated with conscious slips towards drowsiness. Along with this, theta activity has been associated with access to unconscious material, creative inspiration and deep meditation (Sanei & Chambers, 2008).

Alpha activity, on the other hand, has been theorised to represent a state of relaxed awareness without any attention or concentration. Sanei and Chambers (2008) indicate that alpha wave power is reduced by activities such as opening of the eyes, hearing unfamiliar sounds, experiencing anxiety or engaging in mental concentration or attention.

Finally, the high frequency beta wave is associated with the usual waking rhythm of the brain during active thinking, active attention, focus on the outside world or solving concrete problems (Sanei & Chambers, 2008). According to Sanei and Chambers (2008) a high level of beta wave activity may be associated with the feeling of physical pain. This rhythm may be lessened by motor activity or tactile stimulation.

2.5.2 The EEG Activity of Individuals with ADHD

The EEG recorded activity of individuals with ADHD is characteristically different to that of people without the disorder. In ADHD children, it has been found that the resting state EEG is characterised by increased slower wave activity (Swartwood, 2003; Retz & Klein, 2010; Loo & Makeig, 2012). This increased power of slow wave activity has also been found in adults (Bresnahan & Barry, 2002; Koehler et al., 2009; Clarke et al., 2011).

In the EEG literature, individuals with ADHD have been characterised as having a general cortical under arousal in frontal regions (White, Hutchens & Lubar, 2005). As most of these studies utilise theta to beta ratios as an indication of elevated slow wave activity, the increased low frequency activity is characteristically accompanied by a decrease in fast wave power (Schomer & Da Silva, 2012). Consequently, EEG recordings provide evidence of a generalised cortical under arousal in both ADHD children and adults.

2.5.3 Conflicting Findings

Although the majority of contemporary findings describe this decreased fast wave and increased slow wave activity in ADHD, there are investigations that have not found such results in children (Nazari, Wallois, Aarabi & Berquin, 2011), in adolescents (Ogrim, Kropotov & Hestad, 2012) and in adults (Van Dongen-Boomsma et al., 2010). For Loo and Makeig (2012), more research is needed to fully understand the functional significance of theta/beta EEG marker before it can be proposed for clinical application as a diagnostic tool for ADHD.

Based on the presence of contradictory findings, it appears unlikely that this kind of measure on its own is sufficient to sensitively discriminate the complex differences in electrical activity, involved in multiple brain circuits. Along with this, Sklar (2013), states that the majority of contemporary studies that investigate EEG related trends in ADHD do so during resting states (eyes closed and eyes open).

As the symptoms of ADHD manifest themselves to varying degrees, in different individuals, during dissimilar tasks that require attention; it is questionable whether EEG recordings taken during resting states are adequately related to the cortical activity that may occur when an individual engages in tasks that require attention (Sklar, 2013). In short the characteristic EEG differences in ADHD and non-ADHD individuals may be attenuated when these individuals engage in activities that require focused attention.

2.6 Investigating Time Perception

2.6.1 The Multisensory Nature of Time Perception

The task of investigating temporal perception is more complicated than measuring the perception of, for example; sound, touch, smell or taste. The main reason for this is that the category of temporal experience is not clearly defined, and could involve the above mentioned modalities in the perceptual process.

Along with the vast array of modalities that temporal processing may encompass, time perception can also be categorised as ether an implicit or explicit event. The measurement of implicit timing refers to events where an individual is required to make temporal adjustments; such as to the motor activities involved in speech, catching a ball or playing a musical instrument. However, these proprioceptive adjustments not require an explicit judgment of the temporal passage of time.

Explicit measurements on the other hand, refer to those activities were an individual is required to overtly state their perceptions of a specific passage of time. Generalisation of mechanisms involved in time perception is furthered complicated by variance in the duration under investigation. Contemporary studies on explicit time perception apply measurements that range from milliseconds to minutes (Grondin, 2008). Given the difficulty in purely measuring temporal perception, a number of measurement techniques have been developed to quantify different aspects of the same underlying construct.

2.6.2 Prospective and Retrospective Time Perception

In situations where participants are required to make explicit judgments of time, researchers distinguish between a prospective and a retrospective paradigm of enquiry. In retrospective time perception tasks, participants are required to make a temporal judgment after a given activity (Grondin, 2008).

In these instances, participants are not aware that they will be required to make an explicit temporal judgment. According to Grondin (2008), as retrospective timing requires cognisance of past events after an activity, be it in the past hour or past 100ms, such tasks usually assess factors that relate timing to memory processes.

On the other hand, prospective tasks refer to activities in which participants are aware that they will be required to make an explicit temporal judgment (Grondin, 2008). As participants are aware that they have

to attend to a specific temporal interval, prospective measurements are usually associated with the assessment of attentional processes (Grondin, 2008).

2.6.3 Measurement Tasks

Grondin (2008) describes the most contemporary temporal measurement tasks as being verbal estimation; reproduction; production; and method of comparison. In verbal estimation, the participant is required to provide a verbal approximation of a target duration that was presented in stimulus form (e.g. auditory or visual). The utilisation of verbal estimation tasks is aimed at determining whether the effect of factors that influence subjective time become more pronounced at longer durations (Zakay, 1993).

Reproduction pertains to the participant's ability to accurately reproduce a previously presented target duration. In this way reproduction tasks are similar to estimation tasks in that they require an estimation of a target interval, however, they also require a somatic response (e.g. holding down a button for a duration of time) (Zakay, 1993). Because of the involvement of these additional motor processes, reproduction tasks assess more than temporal mechanisms.

In production tasks, participants are required to produce a target interval that is specified in temporal units (seconds and minutes). Since the production of these temporal intervals requires a motor response (finger tapping or holding down a button), motor timing can influence the results of such a measure.

2.6.4 Duration Discrimination

Duration discrimination is a classic method of comparison. In these tasks participants are sequentially presented with two temporal stimuli and instructed to indicate whether the duration of presentation of the second stimuli differed from that of the first. The reminder method of duration discrimination petitions that a standard stimuli duration be presented before the comparison interval on every trial (Grondin, 2008).

Alternatively, the roving method of comparison applies to tasks that have varied standard and comparison intervals that are to be compared. Both the roving and reminder method of comparison present situations in which a participant is required to make two-alternative forced choices (the intervals were either presented for the same amount of time or they were not).

Within the two-alternative forced paradigm, researchers distinguish between another two methods, namely, the method of constant stimuli and the adaptive method. In the latter, the comparison interval is adjusted in order to accommodate for the participant's previous response (Grondin, 2008).

A wrong response will result in the comparison interval being made longer thus making the task easier. Correct responses result in the decreasing of the comparison interval. Tasks that use the adaptive method usually terminate after a certain number of trials, or after a certain number of difficulty reversals have occurred (Grondin, 2008).

In the method of constant stimuli, a number of comparison intervals that are determined in advance, are presented randomly in each trial. In this instance participants may be randomly presented with the same comparison interval more than once during the same task.

The method of constant stimuli allows researchers to determine the probability of attaining a correct response at different magnitudes of comparison intervals between different groups. Plus the threshold to discrimination (smallest possible difference in presentation duration of the two stimuli before a participant claims they were presented for the same duration) for individual participants (Grondin, 2008).

2.6.5 Adaptive and Perceptual Timing

Within the psychophysical paradigm, researchers have developed an arbitrary cut off between temporal perception that is regarded as an adaptive behaviour (automatic processing), and perceptual processes that require higher order cognitive resources.

According to Grondin (2010), temporal perception tasks that have intervals shorter than, plus/minus one second, measures an individual's automatic temporal processing. Tasks that require the processing of longer intervals are hypothesised to draw on more cognitive resources, such as working memory, because successes on these tasks are facilitated through the adoption of segmentation strategies (Grondin, 2010).

Dividing a stimulus interval into smaller equal portions allows for better discrimination accuracy in tasks that have comparison intervals greater than one second (Grondin, Meilleur-Wells & Lachance, 1999). A classic segmentation strategy would be explicitly counting numbers during the stimulus presentation.

Along with the apparent application of different cognitive resources, the less than one second range is also important to researchers because it encompasses phenomena related to indifference intervals and lowest threshold to stimulus discrimination. In relation to verbal estimation tasks, indifference intervals are found (around 700 milliseconds) when participants neither underestimate nor overestimate the duration that a stimulus was presented for (Grondin, 2010).

Along with this, the less than one second range has significance in temporal discrimination tasks. Using progressively shorter comparison intervals in such a task allows for the identification of the lowest possible threshold to stimulus discrimination (Grondin, 2010).

In short, this is the ability to tell the difference in presentation time of two temporal stimuli. According to Drake and Botte (1993) the threshold to accurate discrimination of a comparison interval ranges between 300 and 800 milliseconds, depending on the participant's age.

The distinction between automatic temporal processing and higher order cognitive time perception has been shown to correspond to different regions of brain activation. In a meta-analysis regarding a variety of studies with a diverse array of temporal perception tasks that were both above and below one second, Lewis and Miall (2003a) demonstrated these quantitative differences.

The automatic system is closely linked to the motor and premotor circuits, with some involvement of the auditory cortex (Lewis & Miall, 2003a). These automatic processes do not specifically result in extensive prefrontal cortex involvement.

Conversely, cognitively controlled perceptual processes draw heavily upon the prefrontal and parietal cortices, which are likely to fulfil memory and attentional requirements respectively (Lewis & Miall, 2003a). Along with this, the prefrontal cortex (PFC) is thought to be quite flexible in function, containing modules that can be recruited on demand for any one of several tasks (Lewis & Miall, 2003a).

2.6.6 Habitual Time Perception

Although more objective, psychophysical investigations are not the only methods of studying human time perception. De Volder (1979, as cited in Lopez & Snyder, 2011) defines the perception of time as the preferential direction of an individual's thoughts towards the past, present or future. These thoughts influence experiences, motivation, thinking and behaviour patterns (Lopez & Snyder, 2011).

On a similar note, time perception can also be defined as "the non-conscious personal attitude that each of us holds towards time and the process whereby the continual flow of existence is bundled into time categories that help to give order, coherence, and meaning to our lives" (Zimbardo & Boyd, 2009, p.51). In line with these definitions, an individual's subjective perception of time has the potential to influence a multitude of behaviours.

As noted, psychophysical investigations are vastly mediated by task characteristics such as stimuli type and presentation durations. Though these forms of investigation have provided important insights into temporal information processing and group differences in time reproduction for example, it does not necessarily reflect functional problems in time perception.

Everyday planning and time management do not singularly draw upon the same conative and automatic processing resources used in laboratory type psychophysical investigations (Zimbardo & Boyd, 1999). In line with this, it is reasonable to assume that deficits in planning and timekeeping are not only the product of impairments in motor timing and duration judgments, but also due to biases in how an individual views past experiences and future challenges.

In other words, the systematic biases held by individuals in relation to the past, current situations, and future expectations can influence how one goes about prioritising, planning and initiating tasks that have temporal constraints. For Zimbardo and Boyd (1999) these differences in temporal perspective contribute to functional problems in time management by affecting everyday judgments and actions.

2.6.7 Zimbardo on Time Perception

Essentially, Zimbardo and Boyd (2009) have concluded that individuals are aligned to either a general present, past or future orientation. In order to measure the degree of adherence to a present, past and future temporal orientation, Zimbardo and colleagues developed an instrument called the Zimbardo Time Perspective Inventory (ZTPI), in which they overcame many of the limitations of previous attempts to operationalize time perception.

The ZTPI postulated five perspectives that correspond to these broad time orientations. These perspectives include: past-negative (PN), past-positive (PP), present-fatalistic (PF), present-hedonistic (PH) and future (F). The PN orientation reflects a pessimistic, negative or aversive attitude toward the past, whereas the PP orientation embodies a warm, sentimental, nostalgic and positive construction of the past. The PF perspective is characterized by a helpless and hopeless attitude towards the future life events.

On the other hand, the PH perspective reflects a hedonistic risk-taking attitude towards time. Finally, the F subscale is characterized by a general future orientation where one strives for future goals and rewards. These dimensions are unrelated to each other and will be present in every individual (Zimbardo & Boyd, 2009). Along with this, an individual's time perception, or preferred orientation, corresponds to the dimensions of time that are frequently used in understanding and generating meaning.

Since the advent of the ZTPI, an extensive amount of investigation has been conducted on the behavioural outcomes that different compositions of time orientation produce. Research suggests that particular temporal orientations have implications for various aspects of wellbeing and life satisfaction (Wiberg, Sircova, Wiberg & Carelli 2012).

For example, Boyd and Zimbardo (2005), found that orientation to the future ZTPI subscale was positively correlated with participation in a cancer screening program. In a later study, the same authors found that individuals who have a future orientation tend to make choices in terms of a cost/benefit approach, are less likely to be aggressive and are less impulsive (Zimbardo & Boyd, 2009).

Along with health seeking behaviour, Mello and Worrell (2006) indicate that a positive future outlook can perpetuate more positive functioning, which in turn lead to higher levels of academic achievement. In this way, a future oriented time perspective is related to more optimistic behaviour and an increased planning towards future outcomes.

Alternatively, individuals who display more of a present (PH and PF) orientation will focus on achieving immediate pleasure and gratification, have less impulse control, will study less, are less likely to take part in health seeking behaviour and are more likely to be aggressive (Zimbardo & Boyd, 2009).

Specifically, the PN orientation has been found to have positive correlation with increased levels of depression, anxiety, unhappiness, low self-esteem and aggression (Lyubomirsky & Nolen-Hoeksema, 1995; Boyd & Zimbardo, 2005).

As the above studies suggest, individual differences in TP may have clear implications for goal directed behaviour, as well as wellbeing in particular. These findings also suggest that excessive adherence to any given time perspective, at the expense of other orientations, can to lead to an imbalance that may not be optimal for an individual's physical and mental wellbeing (Wiberg et al., 2012).

The concept of a balanced time perspective, initially proposed by Zimbardo and Boyd (1999), is defined as the mental capacity to flexibly switch among different temporal frames depending on task features, situational considerations and personal resources; rather than being biased toward a specific perspective that is not adaptive across situations.

Thus "in an optimally balanced time perspective, the past, present and future components blend and flexibly engage, depending on a situation's demands and our needs and values" (Zimbardo, 2002, p. 62). Individuals who have this balance are assumed to operate in a manner that is more appropriate for the constraints of the immediate situation.

As opposed to the limiting ability of a bias towards one particular time frame, a balanced individual’s actions are shaped by a consideration of all three temporal zones (Zimbardo & Boyd, 1999). Along with this, higher levels of well-being (subjective happiness) are also associated with balanced time orientation profiles (Drake, Duncan, Sutherland, Abernethy, & Colette, 2008).

2.7 Theoretical Models of Time Perception

2.7.1 An Internal Clock?

In the last fifty years a number of theoretical models have been developed in the hope of accurately describing human timing mechanisms. However, finding a model that consistently fits both behavioural and neurobiological evidence has not been achieved.

Contemporary models of human time perception differ from each other with respect to the existence and nature of the internal clock (Grondin, 2010). Some of the proposed models, such as the intrinsic models, discount the presence of an internal clock altogether. According to Matell and Meck (2000) the hypothesised internal clock models are separated into Oscillator/coincidence-detection models and Pacemaker-accumulator models.

2.7.2 No Internal Clock

Before further deliberating on contemporary models that prescribe an internal clock for the perception of time, it would be appropriate to discuss those explanations that do not. Intrinsic models refer to explanations that do not accredit the involvement of an internal clock.

These models suggest that the perception of time is modality specific. In brief, every coordination depended system (visual, auditory, proprioceptive, etc.); specifically the neural circuits that make up these

systems, are inherently capable of providing information in support of temporal processing (Karmarkar & Buonomano, 2007).

A representative example of this non-dedicated-system understanding of time perception comes in the form of state-depended networks.

Instead of a particular internal clock providing temporal information to executive areas for higher order processing, changes in the state of neural networks that pertain to coordination-dependent systems are the substrates of temporal perception (Karmarkar & Buonomano, 2007).

The networks that make up these specific modalities are capable of representing different durations as unique spatial patterns of activity (Karmarkar & Buonomano, 2007). Therefore, judging the duration of a stimulus requires learning to recognize these spatial patterns of activation.

An essential feature of this model is that temporal representation is context dependent. This implies that time perception is not only modality specific, but also dependent on the initial network state (Karmarkar & Buonomano, 2007).

For example, the visual network's representation of visual stimuli duration is not only related to activity occurring during the presentation of the stimulus, but also to the state of the network at the onset of the task.

Karmarkar and Buonomano (2007) provide evidence for the influence of modality state on the ability to perceive time. These researchers found that the acuity for duration perception is less accurate when the target interval is presented in a variable context compared to a fixed context.

Support for a state depended intrinsic model of time perception is also provided by Johnston, Arnols, and Nishida (2006), who showed that the apparent duration of a visual stimulus can be manipulated in a retinotopic region of visual space by adapting to the oscillatory motion or flicker of a stimulus. Along with this, Shuler and Bear (2006) showed that a proportion of neurons in the primary visual cortex of rats fires in a way that seems to predict the timing of reward administration.

2.7.3 No Internal Clock: Process Decay Frameworks

Theories within the Process-decay framework, which fall into the intrinsic model paradigm, stipulate that the ability to perceive an interval of time is based on the decay of a memory trace that is initiated at the onset of a stimulus.

According to Murray (2008), the cognitive process involved in interval timing becomes an epiphenomenal property of neural activity. The displacements from baseline of the firing rates of groups of neurons are what alter subjective time perception. In this way, the subjective perception of time increases as neural activity decays; or as a recent memory trace decays (Murray, 2008).

In this sense, rather than a dedicated system (internal clock), the perception of time is grounded in mechanisms that track the change in magnitude of neuronal firing rates that correspond to the decay of a memory or perceptual trace.

Murray (2008) stipulates that if one conceives time as occurring in one of three phases, namely: the past, present or future, then the function of the clock is to measure the present and that of memory is to hold records of the past.

With a short term memory store of about five seconds, Murray (2008) illustrates that at some point an individual has to switch between using a clock value to perceive a stimulus situated in the present, to using a memory trace in order to perceive how long ago the stimulus was presented in the past.

For Murray (2008), models that stipulate a dedicated internal clock do not specify whether judgments made about the temporal present are based on the same mechanism that provide a continuous experience of the present.

Along with this, these models do not specify whether accurate time estimation results from the formation of a memory for the current temporal experience, or are based on mechanisms independent of working and long term memory (Murray, 2008).

Therefore, these models need to be more concise regarding the process of transition of a temporal stimulus from a current experience to a memory of an event. As process-decay accounts of temporal processing do not describe the involvement of a dedicated internal clock; this conundrum is avoided.

Thus, any sense of time, be it short term, sensory or long term, is the result of memory decay.

2.7.4 Problems with Process Decay Frameworks

Buhusi and Meck (2006) discount a process decay explanation of time perception with the use of their interval timing experiments. In these tasks participants were instructed to estimate the presentation time of an auditory stimulus.

The tasks differed to normal estimation tasks in that they included a gap in the stimulus presentation. In the middle of the 20 second auditory stimulus, the experimenters presented a gap were there was no auditory sound. Participants were required to estimate the duration of the stimulus, including the time that there was no auditory sound.

Results indicated that a significantly accurate judgment can be made despite the auditory gap in stimulus presentation (Buhusi & Meck, 2006). Process decay models note that temporal perception is based on the decay of a neurochemical signal. In line with this, the absence of a stimulus should result in no sensory signal decay and therefore an inaccurate judgment of a temporal interval. However, this was evidently not the case. Temporal judgments can be made despite the decay of a stimulus trace.

2.7.5 The Oscillator/Coincidence-Detection Paradigm

A proportion of the contemporary models that prescribe an internal clock mechanism are situated within the Oscillator/coincidence-detection paradigm. Neural oscillations are rhythmic or repetitive neural activity. This oscillatory activity can be generated in many ways; driven either by mechanisms localized within individual neurons or by interactions between individual and groups of neurons (Di Giovanni, Di Matteo & Esposito, 2009).

Within individual neurons, oscillations can appear as rhythmic patterns of action potentials which result in the propagation of oscillatory activation in post-synaptic neurons (Di Giovanni et al., 2009). At the level of clustered neuronal tracts, synchronized activity of large numbers of neurons can give rise to explicit electrochemical oscillations, which can be observed using an EEG (Di Giovanni et al., 2009).

Oscillatory activity in groups of neurons arises from feedback connections between the neurons that result in the synchronization of their firing patterns (Di Giovanni et al., 2009). This interaction between neurons can give rise to oscillations that differ in frequency to the firing frequency of individual neurons (Di Giovanni et al., 2009).

According to Grondin (2008), in terms of the application to time perception theory, Oscillator models propose that the formation of temporal correlates (firings of neurons or groups of neurons) are non-linear processes that depend on the flow of events in the immediate environment.

2.7.6 The Oscillator/Coincidence-Detection Paradigm: Dynamic-Attending Theory

Dynamic-attending theory (DAT) falls within the Oscillator/coincidence-detection paradigm and emphasises the entrainment of oscillatory correlates of environmental stimuli with an attentional rhythm.

According to this approach, the temporal structure of events in the surrounding environment causes oscillations in neural pathways that relate to higher order processes of attention (McAuley & Jones, 2003). These oscillations in attentional related networks have epochs similar to the periods produced by stimuli that appear in the environment (McAuley & Jones, 2003).

The concept of entrainment in this model is related to the degree of synchronisation of attentional network firing rates (oscillations) with oscillatory correlates of environmental stimuli (visual, auditory, propreoreceptive, etc.).

As DAT pertains to future orientated attending, the greater the degree of synchronisation, the better an individual will be able react to a temporal stimulus (McAuley & Jones, 2003).

According to Grondin (2008), the structure of environmental events is hierarchical, which corresponds to the hierarchical nature of the induced periods of attention. There are lower level environmental events and lower level attentional periods within short time spans.

During longer time spans, the greater number and more pronounced nature of external events correspond to larger attentional periods and neural oscillations. Therefore, in line with DAT, the accuracy of temporal judgments is not only a function of the capacity to synchronise internal rhythmicity of atonements with the appropriate external level of rhythm offered by the environment, but also the ability to adapt attentional attainments to the stimulus duration under question (Grondin, 2008).

However, because the temporal judgments DAT refers to are of a predictive nature (predicting the onset of a stimulus), tasks that do not have regularities available in the immediate environment, and do not pertain to the prediction of the arrival of an environmental event, are not well explained by such a conjecture (Grondin, 2008).

2.7.7 The Pacemaker/Counter Paradigm

A large majority of the contemporary theories on time perception that prescribe an internal clock are situated within the pacemaker/counter paradigm. According to Goldstein (2010) the general notion of most theories within this paradigm is that a pacemaker emits pulses that are accumulated in a counter, and the number of pulses counted determines the perceived length of an interval.

This pacemaker device singularly constitutes an individual's internal clock. In short, when an individual is required to judge the length of an interval, the number of neuronal pulses accumulated by the functioning of the pacemaker guides such a decision.

In this way, errors in temporal judgment are most often attributed to disturbances in the emitting properties of the pacemaker, and occasionally attributed to fallibility of the counter device (Goldstein, 2010).

2.7.8 The Pacemaker/Counter Paradigm: Scalar-Expectancy Theory

Scalar-expectancy theory (SET) forms part of the Pacemaker-accumulator paradigm and is the most frequently cited contemporary theory of human time perception. The theory departs with the assumptions that there is one internal time keeping device that operates for a large range of durations (Goldstein, 2010).

Along with this, it also assumes that an individual's subjective experience of time and the formulation thereof is linearly related to physical or objective time (Goldstein, 2010). Webber's law explains similar findings in relation to the physical magnitudes and the perceived intensity of visual and auditory stimuli in psychophysical investigations (Goldstein, 2010).

Thus, the variance in an individual's time estimation is proportional to the length of objective time under investigation. In other words, the magnitude of inconsistency produced by an individual in a time estimation task will increase or decrease as the objective duration under investigation increases or decreases.

Wearden (1991) confirms this scalar property of human time perception through the analysis of a number of different time perception experiments. Although time perception is regarded as a scalar property, the SET does not prescribe that all pathology of time perception is the result of a faulty internal time keeping device. The theory also allows for the contribution of memory and decision making activity in the process of time estimation (Goldstein, 2010).

According to Rapp (2001), SET involves three stages: a clock stage, a memory stage and a decision stage. The clock stage comprises of an internal pacemaker that acts as an intramural correlate of objective time. Neuronal pulse emissions, or firing rates, mediate this pace (Rapp, 2001).

The clock stage also includes an accumulator/counter and an attentional gate. When an individual pays attention to a temporal interval, more signals from the pacemaker are available for processing by the accumulator/counter. In this way, environmental stimuli, or queues, are what cause the opening or closing of the attentional gate/switch (Rapp, 2001).

Importantly, a closed gate does not mean that temporal processing does not occur, rather, sensory and motor systems proceed to use the pacemaker information for behaviours that do not require an explicit representation of time (an unconscious clock).

When the task of attending to a temporal stimulus is terminated, the pulses that were explicitly attended to, or let through the gate, are summed in the accumulator/counter to form a dynamic representation of current time (Rapp, 2001).

Upon making a decision regarding a temporal event, the summed value in the accumulator is compared to a reference memory, or the value of the accumulator previously generated during a similar event (Rapp, 2001). In this way, it can be seen that an individual makes a decision regarding a temporal interval based on a comparison between a current temporal event and those held in memory.

An accurate estimation of a temporal interval is seen as reinforcement (Rapp, 2001). This allows for long term encoding of the relationship between the specific event and the value generated in the accumulator. The newly generated accumulator value can therefore be used for future reference.

2.7.9 Scalar-Expectancy Theory and Temporal Perception Deficits

Because SET prescribes the summation of components that make up the three stages of processing in time perception; timing error can be attributed to a specific subcomponent or the integration of these components. The reliability of the pacemaker to accurately emit pulses that are available for accumulation is often cited as being the main cause of timing error (Murray, 2008).

However, before causality is attributed to this component one has to define the exact mode of pulse distribution. According to Murray (2008) pulse emissions are theorised to function in a deterministic or

stochastic manner. Deterministic pulses have regular intervals whereas stochastic pulses have random intervals.

Compared to the pacemaker, a more limited number of explanations have sourced the counting device as a root of timing error. Killeen and Taylor (2000) propose the existence of a number of counter components that specifically count the different kinds of pulses emitted by the pacemaker. In this line of thought the pacemaker would have to emit stochastic pulses that vary with environmental demands.

The cascade of counters available will be specifically applied to pulses that have distinct interval gaps (Killeen & Taylor, 2000). For Killeen and Taylor (2000), the size of timing errors increases disproportionally each time the next stage in a counter must be applied.

In other words, timing errors will be dissimilar for each of the different counters that are being applied to the different interval pulses being emitted. Killeen and Taylor (2000) have linearly modelled the average count registered by an individual as a function of the probability that a new counter has been employed to a change in pulse emission gaps.

More simplistically, this explanation means that uncounted pulses become more costly in larger intervals where larger numbers are counted. This explanation of timing error is therefore in line with Webber's law.

As described above, the attentional switch mediates whether pulses are sent to the counter/accumulator for analysis. In this way, time estimation error has strong reason to be attributed to this component. The component functions in such a way that as more attention is played to a specific temporal event, there will be an increase in a perceived duration and fewer temporal discrimination errors (Rapp, 2001).

Macar, Grondin, and Casini (1994) verified this conjecture through the use of tasks that required the dividing of attention. In these time perception tasks participants were instructed to pay attention to the intensity and duration of a stimulus.

Findings indicated that temporal judgments were less accurate when attention had to be concurrently divided (Macar et al., 1994). Van Wassenhove, Buonomano, Shimojo, and Shams (2008) reported similar results when the presented stimulus was varied between visual and auditory modalities.

Along with attentional factors, it is also believed that the delay between the physical onset of a stimulus and the internal representation of the onset contributes to error variance. To make such a supposition it is required that a more accurate definition of the attentional switch and gate is provided.

According to Block and Zakay (2008), in SET, the gate determines the flow of pulses when attending to a temporal event, whereas the switch refers to the attention played to onset and termination of a stimulus. Decreasing the latency between the physical onset (and termination) of a stimulus and its internal representation will therefore result in less timing error (Mitsudo et al., 2009).

In line with SET, memory and decision making processes cannot be neglected as a source of variance on the performance of psychophysical time perception tasks. As described above, SET suggests that a

representation (accumulation/count of pulses) of the current temporal event is compared to a reference memory of a similar temporal experience in the past.

When making a decision regarding the passage of time, the current experience has to be compared to a memory. Penney, Gibbon, and Meck (2000) suggests that this memory component is dynamic and able to actively supply a number of reference memories for comparison with the current experience.

If one divided these reference memories into, for example, a long and short representations of a temporal event (both functioning within 1 second), then these references will at some point overlap (perhaps at 30 seconds).

In this way, the memory of a temporal event could contribute to misjudgement if the physical time lies too close to two internal representations. This effect was demonstrated by Grondin (2005) in an experiment where blocks of trials with intervals of different duration ranges were used.

It was evident from this study that participants used different memory representations for different duration ranges (e.g. a temporal range of 200-300 milliseconds will require the use of a different memory representation to a duration range of 600-900 milliseconds).

It was also found that interference occurred (resulting in increased task errors) when the task duration ranges were too close together (Grondin, 2005; Klapproth, 2009).

2.8 Neurobiology of Time

The body of neuroscientific explanations regarding temporal processing has increased over the past fifteen years due to the emergence of new brain imaging techniques. Currently, the most salient methods of investigating the neural correlates of time perception involve the use of functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and repeated transcranial magnetic stimulation (rTMS).

Although fMRI provided the most sophisticated spatial resolution of neural processes; EEG recordings have a far better temporal resolution (Grondin, 2010). This advantage of EEG over fMRI recordings makes it a useful tool in studying the cortical activity involved in time perception. According to Grondin (2010) the major brain structures involved during time perception include the cerebellum, cerebral cortices and the basal ganglia.

2.8.1 The Cerebellum

Ivry and Keele (1989) were among the first to confirm the involvement of the cerebellum in temporal processing. The study compared the performance on time production and discrimination tasks (all within the millisecond range) between controls and patients that had Parkinson’s disease and cortical and peripheral neuropathy.

The importance of the cerebellum in timing functions was demonstrated by the finding that the cerebellar neuropathy patients were the only group to show a deficit in both production and discrimination tasks (Ivry & Keele, 1989). This group was found to have increased variability in the performance of rhythmic tapping and less accuracy in discriminating small differences in duration (Ivry & Keele, 1989).

More contemporary studies by Tracy, Faro, Mohamed, Pinsk, and Pinus (2000); Meck (2005) and Fierro et al. (2007), differ with respect to measurement techniques; however, they all demonstrate the importance of the cerebellum in the motor driven millisecond processing of time.

For Buhusi and Meck (2005), the preservation of the scalar property in time perception errors of cerebellar lesions patients support the conjecture that the cerebellum is involved in aspects of timing that are not directly related to the core time perception machinery proposed by SET. Taken together, these findings provide evidence that cerebellar processes relate to action driven millisecond timing such as speech, music and motor control.

2.8.2 The Basal Ganglia

Rao, Mayer, and Harrington (2001), with the use of functional magnetic resonance imaging (fMRI), demonstrated the contribution of the basal ganglia in time perception. Specifically, the caudate and putamen showed activation during timing tasks (Rao et al., 2001).

In terms of the SET, as discussed above, the striatum is hypothesised to play a major role during the clock stage. During temporal perception tasks the striatum receives signals from the frontal cortex which prompts the initiation of synchronised firing of neurons that project in superior directions (Matell, Meck & Nicolelis, 2003).

This pattern of neural activation within the striatum, initiated by the frontal cortex when one attends to a temporal task, is believed to act as the internal pacemaker that generates pulses. These pulses are interpreted by the accumulator/counter before being compared to a reference memory (Matell et al., 2003).

In short, firing rates within the basal ganglia structures are theorised to be the locus of an internal correlate of objective time. Along with the crucial involvement of a striatal pacemaker Fiorillo, Tobler, and Schultz (2003) propose the involvement of nigrostriatal pathways in interval timing.

These authors have trained rats to respond to temporal stimuli at two durations, 10 and 40 seconds. Accurately responding to the stimulus resulted in a food reward. Although the rats responded reliably at both durations, electrophysiological recordings revealed that two distinct subsets of striatal neurons were activated, dissociating motor responses from temporal coding in the striatum.

In one set of striatal neurons the firing pattern peaked at the 10 second reward point, whereas the activity of the other set of neurons gradually increased throughout the 40 second interval. Fiorillo et al. (2003)

propose that the sustained activity in specific negrostriatal projections over delayed intervals is an important feature of striatal activation in time perception.

This communicative activity may be crucial for bridging the interval between the moment when information is acquired to the moment when that information can be used in a decision.

2.8.3 Neurotransmitters and the Subcortical Structures

With the basal ganglia being a possible pacemaker site, Buhusi and Meck (2005), have postulated the involvement of specific neurotransmitters in the rate of pulse emission. These authors base this conjecture on pharmacological manipulations of neurological substrates. The authors also believe that the functioning of different neurotransmitter pathways complements SET in that they differentiate the separate processing stages involved.

In terms of the clock stage, specifically the rate of pulse emissions by the pacemaker (striatum), dopamine has been cited as having an influence on the duration of subjective time being experienced.

Findings by Mancq and Church (1983), in their study using both dopamine agonists and antagonists, indicate that an increased abundance of dopamine caused an acceleration of the subjective experience of time whereas a decreased concentration caused the opposite effect. Rammsayer (1993) confirmed these findings in human participants.

Despite the findings, a number of studies have contested the functioning of dopamine in the speed of pulse emission by a pacemaker. Malapani et al. (1998) found that participants with Parkinson's disease and who were not on medication (resulting in decreased levels of dopamine) both underestimated and overestimate target durations.

This gives evidence that a decreased dopamine concentration also has the effect of increasing a subjective experience of time. Another finding that detracts from experimentally concluding that dopamine is the source of an internal pacemaker is the involvement of this catecholamine in other processes related to time perception.

As discussed above, a source of timing error is postulated to be the result of an offset between the physical occurrence and internal representation of a stimulus. Pharmacological studies have found that, besides its involvement in the speed of pulse emission, dopamine also modulates the attentional processing of temporal perception (Buhusi & Meck, 2002).

In this way alterations in dopamine concentration can result in different degrees of offset between the physical and internal presentation of a stimulus.

2.8.4 The Cerebral Cortex

According to Grondin (2008), temporal processing involves the activation of several areas within the cerebral cortex. The most salient of these include the frontal cortex, parietal cortex, hippocampus and supplementary motor area. Specifically, the involvement of various sub structures within the frontal cortex is still in question due to the lack of consistent findings in neuroimaging studies.

According to Buhusi and Meck (2005), the dorsolateral prefrontal cortex (DLPC), intraparietal sulcus and premotor cortex are involved in cognitively controlled timing during longer durations. Conversely, automatic timing that requires repetitive movements and involves the timing of relatively short durations is found to show patterns of activation in the supplementary motor area (SMA), primary motor cortex and primary somatosensory cortex (Buhusi & Meck, 2005).

A study by Pouthas et al. (2005) implemented the DLPC in the processing of brief intervals, whereas Penney and Vaitilingam (2008) implemented the right PFC in both sub- and suprasecond interval timing tasks. Due to the diversity of timing tasks and neuroimaging methods, the specific activity of cortical areas in time perception is not yet fully understood.

Despite such variability in findings, Pouthas, Garnero, Ferrandez, and Renault (2000), using contingent negative variations (CNVs), were able to describe the gross involvement of the frontal cortex in line with SET. CNV is a type of event-related potential describing a large negative change in potential voltage across the cerebral cortex (Chiappa, 1997).

The electrochemical change develops slowly in a person who is actively anticipating the occurrence of a significant stimulus that will require a response (Chiappa, 1997). CNV's are observable as evoked potentials using EEG and usually occur during the one to two seconds after a start of task signal is given.

During a discrimination task that centred on a 700 millisecond standard, CNV appeared to change in relation to the change in length of the comparison interval (Pouthas et al., 2000). Electrical activity returned to baseline faster when the comparison interval was shorter (Pouthas et al., 2000).

Similarly Macar, Vidal, and Casini (1999) showed that even when an interval was judged to be longer but was not objectively longer than the standard; CNV amplitude took longer to return to normal. Grondin (2010), in line with SET, proposed that CNV reflects the accumulation of temporal information. As discussed earlier, pulses, projecting from the striatum accumulate in the frontal cortex. Longer intervals will result in the accumulation/counting of more pulses and increased measures of CNV (Grondin, 2010).

In this way, frontal regions play the role of the accumulator/counter as described in SET. The frontal cortex is also hypothesised to play a role in the construction of a memory trace which can be used as a reference upon comparison with a newly presented temporal interval (Grondin, 2010).

For Meck (1996) the cerebral cortex has distinct areas of functionality that interact during the process of time perception. This conjecture is based on findings from double dissociation studies.

Disassociations were made between patients that suffered lesions in the frontal cortex and nucleus basalis magnocellularis on the one hand and patients that suffered lesions in the hippocampus, fimbria-fornix and the medial septal area on the other.

Patients with lesions that were situated in the frontal areas tended to overestimate temporal intervals and overproduce the duration of target intervals (Meck, 1996). Conversely, lesions around the hippocampal areas caused patients to underestimate target durations (Meck, 1996).

Disassociations between these two areas were also found to exist in terms of working memory. In a task that required participants to reproduce a target duration that was presented as a stimulus with a gap in presentation time, Meck et al. (1984) found that participants with hippocampal lesions had complete amnesia of the duration that had passed before the gap in the stimulus appeared.

In this way, participants with these lesions produced a large number of incorrect judgments (underestimations of the target duration). Patients with frontal lesions did not show the same degree of deficit (Meck, 1996). Rather than being involved in the memory function of SET, the FC is hypothesised to be involved in more dynamic processes such as attention and planning (Milner & Petrides, 1984; Milner, Petrides, & Smith, 1985).

Meck (1996) demonstrated this conjecture with the use of tasks that require the timing of two simultaneous stimuli. In rat studies, when a second stimulus was presented while the timing of an initial stimulus was still in progress, control rats successfully timed the second stimulus in concurrence with the initially presented stimulus (Meck, 1996). Dissimilarly, rats with lesions in the frontal system were unable to time both stimuli simultaneously. When the second stimulus was presented while the first was in progress, these rats only had the attentional capacity to attend to the newly presented second stimulus (Meck, 1996).

These results support the hypothesis that the FC is important for tasks that require planning and temporal organization of behaviour, and the planning of distributing attention to similar concurrent tasks.

2.8.5 Cross Structure Involvement

As discussed above, in line with SET, evidence is provided for the involvement of dopamine in subcortical, specifically the striatum, pulse emission. In terms of the cerebral cortex, acetylcholine has shown to be influential in time perception.

Similar to the deficits observed by hippocampal lesions, an acetylcholine deficit has the effect of impeding short term and working memory. In tasks that required mature and aged rats to produce a trained temporal interval that had a gap in stimulus presentation, decreased levels of acetylcholine resulted in a similar pattern of amnesia as that observed in hippocampal lesion patients (Meck, 2006).

It was found that the rats lost memory of the presentation duration before the gap in the stimulus occurred, resulting in underestimations of stimulus presentation time. Taken together, these results demonstrate that both working and reference memory for temporal information is sensitive to acetylcholine concentration.

As with the frontal cortex, contemporary research regarding the involvement of the supplementary motor area (SMA) in time perception is inconsistent. Although this brain region steadily shows activation during timing tasks, its activation is not confined to either short or long intervals (Grondin, 2010).

According to Macar, Coull, and Vidal (2006), the SMA plays a role in the striato-cortical pathway. The researchers verified its involvement with the use of fMRI. When compared to reproducing a proprioceptive force, greater activation of the SMA was observed in the skilful control of time (Macar et al., 2006).

Along with this, these authors also demonstrated that increasing attentional allocation to time amplified activity in a cortico-striatal network that included dopaminergic projections to the SMA. Furthermore, the SMA was sensitive to the attentional modulation cued prior to the time processing period (Macar et at., 2006).

2.9 Investigating ADHD and Time Perception

2.9.1 Habitual Time Perception

To date, the only research regarding the subjective experience of time in adults with ADHD was conducted by Carelli and Wiberg (2012). The results of this study suggest clear ADHD related differences in temporal orientation, as measured by the ZTPI, in comparison to a non-ADHD control group.
The two groups showed different patterns of past orientation; the mean of the ADHD group was greater than that of the control group for the PN subscale and lower than the control group for the PP items. In addition, the ADHD group was more present oriented than the control group both in terms of PH and PF items.

Furthermore, the ADHD group showed a more negative view of the future in comparison to the control group. Using logistic regression, Carelli and Wiberg (2012) suggested that the PP and F scales were the primary predictors of ADHD status when differences in education, depression, and response inhibition were taken into consideration.

Carelli and Wiberg's (2012) findings demonstrate that ADHD is associated with systematic biases in self-reported habitual time orientation, and that these differences may contribute to functional problems in ADHD.

In short, those individuals who carry an ADHD diagnosis tend to view themselves as more interested in the present, less interested in future planning and tend to dwell on the negative rather than positive aspects of the past (Carelli & Wiberg, 2012).

The authors attribute these findings to difficulties in higher cognitive control functions and reward regulation. Along with this, Carelli and Wiberg (2012) suggest that participants with a less spontaneous cognitive style (more efficient response inhibition) were more future oriented than participants with a more efficient impulse control.

2.9.2 Psychophysical Time Perception

The body of literature on objective measures of time perception amongst those individuals with and without ADHD is much larger than those that investigate habitual time perception, although most of these studies utilise children groups. As to be discussed below, an assortment of measurements tasks has produced diverse contradictory and confirmatory results in relation to time perception deficits in ADHD and non-ADHD individuals.

The research assessing differences in duration discrimination is vast. Although the exact methodological lines of investigating differ amongst these studies, most findings indicate that the threshold to discrimination is dissimilar amongst those individuals with ADHD (Smith et al., 2002; Radonovich & Mostofsky 2004; Toplak & Tannock, 2005; Toplak, Dockstader & Tannock, 2006). In this way the current investigation is appropriate in that it is confirmatory in nature, and it utilises an adult samples.

2.9.3 Stimulus Discrimination

Researches indicating a larger threshold to stimulus discrimination in the ADHD group include studies by Toplak and Tannock (2005); Radonovich and Mostofsky (2004); Toplak et al. (2003); and Smith et al. (2002).

Toplak and Tannock (2005) used both auditory and visual stimuli with target durations set at 1000 and 200ms. For the 200ms target task increments of the target duration changed by 5ms and for the 1000ms target version increments changed by 25ms.

The authors found that ADHD adolescents had larger discrimination thresholds on both visual (200 and 1000ms) and auditory (200 and 1000ms) tasks with the largest effect size on the visual 1000ms task.

In their study of duration judgments in children with ADHD, Radonovich and Mostofsky (2004) used target durations of 550ms and 4s along with a judgment of pitch task. The two groups (ADHD and controls) did not differ with respect to their judgments of the 550ms interval; however, subjects with ADHD performed more poorly when making judgments involving the 4s interval.

In terms of pitch judgment, the groups did not show any significant differences, thus ruling out a generalized deficit in auditory discrimination.

Radonovich and Mostofsky (2004) suggest that there is a deficiency in the utilization of temporal information in individuals with ADHD, which they postulate is secondary to deficits in working memory, and/or strategy utilization, rather than a problem involving a central timing mechanism.

In a similar design, Toplak et al. (2003) found that ADHD children had larger discrimination thresholds than controls in a task that encompassed an auditory target duration of 400ms. However, no difference was observed for ADHD adolescents.

Similarly to Radonovich and Mostofsky (2004), Toplak et al. (2003) observed no group differences in frequency discrimination of children and adolescents with ADHD. Using both auditory and visual target durations of 1 second, Smith et al. (2002) found that children with ADHD had significantly larger thresholds to discrimination.

Contrary to these findings, Rubia, Taylor, Taylor, and Sergeant (1999) found no group differences in threshold discrimination amongst children with ADHD and controls on visual tasks that had 3s and 5s target durations.

However, in a later study that had the same task characteristics Rubia, Noorloos, Smith, Gunning, and Sergeant (2003) concluded that children with ADHD had increased variability in estimating the difference in presentation time of the comparison stimulus.

In a more contemporary duration discrimination study, Gooch, Snowling, and Hulme (2011) used a three-interval three-alternative forced choice version of a discrimination task. On each trial children heard three auditory target durations, two of which were 1200ms long and a roving comparison duration which were of varying lengths (400ms, 700ms, 800ms, 900ms, 1000ms and 1100ms).

The children were required to decide which tone was the ‘odd one out’. Six easy ‘catch-trials’ consisting of two 1500ms tones and one 200ms tone were interspersed within the experimental trials. The proportion of errors made on these trials was used to monitor attention invested in the task.

The authors found that children with ADHD symptomology had larger discrimination thresholds in comparison to those without symptomology. Along with this, ADHD children made significantly more errors on the ‘catch-trials’ compared to controls.

These findings led Gooch et al. (2011) to the conclusion that temporal perception deficits in individuals with ADHD are due to a faulty attentional capacity.

Himpel et al. (2009) found that children with ADHD, but not their unaffected siblings, were impaired in the discrimination of longer (1s) intervals. In addition, the authors found that both groups were impaired in discriminating brief intervals (50ms).

Himpel et al. (2009) concluded that discrimination of longer intervals appears as a typical ‘disease marker’ whereas discrimination of brief intervals shows up as a ‘vulnerability marker’. Taken together, deficits in

discrimination of brief intervals are postulated to be linked to hereditary factors as well as levels of hyperactivity/impulsivity (Himpel et al., 2009).

In this way, discrimination of brief intervals represents a candidate endophenotype (intermediate between the genotype and the behavioural phenotype that reflect an underlying liability for a disorder) of ADHD.

However, Gomes, Duff, Flores, and Halperin (2013) cautions against the use of discrimination tasks as a marker of a pure ADHD related time perception deficit. Although duration discrimination tasks are somewhat less confounded by other functions (e.g., motor activity), these tasks continue to require working memory, attention and active decision making. Duration discriminations are also criticized as being less reliable and accurate due to their forced choice nature (Gomes et al., 2013).

2.9.4 Temporal Estimation

As with the findings from temporal discrimination tasks, verbal estimation tasks have also produced mixed results as to the existence of performance differences between those individuals who have ADHD and those that do not.

Those investigations that claim a significant difference in estimation accuracy between ADHD diagnosed individuals and controls include studies conducted by McGee, Brodeur, Symons, Andrade, and Fahie (2004); Prevatt, Proctor, Baker, Garrett, and Yelland (2011); Wilson, Heinrichs-Graham, White, Knott, and Wetzel (2013); and Suareza, Lopera, Pineda, and Casini (2013). Investigations that claimed no difference in estimation performance include those conducted by Meaux and Chelonis (2003); Bauermeister et al. (2005); and Smith et al. (2002).

McGee et al. (2004) conducted temporal estimation tasks on children aged 6 to 11 years of age. The tasks were similar to that of the current investigation in that the verbal estimations were made with respect to the passage of time whilst completing a cognitive task.

The task used by McGee et al. (2004) was the Conners' CPT (CCPT). Findings from this investigation showed that children with ADHD were more likely to overestimate the time taken to complete the CCPT. This finding was complemented by the fact that the researchers observed no group differences in the outcome measures of the CCPT.

In a similar line of investigation, Prevatt et al. (2011) conducted estimation tasks on college students. Students estimated the passage of time after completing a novel, complex task that approximated academically oriented activities.

In line with the current investigation, estimations were taken before and after the task, which were then compared to the actual time taken. Prevatt et al. (2011) found that, after controlling for cognitive ability, the ADHD participants were significantly different from the control participants on all dependent measures.

Students with ADHD made retrospective estimates that were significantly longer than the estimates made by non-ADHD students. Along with this, it was found that there was larger variability in retrospective estimations amongst the ADHD group.

The authors hypothesised that impaired estimation ability in ADHD participants may be the result of an inability to hold information in working memory, or, in line with a reward deficiency explanation, a general lack of sustained interest in the task which caused these individuals to find the task boring, repetitive and uninteresting. This lack of intrinsic reward was suggested to result in the task seeming longer than it actually was (Prevatt et al., 2011).

In the Suareza et al. (2013) investigation, researchers conducted temporal estimation tasks on adults who possessed an ADHD diagnosis. Results from this investigation indicated that individuals with ADHD overestimate the presentation duration of both auditory and visual stimuli in comparison to controls.

Along with this, it was found that individuals with ADHD also showed less precision (larger variance) in their estimates than did the control group. Amongst the ADHD group, the trend to overestimate durations and produce a reduced degree of accuracy was evident when stimuli were presented in both auditory and visual form.

Within the pacemaker/counter paradigm, Suareza et al. (2013) have suggested two mechanisms as to why individuals with ADHD may perceive a temporal interval as longer. It is hypothesised that the overestimation of temporal intervals results from overcompensation for the characteristic decreased attentional capacity that individuals with ADHD possess.

Suareza et al. (2013) points out that if individuals with ADHD fail to fully attend to a temporal stimuli the attentional switch/gate would not send the correct amount of pulses to the accumulator/counter resulting in an under representation of pulses; compared to if the switch was closed for longer (paying more attention).

This reasoning would prescribe that Individuals with ADHD tend to under estimate temporal intervals. However, this was not in line with the Suareza et al. (2013) findings. Consequently, Suareza et al. (2013) proposed that individuals with ADHD overcompensate for attentional deficits by paying ‘too much’ attention to the passage of time.

This, along with a hypothesised faster pacemaker rate, causes individuals with ADHD to experience a specific temporal interval as longer. The second explanation that Suareza et al. (2013) provide has to do with the memory phase of the pacemaker/counter explanation of temporal processing.

The researchers’ hypothesise that individuals with ADHD have faulty storage mechanisms of reference memories. This defective ‘transfer to reference’ systematically results in a loss of pulses, causing the production of references than are distortedly shorter that actual time. As a consequence, durations presented in real time are judged as longer than they were actually presented for.

Contrary to the above findings, Meaux and Chelonis (2003) provided evidence that ADHD children aged 9 to 12 years do not have significant impairment on time estimation tasks. The methodology used in this investigation followed a similar structure to those discussed above. The target stimulus used by these researchers was visual in nature.

Despite this non-significant finding, the authors did note differences in time reproduction performance between ADHD children and controls. Meaux and Chelonis (2003) explained these findings by stating that ADHD is a disability of behavioural performance and not simply a deficit of knowledge or skill.

Similar results were reported by Smith et al. (2002). These findings showed that individuals with ADHD are impaired on tasks of temporal reproduction and discrimination, but not estimation.

Smith et al. (2002) suggest that the discrimination of temporal intervals, which differ by several hundreds of milliseconds, utilise a different time perception process from reproduction or verbal estimation of longer intervals (several seconds).

The authors also postulate that tasks involving temporal reproduction load upon processes other than those used in pure time estimation, even if they are in the same temporal range.

In line with this, Smith et al. (2002) hypothesised that the difference between these two tasks (reproduction and estimation) has to do with short-term and working memory.

Compared to time estimation, these memory processes are involved to a greater extent in time reproduction because the interval to be reproduced has to be remembered and held ‘on-line’ for a longer period of time (Smith et al., 2002).

In a similar way, Bauermeister et al. (2005) reported that the lack of a significant difference in temporal estimation between individuals with ADHD and controls is due to sufficient working memory process involved in these tasks, in contrast to those used in reproduction tasks.

2.10 Conclusion

This chapter has provided theoretical insight into the concepts of ADHD and time perception. This was done by firstly explaining the clinical picture of ADHD in line with the DSM-5.

In addition to primary ADHD symptomology, individuals with ADHD were shown to have defects in the ability to appropriately manage time. In the terms of adult ADHD, this deficit has consequences when one considers the demands of the working world.

In addition to symptomology, the neurobiological origins of these deficits were described in line with contemporary research findings that utilised both neuroimaging and cognitive investigative techniques.

The irregular functioning of catecholamines such as dopamine was shown to have a major impact on the performance of cognitive processes that draw upon the operations of both cortical and subcortical structures.

After providing an understanding of ADHD, the literature review then moved on to discuss the concept of time perception. Contemporary investigative techniques and findings regarding normal time perception were examined.

Thereafter, the neurological substrates involved in time perception were brought to light. Time perception processes were shown to draw upon multiple brain regions and communicative pathways that involve both cortical and subcortical structures.

Physical deficits (both in terms of structures and neurotransmitters) were shown to have an influence on the performance of psychophysical time perception tasks. In line with these findings, contemporary models of time perception were described with a specific focus on the neural substrates involved.

The models were classified into two broad paradigms, namely; those that prescribe the existence of an 'internal clock' mechanism and those that do not.

The final discussion surrounded the integration of time perception and ADHD. As evidenced, studies that investigate time perception in ADHD show that these individuals tend to have different attitudes towards the past, present and future.

In addition to this, most of the contemporary psychophysical investigations show that individuals with ADHD have a pure time perception deficit. This is brought to light by poor performance on psychophysical time perception tasks.

Chapter 3: Methodology

3.1 Introduction

This chapter aimed at providing an in depth description of the methods that were utilised in investigating the proposed hypotheses. Firstly, the research design is discussed. This explains the degree of control that the researcher had over the experimental and control group.

Thereafter, the nature of the sample was described, including aspects that pertain to the sampling techniques utilised and stratification of the ADHD and non-ADHD group. In terms of the measurement instruments and procedures of application, in depth descriptions were provided regarding their reliability and method of application.

This included the self-report scales, psychophysical tasks and EEG recording equipment. Thereafter the exact methods of investigation were described in a procedural format. In terms of analysing the data, the techniques utilised were described in line with each measurement instrument. Finally, the ethical considerations surrounding the investigation were brought to light.

3.2 Research Design

It is postulated that differences in time perception accuracy, as measured on time estimation and discrimination tasks, and EEG recorded neural activity while performing these tasks, will exist between young adults with significant ADHD symptomology and controls who do not present with significant ADHD symptomology.

Along with these postulations regarding psychophysical time perception, it is assumed that individuals with ADHD will have a significantly different habitual temporal orientation. In order to test these postulations, the current study utilised a quasi-experimental design.

According to Jackson (2011), quasi experimental designs are utilised when the investigator does not have the ability to self-manipulate the independent variable in question. In the current investigation, the presence of ADHD could not be overtly manipulated by the researcher.

In this way it was not possible to control which group the participants would form part of. Rather, it was the presence or absence of existing ADHD symptomology that determined this.

According to Jackson (2011), when an investigation tests the differences in a certain outcome factor amongst a population with pre-existing stratifications, the design can be classified further as being ex post facto.

With relation to the current investigation, the pre-existing stratifications would be the presence, or lack of, ADHD symptomology. In addition to this, the design was cross sectional in nature. This means that all the

tests that were used to measure the variables of interest were conducted only once on each participant (Jackson, 2011).

In this line of thought, the current design can be classified as a quasi-experimental, cross sectional, ex post facto design.

3.3 Hypotheses

For the purpose of the study, the following hypotheses were formulated:

- Young adults who present with significant ADHD symptomology have noteworthy differences in self-reported habitual time orientation as compared to controls who do not present with significant ADHD symptomology.
- Young adults who present with significant ADHD symptomology have a noteworthy higher threshold to time discrimination as compared to controls who do not present with significant ADHD symptomology.
- Young adults with significant ADHD symptomology show more inaccuracy when verbally estimating time as compared to controls who do not present with significant ADHD symptomology.
- In comparison to non-ADHD controls, young adults who present with significant ADHD symptomology have higher slow wave activity and lower fast wave activity within the frontal lobe, frontal midline and parietal lobe during resting states.
- In comparison to non-ADHD controls, young adults who present with significant ADHD symptomology have higher slow wave activity and lower fast wave activity within the frontal lobe, frontal midline and parietal lobe during temporal discrimination tasks.
- In comparison to non-ADHD controls, young adults who present with significant ADHD symptomology have higher slow wave activity and lower fast wave activity within the frontal lobe, frontal midline and parietal lobe during temporal estimation tasks.

3.4 Sample

Participants were recruited from a population of psychology students at the University of the Witwatersrand. Non-probability sampling was utilised in this regard. The difference between probability and non-probability sampling has to do with a basic assumption regarding the nature of the population under study.

In probability sampling, every item within the population has a chance of being selected (Blaikie, 2009). In non-probability sampling it is assumed that there is an even distribution of characteristics within the population. In this way, population elements are chosen arbitrarily, meaning that there is no way to estimate the probability of any one element being included in the sample (Blaikie, 2009).

Also, no assurance is given that each item has a chance of being included, making it impossible either to estimate sampling variability or to identify possible bias.

The participants' ages ranged from 18 to 38 years ($\bar{x}$=19.8, SD=2.5). A biographical questionnaire was administered to all willing participants. This measure included questions pertaining to: whether the participant is currently on any medication, whether the participant has had a formal diagnosis of depression, whether the participant has had any form of head injury or epilepsy in the past, and whether the participant has been bilingual from an early age.

These factors are all extraneous variables that may influence EEG recorded activity. In a study conducted by Kovelman, Baker, and Petitto (2008) bilingual speaker's exhibited different activation patterns and oxygen metabolism within the frontal cortex, compared to controls.

Along with this, bilingualism may contribute to an increased attentional ability (Yang, Yang & Lust, 2011). With respect to depression, Yuan et al. (2008) found that those individuals who presented with clinical depression, compared to controls, had decreased homogeneity of neural activity within the frontal, temporal and parietal lobes.

The biographical questionnaire also determined whether the participants fell in the ADHD or non-ADHD group based on ADHD diagnostic status. In order to be included in the ADHD group (n=84), participants must have either had a previous or current formal diagnosis of childhood or adult ADHD.

Along with this, participants who showed significant ADHD symptomology, as measured by the Adult ADHD Self-Report Scale (ASRS V1.1), were also stratified as ADHD. In order to be considered for the non-ADHD group (n=129), participants should have had no past/present diagnosis of ADHD.

In addition, these participants had to have scores that were below the cut-off indicated by the ASRS V1.1. Along with the biographical questionnaire and ASRS V1.1, the total sample was also administered the Zimbardo Time Perspective Inventory (ZTPI). The ADHD group consisted of 24 males and 60 females whereas the non-ADHD group consisted of 29 males and 100 females.

From this total sample (n=213), a sub sample (n=22) was generated for the psychophysical investigations (time perception tasks and EEG recording). The range in participant age for this sample was 18 to 30 ($\bar{x}$=20.64, SD=3) with the ADHD group having an average age of 21.56 years (SD=3.68) and the non-ADHD group having an average age of 19.32 years (SD=2.24).

This sub sample was stratified in the same way as the total sample, into an ADHD (n=12) and non-ADHD group (n=10). Those individuals that showed the highest levels of ADHD symptomology, as measured by the ASRS V1.1, constituted the ADHD group whereas those that showed the lowest symptomology constituted the non-ADHD group.

This sub sample was recruited from the main sample after the initial testing phase. As discussed above, a matched sampling procedure was used to formulate the ADHD and non-ADHD groups for this phase of investigation.

The biographical information gathered during the first phase helped in this regard. In this psychophysical sample, the ADHD group consisted of 5 males and 7 females whereas the non-ADHD group consisted of 3 males and 7 female.

3.5 Measurement instruments and Psychophysical tasks

3.5.1 Biographical Questionnaire

The biographical questionnaire, aimed to eliminate confounding differences between the two groups. Age, gender and highest educational level achieved were the three questions that were asked in order to assess the degree of matching between the two groups.

The extraneous variables of; current medication, depression status, head injury and /or epilepsy, and bilingual status were also queried.

3.5.2 The Adult ADHD Self-Report Scale (ASRS V1.1)

In line with the DSM-IV-TR criteria for the diagnosis of ADHD, the World Health Organisation has developed a self-report questionnaire measuring the degree of ADHD impairment. The ASRS V1.1 is an 18 item scale used mainly as a screening tool (Baer & Blais, 2010).

These 18 items are divided into two sections. Section A incorporates 6 items, which focuses on the essential features of ADHD. Section B comprises of 12 items which focuses on the severity of the symptoms. In most cases this scale is used to make a binary decision as to whether a person presents or does not present with ADHD.

The current investigation; however, used the raw scores so that data was presented on an interval scale which increased the possibility of statistical analysis.

Baer and Blais (2010) indicate that the ASRS is a reliable and valid measure. There is a significant correlation with scores on the ASRS and clinical symptoms of severity (Baer & Blais, 2010). The internal consistency is estimated at 0.88 and the test retest reliability ranged from 0.58 to 0.77 (Baer & Blais, 2010).

3.5.3 The Zimbardo Time Perspective Inventory (ZTPI)

The ZTPI is a 56 item self-report questionnaire measuring five global time perspective dimensions or orientations, on a 1 to 5 Likert scale.

According to Strathman and Joireman (2005), the five dimensions include: Past-Negative (the lack of an individual to forget about unpleasant images of the past.), Past-Positive (individuals who enjoy thinking about past experiences), Present-Hedonistic (individuals who live each day as if it were their last), Present-

Fatalistic (individuals who do not worry about the future because they believe there is nothing they can do about it) and Future (individuals who set future orientated goals and develop strategies for achieving them).

Through investigating the degree of affinity to these dimensions, the ZTPI has the power of making conclusions as to whether an individual is globally past-present or future orientated. Zimbardo and Boyd (1999) indicate that the test-retest reliability of the ZTPI ranges from 0.7 to 0.8. Along with this, it was concluded that the inventory had good measures of convergent and discriminant validity (Zimbardo & Boyd, 1999).

3.5.4 Estimation Task

In this study, the estimation task was centred on an actual cognitive task. The cognitive tasks chosen were two of the more difficult Block Design tasks from the Wechsler Adult Intelligence Scale (WAIS-IV). The performance on the two Block Design tasks is not of interest to this study.

Rather, the critical measure will be a comparison of (1) how long the participants actually took to complete the exercises, (2) how long they think they would take before task initiation, and (3) how long they thought they took after task completion. A stopwatch was used to measure actual task completion time.

3.5.5 Discrimination Task

The discrimination task constitutes the second psychophysical time perception measure. This task was constructed using Empirisoft Direct RT V2012 software. The task designed for this part, comprised of two large green dots that were consecutively presented against a black background. In this way the current investigation utilised visual stimuli that were presented on an Acer AL1517 15 inch LCD Monitor.

Along with this, the discrimination task utilised the roving method of comparison. The intervals between stimulus presentations were in the millisecond range (i.e. the difference in presentation time between the two large green circles ranged, in 100ms intervals, between 900ms and 100ms).

According to Grondin, Meilleur-Wells, and Lachance (1999), one second is a good cut-off point for automatic processing of temporal information. With this in mind, the current investigation utilised comparisons that fell in the range of below one second. A roving reference interval (presentation time of the first green circle), was presented at the beginning of each trial.

The comparison interval (presentation of the second green circle) was then presented 400ms after the reference interval. Comparison intervals ranged between 900ms and 100ms longer or shorter than the reference interval.

Participants were asked whether the comparison interval (the presentation time of the second green circle) was either different or the same as the reference interval (the presentation time of the first green

circle), in terms of temporal length. As the method of constant stimuli was used, the task was programmed to terminate after 30 trials.'

3.5.6 BIOPAC MP150 data Acquisition System

The BIOPAC MP150 Data Acquisition System is hardware that has the ability to acquire physiological data from a broad range of applications. The MP150 system consists of 16 analogue and 16 digital channels that can simultaneously record individual signals.

The current investigation utilised this hardware for EEG recordings. This was done by connecting a CAP100C electrode cap to the BIOPAC MP150 system. The electrode cap consisted of 19 tin electrodes that have been positioned in accordance with the international 10/20 montage. The placement of electrodes for the recording of the three cortical areas in question is demonstrated in figure 1.1.

The BIOPAC MP150 system was utilised to record electrical activity during a number of key tasks. The first recordings were taken during resting state (eyes closed and eyes open); the second two recordings were taken during the two temporal estimation tasks and a final set of five recordings during the temporal discrimination task.

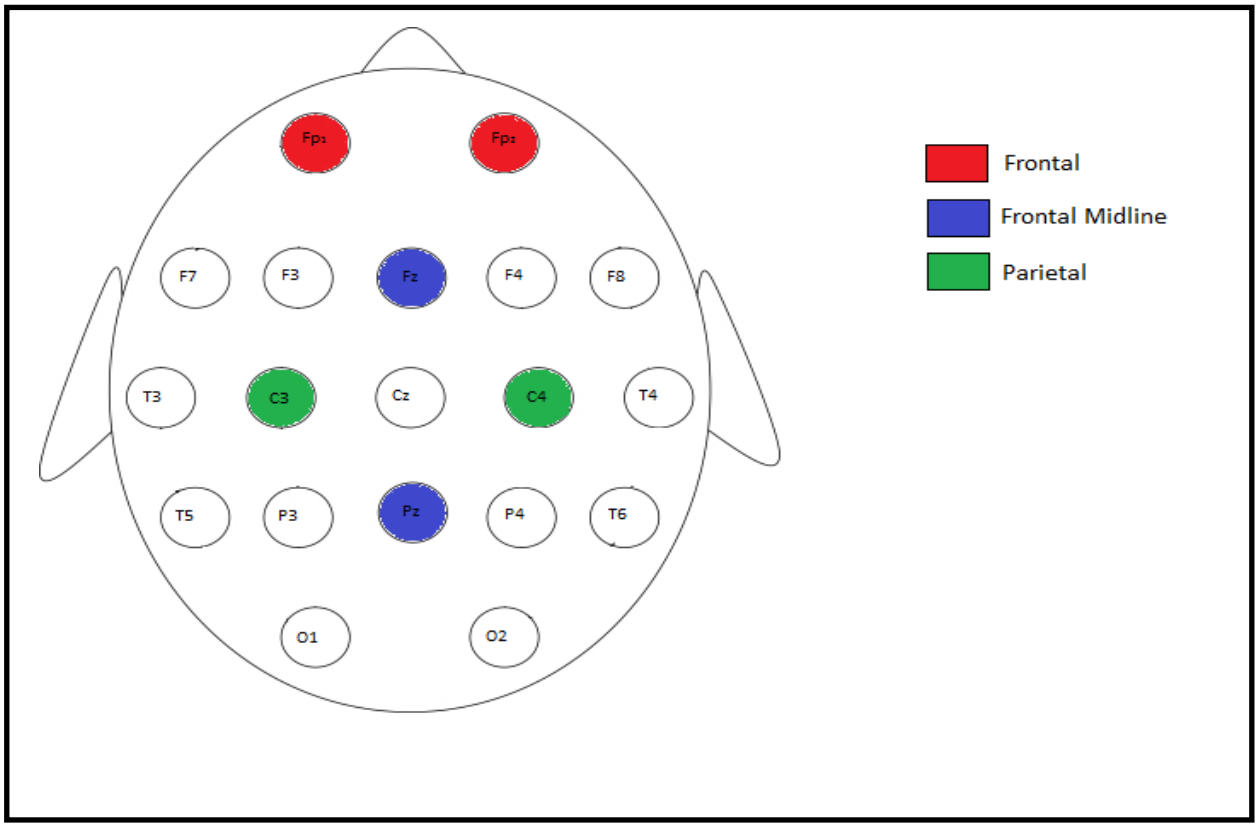

Figure 1.1: 10/20 montage of electrode placement (adapted from Baker, Akrofi, Schiffer & Boyle, 2008)

3.6 Procedure

The current investigation can be split into two sections. The first section deals with questionnaire type data and the second section with the psychophysical investigation.

Section 1:

Potential participants were approached during their undergraduate psychology lecture times during the second half of their second semester. At the end of the class, the researcher made an announcement regarding the nature of the study.

Participants who felt they were interested in taking part were asked to stay behind and complete the questionnaire pack. Before commencing with the questionnaires, participants were given an information sheet regarding the characteristics of the study and asked to sign a consent form. The questioner pack included the biographical questionnaire, ASRS V1.1 and the ZTPI.

These questionnaires were handed back to the researcher upon completion and the process took approximately 15min.

In addition to the biographical information regarding ADHD states, the ASRS V1.1 was used to stratify participants into the ADHD and non-ADHD groups. The prescribed ASRS V1.1 cut-off scores, as identified by Kessler et al. (2007), were used to determine this stratification.

Once the sample had been dichotomised in this manner, comparisons could be made with regards to self-reported habitual time perception (as measured by the five ZTPI subscales) between the two groups.

Section 2:

The second phase of the investigation relates to the psychophysical enquiries. Once the sample had been stratified into the ADHD and non-ADHD symptomology groups, those individuals who had the most symptomology and those who had the least were considered for further psychophysical investigation.

Communication by emails and SMS's were sent out to these individuals after their ASRS V1.1 scores had been calculated. Importantly, participants who met the exclusion criteria (discussed as the confounding variables in the sampling and participants section) were not included in the psychophysical phase of the research. Along with this, participants were excluded if they were on any form of psychoactive medication (including methylphenidate).

Those participants who agreed to take part in the psychophysical investigation were informed as to the venue (on Wits campus) where the testing would take place.

Along with this, each participant who agreed to take part was given a specific half hour slot during which time they would meet with the investigator and commence with testing. When each participant arrived at the venue they were informed as to the duration and nature of the testing procedures that would be conducted.

Thereafter the participants were dressed with the electrode cap. Electro-gel was applied to ensure contact between the electrodes and the participants' skulls. During testing the participants were asked to reduce movement as much as possible in order to reduce false artefacts that may appear in the EEG recordings.

The psychophysical testing can be broken up into three sections, namely: resting states, estimation tasks and discrimination tasks. The procedure that each participant went through was rehearsed by the researcher and kept standard throughout the investigation.

During the two resting state measures, EEG recordings were taken for an epoch of two minutes whilst the participant's eyes were closed and two minutes whilst the participant's eyes were open.

Thereafter, the participant was given three of the Block Design tasks from the WAIS-IV. The first of these was merely a practice run whereas the last two were of importance to the investigation.

During the last two Block Design tasks, EEG recordings were taken before task initiation, when participants estimated how long the task would take them, and after task completion, when participants estimated how long the task took to complete.

As discussed above, an actual task completion time was acquired using a stopwatch. It is of importance to note that all participants under investigation were given the same Block Design task In order to maintain internal consistency.

The final EEG recorded psychophysical measure was the temporal discrimination task. As discussed above, this task consisted of 30 temporal discrimination trials. However, EEG recordings were not taken on each trial.

As the presentation of trials was structured in the same way for each participant, recordings could be taken at specific points during the task. Five EEG recordings were taken in this regard. The first recording took place during the 3rd trial (900ms difference), the second during the 9th trial (400ms difference), the third during the 15th trial (700ms difference), the fourth during the 21st trial (100ms difference) and the last recording took place during the 27th trial (300ms difference).

3.7 Data Analysis

3.7.1 ASRS V1.1

As discussed above, Kessler et al. (2007) has defined appropriate ASRS V1.1 cut-off points that determine the presence of significant ADHD symptomology. This method is called the 0 – 24 strata scoring method.

According to Kessler et al. (2007), section A of the ASRS V1.1 should be the primary indecy of ADHD type symptomology.

The strata scoring method breaks total (Part A) scores up into four groups, consisting of two higher strata (14-17; 18-24) and two lower strata (0-9; 9-13) (Kessler et al., 2007). As the current investigation aimed to dichotomise participants into two groups (ADHD and non-ADHD), a cut-off point of 14 was used.

Participants who scored greater than 14 on section A were considered for the ADHD group whereas those that scored less were considered for the non-ADHD group. In terms of the psychophysical investigation, only participants that populate the extreme higher strata (18-24) and extreme lower strata (0-9) were considered.

3.7.2 ZTPI

As discussed above, the ZTPI consists of five subscales. The average scores for each of these subscales were computed for all participants. This was done by taking an averaging of all the items that relate to a specific time perspective subscale, as defined by Zimbardo and Boyd (1999).

In this way comparisons could be made between the ADHD and non-ADHD group on all five perspectives. As there was equality of variance on all five of the subscales, ANOVA was used to compare the mean past negative, past positive, present fatalistic, present hedonistic and future subscale scores between the two groups.

In addition, the magnitudes of these differences were described in the form of an effect size (η^2). According to Corder and Foreman (2011), the eta squared effect size can be interpreted as follows: small = 0.01, medium = 0.06 and large = 0.14.

3.7.3 EEG Data

The software used to record and transfer the EEG data was Acqknowledge 3.9.1. Approximately 5 minutes of data was recorded for each participant. The 5 minutes were broken up into 11 recording epochs for each participant (2 during the resting states, 4 during the estimation tasks and 5 during the discrimination tasks), as discussed in part two of the procedure section. For each of the 11 epochs of interest, the recorded data was transformed using digital filters that were set at 0.5Hz to 25Hz.

As the EEG analysis in the current investigation aimed at comparing power scores (Voltage) at four different frequencies (delta, theta, alpha and beta), between the two groups, a frequency graph was produced.

This was achieved, using Acqknowledge 3.9.1 by applying a logarithmic function to the recorded data on each channel. Thereafter a Fourier transformation/power spectral density was performed in order to

generate power scores for each frequency band. The power score data was reported as: absolute powers, relative powers and theta beta ratios.

In addition to descriptive statistics, the ADHD group was compared to the non-ADHD group in terms of absolute powers, relative powers and theta beta ratios, for each structural area in question, using an independent samples Mann-Whitney-U test.

This analysis was stable for the current data because the two groups had small samples sizes (n<30) and non-normal distributions of power scores. The magnitude of the differences between the two groups was also reported in the form of an effect size.

According to Corder and Foreman (2011) the most effective way to calculate an affect size for the non-parametric Mann-Whitney-U test is by dividing the test statistic (Z) by the square root of the sample. The absolute value of this calculation can be interpreted as follows: small = 0.10, medium = 0.30 and large = 0.50 (Cohen, 1988 as cited in Corder & Foreman, 2011).

3.7.4 Estimation Task

The key variables that were utilised from this activity were the pre and post task estimations, along with estimation errors. Estimation errors are the difference in participants' estimations (pre task and post task estimations) from actual completion time.

The estimation error was calculated by minusing the pre and post task estimations from the actual completion time. ANOVA was used in order to compare this mean estimation error (for both pre and post estimations), along with actual estimation times, between the ADHD and non-ADHD group.

Four EEG recordings of approximately 9 seconds were performed during the two estimation tasks. The recordings were taking while participants were estimating how long the task would take, and while estimating how long the task took to complete.

3.7.5 Discrimination Task

In this task, the discrimination threshold possessed by each participant was the key variable of interest. In order to determine an individual's threshold to discrimination the current investigation utilised the number of errors made by each participant and the summed differences in stimulus presentation time.

By summing the differences in presentation time between the two circles (e.g. if Circle 1 presented for 500ms and circle 2 is presented for 300ms the difference in presentation time is 200ms) for each discrimination error made (i.e. when an individual claimed that the circles were presented on the screen for the same time when in fact they different by a certain number of milliseconds) a total summed presentation difference value was generated (in milliseconds).

This summed value was then divided by the number of errors an individual made during the task. In turn, this process generated values that denoted an individual's temporal threshold to discrimination.

The values generated in this calculation can be considered as the average presentation difference (difference in presentation time between the two circles) required for an individual to consciously perceive a temporal difference. ANOVA was used to analyse whether there was a significant difference in discrimination threshold between the ADHD and non-ADHD group.

As discussed in the procedure section, five EEG recordings with an epoch of approximately 5 seconds were taken during this task.

3.8 Ethical considerations

An invitation letter along with a consent form, approved by the University of the Witwatersrand Ethics Committee, was provided to willing participants, detailing the purpose and procedure of the study. No participant was forced to take part in the study and emphasis was placed on the fact that participation in this study is completely voluntary.

Along with this, participants were informed that they could withdraw from the investigation at any stage. Confidentiality was ensured at all times as questionnaires were linked through pre-assigned codes rather than any identifying particulars.

Prospective participants contact information, such as e-mail addresses, was only used in order to invite these candidates to take part in the psychophysical investigation. Pre-assigned codes rather than names were linked to contact information. The list linking the participant codes with contact information was destroyed once all data has been collected.

Finally, if ADHD symptomology was found to considerably impede participants overall task performance; these participants were informed of the time management skills workshops offered by the Counselling and Careers Development Unit at the University of the Witwatersrand.

3.9 Conclusion

This chapter has expanded on the methodology utilised in the current investigation. The research design has been classified as a cross sectional, ex post facto, quasi experimental design. After describing the nature of the design, postulated findings were pronounced in the form of hypotheses. Sampling techniques have been classified as non-probability sampling and the methods sub sample stratification, for the psychophysical part of the investigation, were elaborated upon.

Thereafter the exact operational procedures were brought to light. The current line of investigation has been split into two parts. Part one deals with the investigation into self-reported ADHD symptomology and

habitual time perception, whereas part two focused on psychophysical time perception and corresponding EEG recorded activity.

In terms of each measurement instrument, suitable analysis techniques were classified as ether being parametric or nonparametric. ANOVA and Mann-Whitney-U tests were used in this regard. Finally, ethical considerations surrounding the investigation were discussed.

Chapter 4: Results

4.1 Introduction

This chapter presents the findings from the measurements and analyses described in chapter 3. This was done by firstly presenting information that pertained to the questionnaire data. Descriptive statistics and between group comparisons were described in this regard. Thereafter, the psychophysical data was presented. Descriptive statistics regarding the ADHD and non-ADHD subsamples, performance on psychophysical tasks and between group comparisons were described. Finally, the psychophysical EEG data was presented. This was done by describing the findings for each of the three brain areas in question. The absolute power, relative power and theta/beta ratios, along with the between group comparisons of these measures, was presented

4.2 Questionnaire Data

4.2.1 Descriptive Statistics

Table 4.1 summarises the between group descriptive statistics in terms of gender, language and depression status**.**

Table 4.1: Between Group Descriptives

Gender	**Male**	**Female**
ADHD	29	100
Non-ADHD	24	60
Languages	**Monolingual**	**Multilingual**
ADHD	26	103
Non-ADHD	12	72
Depression	**No**	**Yes**
ADHD	123	6
Non-ADHD	80	4

Table 4.2 summarises the between group descriptive statistics for the ASRS.

Table 4.2: Descriptive Statistics for the ASRS V1.1

Group	**n**	**Mean**	**Std. Deviation**
ADHD	84	16.30	3.092
Non-ADHD	129	8.34	2.442

The current investigation revealed that the reliability for the ASRS V1.1 (Cronbach's alpha), in the current sample, was 0.893. The five ZTPI subscales had the following reliabilities (Cronbach's alpha): Past

negative (α=0.831), Present hedonistic (α=0.762), Future (α=0.734), Past positive (α=0.736) and Present fatalistic (α=0.601). Table 4.2 summarises the descriptive statistics for the ADHD and non-ADHD groups on the ASRS V1.1.

4.2.2 ZTPI Subscale Scores as a Function of ADHD Group

Table 4.3 describes the mean ZTPI subscale scores for the ADHD and non-ADHD groups. In addition, between group comparisons are presented in the form of a test statistic, p value and effect size.

Table 4.3: The ZTPI Subscale Data as a Function of ADHD Group

ZTPI Subscale	ADHD (n=84)	Non-ADHD (n=129)	Statistic (F)	P	Effect size (η^2)
Past Negative	3.38	3.11	7.086	0.008*	0.034
Past Positive	3.44	3.50	0.605	0.438	0.003
Present Hedonistic	3.58	3.36	10.802	0.001*	0.051
Present Fatalistic	2.57	2.47	1.935	0.166	0.008
Future	3.26	3.60	24.908	0.000*	0.12

* Significant at the 0.05 level

Despite a small to medium effect size, significant differences between those that present with ADHD and those that do not were found on the past negative, present hedonistic and future subscales. The largest difference between the two groups was found on the future subscale.

4.3 Psychophysical Data

4.3.1 Between Group Descriptive Statistics

Table 4.4 summarises the between group descriptive statistics for the ADHD and non-ADHD groups. Chronic medication status, depression status, the presence of a former head injury and the occurrence of multilingualism are described.

Table 4.4: Between Group Descriptives

Chronic Medication	**Yes**	**No**
ADHD	3	9
Non-ADHD	0	10
Depression	**Yes**	**No**
ADHD	1	11
Non-ADHD	0	10
Head Injury	**Yes**	**No**
ADHD	0	12
Non-ADHD	0	10
Multilingual	**Yes**	**No**
ADHD	8	4
Non-ADHD	3	7

4.3.2 Estimation Task

4.3.2.1 Descriptive Statistics

Table 4.5 summarises the estimation task results for both the ADHD and non-ADHD groups. The average estimation time (both pre and post task) and the average actual completion time is presented.

Table 4.5: Summary of the Estimation Task Results

Task Condition		**ADHD (n=12)**		**Non-ADHD (n=10)**	
		Mean Estimation Time (seconds)	**Mean Time to Complete Task (seconds)**	**Mean Estimation Time (seconds)**	**Mean Time to Complete Task (seconds)**
1st Block Design Task	Pre Task Estimation	77.08 (SD=76.29)	98.33 (SD= 96.26)	127.30 (SD= 176.43)	104.00 (SD=73.30)
	Post Task Estimation	118.08 (SD=148.02)		96.20 (SD= 75.30)	
2nd Block Design Task	Pre Task Estimation	98.50 (SD=87.32)	59.92 (SD= 40.33)	109.00 (SD= 103.52)	81.30 (SD= 71.67)
	Post Task Estimation	66.33 (SD=81.93)		62.00 (SD=43.92)	

4.3.2.2 Between Group Comparisons

The ANOVA revealed that there was no significant difference between the two groups in any of the estimation task variables. In short, this means that there was no difference in the actual time it took to complete the two Block Design tasks; both the pre and post task estimations and the average estimation error (estimation time minus actual completion time) between those that present with ADHD and those that do not. Table 4.6 summarises these insignificant differences.

Table 4.6: ANOVA – Estimation Task Variables as a Function of ADHD Status

Between Group Comparisons	F	Sig.
Block Design Task 1: Pre Task Estimate	0.799	.382
Block Design Task 1: Post Task Estimate	0.179	.677
Block Design Task 1: Actual Completion Time	0.023	.880
Block Design Task 2: Pre Task Estimate	0.067	.799
Block Design Task 2: Post Task Estimate	0.022	.882
Block Design Task 2: Actual Completion Time	0.778	.388
Block Design 1: Pre Task Estimation Error	0.487	.493
Block Design 1: Post Task Estimation Error	0.664	.425
Block Design 2: Pre Task Estimation Error	0.074	.788
Block Design 2: Post Task Estimation Error	1.555	.227

4.3.3 Discrimination Task

4.3.3.1 Descriptive Statistics

Table 4.7 summarises the average discrimination threshold and average number of discrimination errors made by each group.

Table 4.7: Average Discrimination Threshold and Errors Made

	ADHD (n=12)		Non-ADHD (n=10)	
	Mean	Std. Deviation	Mean	Std. Deviation
Discrimination Errors	8.83	2.41	8.90	2.33
Discrimination Threshold (ms)	215.13	56.82	205.06	46.54

4.3.3.2 Between Group Comparisons

There was no significant difference in the number of discrimination errors made between the ADHD and non-ADHD groups ($F(1,20)=0.004$; $p>0.1$). In addition, contrary to that hypothesises, the ADHD and non-ADHD groups did not show any difference in discrimination threshold ($F(1,20)=0.201$; $p>0.1$).

4.4 Psychophysical EEG Data

4.4.1 Frontal Lobe

4.4.1.1 Absolute Power

Table 4.8 summarises the mean power scores and standard deviations at different frequencies for the ADHD and non-ADHD groups across the 11 test conditions in the frontal lobe.

There was no significant differences between the two groups' absolute power scores across the test conditions except for the theta ($Z=-2.11$; $p<0.05$; $r=0.45$) and, at the 0.1 significance level, beta ($Z=-1.846$; $p<0.1$; $r=0.39$) activity during the 3rd discrimination. It should be noted that there was a medium effect size for these differences.

Table 4.8: Mean Absolute Power Scores per Wave and Condition in the Frontal Lobe

Wave	Test Condition	ADHD		Non-ADHD	
		Mean	Std. Deviation	Mean	Std. Deviation
Delta	EC	0.2149	0.1607	0.2534	0.1610
	EO	0.2003	0.1553	0.2931	0.1548
	Block Design 1 (Pre)	0.1293	0.1153	0.1758	0.1263
	Block Design 1 (Post)	0.1380	0.0785	0.1844	0.1266
	Block Design 2 (Pre)	0.1192	0.0666	0.1819	0.1175
	Block Design 2 (Post)	0.1423	0.0994	0.1710	0.1211
	Discrimination Trial 3	0.1170	0.0985	0.1045	0.0478
	Discrimination Trial 9	0.1416	0.1027	0.1608	0.1008
	Discrimination Trial 15	0.1072	0.0678	0.1518	0.0794
	Discrimination Trial 21	0.1388	0.0653	0.1306	0.0595
	Discrimination Trial 27	0.1486	0.1124	0.1239	0.0683
Theta	EC	0.0608	0.0371	0.0873	0.0321
	EO	0.0837	0.0492	0.0816	0.0233
	Block Design 1 (Pre)	0.0636	0.0229	0.0546	0.0405
	Block Design 1 (Post)	0.0506	0.0193	0.0637	0.0357
	Block Design 2 (Pre)	0.0580	0.0319	0.0541	0.0306
	Block Design 2 (Post)	0.0682	0.0339	0.0592	0.0300
	Discrimination Trial 3	0.0862*	0.0439	0.0574*	0.0379
	Discrimination Trial 9	0.0695	0.0235	0.0621	0.0372
	Discrimination Trial 15	0.0740	0.0461	0.0802	0.0416
	Discrimination Trial 21	0.0731	0.0371	0.0869	0.0351
	Discrimination Trial 27	0.0775	0.0360	0.0788	0.0428
Alpha	EC	0.0238	0.0139	0.0358	0.0294
	EO	0.0228	0.0093	0.0415	0.0264
	Block Design 1 (Pre)	0.0192	0.0086	0.0200	0.0145
	Block Design 1 (Post)	0.0175	0.0075	0.0264	0.0156
	Block Design 2 (Pre)	0.0185	0.0087	0.0211	0.0098
	Block Design 2 (Post)	0.0188	0.0077	0.0219	0.0115
	Discrimination Trial 3	0.0232	0.0136	0.0198	0.0136
	Discrimination Trial 9	0.0203	0.0082	0.0237	0.0151
	Discrimination Trial 15	0.0261	0.0190	0.0330	0.0314
	Discrimination Trial 21	0.0235	0.0111	0.0397	0.0424
	Discrimination Trial 27	0.0272	0.0161	0.0355	0.0272
Beta	EC	0.0122	0.0113	0.0229	0.0329
	EO	0.0098	0.0034	0.0238	0.0259
	Block Design 1 (Pre)	0.0081	0.0027	0.0081	0.0057
	Block Design 1 (Post)	0.0068	0.0019	0.0133	0.0147
	Block Design 2 (Pre)	0.0066	0.0026	0.0113	0.0077
	Block Design 2 (Post)	0.0079	0.0036	0.0094	0.0086
	Discrimination Trial 3	0.0107**	0.0048	0.0079**	0.0048
	Discrimination Trial 9	0.0091	0.0037	0.0105	0.0090
	Discrimination Trial 15	0.0094	0.0058	0.0115	0.0082
	Discrimination Trial 21	0.0108	0.0053	0.0155	0.0106
	Discrimination Trial 27	0.0119	0.0081	0.0138	0.0109

** Significant at the 0.1 level
** Significant at the 0.1 level

4.4.1.2 Relative Power

Table 4.9: Mean Relative Power Scores per Wave and Condition in the Frontal Lobe

Wave	Test Condition	ADHD		Non-ADHD	
		Mean	Std. Deviation	Mean	Std. Deviation
Delta	EC	0.6523	0.1636	0.5584	0.2174
	EO	0.5498	0.2344	0.5692	0.2266
	Block Design 1 (Pre)	0.4918	0.2542	0.6387	0.1395
	Block Design 1 (Post)	0.5963	0.1790	0.5725	0.1286
	Block Design 2 (Pre)	0.5650	0.1446	0.5362	0.1160
	Block Design 2 (Post)	0.5540	0.1403	0.6286	0.0921
	Discrimination Trial 3	0.4402**	0.1348	0.5574**	0.1590
	Discrimination Trial 9	0.5206	0.1691	0.5965	0.1320
	Discrimination Trial 15	0.4894	0.1239	0.5276	0.1255
	Discrimination Trial 21	0.5511	0.1380	0.4933	0.1113
	Discrimination Trial 27	0.5093	0.2022	0.5008	0.1408
Theta	EC	0.2132	0.1529	0.2893	0.2063
	EO	0.3255	0.1918	0.2623	0.1656
	Block Design 1 (Pre)	0.3661	0.2084	0.2409	0.0993
	Block Design 1 (Post)	0.2739	0.1313	0.2570	0.0755
	Block Design 2 (Pre)	0.3018	0.1186	0.2390	0.0910
	Block Design 2 (Post)	0.3164*	0.1050	0.2364*	0.0531
	Discrimination Trial 3	0.3979*	0.0940	0.2973*	0.1093
	Discrimination Trial 9	0.3390	0.1272	0.2586	0.0833
	Discrimination Trial 15	0.3487**	0.0923	0.2928**	0.0780
	Discrimination Trial 21	0.3055	0.1160	0.3172	0.0826
	Discrimination Trial 27	0.3291	0.1453	0.3135	0.1194
Alpha	EC	0.0873	0.0350	0.0967	0.0645
	EO	0.0851	0.0371	0.1124	0.0621
	Block Design 1 (Pre)	0.0967	0.0381	0.0837	0.0306
	Block Design 1 (Post)	0.0921	0.0344	0.1146	0.0512
	Block Design 2 (Pre)	0.0967	0.0297	0.0920	0.0258
	Block Design 2 (Post)	0.0909	0.0288	0.0942	0.0397
	Discrimination Trial 3	0.1072	0.0321	0.1036	0.0453
	Discrimination Trial 9	0.0956	0.0295	0.1014	0.0423
	Discrimination Trial 15	0.1158	0.0390	0.1249	0.0642
	Discrimination Trial 21	0.0964	0.0231	0.1333	0.0708
	Discrimination Trial 27	0.1131	0.0500	0.1325	0.0439
Beta	EC	0.0472	0.0395	0.0556	0.0578
	EO	0.0396	0.0217	0.0561	0.0521
	Block Design 1 (Pre)	0.0454	0.0221	0.0367	0.0172
	Block Design 1 (Post)	0.0377	0.0199	0.0560	0.0448
	Block Design 2 (Pre)	0.0365	0.0154	0.0499	0.0278
	Block Design 2 (Post)	0.0387	0.0175	0.0408	0.0341
	Discrimination Trial 3	0.0547	0.0258	0.0417	0.0149
	Discrimination Trial 9	0.0449	0.0198	0.0435	0.0274
	Discrimination Trial 15	0.0461	0.0166	0.0547	0.0494
	Discrimination Trial 21	0.0470	0.0202	0.0563	0.0247
	Discrimination Trial 27	0.0485	0.0214	0.0532	0.0338

* Significant at the 0.05 level
** Significant at the 0.1 level

Table 4.9 summarises the mean relative power scores and standard deviations at different frequencies for the ADHD and non-ADHD groups across the 11 test conditions in the frontal lobe.

For the majority of tasks there was no difference in relative power between the ADHD and non-ADHD groups. However, group differences were found in theta activity elicited by the post estimation of the second Block Design task (Z=-2.110; p<0.05; r=0.45), and the theta activity during the 3rd discrimination task (Z=-2.242; p<0.05; r=048). In addition to these dissimilarities in relative power, differences between the ADHD and non-ADHD groups were also found at the 0.1 significance level.

The relative power in delta activity elicited during the 3rd discrimination task (Z=-1.846; p<0.1; r=0.39) and the theta activity during the 15th discrimination trial (Z=-1.714; p<0.1; r=0.37) were significantly different between the two groups. The magnitudes of these differences were in the medium range.

4.4.1.3 Theta/Beta Ratio

Table 4.10 summarises the mean theta/beta ratio scores and standard deviation for the ADHD and non-ADHD groups across the 11 test conditions in the frontal lobe.

Table 4.10: Mean Theta/Beta Ratio Scores per Condition in the Frontal Lobe

Test Condition	ADHD		Non-ADHD	
	Mean	Std. Deviation	Mean	Std. Deviation
EC	6.1243	3.0590	6.9541	3.1376
EO	8.2970	3.4548	7.0123	3.8979
Block Design 1 (Pre)	7.8661	1.6084	6.9466	1.7857
Block Design 1 (Post)	7.4351	1.4676	6.4063	2.8274
Block Design 2 (Pre)	8.6301*	2.5887	5.6632*	2.2176
Block Design 2 (Post)	8.7753	2.6744	7.6596	3.4026
Discrimination Trial 3	8.2830	2.6757	7.4007	2.1445
Discrimination Trial 9	8.0964	2.5762	7.3700	2.9298
Discrimination Trial 15	8.1276	2.6025	8.2623	4.2768
Discrimination Trial 21	7.1963	3.0787	6.4195	2.9209
Discrimination Trial 27	7.4454	2.7974	7.1284	2.6957

* Significant at the 0.05 level
** Significant at the 0.1 level

The only significant difference between the two groups in theta/beta ratio scores was found for the pre-test temporal estimation during the second Block Design task (z=-2.374; P<0.05; r=-0.51). The magnitude of this difference in theta/beta scores was large.

4.4.2 Frontal Midline

4.4.2.1 Absolute Power

Table 4.11 summarises the mean power scores and standards deviations at different frequencies for each ADHD group, across the 11 test conditions in the frontal midline.

Table 4.11: Mean Absolute Power Scores per Wave and Condition in the Frontal Midline

Wave	Test Condition	ADHD		Non-ADHD	
		Mean	Std. Deviation	Mean	Std. Deviation
Delta	EC	0.0996	0.0988	0.1249	0.1137
	EO	0.1199	0.1144	0.1555	0.1354
	Block Design 1 (Pre)	0.1219	0.1702	0.1028	0.0889
	Block Design 1 (Post)	0.0901	0.0866	0.1177	0.0814
	Block Design 2 (Pre)	0.0803**	0.1093	0.1362**	0.1105
	Block Design 2 (Post)	0.0919	0.0784	0.1040	0.0788
	Discrimination Trial 3	0.0541	0.0350	0.0776	0.0546
	Discrimination Trial 9	0.0541	0.0419	0.0781	0.0591
	Discrimination Trial 15	0.0550	0.0436	0.0651	0.0482
	Discrimination Trial 21	0.0774	0.0432	0.1131	0.0857
	Discrimination Trial 27	0.0622	0.0383	0.0890	0.0728
Theta	EC	0.0447**	0.0298	0.0761**	0.0439
	EO	0.0491	0.0292	0.0523	0.0317
	Block Design 1 (Pre)	0.0515	0.0442	0.0420	0.0181
	Block Design 1 (Post)	0.0327	0.0105	0.0448	0.0177
	Block Design 2 (Pre)	0.0323	0.0138	0.0414	0.0189
	Block Design 2 (Post)	0.0367	0.0192	0.0457	0.0216
	Discrimination Trial 3	0.0385	0.0004	0.0441	0.0188
	Discrimination Trial 9	0.0357	0.0210	0.0414	0.0167
	Discrimination Trial 15	0.0286**	0.0121	0.0375**	0.0147
	Discrimination Trial 21	0.0409	0.0245	0.0420	0.0283
	Discrimination Trial 27	0.0447	0.0354	0.0432	0.0342
Alpha	EC	0.0222	0.0292	0.0403	0.0430
	EO	0.0240	0.0227	0.0309	0.0320
	Block Design 1 (Pre)	0.0178	0.0224	0.0239	0.0298
	Block Design 1 (Post)	0.0104*	0.0032	0.0171*	0.0091
	Block Design 2 (Pre)	0.0123	0.0050	0.0191	0.0145
	Block Design 2 (Post)	0.0121	0.0063	0.0226	0.0238
	Discrimination Trial 3	0.0171	0.0126	0.0161	0.0067
	Discrimination Trial 9	0.0203	0.0182	0.0175	0.0088
	Discrimination Trial 15	0.0137	0.0061	0.0158	0.0084
	Discrimination Trial 21	0.0207	0.0241	0.0214	0.0155
	Discrimination Trial 27	0.0221	0.0256	0.0200	0.0165
Beta	EC	0.0430	0.0252	0.0179	0.0289
	EO	0.0167	0.0217	0.0224	0.0361
	Block Design 1 (Pre)	0.0122	0.0222	0.0126	0.0224
	Block Design 1 (Post)	0.0051*	0.0020	0.0095*	0.0102
	Block Design 2 (Pre)	0.0048	0.0024	0.0123	0.0151
	Block Design 2 (Post)	0.0056	0.0023	0.0109	0.0109
	Discrimination Trial 3	0.0095	0.0136	0.0072	0.0037
	Discrimination Trial 9	0.0156	0.0316	0.0100	0.0001
	Discrimination Trial 15	0.0082	0.0089	0.0083	0.0079
	Discrimination Trial 21	0.0132	0.0235	0.0117	0.0151
	Discrimination Trial 27	0.0149	0.0314	0.0123	0.0133

* Significant at the 0.05 level
** Significant at the 0.1 level

A significant difference in power scorers was found with regards to the alpha ($Z=-2.374$; $p<0.05$; $r=0.51$) and beta ($Z=-2.242$; $p<0.05$; $r=0.48$) activity elicited by the post estimations of the first Block Design task.

At the 0.1 significance level, differences were found with regards to the theta activity during the eyes closed resting state ($Z=-1.780$; $p<0.1$; $r=0.38$), the delta activity elicited by the pre estimation of the second Block Design task ($Z=-1.714$; $p<0.1$; $r=0.37$) and the theta activity during the 15th discrimination trial ($Z=-1.780$; $p<0.1$; $r=0.38$).

The magnitude of these differences was in the medium to large range. The ADHD and non-ADHD groups did not differ, with respect to power scores, in any of the other test conditions.

4.4.2.2 Relative Power

Table 4.12 summarises the mean relative power scores and standard deviations at different frequencies for the ADHD and non-ADHD groups across the 11 test conditions in the frontal midline.

Table 4.12: Mean Relative Power Scores per Wave and Condition in the Frontal Midline

Wave	Test condition	ADHD		Non-ADHD	
		Mean	Std. Deviation	Mean	Std. Deviation
Delta	EC	0.5117	0.1954	0.4405	0.2509
	EO	0.4945	0.2207	0.5232	0.2349
	Block Design 1 (Pre)	0.5236	0.1971	0.5567	0.1742
	Block Design 1 (Post)	0.5717	0.1757	0.5738	0.1630
	Block Design 2 (Pre)	0.5227	0.1685	0.5930	0.1712
	Block Design 2 (Post)	0.5750	0.1653	0.5547	0.1456
	Discrimination Trial 3	0.4279	0.1752	0.5075	0.1548
	Discrimination Trial 9	0.4156	0.2141	0.4937	0.1738
	Discrimination Trial 15	0.4981	0.1190	0.4850	0.1510
	Discrimination Trial 21	0.5299	0.1536	0.5659	0.1374
	Discrimination Trial 27	0.4775	0.1613	0.5393	0.1175
Theta	EC	0.3011	0.1803	0.3599	0.2357
	EO	0.3193	0.1912	0.2779	0.1833
	Block Design 1 (Pre)	0.3083	0.1516	0.2698	0.1201
	Block Design 1 (Post)	0.2924	0.1377	0.2731	0.1121
	Block Design 2 (Pre)	0.3139	0.1090	0.2516	0.1416
	Block Design 2 (Post)	0.2814	0.1125	0.2792	0.1166
	Discrimination Trial 3	0.3524	0.1402	0.3247	0.1112
	Discrimination Trial 9	0.3380	0.1839	0.3111	0.1357
	Discrimination Trial 15	0.2899	0.0749	0.3179	0.1066
	Discrimination Trial 21	0.2804	0.1246	0.2486	0.1066
	Discrimination Trial 27	0.3090	0.1098	0.2560	0.0293
Alpha	EC	0.1141	0.0536	0.1421	0.1127
	EO	0.1199	0.0681	0.1305	0.0619
	Block Design 1 (Pre)	0.1056	0.0450	0.1202	0.0664
	Block Design 1 (Post)	0.0897	0.0307	0.0995	0.0375
	Block Design 2 (Pre)	0.1185	0.0506	0.1030	0.0422
	Block Design 2 (Post)	0.0977	0.0485	0.1119	0.0441
	Discrimination Trial 3	0.1485	0.0571	0.1163	0.0384
	Discrimination Trial 9	0.1575	0.0539	0.1273	0.0493
	Discrimination Trial 15	0.1406	0.0466	0.1319	0.0568
	Discrimination Trial 21	0.1242	0.0489	0.1282	0.0569
	Discrimination Trial 27	0.1437	0.0461	0.1289	0.0599
Beta	EC	0.0730	0.0447	0.0575	0.0431
	EO	0.0662	0.0357	0.0684	0.0607
	Block Design 1 (Pre)	0.0625	0.0435	0.0533	0.0461
	Block Design 1 (Post)	0.0462	0.0205	0.0536	0.0348
	Block Design 2 (Pre)	0.0449	0.0173	0.0524	0.0266
	Block Design 2 (Post)	0.0459	0.0212	0.0542	0.0288
	Discrimination Trial 3	0.0712	0.0453	0.0515	0.0190
	Discrimination Trial 9	0.0889	0.0791	0.0679	0.0259
	Discrimination Trial 15	0.0714	0.0316	0.0652	0.0440
	Discrimination Trial 21	0.0655	0.0508	0.0573	0.0480
	Discrimination Trial 27	0.0698	0.0601	0.0758	0.0523

Non-parametric analysis revealed that there was no significant difference (at the 0.05 and 0.1significance level) in relative power scores, across all frequencies and test conditions, between the ADHD and non-ADHD groups.

4.4.2.3 Theta/Beta Ratio

Table 4.13 summarises the mean theta/beta ratio scores and standard deviations for the ADHD and non-ADHD groups across the 11 test conditions in the frontal midline.

Table 4.13: Mean Theta/Beta Ratio Scores per Condition in the Frontal Midline

Test Condition	ADHD		Non-ADHD	
	Mean	Std. Deviation	Mean	Std. Deviation
EC	5.1157	2.9605	8.1678	4.6162
EO	6.0300	3.8802	5.5260	3.3796
Block Design 1 (Pre)	6.5266	4.1831	6.3973	2.9596
Block Design 1 (Post)	6.9134	2.7077	6.1013	2.5536
Block Design 2 (Pre)	7.1850	1.4550	5.5069	3.0031
Block Design 2 (Post)	6.6997	2.2199	5.9943	2.8029
Discrimination Trial 3	6.0392	2.5159	6.4640	1.4872
Discrimination Trial 9	5.1401	2.8773	4.5933	1.7605
Discrimination Trial 15	4.8182	2.3162	6.8351	3.7002
Discrimination Trial 21	5.2830	2.1906	5.9559	4.0843
Discrimination Trial 27	5.6064	2.2299	4.9337	3.3710

Non-parametric analysis revealed that there was no significant difference (at the 0.05 and 0.1significance level) in theta/beta ratios, across all the test conditions, between the ADHD and non-ADHD groups.

4.4.3 Parietal Lobe

4.4.3.1 Absolute Power

Table 4.14 summarises the mean power scores and standards deviations at different frequencies for each ADHD group, across the 11 test conditions in the Parietal lobe.

Table 4.14: Mean Absolute Power Scores per Wave and Condition in the Parietal Lobe

Wave	Test Condition	ADHD		Non-ADHD	
		Mean	Std. Deviation	Mean	Std. Deviation
Delta	EC	0.1816	0.1490	0.1950	0.1567
	EO	0.1929	0.1490	0.2439	0.1573
	Block Design 1 (Pre)	0.1150	0.0888	0.1694	0.1221
	Block Design 1 (Post)	0.1244	0.0668	0.1673	0.1125
	Block Design 2 (Pre)	0.0959**	0.0834	0.1744**	0.1192
	Block Design 2 (Post)	0.1146	0.0912	0.1490	0.0921
	Discrimination Trial 3	0.0625	0.0357	0.0825	0.0605
	Discrimination Trial 9	0.0740	0.0547	0.1040	0.0712
	Discrimination Trial 15	0.0876	0.0783	0.1022	0.0622
	Discrimination Trial 21	0.0962	0.0544	0.1206	0.0824
	Discrimination Trial 27	0.0775	0.0485	0.1157	0.0790
Theta	EC	0.0734**	0.0441	0.1188**	0.0962
	EO	0.0799	0.0543	0.0815	0.0375
	Block Design 1 (Pre)	0.0681	0.0352	0.0594	0.0408
	Block Design 1 (Post)	0.0478	0.0276	0.0588	0.0375
	Block Design 2 (Pre)	0.0501	0.0303	0.0578	0.0270
	Block Design 2 (Post)	0.0449	0.0186	0.0535	0.0264
	Discrimination Trial 3	0.0466	0.0126	0.0633	0.0216
	Discrimination Trial 9	0.0652	0.0357	0.0585	0.0242
	Discrimination Trial 15	0.0510**	0.0314	0.0555**	0.0272
	Discrimination Trial 21	0.0593	0.0319	0.0543	0.0258
	Discrimination Trial 27	0.0539	0.0342	0.0640	0.0332
Alpha	EC	0.0281	0.0278	0.0355	0.0368
	EO	0.0262	0.0232	0.0397	0.0348
	Block Design 1 (Pre)	0.0286	0.0267	0.0241	0.0234
	Block Design 1 (Post)	0.0170*	0.0074	0.0218*	0.0099
	Block Design 2 (Pre)	0.0162	0.0089	0.0162	0.0153
	Block Design 2 (Post)	0.0154	0.0076	0.0245	0.0156
	Discrimination Trial 3	0.0189	0.0138	0.0215	0.0113
	Discrimination Trial 9	0.0228	0.0201	0.0197	0.0088
	Discrimination Trial 15	0.0226	0.0147	0.0233	0.0147
	Discrimination Trial 21	0.0226	0.0182	0.0250	0.0138
	Discrimination Trial 27	0.0252	0.0255	0.0334	0.0311
Beta	EC	0.0215	0.0261	0.0281	0.0324
	EO	0.0199	0.0224	0.0301	0.0361
	Block Design 1 (Pre)	0.0133	0.0178	0.0145	0.0208
	Block Design 1 (Post)	0.0086*	0.0049	0.0127*	0.0113
	Block Design 2 (Pre)	0.0061	0.0034	0.0120	0.0105
	Block Design 2 (Post)	0.0071	0.0033	0.0146	0.0140
	Discrimination Trial 3	0.0102	0.0121	0.0122	0.0127
	Discrimination Trial 9	0.0140	0.0189	0.0096	0.0054
	Discrimination Trial 15	0.0081	0.0069	0.0120	0.0109
	Discrimination Trial 21	0.0119	0.0152	0.0162	0.0140
	Discrimination Trial 27	0.0167	0.0308	0.0182	0.0200

* Significant at the 0.05 level
** Significant at the 0.1 level

Non-parametric analysis revealed that between group differences existed at the 0.05 and 0.1 significance levels. Both the alpha ($Z=-2.374$; $p<0.05$; $r=-0.51$) and beta ($Z=-2.242$; $p<0.05$; $r=-0.48$) activity elicited by the post estimation of the first Block Design task was significantly different between the two groups.

Along with this, the theta activity during the eyes closed condition ($Z=-1.780$; $p<0.1$; $r=-0.38$), the delta activity elicited by the pre estimation of the second Block Design task ($Z=-1.714$; $p<0.1$; $r=-0.37$) and the theta activity during the 15th discrimination trial ($Z=-1.780$; $p<0.1$; $r=-0.37$) was significantly different between the two groups. The magnitudes of these differences were in the medium to large range.

4.4.3.2 Relative Power

Table 4.15 summarises the mean relative power scores and standards deviations at different frequencies for the ADHD and non-ADHD groups across the 11 test conditions in the Parietal lobe.

Table 4.15: Mean Relative Power Scores per Wave and Condition in the Parietal Lobe

Wave	Test Condition	ADHD		Non-ADHD	
		Mean	Std. Deviation	Mean	Std. Deviation
Delta	EC	0.5529	0.2043	0.4503	0.2625
	EO	0.5751	0.2081	0.5516	0.2330
	Block Design 1 (Pre)	0.4810**	0.1464	0.6288**	0.1976
	Block Design 1 (Post)	0.6091	0.1326	0.6026	0.1854
	Block Design 2 (Pre)	0.5332	0.1574	0.5973	0.1428
	Block Design 2 (Post)	0.5770	0.1599	0.5955	0.1260
	Discrimination Trial 3	0.4279	0.1573	0.4304	0.1710
	Discrimination Trial 9	0.3898	0.1573	0.5043	0.1983
	Discrimination Trial 15	0.4859	0.1244	0.5237	0.1609
	Discrimination Trial 21	0.4831	0.1880	0.4991	0.2088
	Discrimination Trial 27	0.4831	0.1880	0.4991	0.2088
Theta	EC	0.2914	0.2154	0.3805	0.2455
	EO	0.2896	0.2020	0.2768	0.2078
	Block Design 1 (Pre)	0.3347	0.1345	0.2414	0.1406
	Block Design 1 (Post)	0.2491	0.1017	0.2476	0.1644
	Block Design 2 (Pre)	0.3230**	0.1176	0.2506**	0.1089
	Block Design 2 (Post)	0.2859	0.1290	0.2430	0.1101
	Discrimination Trial 3	0.3691	0.1233	0.3815	0.1224
	Discrimination Trial 9	0.4136	0.1422	0.3329	0.1539
	Discrimination Trial 15	0.3219	0.0988	0.2945	0.0974
	Discrimination Trial 21	0.3208	0.1394	0.2968	0.1318
	Discrimination Trial 27	0.3208	0.1394	0.2968	0.1318
Alpha	EC	0.0864	0.0434	0.0908	0.0718
	EO	0.0789	0.0312	0.1027	0.0569
	Block Design 1 (Pre)	0.1267*	0.0514	0.0845*	0.0512
	Block Design 1 (Post)	0.0915	0.0338	0.0952	0.0361
	Block Design 2 (Pre)	0.1036	0.0372	0.1047	0.0448
	Block Design 2 (Post)	0.0921	0.0259	0.1045	0.0314
	Discrimination Trial 3	0.1339	0.0481	0.1236	0.0440
	Discrimination Trial 9	0.1227	0.0349	0.1095	0.0478
	Discrimination Trial 15	0.1421	0.0430	0.1213	0.0611
	Discrimination Trial 21	0.1275	0.0462	0.1348	0.0764
	Discrimination Trial 27	0.1275	0.0462	0.1348	0.0764
Beta	EC	0.0693	0.0459	0.0785	0.0802
	EO	0.0564	0.0366	0.0689	0.0630
	Block Design 1 (Pre)	0.0575	0.0393	0.0453	0.0398
	Block Design 1 (Post)	0.0503	0.0421	0.0547	0.0401
	Block Design 2 (Pre)	0.0403	0.0156	0.0474	0.0246
	Block Design 2 (Post)	0.0449	0.0205	0.0569	0.0250
	Discrimination Trial 3	0.0691	0.0431	0.0645	0.0411
	Discrimination Trial 9	0.0739	0.0422	0.0533	0.0238
	Discrimination Trial 15	0.0500	0.0176	0.0605	0.0363
	Discrimination Trial 21	0.0687	0.0618	0.0693	0.0469
	Discrimination Trial 27	0.0687	0.0618	0.0693	0.0469

* Significant at the 0.05 level
** Significant at the 0.1 level

Between the ADHD and non-ADHD groups, a difference in relative power was found in the alpha activity elicited by the pre estimation of the first Block Design task (Z=-2.044; p<0.05; r=0.44).

Along with this, differences were found in the delta activity caused by the pre estimation of the first Block Design task (Z=-1.780; p<0.1; r=0.38) and the theta activity elicited by the pre estimation of the second Block Design task (Z=-1.714; p<0.1; r=0.37). The magnitude of these differences was in the medium range.

4.4.3.3 Theta/Beta Ratio

Table 4.16 summarises the mean theta/beta ratio scores and standard deviation for the ADHD and non-ADHD groups across the 11 test conditions in the parietal lobe.

Table 4.16: Mean Theta/Beta Ratio Scores per Test Condition in the Parietal Lobe

Test Condition	ADHD		Non-ADHD	
	Mean	Std. Deviation	Mean	Std. Deviation
EC	5.5591	3.5743	8.7895	6.9963
EO	6.3078	3.8225	7.2215	6.3709
Block Design 1 (Pre)	7.5907	3.9151	6.8492	3.1257
Block Design 1 (Post)	6.4377	3.0178	6.0545	3.4348
Block Design 2 (Pre)	8.2046	1.9366	6.3481	3.0061
Block Design 2 (Post)	6.6433**	1.5236	4.8604**	2.2822
Discrimination Trial 3	6.7328	2.8726	7.1956	2.6597
Discrimination Trial 9	6.8970	3.2463	7.0676	3.1294
Discrimination Trial 15	7.2258	3.0886	6.1706	2.9293
Discrimination Trial 21	5.9685	2.0146	5.9627	3.1360
Discrimination Trial 27	5.9685	2.0146	5.9627	3.1360

** Significant at the 0.1 level

The two ADHD groups had significantly different theta/beta ratio scores during the post temporal estimate of the second Block Design task (Z=-1.714; p<0.1; r=0.37). The magnitude of this difference was in the lower medium range.

4.5 Conclusion and Summary of results

This chapter has presented the findings from the current investigation. Results were broken up into three sections.

The first section was concerned with questionnaire date. Descriptive statistics and between group comparisons were described in relation to the questionnaire and biographical information.

Thereafter the descriptive statistics and between group comparisons regarding the psychophysical part of the investigation was presented. These results pertained to the ADHD and non-ADHD groups, stratified from subsamples of those used in the questionnaire part of the investigation.

Finally the EEG results were presented. Descriptive statistics and between group comparisons were described for each of the three cortical regions in question.

A summary of significant findings from the questionnaire (table 4.17) and psychophysical EEG (table 4.18) parts of the investigation is provided below.

Table 4.17: Summary of Significant ZTPI Subscale findings

ZTPI Subscale	ADHD (n=84)	Non-ADHD (n=129)	Statistic (F)	P	Effect size (η^2)
Past Negative	3.38	3.11	7.086	0.008*	0.034
Present Hedonistic	3.58	3.36	10.802	0.001*	0.051
Future	3.26	3.60	24.908	0.000*	0.12

Table 4.18: Summary of significant EEG findings

	Test Condition	Absolute Power	Relative Power	Theta : Beta ratio
Frontal Lobe	**Block Design 2 (Pre)**			ADHD > Non-ADHD
	Block Design 2 (Post)		**Theta**: ADHD > Non-ADHD	
	Discrimination Trial 3	**Theta**: AHD > Non-ADHD	**Delta**: Non-ADHD > ADHD	
		Beta: ADHD > Non-ADHD	**Theta**: ADHD > Non-ADHD	
	Discrimination Trial 15		**Theta**: ADHD > Non-ADHD	
Frontal Midline	**EC**	**Theta**: Non-ADHD > ADHD		
	Block Design 1 (Post)	**Alpha**: Non-ADHD > ADHD		
		Beta: Non-ADHD > ADHD		
	Block Design 2 (Pre)	**Delta**: Non-ADHD > ADHD		
	Discrimination Trial 15	**Theta**: Non-ADHD > ADHD		
Parietal Lobe	**EC**	**Theta**: Non-ADHD > ADHD		
	Block Design 1 (Pre)		**Delta**: Non-ADHD > ADHD	
			Alpha: Non-ADHD > ADHD	
	Block Design 1 (Post)	**Alpha**: Non-ADHD > ADHD		
		Beta: Non ADHD > ADHD		
	Block Design 2 (Pre)	**Delta**: Non-ADHD > ADHD	**Theta**: Non-ADHD > ADHD	
	Block Design 2 (Post)			ADHD > Non-ADHD
	Discrimination Trial 15	**Theta**: Non-ADHD > ADHD		

Significant at the 0.05 level

Significant at the 0.1 level

Chapter 5: Discussion

5.1 Self-Reported Temporal Orientation

The findings from the investigation on self-reported habitual time perception are not entirely consistent with those of Carelli and Wiberg (2012). Dissimilar to their findings, the current investigation did not show differences on all five of the ZTPI temporal orientation sub categories between the ADHD and non-ADHD group.

Individuals with ADHD scored higher on the present hedonistic time orientation subscales. It follows that these individuals tend to place more emphasis on aspects of the immediate environment (e.g. I do things impulsively; I make decisions on the spur of the moment).

This finding relates to archetypal ADHD symptomology. Those that present with significant ADHD symptomology tend to have difficulty in prioritising and organising tasks for the future (Brown, 2002). In this way, these individuals do not have the intentional capacity needed to discount immediate challenges in light of past experiences and future possibilities.

It could be postulated that the impaired functioning of working memory may restrict cognition to stimuli faced in the immediate environment. Such an explanation has appeal to both the DPT and DDT of ADHD. Both these models explain that, in addition to subcortical related behavioural deficits, individuals with ADHD sufferer from dopamine related deficits in higher cognitive functioning such as working memory.

In addition to the neurophysiological explanation regarding working memory, DDT explains why this characteristic 'present hedonistic' behaviour may follow on from childhood into adolescence and adulthood.

Deficits in the capacity to learn from the negative circumstances resulting from hedonistic behaviour, coupled with a reduced capacity to annihilate pathological behaviour, may cause the persistence of a present hedonistic temporal orientation into adulthood.

Lower scores on the future subscale, by the ADHD group; indicate that these individuals do not prioritise planning for the future. This is consistent with observed symptomology that describes ADHD individuals as having deficits in the ability to start tasks on time, even when the task is of high importance (Brown, 2002).

The result is also consistent with the fact that ADHD individuals scored higher on the present hedonistic subscale. An increased affinity towards approaching life in a present hedonistic fashion creates behaviour that results in a decreased capacity to plan for the future.

An increased present hedonistic orientation plus deficits in executive functioning (specifically working memory) and a decreased capacity to learn from the benefits of future oriented behaviour may protract this characteristic decrease in affinity towards a future temporal orientation in those with ADHD.

The ADHD group scored higher than controls on the past negative subscale. This finding may be the result of a poor self-concept. When thinking about the past, individuals with ADHD tend to be hyper vigilant of negative experiences. As discussed by Vorster (2012), these individuals tend to feel as though they constantly underperform due to an insufficient repertoire of successful past achievements.

This low self-esteem is secondary to, and may result from, core ADHD symptomology. In terms of a neurobiological explanation, the negative self-concept may be explained by the characteristic deficit in functioning of reward pathways (mesocortical projections).

In addition to reduced dopaminergic functioning, DDT explains that ADHD individuals do not experience the satisfaction of achievements (past life achievements in this case) to the same degree as those who do not have the syndrome. This is due to the altered ability to appreciate external reinforcement of positive achievements (Sagvolden et al., 2005).

In this way, these individuals have a significantly smaller repertoire of positive experiences. Thus, individuals with ADHD tend to orient themselves towards negative past experiences due to the increased abundance of these memories, and the scarcity of positive experiences.

5.2 Psychophysical Time Perception

5.2.1 Estimation Task

In contrast to that hypothesised, the ADHD group did not show any difference to the non-ADHD group in any of the estimation task variables. There was no significant difference in: actual task completion time, estimation time or estimation accuracy (estimation error).

The current findings are consistent with those of Meaux and Chelonis (2003), Bauermeister et al. (2005) and Smith et al. (2002). Despite this lack of significant difference, the current investigation found that ADHD participants overestimated the task duration on 3 of the 4 estimation trials. The non-ADHD group overestimated the task duration twice. This trend in the ADHD group to overestimate task duration is consistent with the findings of Prevatt et al. (2011).

It may be hypothesised that the overestimation in the ADHD group results from an over compensatory response to the characteristic decrease in attentional capacity. In this way individuals with may be paying ‘too much’ attention to the passage of time causing these individuals to experience a specific temporal interval as longer.

Another explanation, as discussed by Suareza et al. (2013), relates to the memory phase of the pacemaker/counter process in SET. Because of the below average functioning of working memory individuals with ADHD may have a defective storage of reference memories.

This defective ‘transfer to reference’ would results in a loss of temporal information (in the form of counted pulses), causing the accumulation of references that are distortedly shorter that actual time.

As a consequence, durations presented in real time are judged to be longer than they were actually presented for when compared to a memory of a similar event. This process may have occurred thought the first trial run of the block design task thus leading to the observed pattern during the two test runs.

With the current non-significant findings, and conflicting findings in the literature, it may be hypothesised that estimation tasks daw upon cognitive processes that are not affected by ADHD type neuro-deficits (Smith et al., 2002).

Or perhaps a better explanation would be that the neurocognitive processes used in these tasks are not domain specific, and could be substitute by alternative networks that are less affected by the syndrome and not specifically derived for temporal processing.

This explanation would align itself to a neuroconstructivist type framework (Westermann, Thomas & Karmiloff-Smith, 2011). In addition to these postulations, the current task characteristics cannot be overlooked.

The current investigation centred its temporal estimations on the completion of WAIS-IV block design tasks. Perhaps tasks that centred on activities of a longer duration may have yielded different results.

5.2.2 Discrimination Task

In contrast to the hypothesised result, the current investigation found no significant difference in discrimination threshold between the ADHD and non-ADHD group. In addition to this, the accuracy of task performance was not significantly different.

This finding is consistent with Rubia et al. (1999), Toplak et al. (2003), Radonovich and Mostofsky (2004) and Himpel et al. (2009). Despite the lack of statistical difference, the ADHD group on average had a threshold to discrimination that was 10ms higher than the non-ADHD group.

As the current task investigated discrimination thresholds in the sub second range, the environmental and behaviour factors described in DDT may not be suited in explaining why those with ADHD tend to have a higher threshold.

Automatic or psychophysical, time perception has more appeal to models that focus on the dopamine related cortical and sub cortical deficits in ADHD, such as the DPM. Altered dopamine concentration and the resulting irregular functioning of mesocortical tracts may result in the characteristic offset in the discrimination threshold amongst those with ADHD.

During temporal perception tasks the striatum receives signals from the frontal cortex via these pathways, prompting the initiation of synchronised firing of neurons that project in superior directions (Matell et al., 2003). This pattern of neural activation is believed to act as the internal pacemaker.

The pulses are interpreted by an accumulator/counter before being compared to a reference memory (Matell et al., 2003). In this way communicative activity may be crucial in bridging the interval between the moment when information is acquired to the moment when the information can be used in a decision.

Decreased concentrations of dopamine may impede such communicative processes, resulting in larger discrimination thresholds required to consciously perceive a difference in presentation time of two consecutive stimuli (the two green circles in this case).

As the above postulation implements communicative pathways between cortical and subcortical structures, it does not specifically implement central timing mechanisms. This may be the reason for the insignificant difference in discrimination threshold between the two groups.

This poses the question that maybe larger differences would have been found if timing mechanisms, such as the pacemaker and accumulator/counter, were more directly impeded by ADHD type neurodeficits. This explanation is in line with that of Radonovich and Mostofsky (2004) who suggest a deficiency in the utilization of temporal information rather than a problem involving central timing mechanisms.

5.3 EEG Recorded Activity

5.3.1 Frontal Lobe

There was no group differences in the absolute power, relative power and theta/beta ratios of resting state activity (EO and EC) across all frequency bands. Although it was hypothesised that differences would exist, these findings are in line with those of Nazari et al. (2011); Ogrim et al. (2012) and Van Dongen-Boomsma et al. (2010).

For Ogrim et al. (2012) maturation diminished the differences in resting state cortical activity between those that have ADHD and those that do not. As the average age of participants who took part in the psychophysical investigation was just under 21 years, cortical maturating may have attenuated group differences in resting state electrical activity within the frontal lobe.

In addition to this, splitting the ADHD group into hyperactive/impulsive and inattentive subcategories may have aided in identifying group differences. According to Ogrim et al. (2012) the ADHD subcategories show different activation profiles during resting states. A higher level of theta activation is negatively correlated with hyperactivity and impulsivity, whereas the inattentive subcategory is associated with increased theta activity.

Although the majority of literature on EEG recorded activity in ADHD individuals (combined subtype samples) prescribes increased theta wave power, the distribution of sub type categories in the current sample was unknown. Perhaps the current sample consisted of more hyperactive/impulsive individuals. If so, the difference in resting state powers would have been less evident between the ADHD and control group.

Within the frontal lobe, it is evident that estimation tasks produce group differences in activation activity. Significant group differences in relative power and theta/beta ratios were found for the post and pre estimation of the second block design task, respectively.

This finding indicates that, although no significant differences in estimation ability was noted, ADHD individuals tend to have increased power in slow wave (theta) activity during temporal estimation. Slow wave activity is related to sleep and resting states (Sanei & Chambers, 2008).

In this way, the current finding is consistent with EEG literature that proposes a generalised cortical under-arousal in ADHD individuals (Bresnahan & Barry, 2002; Koehler et al., 2009; Clarke et al., 2011).

The escalated slow wave power during this task supports the postulation that ADHD individuals tend to overestimate durations due to a decreased capacity to transfer temporal information into reference memory. Cognitive processes such as working memory would prescribe increased power at higher frequencies (alpha and beta) rather than lower frequencies. This finding associates itself with an ADHD related neurobiological deficit in timing ability.

Although less prominent than the second block design task there were group differences in power scores elicited by the discrimination task. The relative and absolute theta activity was higher for the ADHD group during the third discrimination task trial.

For this trial, the difference in presentation time between the two green circles was 900ms. Once again, despite the lack of significant difference in discrimination task performance, ADHD individuals tend to have a characteristic under arousal during temporal estimation.

This under arousal diminished towards the end of the 30 trials as evidenced by the fact that no differences in frontal activity were noted for the 21st and 27th trials. Taken together this finding shows that ADHD individuals tend to have higher discrimination thresholds (as evidenced by the literature and to a lesser extent the current investigation). This is because of a weakened engagement of frontal cortex related activities such as higher order cognitive processing, including attention and working memory during discrimination tasks.

The characteristically higher slow wave activity complements this postulation. However, it should be noted that, in the current sample, frontal activity returned to normal once ADHD participants became more familiar with the discrimination task (i.e. on the 21st and 27th discrimination trial). This shows that the ADHD group had protracted adaption and/or compensation, to the task demands over time.

5.3.2 Frontal Midline

The only difference in frontal midline activity occurred in relation to absolute power. No differences were observed in relative power or theta/beta ratios. In general this shows that midline activity is not affected by ADHD related neurodeficits to the same degree as frontal and parietal structures.

In contrast to explanations that propose generalised cortical under arousal, it was found that ADHD participants had decreased slow wave activity (theta) during the eyes closed resting state. This finding is consistent with that of Ogrim et al. (2012) and Van Dongen-Boomsma et al. (2010). It shows that within frontal areas, cross brain communicative processes were not under active in ADHD participants.

This finding may also explain that ADHD participants had less self-reflective thought processes during the two minute eyes closed state. In addition, because theta wave activity has a hypothesised thalamic origin, the current finding may suggest differences in sub cortical activity during resting states in those with ADHD (Sanei & Chambers, 2008).

Further investigation would be needed to confirm this subcortical influence on frontal midline processes. However, it is important to note that the group difference in theta activity was only significant at the 0.1 level.

As with the frontal lobe, frontal midline activity during the estimation tasks in the ADHD group was significantly different from controls. The largest difference in power scores occurred during the post estimation of the first block design task. It was found that young adults with ADHD had significantly lower fast wave activity during this task.

This finding is consistent with the literature that specifies a generalised cortical under arousal in individuals with ADHD (Bresnahan & Barry, 2002; Koehler et al., 2009; Clarke et al., 2011). In this case the cortical under arousal was the result of decreased fast wave activity rather than increased slow wave activity. Though, there was evidence of increased slow wave activity during the pre-estimation of the second block design task.

As discussed above, the decreased power of fast wave frequencies may have caused ADHD participants to slightly overestimate temporal durations due to the lessened engagement of higher order cognitive processes. The ability to manipulate information in working memory and fully attend to temporal information is confounded by decreased fast wave activity (Sanei & Chambers, 2008).

In terms of the discrimination task, only one group difference was found. This difference was at the 0.1 significance level. As with the resting state finding, decreased theta activity during the 15th discrimination task is in contrast to literature that suggests lower cortical arousal in ADHD individuals. The 700ms difference in presentation time specifies that this was one of the easier discrimination trials.

As discussed with relation to the frontal lobe, the decrease in slow wave power may represent a protracted adaption by ADHD individuals to task demands. While the non-ADHD group had relatively consistent theta wave power across all discrimination conditions, the ADHD group showed a steady decline in power until the 15th trial.

This may be a compensatory reaction used to increase cortical arousal and in turn adapt to task demands through the utilisation of appropriate cognitive processes rather than internally focused resting state processes. This finding complements those discussed in relation to the frontal cortex.

This may provide evidence that the protracted compensatory activity is achieved across brain regions through changes in frontal midline activity. However, further investigation into the temporal occurrence of these changes would have to be conducted in order to confirm this postulation.

5.3.3 Parietal Lobe

Group differences in absolute theta power were found during the eyes closed resting state condition. As with the frontal midline, this difference was found at the 0.1 significance level. Because the direction of this difference is in opposition to the generalised cortical under arousal hypothesis, it complements the postulation made with regards to the frontal midline. These postulations had to do with altered subcortical activity and self-reflective thought processes.

Although, as discussed in relation to the frontal lobe, the unknown distribution of ADHD sub categories may have played a role in skewing the data in an unexpected direction (Ogrim et al., 2012). However, taken together, these findings show that the ADHD group did not possess cortical under arousal during the eyes closed resting state.

The parietal lobe activities elicited by the estimation tasks were of mixed results. With respect to the slow wave (delta) frequency range, both the absolute and relative power scores produced by the pre estimations of the first and second block design task, respectively, were not consistent with cortical under arousal hypothesis.

For both these tasks, the ADHD group showed less slow wave activity when compared to the non-ADHD group. Conversely, the relative theta power elicited by the pre estimation of the second block design task was higher in the ADHD group. Although the majority of the slow wave findings show decreased power scores, the findings from fast wave frequencies are more in line with a cortical under arousal hypothesis.

In terms of absolute power, the ADHD group showed lower alpha and beta scores during the post estimation of the first block design task. In addition to this, the relative alpha power was lower during the pre-estimation of the first block design task.

Finally, the theta/beta ratio produced by the post estimation of the second block design task was also more in line with a cortical under arousal hypothesis, with the ADHD group having a significantly higher value.

As a whole the findings from the estimation tasks showed that the ADHD group possessed elements of cortical under arousal. In this case it was not the slow wave activity but rather the decreased fast wave activity that suggested cortical under arousal.

As the parietal cortex is involved in both automatic and cognitively controlled time perception, the decreased fast wave activity may have resulted in the characteristic tendancy to overestimate temporal intervals (although not significant in the current investigation) (Lewis & Miall, 2003b). However, these typical over estimations may have been larger if the ADHD group showed closer alignment to the under arousal hypothesis by possessing greater slow wave powers.

In terms of the discrimination task, results were similar to those found in the frontal midline. The ADHD group had significantly lower absolute theta power when compared to controls. The finding is in contrast to a cortical under arousal hypothesis.

As the parietal cortex is involved with cognitively controlled timing processes (including processes that take place in the below 1s range), the current finding may explain why the ADHD group did not significantly differ from controls in terms of their discrimination threshold, or ability.

The parietal activity during all the discrimination tasks did not indicate signs of under arousal. In this way the functioning of somatosensory and motor circuits, involved in time perception tasks such as the current, may have been adequate for task demands. The current explanation is in line with the proposed postulation that the ADHD group had a protracted adaption to task demands, although, not as dramatic as that found in frontal cortex and frontal midline as discussed above.

5.4 Limitations

A major limitation regarding the current investigation concerns with sample size. A larger sample would have allowed for more accurate generalisations to the ADHD target population. The current sample of 12 ADHD participants was too small to draw any final conclusions in this regard.

The reason for this small sample was the lengthy EEG data extraction process that had to be conducted manually. In addition to sample size, gender distribution is an important factor to consider. The current sample did not have a matched distribution in terms of males and females. In this way it may not have accurately represented South Africa's ADHD population parameters.

However, due to the lack of prevalence studies, these parameters are difficult to define. With regard to stratification of the ADHD and non-ADHD groups, the ASRS V1.1 was used as a screening tool. Although this scale has been approved by the World Health Organisation as an appropriate tool, screening methods could have been more rigorous.

Rather than applying this self-report scale and asking participants if they have a diagnosis, the investigation may have allowed for more accurate stratification if the ADHD group were recruited from a population of diagnosed individuals from a healthcare practice. This exercise may have also helped in identifying ADHD sub groups.

As discussed with regard to the EEG recorded activity, ADHD sub group stratification may have helped in understanding conflicting results. The current investigation did not make any provisions for analysis into different ADHD subtypes. In relation to DSM-V classification, ADHD should not be simplified as homogenous syndrome.

Owing to the quasi-experimental nature of the current design, confounding variables could not be controlled. This ex post facto characteristic meant that any conclusions and postulations made remain speculative in nature. In addition to the design, the estimation task may have had experimental shortcomings.

Although actual block design task performance was of no interest, the task aimed to mimic real world activities (In the working and studying environment) faced by individuals on a daily basis. However, this may not have been the case as the task drew upon on spatial reasoning rather than verbal and/or numerical reasoning skills. Perhaps activities other than the WAIS-IV Block Design may have been better suited in mimicking a real life, non-lab based, task.

In addition, although effort was made to reduce the effect of environmental factors on results, features within the testing environment, such as the air conditioning, lighting, noise and participants stress levels (some of participants who took part in the recordings had an exam thereafter) may have influenced EEG recorded activity.

Finally, another environmental influence that was not controlled or factored in has to do with circadian rhythm. Not all of the participants were tested at the same time of day; some participants were tested in the morning and some in the afternoon; this time of day factor may have influenced EEG recorded neural activity.

5.5 Recommendations

In light of the limitations discussed above, a number of recommendations can be made for future investigations. The first of these recommendations concerns sample size. Using a larger sample would improve the generalisation of the overall findings.

In addition to this, it is recommended that better screening methods be used in stratifying the ADHD and non-ADHD group. This could be done by recruiting ADHD participants from healthcare institutes where a current diagnosis has been made. In addition to providing a more representative sample, this would help in identifying ADHD subgroup stratification.

Investigating the time perception related behaviour of ADHD sub groups is insinuated because it would provide important insight into the how the disorder manifests in individuals with different ADHD type variants.

As the aim of similar investigations would be to provide insight into diagnostic processes, data collection procedures should intend to investigate a larger number of cortical sites. This would provide a more holistic picture of the disorders influence on cortical activity.

In addition, measures could be taken on more than one occasion in order to counteract and nullify the environmental influences on results. A longitudinal type design will aid in improving both the internal and external validity of findings.

5.6 Conclusion

The current investigation allows for conclusions to be made as to temporal perception deficits in ADHD. Hoverer, in making these conclusions, the limitations discussed in the previous section should be kept in mind.

It was hypothesised that ADHD individuals have a pure time perception deficit in addition to a characteristic self-reported temporal orientation. This was investigated using self-report measures, psychophysical time perception tasks and EEG recorded neural activity within the frontal, frontal midline and parietal cortices. Because previous investigations regarding these aspects of time perception have produced conflicting results, the current investigation was important in its confirmatory nature.

In terms of self-reported time perception, it is evident that individuals with ADHD tend to focus on the negative aspects of past and present life experiences. In addition to this, ADHD individuals report that they do not often plan for the future. In relation to psychophysical time perception, the current investigation found that ADHD individuals are not significantly deficient in their ability to estimate temporal intervals that are above the 1min range.

Furthermore, the ADHD group was not impaired on the temporal discrimination task that cantered around the less than 1s range. Despite the lack of deficit in temporal abilities, in general, it was found that ADHD individuals have dissimilar neural activation patterns when performing these tasks.

Overall, it was found that that the ADHD group tended to have slower adaption to task demands though a characteristic generalised cortical under arousal. Taken together these findings indicate that ADHD individuals do not only consciously perceive time differently to those who do not have the disorder, but also show different neurophysiological processes when performing tasks that require the utilisation temporal processing.

Therefore it can be concluded that ADHD individuals have both behavioural and physiological differences when it comes to conscious and unconscious/automatic time perception.

The findings provide important insight into the ADHD syndrome. It may be postulated that time perception tasks be included as a diagnostic medium for ADHD. This endorsement aims to provide clinicians with a more objective measure for the diagnosis process.

In addition to both self-reported and third person reported behavioural deficits as an indices of ADHD related impairment, the current findings add to the body of literature that propose more objective methods of diagnosis, such as the use of psychophysical tests and brain imaging techniques such as EEG and MRI.

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Appendices

APPENDIX A: ADHD Criteria

Table 1: DSM-V Criteria for ADHD	
Criterion A1 *Six or more of the following symptoms of inattention have been present for at least 6 months to a degree that is inconsistent with developmental level and that impact directly on social and academic/occupational activities.*	Inattention • Often does not give close attention to details or makes careless mistakes in schoolwork, work, or other activities (e.g., overlooks or misses details, work is inaccurate). • Often has difficulty sustaining attention in tasks or play activities (e.g., has difficulty remaining focused during lectures, conversations, or reading lengthy writings). • Often does not seem to listen when spoken to directly (e.g., mind seems elsewhere, even in the absence of any obvious distraction). • Often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace (e.g., starts tasks but quickly loses focus and is easily side-tracked; fails to finish schoolwork, household chores, or tasks in the workplace). • Often has difficulty organizing tasks and activities (e.g., difficulty managing sequential tasks; difficulty keeping materials and belongings in order; messy, disorganized, work; poor time management; tends to fail to meet deadlines). • Often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (e.g., schoolwork or homework; for older adolescents and adults, preparing reports, completing forms, or reviewing lengthy papers). • Often loses things needed for tasks and activities (e.g., school materials, pencils, books, tools, wallets, keys, paperwork, eyeglasses, or mobile telephones). • Is often easily distracted by extraneous stimuli (for older adolescents and adults, may include unrelated thoughts). • Is often forgetful in daily activities (e.g., chores, running errands; for older adolescents and adults, returning calls, paying bills, keeping appointments)

Criterion A2 *Six or more of the following symptoms of Hyperactivity/Impulsivity have been present for at least 6 months to a degree that is inconsistent with developmental level and that impact directly on social and academic/occupational activities.*	Hyperactivity/Impulsivity • Often fidgets with hands or feet or squirms in seat. • Often leaves seat in situations when remaining seated is expected (e.g., leaves his or her place in the classroom, office or other workplace, or in other situations that require remaining seated). • Often runs about or climbs in situations where it is inappropriate. (In adolescents or adults, may be limited to feeling restless). • Often unable to play or engage in leisure activities quietly. • Is often "on the go" or often acts as if "driven by a motor" (e.g., is unable or uncomfortable being still for an extended time, as in restaurants, meetings, etc.; may be experienced by others as being restless and difficult to keep up with). • Often talks excessively. • Often blurts out answers before questions have been completed (e.g., completes people's sentences and "jumps the gun" in conversations, cannot wait for next turn in conversation) • Often has trouble waiting his or her turn (e.g., while waiting in line). • Often interrupts or intrudes on others (e.g., butts into conversations or games or activities; may start using other people's things without asking or receiving permission, adolescents or adults may intrude into or take over what others are doing).
Conditions to Diagnosis	• Some symptoms that cause impairment were presented prior to age 12. Some impairment from the symptoms is present in two or more settings (e.g. at school/work and at home). • Criteria for the disorder are met in two or more settings (e.g., at home, school or work, with friends or relatives, or in other activities). • The symptoms do not occur exclusively during the course of schizophrenia or another psychotic disorder and are not better accounted for by another mental disorder (e.g., mood disorder, anxiety disorder, dissociative disorder, or a personality disorder).
Based on these criteria, four types of ADHD are Identified	• **Combined Presentation**: If both Criterion **A1** (Inattention) and Criterion **A2** (Hyperactivity-Impulsivity) are met for the past 6 months. • **Predominantly Inattentive Presentation**: If Criterion **A1** (Inattention) is met but Criterion **A2** (Hyperactivity/Impulsivity) is not met and 3 or more symptoms from Criterion **A2** have been present for the past 6 months. • **Inattentive Presentation (Restrictive)**: If Criterion **A1** (Inattention) is met but no more than 2 symptoms from Criterion **A2** (Hyperactivity-Impulsivity) have been present for the past 6 months. • **Predominantly Hyperactive/Impulsive Presentation**: If Criterion **A2** (Hyperactivity-Impulsivity) is met and Criterion **A1** (Inattention) is not met for the past 6 months.

(Source: American Psychiatric Association, 2013)

APPENDIX B: ASRS

Adult ADHD Self-Report Scale (ASRS-v1.1) Symptom Checklist

Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, place an X in the box that best describes how you have felt and conducted yourself over the past 6 months.	**Never**	**Rarely**	**Sometimes**	**Often**	**Very Often**
1. How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?					
2. How often do you have difficulty getting things in order when you have to do a task that requires organization?					
3. How often do you have problems remembering appointments or obligations?					
4. When you have a task that requires a lot of thought, how often do you avoid or delay getting started?					
5. How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?					
6. How often do you feel overly active and compelled to do things, like you were driven by a motor?					
Part A					
7. How often do you make careless mistakes when you have to work on a boring or difficult project?					
8. How often do you have difficulty keeping your attention when you are doing boring or repetitive work?					
9. How often do you have difficulty concentrating on what people say to you, even when they are speaking to you directly?					
10. How often do you misplace or have difficulty finding things at home or at work?					
11. How often are you distracted by activity or noise around you?					
12. How often do you leave your seat in meetings or other situations in which you are expected to remain seated?					
13. How often do you feel restless or fidgety?					
14. How often do you have difficulty unwinding and relaxing when you have time to yourself?					
15. How often do you find yourself talking too much when you are in social situations?					
16. When you're in a conversation, how often do you find yourself finishing the sentences of the people you are talking to, before they can finish them themselves?					
17. How often do you have difficulty waiting your turn in situations when turn taking is required?					
18. How often do you interrupt others when they are busy?					
Part B					

APPENDIX C: BIOGRAPHICAL QUESTIONNAIRE

Student/Person Number	
E-Mail Address (please enter a valid e-mail address)	
Cell Phone Number (please enter your cell phone number)	

Please complete the following questionnaire as honestly as possible

Age (in years):			
Gender (Please indicate male or female with an X)	Male	Female	
Highest Educational Qualification (Please Choose One and put an x next to it):	Completed Grade 12		
	Completed 1st Year of University Studies		
	Completed 2nd Year of University Studies		
	Completed 3rd Year of University Studies		
	Completed 4th Year of University Studies/Honours Degree		
Are you currently on any chronic medication? (Please indicate yes or no with an X):	Yes	NO	If yes, please indicate type and dosage:_____
Do you have a current diagnosis of ADD/ADHD? (Please indicate yes or no with an X):	Yes	NO	If yes please indicate whether it is ADHD or ADD:_____
Do you have a former diagnosis of childhood ADD/ADHD? (Please indicate yes or no with an X):	Yes	NO	If yes please indicate whether it is ADHD or ADD:_____
Do you have a current diagnosis of depression? (Please indicate yes or no with an X)	Yes	NO	
Have you had any form of serious head injury or epilepsy in the past? (e.g. fits or black outs, etc.) (Please indicate yes or no with an X):	Yes	NO	
Are you bilingual/multilingual? (Speak two or more languages) (Please indicate yes or no with an X):	Yes	NO	If yes, then please indicate: How many languages do you speak? _____ From what age have you spoken more than one language? _____ What is your estimated level of proficiency for your first language? (please indicate whether it is weak, average or fluent with an X)
	Weak	Average	Fluent
	What is your estimated level of proficiency for your second language? (please indicate whether it is weak, average or fluent with an X)		
	Weak	Average	Fluent

APPENDIX D: ZTPI

Read each item and, as honestly as you can, answer the question: "How characteristic or true is this of you?" Please mark the appropriate box with X. Please answer ALL of the following questions	**Very Untrue**	**Untrue**	**Neutral**	**True**	**Very True**
1. I believe that getting together with one's friends to party is one of life's important pleasures.					
2. Familiar childhood sights, sounds, smells often bring back a flood of wonderful memories.					
3. Fate determines much in my life.					
4. I often think of what I should have done differently in my life.					
5. My decisions are mostly influenced by people and things around me.					
6. I believe that a person's day should be planned ahead each morning.					
7. It gives me pleasure to think about my past.					
8. I do things impulsively.					
9. If things don't get done on time, I don't worry about it.					
10. When I want to achieve something, I set goals and consider specific means for reaching those goals.					
11. On balance, there is much more good to recall than bad in my past.					
12. When listening to my favorite music, I often lose all track of time.					
13. Meeting tomorrow's deadlines and doing other necessary work comes before tonight's play.					
14. Since whatever will be will be, it doesn't really matter what I do.					
15. I enjoy stories about how things used to be in the "good old times."					
16. Painful past experiences keep being replayed in my mind.					
17. I try to live my life as fully as possible, one day at a time.					
18. It upsets me to be late for appointments.					
19. Ideally, I would live each day as if it were my last.					
20. Happy memories of good times spring readily to mind.					
21. I meet my obligations to friends and authorities on time.					
22. I've taken my share of abuse and rejection in the past.					
23. I make decisions on the spur of the moment.					
24. I take each day as it is rather than try to plan it out.					
25. The past has too many unpleasant memories that I prefer not to think about.					
26. It is important to put excitement in my life.					
27. I've made mistakes in the past that I wish I could undo.					
28. I feel that it's more important to enjoy what you're doing than to get work done on time.					
29. I get nostalgic about my childhood.					
30. Before making a decision, I weigh the costs against the benefits.					

	Very Untrue	Untrue	Neutral	True	Very True
31. Taking risks keeps my life from becoming boring.					
32. It is more important for me to enjoy life's journey than to focus only on the destination.					
33. Things rarely work out as I expected.					
34. It's hard for me to forget unpleasant images of my youth.					
35. It takes joy out of the process and flow of my activities, if I have to think about goals, outcomes, and products.					
36. Even when I am enjoying the present, I am drawn back to comparisons with similar past experiences.					
37. You can't really plan for the future because things change so much.					
38. My life path is controlled by forces I cannot influence.					
39. It doesn't make sense to worry about the future, since there is nothing that I can do about it anyway.					
40. I complete projects on time by making steady progress.					
41. I find myself tuning out when family members talk about the way things used to be.					
42. I take risks to put excitement in my life.					
43. I make lists of things to do.					
44. I often follow my heart more than my head.					
45. I am able to resist temptations when I know that there is work to be done.					
46. I find myself getting swept up in the excitement of the moment.					
47. Life today is too complicated; I would prefer the simpler life of the past.					
48. I prefer friends who are spontaneous rather than predictable.					
49. I like family rituals and traditions that are regularly repeated.					
50. I think about the bad things that have happened to me in the past.					
51. I keep working at difficult, uninteresting tasks if they will help me get ahead.					
52. Spending what I earn on pleasures today is better than saving for tomorrow's security.					
53. Often luck pays off better than hard work.					
54. I think about the good things that I have missed out on in my life.					
55. I like my close relationships to be passionate.					
56. There will always be time to catch up on my work.					

APPENDIX E: PARTICIPANT INFORMATION SHEET

Psychology Department

School of Human and Community Development

University of the Witwatersrand

Private Bag 3, WITS, 2050

Tel: (011)717 4500 Fax: (011) 717 4559

Participant Information Form

EXPLORING TIME PERCEPTION AND RELATED NEURAL ACTIVITY IN ADHD AND NON-ADHD YOUNG ADULTS

To Whom It May Concern

Dear Sir/Madam

I am Jean-Pierre Viviers and I am currently doing my Masters in Research Psychology at the University of the Witwatersrand. I am expected to conduct research in the field of psychology as part of course requirements. The aim of my research is to explore time perception and related neural activity in ADHD and non-ADHD young adults.

In order to conduct my research, data collection will be necessary. This will happen by means of the completion of 3 questionnaires and 2 time perception tasks. The overall process should take approximately 30 minutes.

Your participation will be of benefit to me in the collection of my data. As such, I invite prospective participants to participate in my research and give informed consent by signing this form. Please note that by signing this form, you are consenting to take part in my study and not to any form of treatment.

My questionnaires and time perception tasks will be administered individually to each person. As I want to ensure that confidentiality is maintained, you do not need to provide me with any identifying particulars. I will add codes to the questionnaires later. However, given that I need to contact you to schedule an individual appointment for the time perception tasks, I would really appreciate if you can add your contact details to the questionnaires.

Please note that participation in my study is completely voluntary and it is your personal choice as to whether you would like to partake in this study. Refusal to participate will not involve any kind of penalty. You may withdraw from the study at any time. Should you wish to withdraw, this will be respected and your

completed questionnaires will not be used in the study. This data collection includes no risks and should not cause any harm or discomfort.

At the end of the study, the data will be analysed and the findings will be collated into a research report for publication in an accredited journal. Should you wish to have access to a summary of the results, this can be done via e-mail upon your request. This feedback may help you to understand the link between time perception and ADHD and the impact thereof on you or others' functioning.

It is important to take cognisance of the fact that during the analysis of the data, the raw data will only be viewed by me and my supervisor so that confidentiality can be ensured at all times. The raw data will be kept for up to three years in a locked cupboard, thereafter all raw data will be destroyed.

I warmly invite you to participate in my study. Should you have any questions or concerns, please direct these to me personally as per my contact details below.

Kind Regards

Jean-Pierre Viviers (Researcher):

jeanpv@global.co.za

Adri Vorster (Supervisor):

adri.vorster@wits.ac.za

APPENDIX F: PARTICIPANT CONSENT FORM

Psychology Department

School of Human and Community Development

University of the Witwatersrand

Private Bag 3, WITS, 2050

Tel: (011)717 4500 Fax: (011) 717 4559

Participant Consent Form

I _____, have read through the attached information form and give consent that I will take part in the mentioned study.

I understand that:

- Participation in this study is voluntary
- I may refuse to answer any questions I would prefer not to.
- I can withdraw from the study at any time
- No information that may identify me will be included in the research report and my responses will remain confidential.
- There are not direct risks or benefits for participation in this study.

Signed: _____

Date: _____