TESTING DEFICITS IN BEHAVIOURAL PLANNING, SET- SHIFTING/ COGNITIVE FLEXIBILITY AND WORKING MEMORY IN CHILDREN WITH HIGH LEVELS OF ATTENTION DEFICIT/HYPERACTIVITY DISORDER SYMPTOMS

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2022

DECLARATION

I, Tshikani Theodore Boshomane declare that:

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DEDICATION

To my late grandmother Nkiyasi Betty Nkanyani and my late parents Khazamula Isaac and Joyce Madali Nkanyani, who always believed in me, supported me and encouraged me to achieve my dreams.

ACKNOWLEDGEMENTS

My deepest gratitude for the accomplishment of this degree is accorded to the following: My supervisor, Professor Basil J. Pillay, for sharing his knowledge and for his continued support.

My co-supervisor, Professor Anneke Meyer for her expertise, time, wisdom and continued support.

To Pam Pillay, thank you for your continuous support and sharing most valuable information during my study.

To Professor Wim Meyer, for your support during our supervision visits.

My husband, Tlou Victor Boshomane, and children Risuna Lloyd, Tumelo, Pabalelo, Mashela Tebogo and Malesela Mokgau, for the love and unwavering support and understanding throughout this journey. I am also grateful for their understanding and patience, in order for me to complete this research.

My dearest parents, Khazamula Isaac Nkanyani and Joyce Madali Nkanyani, for their love, guidance and for always recognising my potential for learning and encouraging it.

To my late uncle, Dr R.W. Chabalala, thank you for being my exemplary, for the love and support you provided after the loss of our beloved mother.

The Department of Education for granting me permission to conduct the research. A special thank you to the principals, teachers and learners of the schools where data was collected.

The University of Kwazulu-Natal, for financial help with registration, publications and support that was offered during this endeavour.

To my mother-in-law, Pheladi Margaret Boshomane, thank for your love and support during my study.

My siblings, Chaka Shadrack, Mikateko Lisbeth, Mbhendle Harold, Tirhani Iris, Amathonga Beverly, Phanghani Stanford, Phikani Pelton and Dangisa Petunia, thank you for always being there for me.

My friends: Dr Khesani Maluleke-Baloyi, Basani Hlaneki, Amanda Mabunda, Dr Maria Mokobane, Dr Gloria Pila-Nemutandani, Dr Wandile Tsabedze and Dr Mandu Selepe, thank you for encouraging me to study more and for your unwavering support throughout my study.

To my assistants, Rotakala Sadiki, Khutadzo Matidza, Penny Mafela and Xichavo Hobyani, thank you for assisting me with the data collection.

To my Clinical Manager at Dr C.N. Phatudi hospital, Dr M.I. Nhlangwana, thank you for encouraging me to study, for your love and support ever since I started working with you.

To my IT specialist, Ms Gavaza Sambo, thank you for assisting me with your IT knowledge.

I would not forget my late grandmother, Nkiyasi Betty Nkanyani who always stood by me and recognise my potential for learning and encouraging it, even in difficult times.

Above all, I would like to thank God for giving me strength and courage.

LIST OF PAPERS

Paper 1: Boshomane, T.T., Pillay B. J., & Meyer, A. (2020).

Attention-Deficit/Hyperactivity Disorder and behavioural planning deficiencies in South African primary school children. *South African Journal of Psychiatry*, *26*(0), a1411. https://doi.org/10.4102/sajppsychiatry.v26io.1411

Paper 2: Boshomane, T.T., Pillay B.J., & Meyer, A. (2021).

Mental flexibility (set-shifting) deficits in children with ADHD: A replication and extension study. *Journal of Psychology in Africa*, *31*(), X-XX, https://doi.org/10.1080/14330237.2021.1952637

Paper 3: Boshomane, T.T., Pillay B.J., & Meyer, A. (submitted to the *Journal of Child and adolescent Mental health*).

Working memory and cognitive flexibility Impairments in primary school children with Attention-Deficit/ Hyperactivity Disorder

Paper 4: Boshomane, T.T., Pillay B.J., & Meyer, A. (2021).

Measures of executive functions predicting Attention-Deficit/Hyperactivity Disorder core symptoms. *African Journal of Psychological Assessment*, *3*(0), a48. https://doi.org/10.4102/ajopa.v3i0.48

ABSTRACT

Attention Deficit/Hyperactivity Disorder (ADHD) is a common neurodevelopmental disorder characterised by age-inappropriate symptoms of inattention, impulsiveness and hyperactivity that persist into adulthood. The symptoms are thought to result from a deficit in executive functions (EFs), such as inhibition, working memory, planning and set-shifting or cognitive flexibility. The study was aimed at investigating deficits in behavioural planning, cognitive flexibility and working memory in children with ADHD, with the use of specific neuropsychological tests, designed to measure deficiencies in the cortical areas of EFs, and compare this performance with a neurotypical control group. Further, the study investigated whether commonly used EF measurements were able to predict the core symptoms of ADHD. One hundred and fifty-six Sepedi and Xitsonga speaking primary school children (78 with ADHD and 78 matched controls without ADHD) aged between 6 and 15 years (*M*=11.7 years, *SD*=1.7), both males and females, participated in the study. The Tower of London (ToL) was used to measure planning, Memory for Digits (MFD) was used to measure working memory, Trail Making Test (TMT) to measure cognitive flexibility and Wisconsin Card Sorting Test (WCST) to measure set-shifting.

Our results showed that, on the ToL, children with ADHD, especially ADHD-PI and ADHD-C, used more moves and took a longer time to complete the task compared to the neurotypical controls. There were no differences in the number of moves and time taken by the ADHD-HI when compared to controls. Further, the results showed that, on the WCST, children with ADHD presentations /subtypes (ADHD-Hyperactive/impulsiveness, ADHD-Inattention and ADHD-combined) met with more set-shifting problems than the neurotypical comparison group, as they made more total errors, perseverative responses, perseverative errors and non-perseverative errors. Children with ADHD also exhibited poorer performance on both the

Digits Backwards (DB) and Trails-B when compared to the control group. No significant effect between the ADHD and control group were found on the Trails-A test. Sex and age did not influence the performance of set-shifting, working memory and cognitive flexibility tasks. All the tests (ToL, DF and DB, Trails-B and WCST) were found to predict ADHD symptomatology, except Trails-A. The WCST (total errors and perseverative errors) was the best predictor of ADHD symptomatology and H/I, followed by DB and Trails-B which predicted more inattention. In conclusion, the study revealed behavioural planning, set-shifting and working memory deficits in children with ADHD compared to neurotypical comparisons. The study also showed commonly used EFs tests could predict ADHD symptomatology. Since children with ADHD show behavioural planning, cognitive flexibility and working memory deficiencies which affect their academic and social functioning, it is recommended that tests of EF are included in the assessment to complement the diagnosis of ADHD.

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CHAPTER 1

INTRODUCTION

Attention Deficit/Hyperactivity Disorder (ADHD) is a neuropsychological heterogenous disorder with multiple sub-groups of individuals who are affected by different neuropsychological deficits (Polanczyk et al., 2015). It is a common childhood neuropsychiatric disorder (Chiang et al., 2010; Gau et al., 2005; Polanczyk et al., 2007; Polanczyk et al., 2014), which may be mediated by impaired executive functioning (Diamantopoulou et al., 2007). Literature suggests lifelong executive functioning deficits in ADHD (Miyake et al., 2000; Nigg, 2017; Seidman, 2006; Willcutt et al., 2005), particularly for planning, working memory, inhibition, and set-shifting tasks (Pennington & Ozonoff, 1996; Tseng & Gau, 2013). Children with high levels of ADHD symptoms show poorer performance compared to children without ADHD on tasks requiring planning, inhibition, task-shifting and working memory (Ahmadi et al., 2014; Kofler et al. 2010; Lijffijt et al., 2005; Toplak et al., 2013). Executive functioning (EF) is an umbrella term which embraces a range of cognitive processes and abilities that facilitate goal-orientated behaviour and thought processes, such as planning, insight, judgement, reasoning and cognitive flexibility (Ogilvie et al., 2011). Although children with high levels of ADHD often exhibited poor EFs (Thorell & Wåhlstedt, 2006), these deficits are not present in all children with the disorder.

ADHD is one of the most prevalent childhood disorders (Barkley, 2015), with an estimated worldwide prevalence of 7.2% in children under 18 years of age (Thomas et al., 2015). Male-to-female ratios of an ADHD diagnosis range from 2:1 to 10:1 (Arnett et al., 2012; Ramtekkar et al., 2010; Reiersen, 2011), with higher male-to-female ratios occurring in clinical versus population-based samples (Skogli et al., 2013). Gender has been considered a significant factor in ADHD research for many years (Arnold, 1996), and its role is not well understood

(Hasson & Fine, 2013). Generally, boys are more likely to be referred, diagnosed, and treated for ADHD symptoms than girls (Slobodin & Davidovitch, 2019). Research on gender differences in ADHD indicates that girls maybe under-identified and underdiagnosed because of gender differences in the expression of the disorder (Biederman et al., 2002; Gudjonsson et al., 2014). Girls with ADHD are reported to have fewer hyperactive/impulsive symptoms when compared to boys (Biederman et al., 2004; Gershon, 2002). However, (Hinshaw et al., 2012; Seidman et al., 2005) found that girls with ADHD have a very similar EF profile compared to boys with the disorder.

To diagnose ADHD, key symptoms in the *Diagnostic and Statistical Manual* (5th edition) (DSM-5) and *International Classification of Diseases and Related Health Problems* (10th edition) (ICD-10) involve the person's age, severity, the number of symptoms, duration of symptoms and whether these symptoms occur in two or more settings, that is, school, home or work (American Psychiatric Association, 2013) or two independent settings World Health Organization (WHO), (1992). Moreover, the ICD-10 discourages the use of multiple diagnoses. When other disorders are present, the diagnostician is encouraged to diagnose the co-occurring disorder. By contrast, the DSM-5 permits multiple comorbid diagnosis to co-occur with ADHD (Lee et al., 2008). Although symptoms of inattention, hyperactivity and impulsiveness typically characterise ADHD, children with ADHD often present with executive dysfunctions such as poor working memory, planning and cognitive flexibility.

Difficulty with EF is generally attributed to structural and/or functional pathology (Miyaki & Friedman, 2012). Ardila (2008); Faraone (2015); Miyake et al., (2000); Miyake and Friedman (2012) and Willcutt et al., (2005) all indicated that the prefrontal cortex (PFC) plays a role in EFs, but other brain areas are also involved. EFs are thought to be related to prefrontal/frontal lobe lesions (Miyake et al., 2000; Romine & Reynolds, 2005; Squire et al., 2004). Prefrontal lesions produce behavioural hyperactivity, distractibility or impulsiveness, as well as deficits on EF tasks (Koechlin, 2016; Miyake & Friedman, 2012). Neuropsychological and imaging studies indicate that PFC functions are weaker in children with ADHD (Arnsten & Li, 2005). The dorsolateral prefrontal cortex (PFC) is linked to working memory, while the ventromedial PFC is responsible for decision-making and strategic planning (Cortese et al., 2012; Faraone, 2015). Set- and task-switching performance relies on connections between the dorsolateral PFC or medial PFC and striatum (Graham-Day et al., 2010; Manes et al., 2002; Ragozzino, 2007; Wood et al., 2016). The dopamine system also plays an important part in planning, cognitive flexibility and prefrontal functioning (Arnsten & Li, 2005; Sagvolden et al., 2005). A hypofunctioning mesocortical dopamine branch may result in poor behaviour planning, poor working memory and poor cognitive flexibility (Sagvolden et al., 2005).

1.1 Problem Statement

The literature suggests that children with ADHD have difficulty adjusting to new demands in everyday functioning because of deficits in concentration, attention, abstract reasoning, planning, cognitive flexibility and problem-solving. The main purpose of the study was to investigate deficits in behavioural planning, cognitive flexibility/ set-shifting and working memory in children with ADHD, with the use of specific neuropsychological tests, designed to measure deficiencies in the cortical areas of EFs, and compare this performance with a neurotypical control group. Further, the study investigated whether commonly used EF measurements were able to predict the core symptoms of ADHD since deficits in EF impedes optimal function in academic, social and occupational functioning. There is a dearth of ADHD studies among rural, black children especially on deficits in EF (Boshomane et al., 2020; Boshomane et al., 2021; Mathivha, 2005; Mokobane et al., 2020, Mphahlele et al., 2022; Pila-Nemuntandani & Meyer, 2016 & Shikwambana, 2006). The study will add to the limited knowledge by being conducted in the Greater Tzaneen Municipality, Limpopo Province, South Africa.

1.1.1 Research Questions

The research questions in this study were as follows:

i. Do children with high levels of ADHD symptoms have more deficiencies in behaviour planning than their neurotypical peers?
ii. Do children with high levels of ADHD symptoms have set-shifting deficiencies compared to their neurotypical peers, according to ADHD subtype, gender and age?
iii. Do children with high levels of ADHD symptoms have working memory and cognitive flexibility deficiencies compared to their neurotypical peers?
iv. Can commonly used EF instruments predict the core symptoms of ADHD?

1.2 Aims and Objectives of the Study

The main aim of the study was to investigate deficits in behavioural planning, cognitive flexibility/ set- shifting and working memory in children with ADHD, with the use of specific neuropsychological tests, designed to measure deficiencies in the cortical areas of EFs, and compare this performance with a neurotypical control group. Further, the study investigated whether commonly used EF measurements were able to predict the core symptoms of ADHD.

The objectives of the current study were to:

i. Establish whether children with high levels of ADHD symptoms have deficiencies in behavioural planning when compared to typically developing children without ADHD symptoms (Paper 1).

ii. Determine whether children with high levels of ADHD symptoms have mental or set-shifting deficiencies compared to children without ADHD symptomatology, and to determine whether the three ADHD subtypes, age and gender, affect their mental shifting performance (Paper 2).

iii. Explore whether children with high levels of ADHD symptoms have working memory and cognitive flexibility deficiencies compared to neurotypical children (Paper 3).

iv. Investigate whether the commonly used EF neuropsychology assessments employed can predict the core symptoms of ADHD: hyperactivity/impulsiveness and inattention (Paper 4).

1.3 Rationale for the study

The main purpose of the study was to investigate deficits in behavioural planning, cognitive flexibility/ set- shifting and working memory in children with ADHD, with the use of specific neuropsychological tests, designed to measure deficiencies in the cortical areas of EFs, and compare this performance with a neurotypical control group. Further, the study investigated whether commonly used EF measurements were able to predict the core symptoms of ADHD. Therefore, if the deficits could be detected at an early age, intervention can take place and children may be able to cope with demands of academic, social and occupational challenges. The outcome of the study will add to the understanding of treatment methods that address the underlying neuropsychological deficiencies and a positive contribution can be made to an improved and more focused approach to intervention of this debilitating disorder. This may also lead to the understanding of EF's measures that may detect ADHD symptomatology and supply valuable information for a successful diagnosis.

1.4 Hypotheses

Hypothesis 1: Children with high levels of ADHD symptoms will show more deficiencies in tasks of behaviour planning than children without ADHD symptomatology.

Hypothesis 2: Children with high levels of ADHD symptoms will show more deficiencies on tests of set-shifting than children without ADHD symptoms, based on the ADHD subtype and the age and gender of participants.

Hypothesis 3: Children with high levels of ADHD symptoms will display more problems with working memory and cognitive flexibility than children without ADHD symptoms.

Hypothesis 4: The Tower of London (ToL), The Wisconsin Card Sorting Test (WCST), The Trail Making Test (TMT) and Memory for Digits (MFD) can predict the ADHD core symptoms of hyperactivity/impulsiveness and inattention.

1.4.1 Outline of the Study

The next chapter of the thesis will review relevant literature on ADHD, with special emphasis on behaviour planning, working memory, cognitive flexibility, assessment, aetiology, and the theoretical framework underlying EF.

Chapter 3 will outline the research methodology used in the study. The chapter includes a description of the study population, sample size, inclusion, and exclusion criteria, as well as the data collection process, data management and analysis used. Issues of reliability, validity and ethical considerations are also included in this chapter.

The results of the study are presented in Chapter 4. Following a general description, specific results are presented as separate published papers as follows:

i. Paper 1: Attention-Deficit/Hyperactivity Disorder and behaviour planning deficiencies in South African primary school children.
ii. Paper 2: Mental flexibility or/set-shifting deficits in children with ADHD: A replication and extension study.
iii. Paper 3: Working memory and cognitive flexibility impairment in primary school children with Attention-Deficit/Hyperactivity Disorder.
iv. Paper 4: Measures of Executive functions predicting ADHD core symptoms.

Finally, in Chapter 5, a discussion of the results is provided. Further, some implications of the study's findings and limitations are presented, and the chapter ends with concluding remarks.

CHAPTER 2

LITERATURE REVIEW

Attention Deficit-Hyperactivity Disorder (ADHD) is a common neurodevelopmental disorder characterised by age-inappropriate symptoms of inattention, impulsiveness and hyperactivity that persist into adulthood (Rovira et al., 2020). It is a neurological condition with primary deficits in executive functions (EFs) (Miyake et al., 2000; Nigg, 2017; Westby & Watson, 2004; Willcutt et al., 2005). EF is an umbrella term encompassing a diverse range of cognitive processes and behavioural competencies needed to facilitate the initiation, planning, regulation, sequencing, and achievement of complex goal-oriented behaviour and thought (Crippa et al., 2015; Stuss & Knight, 2013). There are three core executive functions: inhibition, working memory and cognitive flexibility (Barkley, 1997; Hudec et al., 2015; Kasper et al., 2012; Rubia et al., 2014). Reasoning, problem-solving, and planning are considered higher-order executive functions (Diamond, 2013).

2.1 Epidemiology

2.1.1 Prevalence

ADHD is a common disorder that affects 5% of children and adolescents and 2.5% of adults worldwide (Faraone, 2015; Simon et al., 2009). Globally, the prevalence of ADHD is reported to be at 3-5% (American Psychiatric Association, 2013). Arnett et al. (2012), Barkley et al. (2006), Polanczyk et al. (2007), Polanczyk et al. (2014) and Visser et al. (2014) reported the prevalence of ADHD among school-age children to be between 5.9% and 11.4% but indicated that the prevalence varies across the age span. Children with ADHD develop more slowly than neurotypical comparisons of the same age and therefore show age-inappropriate levels of attention and motor activity, and display levels of impulsiveness that interfere with social and academic functioning (Bálint et al., 2009).

The prevalence rates for children between 6-12 years are 11.4%, those in the age range 13-18 years are 8%, whereas those 19 and over are at 5% (Arnett et al., 2012; Polanczyk et al., 2007). Bakare (2012) suggests that the prevalence of ADHD amongst school children in Africa varies between 5.4% and 8.7%. In South Africa, Meyer et al. (2004) found the prevalence of ADHD among primary school children of all ethnic populations in the Limpopo Province to be 5.5%.

2.1.2 Adult onset-ADHD

ADHD is a disorder that frequently continues into adulthood. Globally, it is estimated that 5% of adults are affected by ADHD (Song et al., 2021), in South Africa the prevalence of adult-onset ADHD range between 2.5% and 4,3% (Schoeman et al, 2017). Previous research on ADHD in younger adulthood has shown that poor EF (working memory, switching, inhibitory control and planning is of central importance in the disorder (Boonstra et al., 2005). Deficits in EF appeared to contribute to occupational and interpersonal problems in adults with ADHD (Barkley & Murphy, 2010; Schoeman et al., 2017). Older adults with ADHD showed serious impairments in their quality of life comparable to the levels found in younger adults and can impair their educational attainment, work performance, such as reduced productivity, increased absenteeism, substance abuse, financial problems and accidents (Rosello et al., 2020).

2.1.3 Age

ADHD emerges in childhood, with the age of onset before 12 years and the mean age of onset between infancy and seven years (Bálint et al., 2009; Barkley, 1997), and continues into to adulthood (American Psychiatric Association, 2013). ADHD is characterised by a delayed maturation of the cortical cerebral cortex. There are age differences reported in EF performance as a result of the cortex of a seven-year-old being less mature than that of a 12-year-old (Diamond, 2002; Shaw et al., 2012). The maturational delay affects core cognitive processes such as response inhibition, temporal processing and working memory (Barkley, 1997; Castellanos & Tannock, 2002; Nigg & Casey, 2005; Sonuga-Barke, 2002; Toplak et al., 2006). The age of attaining peak cortical thickness is 10.5 years in children with ADHD and 7.5 years for unaffected children. The delay is most prominent in the prefrontal regions that are important for EFs, attention and motor planning (Shaw et al., 2007).

2.1.4 Gender

Epidemiological studies suggest that ADHD is three to four times more common in male than in female children. The male-to-female ratios of ADHD range from 2:1 to 10:1 (Nøvik et al., 2006; Ramtekkar et al., 2010; Willcutt, 2012), with higher male-to-female ratios found in clinical versus population-based samples (Skogli et al., 2013; Slobodin & Davidovitch, 2019). Boys with ADHD tend to have more externalising disorders such as Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD), and girls tend to have more internalising symptoms such as depression and anxiety disorders (Skogli et al., 2013). Furthermore, research on gender differences suggests that girls with ADHD may be more consistently under-identified and underdiagnosed because of differences in the expression of the disorder (Gaub & Carlson, 1997; Quinn, 2008; Sciutto & Eisenberg, 2007).

Females with ADHD are reported to have fewer hyperactivity/impulsiveness (H/I) symptoms and more inattention symptoms when compared with males with ADHD (Biederman, 2005; Gaub & Carlson, 1997; Gershon, 2002). Most researchers find no gender differences in EF tasks such as working memory, set-shifting and inhibition (Barkley, 1997;

Biederman et al., 2007; Castellanos et al., 2006; Fares, 2010; Houghton et al., 1999; Roufael et al., 2012; Rucklidge, 2010; Seidman et al., 2005; Sjöwall et al., 2012; Skogli et al., 2013; Welsh et al., 1991; Willcutt et al., 2005). However, some studies have shown gender differences in EF in children with ADHD (Newcorn et al., 2001; Rucklidge & Tannock, 2002).

2.2 Aetiology

ADHD is regarded as a hereditary disorder (Cheung et al., 2012; Faraone & Larsson, 2019; Faraone et al., 2005; Paloyelis et al., 2010; Willcutt et al., 2007). The heritability of ADHD is estimated to be 77-88%, with genes playing a vital role in the aetiology of ADHD (Faraone & Larsson, 2019). However, no single genetic risk factor has been identified (Rovira et al., 2020), and it is understood to result from the interaction of multiple genetic variants, each of small effect (Thapar et al., 2013). ADHD does appear to run in families, where one or two of the children present with ADHD and/or a parent are similarly affected, although the degree of severity of symptoms may vary across family members (Gillberg, 2003; Faraone & Larsson, 2019). Evidence for a genetic basis for ADHD includes greater concordance in monozygotic than in dizygotic twins, and biological parents of children with the disorder have a higher risk for ADHD than adoptive parents (Biederman & Faraone, 2005; Castellanos et al., 2005; Castellanos & Proal, 2012; Castellanos & Tannock, 2002).

A meta-analysis of genome-wide association studies of ADHD revealed the first genome-wide significant risk loci and indicates the role for common variants in the polygenic architecture of ADHD (Demontis et al., 2019). It indicated several of the loci are located in or near genes that implicate neurodevelopmental processes that are likely to be relevant to ADHD, including FOXP2, SORCS3 and DUSP6. The GWAS meta-analysis implicates FOXP2 and other biologically informative genes as well as constrained regions of the genome, as important contributions to the aetiology of ADHD (Demontis et al., 2019).

There is evidence, that the genes involved are especially the dopaminergic transmission and serotonin transporter genes (Conley, 2016; Daley et al., 2008). The dopamine genes that have been associated with ADHD are the dopamine transporter (DAT1) gene (Conley, 2016) and the dopamine receptor gene (DRD4) (Conley, 2016; Smalley et al., 1998; Swanson et al., 1998). Impaired dopamine transmission has a strong correlation with typical ADHD symptoms such as hyperactivity, impulsiveness, and inattention. Swanson and Castellanos (1998) have suggested that specific alleles of these dopamine genes may alter dopamine transmission in the neural networks implicated in ADHD. The 10-repeat allele of the DAT1 gene may be associated with increased dopamine re-uptake, and the 7-repeat allele of the DRD4 gene may be associated with a sub-sensitive postsynaptic receptor. The DAT1 allele, according to Cook et al. (1995), is a high-risk allele for ADHD symptoms, as well as the DRD4 allele (Conley et al., 2016; Swanson et al., 2000). The DRD4 seems to show differential association with ADHD and may be one of the strongest risk factors among the common genetic variants (Brookes et al., 2006; Gizer et al., 2009). The DRD4 is expressed in areas of the brain which include the frontal lobe regions such as the orbitofrontal cortex and the anterior cingulate (De La Garza & Madras, 2000; Li et al., 2007) and may produce underactivity in the dopamine pathways, in both the mesocortical and mesolimbic pathways (which are rich in D4-dopamine receptors in the frontal lobes).

As suggested above, dopamine dysfunction plays a vital role in the neurobiology of ADHD. ADHD-like symptoms might be produced by genetic factors and environmental factors which may alter dopamine agonist (DA) functioning (Thapar et al., 2012). The chronic intake of DAs, such as cocaine, crack and amphetamines, will produce a down-regulation of dopamine synthesis. This down-regulation will persist for some weeks after the drug intake, and ADHD-like symptoms are observed during the period until the dopamine functions normalise (Johansen, 2002, Sagvolden et al., 2005). Petersen and Posner (2012) and Sagvolden (2000) propose that low levels of DA in the prefrontal-striatal circuits can lead to the inattention, impulsiveness, and hyperactivity symptoms of ADHD; this is associated with the dopamine-beta hydroxylase (DβH) enzyme, which converts dopamine into noradrenaline (Hawi et al., 2003, Smith et al., 2003).

ADHD also involves impaired neurotransmitter activity in the functional regions of the brain (i.e., the frontal cortex that controls high-level functioning, including maintaining attention, organisation and executive function). A deficiency of noradrenaline within this region may cause inattention, problems with organisation, and impaired executive functioning (Sagvolden et al., 2005). On the other hand, the lack of noradrenaline in the reticular activating system (RAS) can also cause inattention, impulsiveness, or hyperactivity (Riccio et al., 2002)

Environmental factors, including the prenatal factors to which the foetus is exposed before birth (Conley et al., 2015; Glover, 2011, Thapar et al., 2013), have been described as risk factors for developing ADHD. Maternal smoking during pregnancy has been indicated as a risk factor for ADHD (Thapar et al., 2009; Thapar et al., 2013). D'Onofrio et al. (2008) and He et al. (2020) proposed that there is a relationship between prenatal maternal exposure to cigarette smoke and children with ADHD symptoms. It is understood that smoking during pregnancy, or exposing a child to cigarette smoke, affects many of their physiological processes, which in turn generate a greater risk of developing ADHD. It impairs cognitive function, especially working memory and response inhibition (Bennett et al., 2013). Dopaminergic activity is also modulated by the effects of nicotinic receptors in maternal smoking during pregnancy (Biederman, 2005; Curatolo et al., 2010; Kotimaa et al., 2003). Low birth weight is also an increased risk for ADHD and children born pre-term are four times more likely to be diagnosed with ADHD, particularly the inattentive subtype (Johnson et al., 2010). Further, maternal stress during pregnancy is also associated with ADHD (Glover, 2011). Pregnancy and delivery complications may also be considered to cause ADHD by harming the brain at early stages of its development, while oxygen deprivation tends to involve exposure of the foetus to the risk of low birth weight, cerebral palsy and autism (Smith et al., 2016). In addition, children with mild traumatic brain injuries are also at risk for developing ADHD (Faraone & Larsson, 2019).

Neuro-anatomical abnormalities in children with ADHD are demonstrated in several studies (Castellanos & Tannock, 2002; Orylska et al., 2019; Qian et al., 2010), which reported decreased cortical volume, decreased grey matter, decreased white matter, cortical thickness and asymmetrical abnormality, as well as delay in cortical maturation of the frontal cortex. The ENIGMA study identified amygdala, accumbens and hippocampus volumes to be smaller in participants with ADHD (Hoogman et al., 2017, 2019). Structural imaging studies have also shown reduced size of the PFC in persons with ADHD and evidence of reduced blood flow or metabolism in the PFC (Arnsten & Li, 2005). Several other brain regions, such as the basal ganglia, cerebellum and corpus callosum, are also found to be smaller in children with ADHD, when compared to neurotypical children (Castellanos et al., 2001; Seidman et al., 2004; Sowell et al., 2003). The mean age at which peak cortical thickness is attained in the cerebrum is around seven years in normally developing children, whereas in children with ADHD peak cortical thickness is reached around 10 years, with the delay most prominent in the lateral prefrontal cortex. Grey matter volumes reach their peak only at 12 years in the frontal lobes (Shaw et al., 2007). Frontal lobe dysfunction is associated with deficits in various areas of executive functioning (Castellanos & Proal, 2012; Conley et al., 2015).

2.3 ADHD Comorbidities

Children with ADHD may present with externalising and/or internalising comorbidities (Antshel et al., 2016; Armstrong et al., 2015; Brown, 2013; Hinshaw, 2018). About 64% of children with ADHD present with internalising disorders (Franke et al., 2018; Meinzer et al., 2013; Sciberras et al., 2014), while up to 50-70% of children with ADHD present with externalising disorders.

2.2.1 Externalising Comorbidities

The most common externalising comorbidities in children with ADHD are Oppositional Defiant Disorder (ODD), Conduct Disorder (CD) and substance use disorders, which become more of a problem during adolescence and even more so in adulthood (Franke et al., 2018). The externalising comorbidities are more prevalent in males, as they are linked to the H/I component which occurs more in males (American Psychiatric Association, 2013; Biederman et al., 2006; Edvinsson et al., 2013). Many cross-sectional studies indicated that children with ADHD and externalising comorbidities are at greater risk of poorer peer functioning, peer rejection, and lower social preference because of their impulsive behaviour (Bastiaansen et al., 2004; Hoza et al., 2005; 2007; Normand et al., 2011; Steinhausen et al., 2006).

2.2.2 Internalising Comorbidities

The internalising comorbidities in children with ADHD mainly involve depression and anxiety disorders. Eyre et al. (2017), Leirbakk et al. (2015) and Mphahlele et al. (2020) indicate that children with ADHD display more symptoms of anxiety and depression compared to their neurotypical peers. The internalising comorbidities are higher in females because of inattention, which occurs more in females (American Psychiatric Association, 2013; Biederman et al., 2006; Edvinsson et al., 2013).

2.2.3 Learning Disabilities

ADHD is characterised by developmentally inappropriate and disabling levels of inattentiveness, hyperactivity and/or impulsiveness which are often accompanied by associated learning problems (Barkley & Murphy, 2006; Yoshimasu et al., 2010). About 20-30% of children with ADHD also have a specific learning disability in reading, mathematics or writing (DuPaul et al., 2013; Klorman et al., 1999; Semrud-Clikeman et al., 1992; Volpe et al., 2006). Literature supports that there is a high degree of overlap between reading disorder, mathematics

skills, and symptoms of ADHD; this is because of shared limitations in working memory (Denckla, 1996; Hart et al., 2010). Children with ADHD and learning disabilities have more pronounced problems with attention (Mayes et al., 2000), processing speed and memory (Webster-Stratton, 1996), than children with only ADHD. There is also evidence of genetic abnormalities and neurochemical factors that are common to both ADHD and learning disability (Katz et al., 2011; Willcutt et al., 2005). Children with ADHD have difficulties with learning, as their attention, hyperactivity or impulsive behaviour in school may affect their academic productivity (Dietz & Montague, 2006; DuPaul & Volpe, 2009; Willcutt et al., 2005; Yoshimasu et al., 2010), and they are at a higher risk for grade retention, placement in a special education classroom and dropping out of school (Barkley, 2008; DuPaul & Volpe, 2009).

2.4 Protective factors of ADHD

There are several protective factors that are associated with ADHD. These factors may also assist in destigmatizing ADHD and improve mental health of children with ADHD. Examples of protective factors included: healthy socio-economic status of families, social support and stable social environment which can protect a child from the expression of serious ADHD symptoms. Early intervention of ADHD, the use of medication and psychoeducation for teachers and parents can also protect the child from the stigma associated with ADHD and promote a high sense of coherence and self- efficacy. Self- efficacy is a concept that describes one’s own belief in their competences to reach goals. Positive self-perceptions of one’s own competence protects children from negative outcomes of ADHD (Dvorsky & Langeberg, 2016; Wűstner, 2019).

2.5 Cross cultural context highlighting the most important causal factors

In South Africa, the diagnosis of ADHD in the various children’s populations is hampered by lack of knowledge, stigma surrounding the disorder, lack of access to health care services, lack of resources and cultural beliefs. Little is understood has the causal factors that operate within the populations studied. In both urban and rural areas most people still believe in traditional healers, with a minority of people in remote rural areas believing that their children are bewitched. Such beliefs delay or become a barrier for seeking health care timeously.

2.6 Executive Functioning (EF)

According to Brown (2009) and Ciuluvica et al. (2013), ADHD is not only a behavioural disorder that is characterised by hyperactivity and inattention in children, and excessive restlessness and impulsiveness in adults, it is also a cognitive disorder. It involves a developmental impairment of EF, the controlling system of the brain (Ciuluvica et al., 2013). EF is a complex cognitive control process, which enables self-regulation and self-directed behaviour towards a goal, modifies behaviour in the light of new information, makes decisions and evaluates risks, plans, prioritises and sequences actions and solves novel problems (Miyake et al., 2000; Miyake & Friedman, 2012; Nejati et al., 2020).

Symptoms of ADHD arise from a primary deficit in specific EF domains, such as response inhibition, working memory, cognitive flexibility/or shifting and planning (Arnsten et al., 2015; Ciuluvica et al., 2013; Faraone, 2015; Garon et al., 2008; Zelazo et al., 2016). Children with ADHD show impairments in judgement, organisation, planning and decision-making, as well as in behavioural disinhibition and cognitive flexibility (Nigg 2002; Ogilvie et al., 2011). As a result, they experience problems with social skills and often exhibit low self-

esteem, low frustration tolerance and impaired academic performance (Rhodes & Kelley, 2005; Titz & Karbach, 2014). The focus in this study is on deficits in planning behaviour, working memory, and cognitive flexibility or set-shifting in children with ADHD that are commonly reported in the literature (Faraone, 2015; Miyake et al., 2000; Willcutt et al., 2005).

2.6.1 Behaviour Planning

Behaviour planning is one of the key components of EF deficits in ADHD and is defined as the categorising and organising of the steps and elements required to carry out an intention (Chiang & Gau, 2014). According to Allain et al. (2005), planning involves the ability to categorise behaviour to achieve a specific goal and to envisage the series of intermediate steps required to achieve the goal. The planner must also be able to conceive alternatives, weigh and make choices, and entertain both sequential and hierarchical ideas necessary for the development of a conceptual framework or structure that will give direction to the carrying out of a plan. For example for a child to study, they would set aside some time, create a study time table and draw a mind map. Good impulse control and reasonably intact memory functions are also necessary in planning (Kaller et al., 2012).

The literature suggests that children with ADHD often show poor performance on tasks that require strategic planning. Boshomane et al. (2020), Kofman et al. (2008), Mokobane et al. (2020), Pila-Nemutandani and Meyer (2016) and Schmitz et al. (2002) noticed that children with the combined (ADHD-C) presentation were highly deficient in behavioural planning, and faced more difficulties, when compared to both the predominantly hyperactive- impulsive (ADHD-HI) and predominantly inattentive (ADHD-PI) presentations and neurotypically children. Nigg et al. (2002) also found that children with ADHD-C typically had problems with planning ahead. Lezak et al. (2012) further indicate that persons with ADHD experience a lack of planning due to their inability to think ahead about the future arrangements they should make. Individuals with such problems might experience issues regarding the timely completion of projects, keeping appointments, and inability to fulfil an obligation due to a failure in planning.

2.6.2 Working Memory

Working memory is the ability to both retain and manipulate information during a short period of time (Nee et al., 2013), for example remembering three objects or looking at words on a card and recalling it. It plays a critical role in guiding everyday behaviour and underlies the capacity to perform complex tasks such as learning, comprehension, reasoning and planning (Baddeley, 2007). Children’s working memory skills are associated with their academic progress in reading and mathematics (Gathercole et al., 2006; Pickering & Gathercole, 2004). Impairment in working memory is consistent with symptoms that define ADHD, such as making careless mistakes, the inability to follow through on instructions, failing to finish tasks and/or difficulty with organising (American Psychiatric Association, 2013).

Children with deficits in working memory often have difficulty remembering things, even for a few seconds, and tend to lose track of what they are doing as they work (Stievano et al., 2017). Cockcroft (2011) and Stievano et al. (2017) indicated that children with ADHD often experience working memory difficulties. They have problems with suppressing competing stimuli and are less likely to hold information in mind as they are more distractable (Barkley, 1997). Barkley (1997) indicated that a core deficit in inhibitory processes offers the simplest explanation of the working memory deficits in children with ADHD. The working memory of children with ADHD reflects developmental delays in cortical maturation of the prefrontal cerebral regions, and in a range of central executive functions such as attention, motor planning, inhibition, shifting and updating (Shaw et al., 2007).

2.6.3 Cognitive Flexibility or Set shifting

Cognitive flexibility or set shifting is the ability to shift strategies between multiple operations and mental states (Buttelmann & Karbach, 2017; Diamond, 2013; Miyake et al., 2000; Monsell, 1996; Re et al., 2016). For example, attending to food cooking while washing the dishes. It is usually assumed that the ability to shift between tasks or mental sets is an essential aspect of executive control and is thus a component of EF. The shifting process involves the disengagement from an irrelevant task set and the subsequent active engagement with a relevant one (Monsell, 1996). In a changing environment, behaviour has to be adaptive and flexible (Kehagia et al., 2010). Children with ADHD can be slow at switching between stimuli or between sets of stimuli to control behaviour which is appropriate to changing situations (Oades & Christiansen, 2008).

The executive-oriented shifts are regulated primarily by the frontal lobes, including the anterior cingulate or the ‘anterior attention network’ (Miyake et al., 2000). One key symptom of frontal lobe impairment is perseveration or repetition of the same response repeatedly, even when it is no longer appropriate. Maturation of the prefrontal cortex plays an important role in the development of shifting. It is often understood in terms of difficulty in shifting of mental sets (Ardila, 2008). Lesions of the dorsolateral PFC impair the ability to shift attentional sets (Manes et al., 2002).

Individuals of all ages afflicted with ADHD have reported difficulty with set-shifting that are related to abnormal activity of the PFC, a brain region that has been associated with cognitive flexibility (Dalley et al., 2004; Wood et al., 2016). Neurophysiological and neuro-imaging studies report roles for the inferior frontal regions in switching between stimuli (Beck et al., 2001; Jemel et al., 2002; Moriguchi & Hiraki, 2009), as well as roles for parts of the intraparietal sulcus in switching between plans contingent on set.

Dopamine dysfunction plays a pivotal role in the neurobiology of cognitive flexibility, especially a hypofunctioning mesocortical dopamine branch, which supplies the prefrontal cortex (Johansen et al., 2002; Sagvolden et al., 2005; Tripp & Wickens, 2009). Dopamine neurotransmission in the medial striatum and PFC is critical for basic reinforcement learning and the integration of negative feedback during reversal learning, whilst orbitofrontal serotonin

likely mediates low-level flexibility, by reducing interference from prominent stimuli (Kehagia et al., 2010). Dopamine neurons are thought to be important for learning. The deficient functioning of the D1 and D2 receptors in the lateral PFC impairs learning of new stimulus- response associations and cognitive flexibility (Klanker et al., 2013). Damage to different prefrontal areas results in deficits in separate forms of cognitive flexibility. Damage to the orbitofrontal cortex (OFC) is thought to impair reversal learning but not attentional set-shifting (Boulougouris et al., 2007; Hornak et al., 2004). Cognitive flexibility has been associated with lower academic achievement, lower intelligence, and increased ODD and hyperactive/impulsive ADHD symptoms (Magalhães et al., 2020; Nigg, 2017; Ropovik, 2014; Titz & Karbach, 2014).

2.7 Theoretical Framework

Many theoretical models have been proposed to understand the aetiology and development of ADHD and to provide intervention strategies (Barkley, 1997; Cornblatt & Malhotra, 2001). This is partly due to the complex nature of ADHD and because, neuro-anatomically, it seems to involve many brain structures and this further complicates our understanding. Each model has its own strengths and weakness. For this study, four theories are used to explain planning, working memory and set-shifting in children with high levels of ADHD symptoms. These models are Dynamic Development Theory (DDT), Barkley Theory of Executive Functioning and the Dual Pathway Model. Baddeley's Model is included to explain specifically aspects on working memory. The four theoretical models individually and collectively are used to explain the findings of our study.

2.7.1 Dynamic Developmental Theory (DDT)

The DDT (Sagvolden et al., 2005) is an extension of these authors' neurobiological theory (Johansen et al., 2002), which postulates that ADHD symptoms could be a result of altered dopamine functioning, which fails to appropriately modulate non-dopaminergic (primarily glutamate and GABA) signal transmission. The various dopaminergic systems might not be equally dysfunctional in all individuals with ADHD. Further, these systems are not operating in isolation, but are closely linked with other neurotransmitters and neuromodulator systems, and an imbalance in one will inevitably to some degree also affect the functioning of the other systems.

As suggested above, ADHD is associated with altered dopamine function (Cook et al., 1995; LaHoste et al., 1995; Sagvolden et al., 2005; Swanson et al., 1998). Dopamine release in the nucleus accumbens is associated with reinforcement. Dopamine release may be seen as a teaching signal working according to a prediction rule (Aase & Sagvolden, 2005). The behaviour of children with ADHD and neurotypical children is differently affected by reinforcement contingencies. The reinforcement contingencies are the conditions under which a response produces a reinforcer. Reinforcers act on responses that have already taken place by increasing the probability of future responding.

Reinforcers may vary along several dimensions like density (frequency), the temporal response-reinforcer relationship (contiguity), predictability, and value (attractiveness). This relation between response and reinforcer is commonly known as the ‘delay-of-reinforcement gradient’ or simply as the ‘delay gradient’.

Reinforcers are required both in acquisition and in maintenance of behaviour (Johansen et al., 2002; Sagvolden et al., 2005). Children with ADHD often experience difficulty sustaining attention, which is associated with a lack of motivation (Luman et al., 2005; Sonuga-Barke, 2005) and altered reinforcement (Sagvolden et al., 2005), and is marked by narrower than normal (shorter and steeper) delay gradients when behaviour is associated with consequences (Johansen et al., 2002). These children prefer an immediate reinforcement and cannot wait for a delayed one (Sonuga-Barke et al., 1992; Sonuga-Barke et al., 1998).

Dopamine hypofunctioning might in most cases be genetically determined, while in other cases, it might be induced by environmental factors like drugs of abuse or pollutants

(Johansen et al., 2002; Sagvolden et al., 2005). The prefrontal loop is involved in directing attention and selecting the behaviour needed to achieve a specific goal in a given situation. A dysfunctioning mesocortical dopamine branch will cause attention response deficiencies (poor attention responses toward a target and poor behavioural planning - poor EFs). This theory further postulates that the hypofunctioning dopamine branches give rise to primary individual predispositions, as they predict that behaviour and symptoms in ADHD result from an interplay between individual predispositions and their surroundings (Tripp & Wickens, 2009). The mesocortical branch connects the ventral tegmentum to the cerebral cortex, in particular, the frontal lobes. This branch is crucial to the normal cognitive function of the dorsolateral PFC, which is associated with behaviour planning, working memory and cognitive flexibility (Gendle et al., 2013; Oades et al., 2005; Sagvolden et al, 2005).

The functioning of the midbrain dopaminergic neurons and their projection areas, particularly the prefrontal cortex and striatum, is implicated in ADHD (Castellanos et al., 1997; Castellanos & Tannock, 2002; Drevets et al., 2001; Sagvolden & Sergeant, 1998; Solanto et al., 2001; Teicher et al., 2000). The neurons in the frontal cortical areas send excitatory glutamatergic projections to the generally silent neurons of the striatum, including the nucleus accumbens (ventral striatum). These structures then send inhibitory GABAergic projections to the normally active neurons of the pallidum and the substantia nigra, which in turn inhibit thalamic nuclei through GABAergic connections. It is the thalamus that completes the circuit by sending excitatory glutamatergic projections to cortical neurons.

Three circuits have distinct/specific functions: *the prefrontal loop* (mesocortical) is involved in functions such as planning of future behaviour, short-term memory and directing attention (Petersen & Posner, 2012; Sagvolden et al., 2005). The *limbic loop* (mesolimbic) is responsible for reinforcement and extinction of behaviour (Schultz, 2002; Waelti et al., 2001) and the third, the *motor loop* (nigrostriatal), is involved with timing, and starting and stopping responses in the acquisition, retrieval and relearning of programmes for sequential motor tasks and non-declarative habit learning (Johansen et al., 2002). The authors stated that these three branches (mesolimbic, mesocortical and nigrostriatal) are dysfunctional in ADHD. For this study, the focus was on testing the function of the cortical areas supplied by the mesocortical branch, which cause various attention and EF deficiencies.

The DDT emphasises that the neurotransmitters (dopamine system) play an essential part in EFs, especially in planning and cognitive flexibility supplying the PFC (Arnsten & Li, 2005; Miyake & Friedman, 2012; Sagvolden et al., 2005). The model also emphasises that the prefrontal loop (mesocortical) is involved in functions such as planning of future behaviour, short-term memory and directing attention. Further, it gives rise to poor working memory, planning, and also explains that altered dopaminergic functions play a pivotal role in explaining the symptoms of ADHD, namely inattentiveness, hyperactivity and impulsiveness. A hypofunctioning mesocortical dopamine branch will contribute to deficits in EFs.

The benefit of the DDT is that it holds a theoretical position on all three symptoms of ADHD, hyperactivity, impulsivity and inattention. It is based on the hypothesis that altered dopaminergic functions play a pivotal role in explaining the symptoms of ADHD. The DDT helps explains that a dysfunctioning mesocortical dopamine branch will cause attention response deficiencies associated with behavioural planning, working memory and set-shifting. The shortcoming of this model is that the data supporting this theory is based on animal data, although the theory is based on behaviourism (Johansen et al., 2005).

2.7.2 Barkley's Theory of Executive Functioning

Barkley (1997) proposes that a deficit in behavioural inhibition is the core deficit of ADHD, which in turn, creates disturbances in five neuropsychological functions: working memory; internalisation of speech; self-regulation of affect, motivation, and arousal; behaviour analysis and synthesis; and motor control, fluency, and syntax. Barkley also indicates that this deficit might lead to the impairments observed in the psychological and social abilities associated with the other four EFs (Barkley, 1997; Yazdi et al., 2018). According to Barkley (1997), the configuration of deficits found in children with ADHD suggests the involvement of EFs, including working memory. EFs have been found to correspond with the symptoms of ADHD.

Firstly, Barkley (1997) suggests that behavioural inhibition affects motor control, fluency and syntax, that is, the execution of behavioural programmes and motor execution systems. Barkley proposes that disinhibition is the core deficit in ADHD (Barkley, 1997). Secondly, there is nonverbal memory, which enables a person to have a sense of the past, the future, and cognitive awareness of the self. Thirdly, internalisation of speech is another EF (i.e.,

self-talk) used to evaluate and direct behaviour of the self; this allows a person to reflect before acting and select a behaviour or action that is going to help them reach their goal (Barkley, 1997).

Fourthly, self-regulation of affect allows a person to consider their emotional responses before responding; this helps to modify inappropriate responses. Further, self-regulation promotes self-motivation and helps the person carry out boring and repetitive tasks that have no motivating factors. Self-regulation also helps a person to be more objective and realistic in their self-evaluation (Barkley, 1997). Lastly, is reconstitution, a form of play that allows the person to analyse the experience in their working memory to synthesise new responses, which they accept or reject based on the likelihood that the response can help them to achieve their goal. Reconstitution also promotes effective and flexible problem-solving in cases requiring the generation of alternative plans or actions (Barkley, 1997).

The model emphasises nonverbal memory and reconstitution, which allow a person to analyse their experiences in their working memory to synthesise new responses (Barkley, 1997). According to Barkley, (1997) the pattern of deficits found in children with ADHD includes in EFs and working memory. In Barkley's model, working memory is held responsible not only for keeping stimuli in mind, but also for allowing goal-directed behaviour.

Barkley emphasised EF and stated that although people with ADHD, often report having a good memory, they experience difficulty with information retrieval when necessary and struggle to keep track while attending to different tasks. Barkley's model stresses the importance of self-directed behaviour to explain the difficulties of children with ADHD.

According to this model, successful EF related behaviour is regulated in the prefrontal cortex and requires the individual to use six self-directed actions: attention, restraint (e.g., inhibition), sensing (e.g., non-verbal working memory), speech (verbal working memory), emotions and motivations, and finally planning, to adapt their behaviour and achieve a desired goal. The shortcoming of this model is that Barkley focuses on one function more than the others. He has proposed that out of the five EFs, response inhibition is most obviously deficient in individuals with ADHD and this deficit might lead to the impairment observed in the psychological and social abilities associated with other four EFs (Barkley, 1997).

2.7.3 Baddeley's Model

Baddeley et al.'s (1986) influential multi-component model of working memory includes three components, two of which are specialised for the maintenance of speech-based, phonological information (the phonological loop) and visual and spatial information (the visuospatial sketchpad). The model also includes a central control structure, called the central executive, which is considered responsible for the control and regulation of cognitive processes (executive functions) and is often linked to the functioning of the frontal lobes (Miyake et al., 2000). Working memory is comprised of the central executive which is primarily responsible for focusing and dividing controlled attention among concurrent tasks and independent phonological and visuospatial storage/rehearsal subsystems (Baddeley, 2007). ADHD-related working memory deficits were apparent across all three cognitive systems, with the largest magnitude of deficits apparent in the central executive.

Verbal and auditory information is temporarily stored and processed in the phonological loop. The phonological loop system stores and rehearses speech-based information and is necessary for language acquisition. It is for temporary storage of phonological information. The visuospatial sketchpad system manipulates memories of visual images and spatial information in the temporary storage of visuospatial information. The central executive is assumed to be an attention-control system which processes information from these two short-term storage systems (Kokubo et al., 2012). It allows for the manipulation and storage of information in working memory by means of supervising and co-ordinating assistant systems (Repovš & Baddeley, 2006). It is also a general domain system that facilitates the ongoing interaction of domain-specific storage, that is phonological or visuospatial information, controlling attention rather than storing information (Kane et al., 2007). The main functions of the central executive are switching, updating and inhibition (Dehn, 2008; Miyake et al., 2000).

Baddeley's model explains that working memory impairments in children with ADHD are likely to be affected by the attentional process. It also indicates that children with ADHD tend to perform poorly in complex working memory tasks that rely heavily on the central executive (Mariani & Barkley, 1997; Rosenthal et al., 2006).

The model emphasizes the central executive which is considered responsible for working memory, switching and inhibition and is often linked to the functioning of the frontal lobes. While Barkley referred to non-verbal working memory, his theory does not focused on it. Baddeley however, emphasised the visuospatial sketchpad in his information processing rendition of working memory (Baddeley, 1986).

2.7.4 Dual Pathway Model

According to Sonuga-Barke's dual pathway model (2002), children with ADHD display problems with set-shifting and working memory, because ADHD may not only pertain to dysregulation of the thought and action pathway, but also to the motivational style pathway.

The first of these pathways is manifested in a primary, inhibitory dysfunction, which is mediated by secondary cognitive and behavioural dysfunctions, which in turn leads to faulty task engagement (deficits of set-shifting and working memory) and to symptomatic behaviour (i.e., hyperactivity and inattentiveness).

The second pathway, on the other hand, is involved in reward mechanisms (Sonuga-Barke et al., 2003). According to the delay aversion concept, children with ADHD experience higher sensitivity to delays than their peers. This leads to decisions that entail choosing a smaller-sooner reward over larger-later rewards on tasks designed to measure the relationship between impulsivity and delay aversion. Delay aversion is expressed as certain behaviour theorised to be motivated by the desire to escape or avoid delay. Children with ADHD are more likely to act thoughtlessly because they avoid waiting. They may demonstrate elevated frustration when they feel annoyed owing to an unexpected delay during task performance and may show early detachment and inattention during long and tedious tasks. This leads to impulsive choices and perseverating responses. Sonuga-Barke's dual pathway model indicates that children with ADHD display problems with set-shifting and working memory.

One of the advantages of the dual pathway model is that it is first model to combine the two theories of ADHD – one which is characterised by the inhibitory deficits and the other by delay aversion (Sonuga-Barke, 2003). The theory explains the problems with set-shifting and working memory due to dysregulation of the thought and action pathway. The main focus of this theory is on impulsiveness, inattentiveness and hyperactivity are considered to reflect attempts to reduce subjective experience of delay in situations – where delay cannot be avoided. The theory places less emphasis on EF and adopts a more general explanation for ADHD symptomatology. The shortcoming of this theory is that it requires further modification and clarity regarding motor delays – a characteristics of ADHD.

2.8 Conclusion

This chapter presented a review of the research on ADHD, defined in terms of epidemiology, aetiology, age, gender, comorbidities and theoretical models. The literature review supports the view that ADHD is a common childhood disorder, with a high incidence of comorbidity, and that it is a neurological disorder with primary deficits in EF. The next chapter presents the methodology of the study.

CHAPTER 3

METHOD

This chapter details the methodology used in the study and includes the study design, study setting, data collection procedure, inclusion and exclusion criteria and instruments. The population sample size, specific procedure, instruments and data analysis are discussed in each manuscript. However, the data management and ethical considerations have also been considered in this chapter.

3.1 Research Design

For the main study, a quantitative, cross-sectional, case-control study design was used. Case-control studies are often used to identify factors that may contribute to a medical condition by comparing subjects who have that condition or disease (the ‘cases’) with people who do not have the condition or disease but are similar (the ‘controls’) (Mann, 2003). The study had another component: a predictive design has been used. The predictive design is a statistical technique in which probability is applied to predict the outcome. It is chiefly concerned with forecasting (predicting) outcomes (Johnson, 2001).

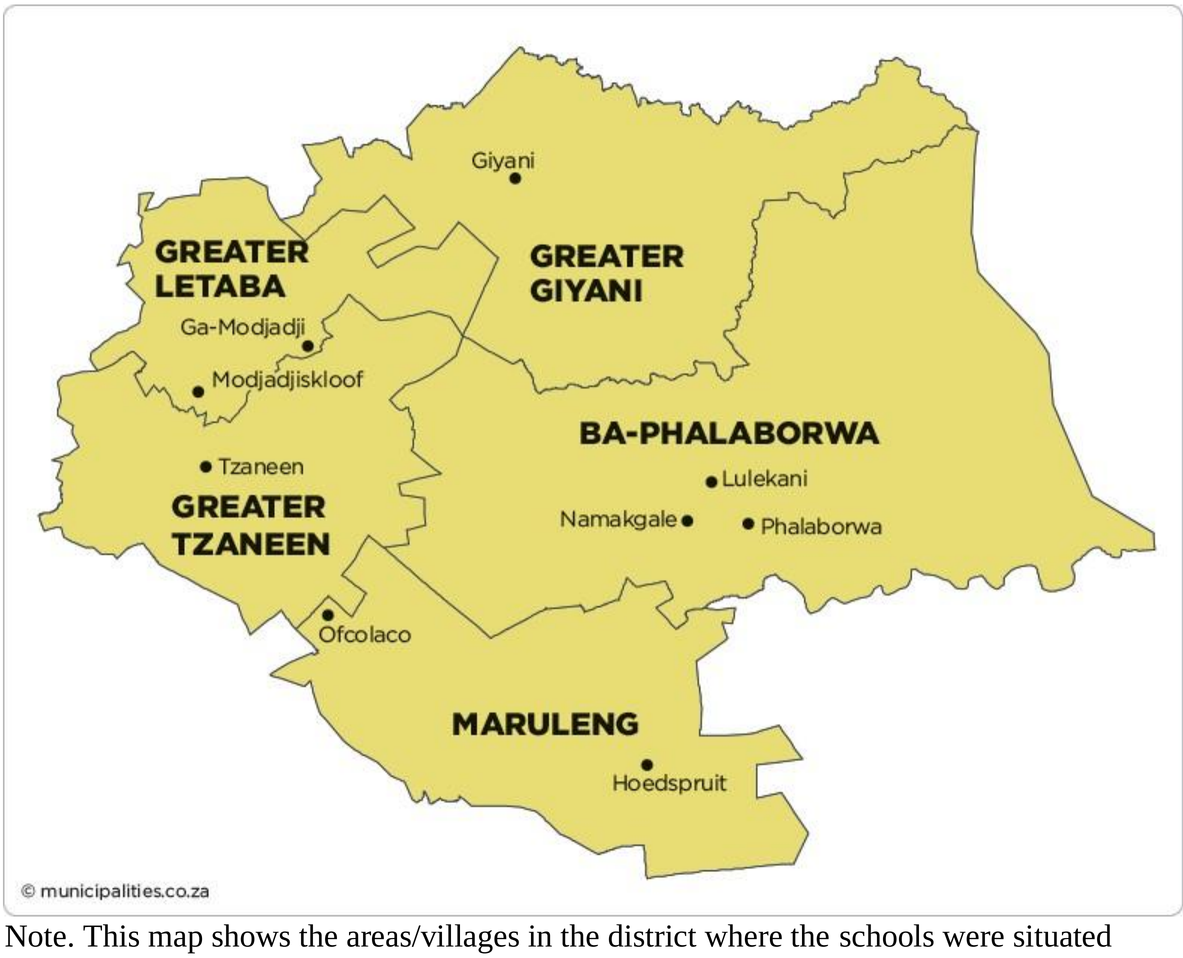
3.2 Study Area

The study was conducted in the Greater Tzaneen Municipality, Limpopo Province, South Africa (see Figure 1), which is one of the five municipalities of the Mopani District Municipality. According to Statistics South Africa (2016), the population of Greater Tzaneen Municipality is 416 146, with 52% being female. The age distribution is as follows: 4.4% are over 65 years, 66% are 15 to 64 years and 29.6% are younger than 14 years. Several languages are spoken in the province: 48% are Sepedi-speaking, 42% speak Xitsonga, 3% Sesotho, 2% Afrikaans and 1% English. Greater Tzaneen Municipality has three tribal authorities:

Bathlabine, Maake and Nkuna (Mohlaba). The data for the study was collected in all three of these areas.

Figure 1

Map of the Greater Tzaneen Area



Note. This map shows the areas/villages in the district where the schools were situated and data was collected.

3.3 Sampling

The researcher used non-probability sampling (convenience sampling). This sampling method is a procedure where the study population is selected as they are easily accessible

(Maree, 2016; Struwig & Stead, 2013). The disadvantage of convenience sampling is that bias and variability of estimates cannot be measured, and it does not result in a representative sample (Maree, 2016; Struwig & Stead, 2013)

3.3.1 Sample Size

One hundred and fifty-six children, between 6 and 15 years of age (*M*=11.7; *SD*=1.7) were recruited through a screening process from public primary schools around Tzaneen, in the Limpopo Province, South Africa. The sample consisted of Grade 1 to Grade 7 learners from six out of ten schools in the circuit; the learners were randomly selected. The home languages of the learners were Sepedi and Xitsonga.

3.4 Procedure

Participation in the study was voluntary. Informed consent was obtained from the children' parents or legal guardians. In addition, the children signed assent forms which were written in Sepedi and Xitsonga. All assessments were completed during school hours. The Disruptive Behaviour Disorders Rating Scale (DBD) was used to screen for ADHD symptoms (Pelham et al., 1992; Pillow et al., 1998). Teachers and parents were given the rating scale to complete. Using the cut-off points established by Meyer et al. (2004), children were assigned to either the clinical or control groups, In addition, the following assessments were administered: the Memory for Digits (Digits Forward and Digits Backwards), Tower of London (ToL), Trail Making Test (Trails-A and Trails-B) and Wisconsin Card Sort Test (WCST). The administration of the assessments lasted ± 60 minutes and was administered by a clinical psychologist and four research assistants who had a Bachelor's degree in psychology and who were fluent in Sepedi and Xitsonga.

3.5 Inclusion and Exclusion Criteria

Participants who were primary school children, six to fifteen years of age, whose parents/guardians gave consent for their participation, were included in the study. Children with a history of severe neurological disorders or head injury, epilepsy, cerebral palsy, cerebral malaria, autism spectrum disorder, learning disabilities or severe psychiatric disorders were excluded from the study.

3.6 Data Collection

3.6.1 Instruments

The following instruments were used in the study.

3.6.1.1 Demographic Questionnaire. The parent or guardian of each participant was requested to complete a demographic questionnaire (see Appendix 1), which included biographical, socio-economic, developmental, and medical history.

3.6.1.2 Disruptive Behaviour Rating Scale (DBD). The DBD (Molina et al., 1998; Pelham et al., 1992; Pillow et al., 1998) (see Appendix 2) was used to screen for ADHD and, based on their scores, each participant was assigned to either the clinical or control group. The DBD is standardised for the population in which the study took place, and the scale has been translated into Sepedi, Setswana, Xitsonga, and Afrikaans (Meyer et al., 2004). For this study, the Sepedi and Xitsonga versions of the DBD were used. The 42-item questionnaire has four subscales: ADHD-Inattention (9 items), ADHD-Hyperactivity/Impulsivity (9 items), Oppositional Defiant Disorder (8 items), and Conduct Disorder (16 items). The parents and teachers were asked to rate the behaviour of the child on a four-point Likert scale consisting of the following options: not at all (0), just a little (1), pretty much (2), and very much (3).

The participants with scores ≥17 on the Hyperactivity/Impulsivity subscale of the DBD were classified hyperactive/impulsive (ADHD-HI), and those with a score ≥20 on the Inattentive subscale were classified inattentive (ADHD-PI). If these criteria were met on both scales, the participants were classified as ADHD-Combined (ADHD-C). Children with scores ≤15 on the ADHD-H/I and on the Inattention scale ≤15 were selected for the comparisons group. Cronbach α for the Inattention subscale was 0.92 and for the Hyperactivity/Impulsivity sub-scale, it was 0.90.

3.6.2 Memory for Digits

The Memory for Digits (MFD) is a subtest of the Senior South African Individual Scales-Revised (SSAIS-R) (Cockcroft & Blackburn, 2008; Van Eeden & Visser, 1992). The MFD tests working memory, auditory sequencing and auditory attention ability (Van Eeden & Visser, 1992). The test has been used in other South African studies and found to be a suitable assessment instrument for South African populations (Cockcroft, 2011; Shikwambana, 2006) particularly identifying impairment in working memory.

The MFD consists of two parts, the Digits Forward (DF) and Digits Backward (DB); in both parts, strings of digits are read at a steady rate to the participant, who has to repeat the string back exactly to the researcher. In DB, the order of the digits in the string must be reversed. In the DF, two series of eight sets of digits are read to the participant and in the DB, two series of seven digits are read to the participant. The DF and DB are discontinued after two consecutive items are incorrectly answered (Van Eeden & Visser, 1992). The score of 2 is awarded if the participant repeats the first series of an item correctly, 1 point is given if the participant repeats only the second series of an item correctly, and 0 if they repeat both series incorrectly. The total maximum score is 16. The internal reliability of the test ranges from 0.83

to 0.90 and construct validity ranges from 0.1 to 0.5 (Cockcroft, 2013). The Cronbach α for the study was 0.78.

3.6.3 Tower of London (ToL)

The ToL was carefully considered and used because it is primarily non-verbal. The ToL is a widely used instrument for assessing planning ability; it consists of two tower boards which contain three pegs of different lengths and three balls, usually coloured red, blue and green (Boccia et al., 2017). The test consists of 12 problems, of which the first two are a practice problem and ten are test problems. The participants are shown two identical tower boards, one for the participant and one for the examiner. The examiner places the participant's beads in the start configuration and sets up the practice problem. In the practice problems, two steps are needed to reach a solution. The participants are asked to transform the start state into the goal state in a predetermined minimum number of moves while following three rules: 1) they have to move only one ball at a time; 2) a ball in the lower row cannot be moved when another ball is lying above it; and 3) three balls may be placed on the tallest peg, two balls on the middle peg, and one ball on the shortest peg. From the start position, the participants are required to use the fewest steps to move the beads to the end position. The minimum number of moves required is seven. The number of moves required to reach the goal position and time taken to complete the test are counted.

Good planning is indicated by a lower total number of moves. The total number of moves and time taken are manually recorded on a scoring sheet. The scoring for moves depends on the minimum number of solutions moves for each test problem subtracted from the participant's actual move count to determine the move score. The raw scores were used. The length of time taken to complete the test is 10-15 minutes.

The split-half reliability co-efficient for the test is: r = 0.72, and internal consistency: Cronbach α = 0.69 (Kaller et al., 2012). A Cronbach α of 0.62 was established in the present study. The test was previously used and found to be suitable and reliable for rural South African children (Boshomane et al., 2020; Mokobane et al., 2020; Pila-Nemutandani & Meyer, 2016). Mokobane et al., (2020) and Pila- Nemuntandani & Meyer, (2016) indicated the ToL identifies impaired planning behaviour and problem solving.

3.6.4 Trail Making Test

The Trail Making Test (TMT) was used to measure visual scanning, graphomotor speed, executive function, working memory and inhibition (Lezak et al., 2012); it is also a test of visual search, attention, mental flexibility and motor function. The TMT is a timed task, consisting of two subtests: Part A measures visual search, attention and mental tracking ability, while Part B measures cognitive abilities such as flexibility and the capacity to deal with more than one stimulus at a time (Kokubo et al., 2012).

Both parts of the TMT comprise 25 circles distributed over a sheet of paper. In Part A, the circles are numbered 1-25, and the participant is expected to draw lines to connect the numbers, in ascending order. In Part B, the circles contain 13 numbers and 12 letters; participants need to connect circles, alternating both numerically and alphabetically, in increasing order. Any errors made by the participants are recorded. In both parts, a participant's performance (score) is the time taken to complete each trial correctly. Kofler et al. (2020) found that the Trails- B, reliably measured cognitive flexibility. In South Africa, Mphahlele et al. (2022) indicated that TMT-B identifies impaired set shifting in children with ADHD symptoms. The test-retest reliability for the TMT is between 0.60 and 0.90 (Wagner et al., 2011). A Cronbach α of 0.67 and 0.72, for Parts A and B respectively, was established in the current study.

3.6.5 Wisconsin Card Sorting Test (WCST)

The WCST consists of 128 cards which present sets of geometric designs that vary according to colour, form, and number. In the computerised version of the WCST (CV4-Research edition), the stimulus cards remain at the top of the screen, and a single response card appears at the bottom of the screen. The participant is required, with the use of a computer mouse, to select a stimulus card that they believe to be correctly ‘matched’ to the response card. After each attempt, the computer provides positive or negative feedback by displaying the word “right” or “wrong” at the bottom of the screen (Williams et al., 2013; Williams & Jarrold, 2013). The purpose of the test is to measure mental flexibility. The classification rule changes after every ten cards, which means that once the child has worked out the rule, they may begin to make a single mistake (or more) when the rule changes. In this study, the numbers of total errors (TE), perseverative errors (PE), perseverative responses (PR) and non-perseverative errors (NPE) were used as the main scores to assess set-shifting.

The inter-rater reliability for the WCST is between 0.88 and 0.93 (Mitrushina et al., 2005), with Cronbach α of 0.90. This test has indicated the validity for the present sample with Cronbach α of 0.89. The test was used and found to be reliable for use among rural children in South Africa (Boshomane et al., 2020; Gadd & Phipps, 2012; Mathivha, 2005).

3.7 Data Analysis

Statistica version 13 (Dell, 2015) was used to analyse the data. An analysis of variance (ANOVA) model was employed to investigate between-group differences (ADHD versus neurotypical controls).

Multivariate analysis of variance (MANOVA) models were employed to determine between-group differences as a function of age, gender and ADHD presentation. Post hoc tests consisted of multiple comparisons using the Bonferroni method. A multiple regression analysis was used. The raw scores of measures were introduced in the analysis as predictor variables, while the DBD scores on the Hyperactivity/Impulsiveness and Inattention scales, as well as the total ADHD score, were dependent variables.

3.8 Data Management

Strict measures were taken to protect all data. All the completed questionnaires were collected by the researcher and stored and locked in a secure cupboard in the researcher's office. After data was entered into the Statistica software, the digital data was saved as a password- protected file. The questionnaires, test protocols and answer sheets are securely stored in a locked cabinet and will be appropriately destroyed after five years.

3.9 Ethical Considerations

Ethical approval was obtained from the Humanities and Social Sciences Research Ethics Committee of the University of KwaZulu-Natal (HSS/1452/015D; see Appendix 5). In addition, permission to conduct the study was obtained from the Department of Education in the Limpopo Province (see Appendix 6), and consent was obtained from the relevant school principals to conduct the study at their institutions. Participation in the study was voluntary, and participants could withdraw from the study at any time they wanted to. Informed consent was obtained from the children's parents or legal guardians, and all participants signed assent forms which were written in Sepedi and Xitsonga (see Appendix 3 and Appendix 4).

CHAPTER 4

RESULTS

This chapter presents four papers that emanated from the study. All papers except one have been published.

4.1 Paper 1

Paper 1 reports on whether children with ADHD deficiencies in behavioural planning have when compared to typically developing children without ADHD symptoms. This paper was published in the *South African Journal of Psychiatry*.

4.1.1 Reference

Boshomane, T. T., Pillay, B. J., & Meyer A. (2020). Attention-deficit/hyperactivity disorder and behavioural planning deficiencies in South African primary school children. *South African Journal of Psychiatry*, 26(0), a1411. https://doi.org/10.4102/ sajpsychiatry. v26i0.1411

South African Journal of Psychiatry
ISSN: (Online) 2078-6786, (Print) 1608-9685

Attention-deficit/hyperactivity disorder and behavioural planning deficiencies in South African primary school children

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Dates:
Received: 22 May 2019
Accepted: 04 Aug. 2020
Published: 22 Oct. 2020

How to cite this article:
Boshomane TT, Pillay BJ, Meyer A. 2020, Attention-deficit/hyperactivity disorder and behavioural planning deficiencies in South African primary school children. S Afr J Psychiat. 2020;26(0), a1411. https://doi.org/10.4102/sajpsychiatry.v26i0.1411

Background: Attention-deficit/hyperactivity disorder (ADHD) is defined as a cognitive or behavioural developmental disorder. Inattentiveness, overactivity and impulsivity are regarded as the main clinical symptoms of ADHD. These symptoms may occur together or separately resulting in three recognised presentations: predominantly inattentive, predominantly hyperactive–impulsive and combined presentations.

Aim: This study investigated deficiencies in behavioural planning in South African primary school children with and without ADHD.

Setting: Tzaneen area in Limpopo province, South Africa.

Methods: A total of 156 children (78 with ADHD and 78 matched controls without ADHD) of both genders, who were medication naïve and aged 6–15 years, participated in the study. The performance of the two groups was compared on a test of planning and problem-solving, the Tower of London (ToL) task. The results were analysed as a function of gender, age and ADHD presentation.

Results: Children with ADHD especially ADHD-PI and ADHD-C used significantly more moves and took a longer time to complete the task than the controls ($p < 0.001$). There were no significant differences in the number of moves and time taken by the predominantly hyperactive-impulsive presentations of ADHD when compared to the controls. Gender and age did not influence the performance.

Conclusion: The results showed that children with ADHD showed significantly more deficits mainly the ADHD-PI and ADHD-C presentations, which indicates that inattention is mainly responsible for deficiencies in behaviour planning. The ADHD-HI presentations and the control group were not affected.

Keywords: attention-deficit/hyperactivity disorder; behavioural planning; developmental disorder; primary school children; hyperactive.

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a common heterogeneous neurodevelopmental disorder of genetic origin, with a childhood onset and which often persists into adulthood.[1,2] According to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5), ADHD is characterised by symptoms of overactivity, impulsivity and inattention, which are presently regarded as the main clinical symptoms.[3]

Globally, the prevalence of ADHD does not significantly differ between America, Australia and Africa.[2,4] The prevalence of ADHD in children and adolescents worldwide is estimated to be 5.3%.[2] In South Africa, Meyer et al.[5] found that the prevalence of ADHD among primary school children of all ethnic populations in the Limpopo province to be 5.5%.

In children and adolescents, ADHD predominantly affects males with a male–female sex ratio of 4:1 in clinical samples and 2.4:1 in population studies.[2] Attention-deficit/hyperactivity disorder is found to be as prevalent and with similar same-sex ratios on the African continent as in Western countries.[2,5]

It is widely recognised that ADHD is not only a behaviour disorder characterised by hyperactivity, impulsivity and inattention, but it is fundamentally a cognitive disorder, involving a developmental impairment of executive functions (EFs), which are the controlling system of the brain.[6] Executive functioning is a complex cognitive control process, which enables self-regulation and self-directed behaviour towards a goal; modifies behaviour in the light of new information; makes decisions and evaluates risks, plans for the future, prioritises and sequences actions, and solves novel problems.[7]

Symptoms of ADHD arise from a primary deficit in specific EF domains, such as response inhibition, working memory, set-shifting and planning.[1,2,6] Children with ADHD show impairments in judgement, organisation, planning and decision-making as well as in behavioural disinhibition and cognitive flexibility.[8] As a result, they experience problems with social skills, and exhibit low self-esteem, low frustration tolerance and impaired academic performance.[9]

Executive dysfunction is generally attributed to structural and functional frontal pathology.[1,10] The ventromedial prefrontal cortex (PFC) is associated with complex decision-making and strategic planning, while dorsolateral (PFC) is linked to working memory and behaviour planning.[1,11,12] There is abundant support for the role of the PFC in the ability to plan and carry out a strategy for completion. Neurotransmitter circuits are involved in EFs, with the dopamine system, especially, playing an essential part in planning and cognitive flexibility by supplying the PFC.[7,13,14] Therefore, a hypofunctioning mesocortical dopamine branch will cause poor behaviour planning.[14] In this study the focus was on behaviour planning. Children who are deficient in planning behaviour display insufficient problem-solving strategies, which, in turn, compromise their learning ability at school.

Planning can be described as the execution of goal-directed behaviour to predict and evaluate outcomes. Also identifying, organising steps and elements needed to carry out an intention.[15,16] To plan, one must be able to conceptualise changes from present circumstances (look ahead, deal objectively with oneself concerning the environment and view the environment objectively). The planner must also be able to conceive of alternatives, weigh and make choices, and entertain both sequential and hierarchical ideas necessary for the development of a conceptual framework or structure that will give direction to the carrying out of a plan. Good impulse control and reasonably intact memory functions are also necessary in planning.[17] Moreover, all of this conceptual activity requires a capacity for sustained attention.[18] The literature suggests that children with ADHD often show poor performance on tasks that require strategic planning.[19]

A study by Kofman et al.[19] stated that children with ADHD exhibited poor performance where planning or a proper strategy was needed. Pila-Nemutandani and Meyer.[20], Schmitz et al.[21] and Mokobane et al.[22] noticed that children with the combined (ADHD-C) presentation were highly deficient in behavioural planning and faced more difficulties when compared to both the predominantly hyperactive-impulsive (ADHD-HI) and predominantly inattentive (ADHD-PI) presentations and neurotypically children. However, a study by Geurts et al.[23] showed no deficiencies in children with ADHD and normal controls with regard to planning.

The purpose of the study was to investigate whether children with ADHD have deficits in behaviour planning as measured by the Tower of London (TOL)

Research methods and design

Study design

The study was conducted in primary schools in the Tzaneen area, Limpopo, during 2017. A quantitative, cross-sectional case–control study, experimental design was used. To establish whether children with ADHD are deficient in behaviour planning, the sample was divided into participants with ADHD and matched controls without symptoms of ADHD.

Setting

The selected regions were in a rural area in which assessment of this nature is very rare. The areas were selected based on the remoteness of the regions so that the community could benefit from such research.

Study population and sampling strategy

The sample ($n = 156$) was divided equally in terms of gender (76 boys and 80 girls), aged 6–15 years of age, were recruited from a school-based population in the Tzaneen area in the Limpopo province, South Africa. They were Sepedi and Xitsonga speaking, grade 1–grade 7 learners. The participants were divided into two age groups: 6–10 and 11–15 years. The sample was chosen because of its accessibility. To detect symptoms of ADHD, the learners were screened using the disruptive behavioural disorder (DBD) rating scale, based on ratings from parents and teachers.[24,25] A total number of 5480 children were screened for ADHD using the DBD rating scale. Cut-off points were based on the results obtained from a previous study that had been conducted in Limpopo by Meyer et al.[5] Learners who met the criteria for ADHD were assigned by the researcher as follows: participants with scores $\geq$ 17 on the hyperactivity and impulsiveness scale were classified as ADHD-HI presentations and those having a score $\geq$ 20 on the inattention scale were classified as ADHD-PI presentations, based on the epidemiological study by Meyer et al.[5] Participants who met the criteria on both scales, ADHD-HI and ADHD-PI, were categorised as ADHD-C presentations. The cut-off point for the neurotypical control group was set at the 85th percentile or below to decrease the risk for false-positives in the group. Thus, children with scores of less than 15 on the hyperactivity and impulsivity scale and the inattention scale, matched for gender, age and home language, were selected as controls. Children were divided into an ADHD group and a control group, without ADHD symptoms. Seventy-eight children were found positive for ADHD symptoms (ADHD group) and they were matched for gender, age and home language with children without ADHD (control group, $n = 78$). Children with an intelligence quotient (IQ) lower than 80 and/or who are suffering from any head injury, epilepsy, cerebral palsy, cerebral malaria, autism spectrum disorder or severe psychiatric disorders, as reported on the demographic questionnaire by parents and confirmed by the teachers, were excluded from this study. At the time of testing, the researcher ensured that none of the children were taking psychostimulant medication.

Data collection

Data were collected from primary school children within the Tzaneen area in Limpopo province during 2017. School principals gave their permission to conduct the study at their schools. Informed, written consent was obtained from the parents. The return rate of the questionnaires was 98%. The study was explained to all children selected for testing, and their assent was obtained. The assessments were conducted in the mornings. The children were assessed individually in a quiet room during school hours. The total number of correct responses for the TOL (total score) and the time taken to complete the specific response were recorded. The testing procedure for each child lasted 30 min and was conducted by a clinical psychologist and four research assistants (who held bachelor's degrees in psychology) and were fluent in the child's home language.

Instruments

Screening instruments: Disruptive behaviour disorder rating scale. The disruptive behaviour disorder rating scale (DBD), by Pelham et al.[24,25] used to screen for ADHD symptoms, was completed by parents and teachers. The scale was standardised and normed for all language and population groups in Limpopo province, South Africa.[5] The DBD assesses the presence and degree of ADHD-related symptoms (inattention and hyperactivity/impulsivity), oppositional defiant disorder (ODD) and conduct disorder (CD) as formulated in the DSM-IV-TR. The DBD has been translated into five South African languages, namely, Sepedi, Tshivenda, Afrikaans, Tsonga and Tswana, which are spoken in the Limpopo province. Internal consistency and norms for each language group have been established.[5]

Cronbach's α for the primary school population in the Limpopo province was calculated at 0.90 for the HI scale and 0.92 for the inattention scale.[5] For this study, the sample's Cronbach's α for the HI scale was calculated at 0.74, and at 0.79 for the inattention scale.

Assessment of behaviour planning

The Tower of London: The TOL is a widely used instrument for assessing planning ability. Shallice[26] developed the instrument to assess higher order problem-solving capacity, specifically executive planning. It can also be used in a neuropsychological battery to assess motor planning and processing information.[27] The TOL requires 'forward thinking' or planning and measures spatial planning and problem-solving because an early incorrect move can render the problem almost unsolvable.[28,29,30] The TOL is considered to be a frontal lobe test which is believed to measure EFs involved with strategic planning.[31,32] It has been proven to be sensitive in distinguishing planning behaviour deficits in children with ADHD and in neurotypically children.[20,33]

The apparatus consisting of three wooden beads (red, yellow and blue) had been placed. The researcher presented an example of the problems, on cards, which were to be solved in two to five steps. In a practice problem, the same initial position was used, where two steps were needed to reach a solution. The task consisted of 12 problems, which had been graded in terms of their difficulty. From the start position, the participants were expected to move the beads to the finish position shown on the cards, making use of the least number of steps. The reliability coefficients were split-half reliability, $r = 0.72$, and internal consistency, Cronbach's $\alpha = 0.69$.[17,34]

Data analysis

Analysis of variance (ANOVA) was used to investigate possible between-group differences using the ToL raw scores. Analysis was done using Statistica 10 StatSoft.[35] The results for each test were analysed with 4×2 (ADHD presentation $\times$ gender) ANOVA's for independent samples. *Post hoc* tests consisted of multiple comparisons using the Bonferroni method.[36]

Ethical consideration

We confirm that this manuscript is the original and has not been submitted to any other journal for publication. University of KwaZulu-Natal, is fully aware of this submission. Ethical approval to conduct the study was obtained (from the Biomedical Research Ethics Committee of the University of KwaZulu-Natal (Ethical Clearance Number HSS/1452/015D). In addition, permission was obtained from the Department of Education, Limpopo province, and school principals of the selected schools. Informed consent was obtained from the parents or legal guardians of the learners to participate in the study. The children also assented to their participation in the study. Participation in the study was voluntary, and participants were informed that they could withdraw at any stage.

Results

The study hypothesised that children with ADHD will have impairments in behaviour planning when compared with neurotypically children. Age did not affect the results; therefore, it was not taken into account for further analysis. Statistically significant differences were found for the inattention scores ($p < 0.001$) and the HI scores ($p < 0.001$) of the DBD rating when the ADHD and control group were compared. The demographics and DBD scores for the sample are presented in Table 1.

The descriptive statistics, the results of the ANOVA and the *post hoc* analysis for the number of moves and the time taken in seconds on the TOL are shown in Table 2.

Number of moves

There was neither main nor interacting effect for gender and age; therefore, the gender and age groups were analysed together. There was, however, a statistically significant difference in performance between the ADHD and control groups: $F(3, 149) = 10.54$, $p < 0.001$, $\eta_p^2 = 0.18$. *Post hoc* analysis (Bonferroni) revealed that there was a statistically significant difference in performance between both the ADHD-PI and ADHD-C presentations and the control group ($p < 0.001$). The ADHD-PI and ADHD-C subtypes used significantly more moves than the controls. There was no significant difference in the number of moves used by the ADHD-HI subtype when compared to the controls.

Time taken to complete the task

There was neither main nor interacting effect for gender and age. Therefore, the gender groups were not analysed separately. There was, however, a statistically significant difference in performance between the ADHD and control groups: $F(3, 149) = 11.52$, $p < 0.001$, $\eta_p^2 = 0.19$. *Post hoc* analysis (Bonferroni) revealed that the differences between the ADHD-PI and ADHD-C and the control group were statistically significant, both at the $p < 0.001$ level. The children with ADHD-PI and ADHD-C took significantly more time than the controls to move the beads. There was no significant difference in the time taken by the ADHD-HI presentation when compared to the controls. Effect sizes (η_p^2) of 0.18 (number of moves) and of 0.19 (time taken) are considered to be large.[37]

TABLE 1: Demographics of the sample (N = 156).

Variables	ADHD				Control			
	N	%	*M*	SD	*N*	%	*M*	SD
Gender								
Male	38	24.4	-	-	38	24.4	-	-
Female	40	25.6	-	-	40	25.6	-	-
Age group				-				
6–10	15	9.6	9.47	1.19	15	9.6	9.60	1.18
11–15	63	40.4	12.24	1.25	63	40.4	12.32	1.36
Language								
Sepedi	72	46.2	-	-	72	46.2	-	-
Xitsonga	6	3.8	-	-	6	3.8	-	-
Presentation				-				-
ADHD-HI	12	7.7	-	-	-	-	-	-
ADHD-PI	30	19.2	-	-	-	-	-	-
ADHD-C	36	23.1	-	-	-	-	-	-
Total	**78**	**50**	-	-	**78**	**50**	-	-

ADHD, attention-deficit/hyperactivity disorder; ADHD-HI, hyperactive-impulsive presentation; ADHD-PI, predominantly inattentive presentation; ADHD-C, combined presentation; *M*, mean; SD, standard deviation.

Discussion

The study compared the performance of children with ADHD and a non-ADHD control group on measures of behaviour planning and problem-solving. No gender and age differences on task performance were found in this study. This was consistent with the study done by Biederman et al.[38] and Seidman et al.[39] who also found no significant differences between males and females with ADHD and neurotypically children. Several studies have reported that children with ADHD scored significantly lower on tests that measure especially planning, problem-solving, mental flexibility and spatial working memory than their matched peers.[8,40,41,42,43] However, Houghton et al.[44] did not find that the ToL discriminated between children with and without ADHD. This was also the conclusion of a Mexican study. Yanez-Tellez et al.[45] found a great variety of cognitive deficiencies in children aged 7–12 years with ADHD, but the ToL could not differentiate between them and a control group without ADHD.

Chhabildas et al.[46] have suggested that EF deficits in ADHD can be mainly accounted for by symptoms of inattention. Attention problems of ADHD usually occur in situations where stimuli are widely spaced in time. There are indications that development of functional units of behaviour, or performance of integrated behavioural sequences is hampered in children with ADHD when the task gets increasingly complicated or demands higher level processing.[47,48,49] Children with ADHD has the inability to finish tasks, organise and sustain efforts as well as forgetfulness. The literature shows that they were found to be poor problem-solvers, by selecting the most relevant information included in the problems and they remembering smaller amounts of relevant and a greater amount of irrelevant information when compared to neurotypically children.[50,51] This might be the result from changed motivational processes and they seemed to be evident when the ability to concentrate is stressed by the task being unwelcomed or uninteresting.[52] According to Oosterlaan et al.,[53] poor performance on the ToL is indicative of ADHD children making the first move before they had successfully generated an appropriate solution to the problem. Therefore, the fast planning times in ADHD children could be interpreted

TABLE 2: Analysis of variance: Number of moves and time taken for the Tower of London.

Variables	ADHD N = 78 (50%)		ADHD-HI N = 12 (8%)		ADHD-PI N = 30 (19%)		ADHD-C N = 36 (23%)		Control N = 78 (50%)		Group comparison ANOVA DF (3, 148)			*Post hoc*	*p*
	M	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*F*	*p*	η_p^2		
Moves	46.06	27.82	32.00	23.28	50.03	28.32	47.44	28.02	27.32	17.10	10.54	< 0.001	0.18	PI, C > Control	< 0.001
Time†	117.32	88.98	94.42	45.90	132.13	119.88	112.61	66.76	51.52	37.51	11.52	< 0.001	0.19	PI, C > Control	< 0.001

ADHD, attention-deficit/hyperactivity disorder (all presentations); ADHD-HI, hyperactive-impulsive presentation; ADHD-PI, predominantly inattentive presentation; ADHD-C, combined presentation; ANOVA, analysis of variance, *M*, mean; SD, standard deviation; DF, degree of freedom.

†, In seconds.

as impulsiveness which does not arise from a tendency towards fast motor response and equivalent to poor performance because of sustained inattention. The impulsive behaviour may aggravate the inattention problems that cause poor performance.

The results show that children with ADHD are significantly more impaired on measures of planning behaviour and problem-solving, especially the ADHD-PI and ADHD-C presentations when compared to ADHD-HI and the control group of non-ADHD children. The ADHD-C presentation's poor performance indicated that children with symptoms of both inattention and hyperactivity-impulsivity are struggling to perform tasks by not being able to select strategies that entail reasoning. The findings were consistent with the study conducted by Sarkis et al.[54] who found that the ADHD-C subtype performed significantly worse than the non-ADHD groups on the TOL. Similarly, Pila-Nemutandani and Meyer,[20] Schmitz et al.,[21] Mokobane et al.[22] and Solanto et al.[55] noticed that children with the ADHD-C presentations were deficient in behavioural planning and that they faced more difficulties when compared to both the ADHD-HI and ADHD-PI presentations and a control group of non-ADHD children. Saydam et al.[56] also found that ADHD-C presentations had impaired planning strategies compared to the ADHD-PI presentation.

Generally, children diagnosed with ADHD-C struggle to remember instructions and to plan new strategies in a different situation.[56] Children with ADHD-C had problems carrying out tasks to their conclusion and paying attention to instructions, and they were quick and disorderly when they plan their tasks.

However, the current study differs from the study by Houghton et al.[44] who found that the TOL did not discriminate children with and without ADHD. On the contrary, Geurts et al.[23] found conflicting results amongst children with ADHD-C and ADHD-PI; however, these children did not differ from the controls on any of the planning measures with increasing planning load. The incongruences between the Geurts et al.[23] study and the findings of this study may be because of a smaller sample that they used. Further, the current research results differ with the findings of Barkley,[57] who suggested that deficits in EF (behaviour planning and problem-solving) are related only to ADHD-C not to ADHD-PI and ADHD-HI. Barkley's findings is supported by several other studies which show that ADHD-C is accompanied by more serious impairment than ADHD-PI.[58] Therefore, the ADHD-C and the ADHD-PI presentations seemed to have more difficulty in planning ahead than the ADHD-HI and the non-ADHD comparison group.

The posterior parietal cortex is connected with the PFC and has been shown to represent neural correlates of decision-making and planning.[59] These areas, especially the prefrontal areas, seem to be dysfunctional in children with ADHD, probably because of a hypofunctioning mesocortical dopamine branch, causing deficient attention and poor behavioural organisation.[14]

Implication

Children with ADHD usually are hasty and disorderly when they plan behaviour.[58] They have a compromised learning ability at school, which makes it difficult for them to apply new skills. It is essential that teachers and parents recognise children with ADHD early so that they can provide appropriate and effective intervention. Early referrals and necessary follow-up treatment at an early age is essential. In this regard, early pharmacological and/or behavioural treatment should be provided when applicable.

Limitations

The sample size was small, especially when the ADHD group was subdivided into three presentations. This may have influenced on the statistical outcome. Caution should be exercised when generalising these results to all South African children as the sample was homogeneous, consisting of rural Sepedi and Xitsonga speaking children only from the same geographical area. It is recommended for future studies to include more language groups. The TOL instructions should be standardised in different languages.

Conclusion

The goal of the study was to assess the behaviour planning deficits in children with ADHD. The study showed that especially the inattentive and combined ADHD presentations have problems with planning, and problem-solving using the TOL.

Acknowledgements

The authors acknowledge the following field workers: Xichavo Lobyana, Khuliso Matidza, Penny Mafela and Rotakala Sadiki.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

T.T.B. made an extensive contribution to the concept and design of the article, collected data and drafted the article, and finalised the version to be published. B.J.P. assisted with overseeing, made substantial remarks on the prepared article and approved the final version to be published. A.M. provided the data analysis and tables, revised the article and approved the version to be published.

Funding information

This project was partially funded by the University of KwaZulu-Natal.

Data availability statement

Data will be available in the University of KwaZulu-Natal library, no data sharing.

Disclaimer

The views expressed in this article are those of the authors and not an official position of the institution or funder.

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4.2 Paper 2

Paper 2 determined whether children with ADHD have mental or set-shifting deficiencies compared to children without ADHD symptomatology and determined whether the three ADHD subtypes, age and gender affect their mental shifting performance. Paper 2 was published in the *Journal of Psychology in Africa*.

4.2.1 Reference

Boshomane, T. T., Pillay, B. J., & Meyer, A. (2021). Mental flexibility (set-shifting) deficits in children with ADHD: A replication and extension study. *Journal of Psychology in Africa*, *31*(4), 344-349. https://doi.org/10.1080/14330237.2021.1952637

Journal of Psychology in Africa, 2021
Vol. 31, No. 4, 344–349, https://doi.org/10.1080/14330237.2021.1952637

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Mental flexibility (set-shifting) deficits in children with ADHD: A replication and extension study

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The study investigated set-shifting impairment differences in children by Attention Deficit Hyperactive Disorder (ADHD) subtype compared to neurotypical peers. The sample consisted of 156 primary school children from the Limpopo Province of South Africa (ADHD = 78, neurotypical = 78). The children were assessed on the computerised Wisconsin Card Sorting Test, which provides set-shifting error scores as follows: total errors, perseverating responses, perseverating errors, and non-perseverating errors. Following Multivariate Analysis of Variance (MANOVA) for between-group differences, results showed that children with ADHD subtypes, across subtypes, were with more set-shifting deficits than the neurotypical comparison group on total errors, perseverative responses, perseverative errors, and non-perseverative errors. Sex and age did not influence the performance of set-shifting tasks. From these findings, we conclude that children with ADHD present with set-shifting difficulties that could be the target of early interventions.

Keywords: ADHD, errors, mental flexibility, perseveration, set-shifting, subtypes

Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is the most prevalent childhood neuro-behavioural disorder with a worldwide prevalence rate of 5% (Polanczyk et al., 2014), affecting 1 in 18 children and 7.47% in African countries (Ayano et al., 2020). In South Africa, Meyer and colleagues (2004) reported a 5.5% prevalence of ADHD among primary school children of all ethnic populations in the Limpopo province. Children with ADHD may present with inattention, hyperactive and impulsive behaviour, or a combination of these two symptom domains. Further, children with ADHD often fail to give close attention to details or make careless mistakes, frequently have difficulty maintaining an interest in tasks, and are often easily distracted by extraneous stimuli (Tripp & Wickens, 2009). Children with hyperactivity/impulsiveness also display excessive motor activity and impulsive responses which may cause unnecessary errors (Lahey et al., 1998). They present with impaired executive functions (EF) necessary for task execution (Barkley, 1997; Ciuluvica et al., 2013. Miyake et al., 2000; Seidman et al., 2006). EF encompasses a series of abilities critical to performance to achieve a goal requiring set-shifting (Taşcu et al., 2012).

Set-shifting is an EF when attending to multiple tasks, operations, or mental processes (Miyake et al., 2000; Monsell, 1996; Re et al., 2016). The shifting process requires the separation of an irrelevant task set and the subsequent active engagement of a relevant task set (Monsell, 1996). Children with ADHD are slow at switching between stimuli, or between sets of stimuli, or to control behaviour appropriate to changing situations (Oades & Christiansen, 2008). Reinforcement deficiencies may play a role in differences in set-shifting scores among children. Children with ADHD have displayed altered responses to reinforcement (Sagvolden et al., 2005; Sonuga-Barke, 2003; Tripp, & Wickens, 2008). They seem to learn less from previous mistakes, and also need more frequent reinforcement than their neurotypical peers. They seem less able to change behaviours or plans according to environmental demands and have difficulties reorganising an alternate plan when presented with new situations or tasks. They tend not to shift between tasks easily; instead, they are hyper-focused on a specific task (Hosenbocus & Chahal, 2012). Furthermore, children with ADHD often exhibit impairment in set-shifting that are related to abnormal activity of the prefrontal cortex, the brain region that has been associated with set-shifting (Dalley et al., 2004; Wood et al., 2016). Dopamine dysfunction is considered to play a role in the neurobiology of set-shifting, especially a hypo-functioning dopamine branch which supplies the prefrontal cortex (Johansen et al., 2002; Sagvolden et al., 2005; Tripp & Wickens, 2009). The executive-orientated shifts may be regulated by the frontal lobes and frontal lobe impairment may be expressed as preservation or repeating the same responses over and over, even when it is no longer appropriate and is often interpreted as difficulty in shifting mental sets (Ardila, 2008). Lesions of the dorsolateral prefrontal cortex (DLPFC) impair the ability to shift attentional set (Manes et al., 2002). We sought to replicate these findings in a South African setting, differentiating the children by ADHD subtypes and comparing their set-shifting performance to that of neurotypical others.

ADHD subtypes

ADHD can be divided into three subtypes in the DSM-IV-TR (American Psychiatric Association, 2000) or into three presentations according to DSM-5 (American Psychiatric Association, 2013): predominantly inattentive (six or more of inattentive ADHD symptoms), predominantly hyperactive-impulsive (six or more of impulsive and hyperactive symptoms), and a combined type (six or more of both inattentive and hyperactive symptoms).

Children with Attention-Deficit/Hyperactivity Disorder-Combined presentation (ADHD-C) and

Attention-Deficit/Hyperactivity Disorder-Hyperactive/ Impulsive presentation (ADHD-H) are more like to present with EF deficits than those with Attention-Deficit/Hyperactivity Disorder-Predominantly Inattentive presentation (ADHD-PI) (Barkley, 1997; Marchetta et al., 2008; Roberts et al., 2018; Romine et al., 2004). For instance, children with ADHD-C had poor set-shifting when compared to neurotypical children of the same age (Marchetta et al., 2008; Roberts et al., 2018; Romine et al., 2004). Some studies showed that the ADHD-C presentation performed worse than both the ADHD-PI subtype and neurotypical comparisons on task shifting (Klorman et al., 1999; Nigg et al., 2002; Hinshaw et al., 2002; Solanto et al., 2007). However, other studies reported no such differences (Rapport et al., 2001; Saydam et al., 2015; Stavro et al., 2007). Similarly, ADHD subtypes were not different from neurotypical children in perseverative errors (Geurts et al., 2005; Willcutt et al., 2005), although the evidence is not consistent across studies (Tsuchiya et al., 2005).

Influences of age on set-shifting

Set-shifting becomes more pronounced by five years of age (Miyake et al., 2000). The growth of EF is mirrored by rapid brain maturation processes such as increased myelination, synaptic pruning, and the formation of neural networks in the prefrontal cortex that takes place when children are around five years old (Casey et al., 2005; Gandotra et al., 2020). The development of set-shifting continues into adolescence, while working memory and planning development continues into young adulthood (Huizinga et al., 2006). Gandotra and colleagues (2020) indicated age differences on performance in all EF tests. No sex differences in set-shifting with ADHD have been reported (Castellanos et al., 2006; Seidman, 2006; Skogli et al., 2013).

The South African diagnostic setting

In South Africa, children are mostly screened for ADHD based on their performance on a locally developed measure, the Disruptive Behavioural Disorder Rating scale (DBD: Meyer et al., 2004). Following the procedures by Meyer and colleagues (2004) the learners may be diagnosed with specific ADHD subtypes using the following score cut-off points: ≥ 17 = ADHD-HI (Predominantly-hyperactive/ impulsive); or ≥ 20 on the inattention scale = ADHD-PI (Predominantly-inattentive). Participants who meet the criteria on both scales, ADHD-HI and ADHD-PI are categorised as ADHD-C (combined). The cut-off point for the neurotypical comparison group is set at the 85th percentile or below to decrease the risk for false positives in the group (or with scores of less than 15 on the hyperactivity and impulsivity scale and the inattention scale).

Goal of the study

This study investigated whether children with ADHD differed in their set-shifting when compared to a neurotypical group, by subtype, and if any differences by sex or age existed. Thus, our specific research question was: Do children with ADHD subtypes have problems with set-shifting compared to neurotypical others and by age and sex?

Methods

Participants and setting

Our study participants were a convenience sample of 156 primary school children (girls = 51.3%; mean age = 11.7 years, SD = 1.7 years) from the Limpopo province, South Africa. They were Sepedi and Xitsonga speaking. Inclusion criteria for ADHD assignment followed the procedures by Meyer and colleagues (2004) as previously described. Exclusion criteria included: children with a history of head injury, epilepsy, cerebral palsy, cerebral malaria, autism spectrum disorder, or severe psychiatric disorders as reported by parents and teachers at the time of the study.

Instruments

The Wisconsin Card Sorting Test (WCST: Heaton & Par, 2000) consists of 128 cards which contain sets of geometric designs that vary according to colour, form, and number. In the computerised version of the WCST: CV4-Research edition (Heaton & Par, 2000), the child is required, with the use of a computer mouse, to select a stimulus card they believed to be the correct "matched" response card. After each attempt, the computer provides positive or negative feedback by displaying the word "right" or "wrong" at the bottom of the screen. The classification rule changes after every ten cards. Once the children have figured out the rule, they should apply that rule.

The participants' performance is evaluated according to the following criteria:

- Total errors – the sum of perseverative and non-perseverative errors defined as the total number of trials needed to complete the task;
- Perseverative responses – the total number of perseverative responses divided by the number of trials administered;
- Perseverative errors – the number of errors where a participant continuously responds incorrectly, using the same pattern; and
- Non perseverative errors – responses that are incorrect but not perseverative.

We provided the test instructions in the child's home language, Tsonga or Sepedi. All instructions were verbally similar and translated from the original English by the researcher. A Cronbach's α of 0.89 was established for the present sample.

Procedure

The Ethics Committee of the University of Kwazulu-Natal (UKZN), Durban, South Africa, approved the study (HSS/1452/015D). The Department of Education of Limpopo Province and the school principals granted study permission. The parents or legal guardians of the learners gave written informed consent, and children assented to the study. The researcher and trained research assistants collected the data in a quiet room, during school hours. The assessment lasted for 20–30 minutes per child.

Table 1. MANOVA: WCST

	Subtypes			Control	*p*
	ADHD-HI	ADHD-PI	ADHD-C		
N	12 (7%)	30 (20%)	36 (23%)	78 (50%)	
	M (SD)	*M* (SD)	*M* (SD)	*M* (SD)	
TE	55.09 (12.24)	46.77 (18.47)	53.50 (19.54)	21.73 (10.16)	HI v Control < 0.001** PI v Control < 0.001** C v Control < 0.001**
PR	33.36 (8.69)	26.23 (16.95)	29.28 (18.37)	14.49 (8.78)	HI v Control < 0.001** PI v Control < 0.01* C v Control < 0.001**
PE	32.36 (6.99)	21.50 (11.21)	26.06 (13.82)	10.81 (7.81)	HI v Control < 0.001** PI v Control < 0.001** C v Control < 0.001**
NE	22.73 (8.86)	25.13 (12.06)	25.13 (12.06)	11.56 (5.93)	HI v Control < 0.01* PI v Control < 0.001** C v Control < 0.001**

Note. *$p < 0.01$; **$p < 0.001$; TE = Total Errors, PR = Perseverative Responses; PE = Perseverative Errors; NE = Non-perseverative Errors

Data analysis

The analysis was conducted using Statistica 13 (Dell, 2015). We computed Multivariate Analysis of Variance (MANOVA) to investigate possible between-group differences in set-shifting performance by ADHD subtype, sex, and age. This was a 4 x 2 x 2 (ADHD subtype x sex x age group) analysis design. We also applied Scheffé's post-hoc test for differences on the various set-shifting scores (Scheffe, 1999). For effect size measures we followed the guidelines by Cohen (1988), η_p^2 (partial eta squared): small = 0.01, medium = 0.06, and large = 0.14.

Results and discussion

Table 1 provides the test results for WCST, the MANOVA, and post-hoc (Scheffé) analysis of the number of total errors, perseverative responses, perseverative, and non-perseverative errors.

Age and sex differences

Since no statistically significant differences for age and sex were found between the ADHD and neurotypical peers, the study compared the set-shifting scores of children with ADHD with matched non-ADHD neurotypicals (see Table 1). Our findings are consistent with those by Lee and colleagues (2006) and Tsuchiya and colleagues (2005) who found no age or sex differences in set-shifting scores in both the children with ADHD and neurotypical others. Given this finding, our analysis focused on children with ADHD and neurotypical others without regard for sex and age.

Subtype differences

We observed statistically significant differences in performance on the WCST between the children with ADHD presentations and neurotypicals across set-shifting scores, with Wilks $\Lambda = 0.48$, $F(15, 373) = 7.61$, $p < 0.001$, $\eta_p^2 = 0.23$. The ADHD-HI, ADHD-PI, and ADHD-C presentations performed significantly poorer than the neurotypicals: Total errors (all three presentations, $p < 0.001$), perseverating responses (ADHD-PI $p = 0.01$, ADHD-HI and ADHD-C $p < 0.001$), perseverating errors (all three presentations $p < 0.001$), and non-perseverating errors (ADHD-HI $p = 0.01$, ADHD-PI and ADHD-C $p < 0.001$). The effect size (partially eta squared, η_p^2) of 0.23 is considered as large (Cohen, 1988).

These findings are similar to those of previous studies (Sergeant et al., 2002; Geurts et al., 2005; Lawrence et al., 2004). Our study replicates the findings on children with ADHD making significantly more set-shifting total errors, perseverative and non-perseverative errors, and perseverative responses than their neurotypical peers (Geurts et al., 2005; Lawrence et al., 2004; Mathivha, 2005; Romine et al., 2004; Sergeant et al., 2002; Saydam et al., 2015). Findings may be explained by the fact that children with ADHD tend to perform tasks with high aversion to delay (Sonuga-Barke et al., 1992), which would impair their performance. According to Romine and colleagues (2004), impaired performance may be indicative of an underlying neurological disorder affecting goal-directed behaviour.

However, our findings differ from those by Klorman and colleauges (1999) who found that children with ADHD-C make more non-perseverative errors than the ADHD-PI presentations. Therefore, the results of Klorman and colleagues (1999) are not consistent with those of our study which indicate that all ADHD presentations made more non-perseverative errors than the neurotypical group.

Implications for research and practice

The results of the study show that children with ADHD show deficiencies in set-shifting (mental flexibility) which will affect their academic and social functioning (Biederman et al., 2004; Fenesy & Lee, 2018; Lambek et al., 2010). Therefore, the WCST can be used to compliment the diagnostic instruments for ADHD to provide additional information on executive functioning, specifically on cognitive flexibility.

Limitations and suggestions for future research

The sample size used during this study was small and is not representative of the general population of primary school children in Limpopo Province. A further limitation was the small sample size of the ADHD-HI presentation. However, this was expected as this presentation is generally underrepresented in the general population. This may have influenced statistical analyses. The sample was homogeneous as it consisted of only rural primary school children of a specific area in Limpopo. Future studies should be aimed at a more heterogeneous population consisting of different ethnic groups and a wider age range locality.

Conclusion

The goal of the study was to assess whether children with ADHD differed in their set-shifting when compared to a neurotypical group by subtypes, sex, and age. The study showed differences between the children with ADHD subtypes and neurotypicals across set-shifting. The ADHD-HI, ADHD-PI, and ADHD-C subtypes performed poorer than the neurotypicals. No differences were found in terms of age and sex between ADHD and neurotypical peers. In conclusion, the study showed that children with ADHD have deficits in set-shifting, which is an important executive learner function.

Author notes

The authors acknowledge the participation of all learners, parents, and teachers in the study. They also acknowledge the following field workers: Xichavo Hobyana, Khuliso Matidza, Penny Mafela and Rotakala Sadiki. The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in the writing of this article. This study was funded partially by College Research office at the University of Kwazulu-Natal. Data will be available in the University of Kwazulu-Natal library, no data sharing.

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4.3 Paper 3

This paper explored whether children with ADHD have working memory and cognitive flexibility deficiencies compared to neurotypical children. This manuscript was submitted to the *Journal of Child and Mental Health* and is awaiting publication.

A copy of the article that is in peer review is inserted below

Journal of Child &
Adolescent Mental Health
Routledge
Taylor & Francis Group

Working Memory and Cognitive Flexibility Impairments in Primary School Children with Attention-Deficit/Hyperactivity Disorder.

Journal:	*Journal of Child & Adolescent Mental Health*
Manuscript ID	JCAMH-2020-038
Manuscript Type:	Research Paper
Keywords:	ADHD, Cognitive Flexibility, Digits Forward and Backward, Executive Functioning, Working Memory

Working Memory and Cognitive Flexibility Impairments in Primary School Children with Attention-Deficit/Hyperactivity Disorder.

Abstract

Objective: To test working memory and cognitive flexibility in children with ADHD and compare them to a neurotypical control group.

Methods: A sample of primary school children (N=156), six to 14 years, from Limpopo, South Africa, comprising an ADHD group (n=78) and a matched, control group without ADHD (n=78) was administered the Digit Forward, Digit Backward and Trail Making Test A and B. Multivariate Analysis of Variance was employed to establish between-group differences and *post-hoc* analysis (Bonferroni) to show within-group differences.

Results: There was no effect for age and gender on all measures. There was a significant difference in performance between the ADHD and the control groups. All three ADHD presentations performed significantly poorer than the controls on the Digit Backwards and Trails Making Test B. The ADHD, Inattentive and Combined presentations performed significantly poorer than the controls on the Digit Forward. No statistical difference between the ADHD (all three presentations) and the control groups were found on the Trails A test.

Conclusion: Children with ADHD have deficits in cognitive flexibility or mental set-shifting and working memory.

Keywords: ADHD, Cognitive Flexibility, Digits Forward and Backward, Executive Functioning, Prefrontal Cortex, Trails-A and B, Working Memory.

Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder, characterised by symptoms of overactivity, impulsiveness and inattentiveness (American Psychiatric Association, 2013). Problems associated with ADHD can adversely affect school performance, families, relationships and social interactions (Bener, Qahtani, & Abdelaal, 2006). Children with ADHD are less social preferred by their classmates, have fewer dyadic friends, (Hoza et al., 2005) and experience lower academic achievement (Barkley & Lindsey, 2005, Frazier, Youngstrom, Glutting, & Watkins, 2007). ADHD also places children at risk of school failure and drop out, juvenile delinquency, criminality, substance abuse, sexual promiscuity and many other problems later in life (Aase, Meyer, & Sagvolden, 2006). According to Rasmussen and Gillberg (2000), people with ADHD have poor outcomes such as Antisocial Personality Disorder, alcohol abuse, criminal offending, Reading Disorders and low educational level.

ADHD affects 3% to 5% of school going age children world-wide (Klingberg et al., 2005). Moreover ADHD persists into adulthood (Biederman, Mick, & Faraone, 2000; Rasmussen & Gillberg, 2000) although Biederman et al., (2000) showed a decline in ADHD symptoms with increasing age among different age groups of children with ADHD. Child and adolescence studies show that ADHD predominantly affects males, with a male-female ratio of 4:1 in clinical studies and 2.4:1 in population studies (Polanczyk, De Lima, Horta, Biederman, & Rohde, 2007). According to Wamulugwa et al. (2017) children <10 years of age were four times more likely to have ADHD than those older. However, this observation may be attributed to the tendency that more children <10 ten years of age (56%) more often attend neurology and psychiatric clinics.

Symptoms of ADHD arise from a primary deficit in specific executive functions (EF), (Barkley, 1997; Castellanos & Tannock, 2002; Pennington & Ozonoff, 1996; Schachar, Mota, Logan, Tannock, & Klim, 2000). EF is an umbrella term used to describe the systems involved in the high-level control of cognitive processes. These are required for goal-directed behaviour, associated with the frontal lobes and include among other functions, the ability to inhibit a prepotent response, planning, reasoning and working memory (Klingberg et al., 2005). A theory by Barkley (1997) considers inhibitory dysfunction as a core deficit in children with ADHD, which causes deficiencies in other EFs such as working memory (visuo-spatial and verbal), cognitive flexibility and planning behaviour. Working memory impairments are reported in 30% to 37% of children with ADHD (Coghill, Seth, & Matthews, 2014; Fair, Bathula, Nikolas, & Nigg, 2012). Difficulties with verbal working memory usually manifest as forgetfulness in daily activities (American Psychiatric Association, 2013).

Working memory *(WM)* is the ability to both retain and manipulate information during a short period of time. WM also plays a critical role in guiding everyday behaviour and underlies the capacity to perform complex tasks such as learning, comprehension, reasoning and planning (Baddeley, 2007). Children with ADHD have working memory deficits which are attributed to impaired frontal lobe functioning (Klingberg, Forssberg, & Westerberg, 2002) and express as inattention and short attention span (Gathercole et al., 2008; Alloway, Gathercole, Kirkwood, & Elliott, 2009; Archibald, Joanisse, & Edmunds, 2011). Furthermore, children with ADHD display impaired ability with tasks which require working memory, specifically prefrontal cortex (PFC) functions (Bedard et al., 2003; Itami & Uno, 2002; McLean & Fetcho, 2004). The PFC is said to play a central role in working memory (Baker & Heller, 1996; Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2005; Tripp, Ryan, & Peace, 2002). PFC lesions impair the ability to sustain attention particularly over long delays, (Wilkins, Shallice, & McCarthy, 1987) resulting in symptoms such as forgetfulness, impulsiveness, distractibility and disorganisation (Arnsten & Li, 2005).

fMRI studies have identified functional abnormalities in working memory-related brain regions such as the bilateral dorsolateral prefrontal cortex (DLPFC), the right parieto-occipital area, the right inferior parietal lobe and the right caudate nucleus and less functional connectivity between frontal and subcortical regions (Depue et al., 2010; Sheridan, Hinshaw, & D'ESposito, 2007). According to Burgers et al. (2010) and Sheridan et al. (2007) higher working memory ability predicts increased activation of the left prefrontal cortex. The DLPFC is linked to working memory (Faraone et al., 2015) and lesions of the DLPFC impair the ability to shift attentional set (Arnsten & Li, 2005; Manes et al., 2002). Furthermore, neurotransmitter circuits, such as the dopaminergic, serotoninergic and noradrenergic, are also associated with symptoms of ADHD. The dopamine system plays an essential part in planning and initiation of motor response activation, a switching reaction to novelty and reinforcing stimuli (Faraone et al., 2015; Johansen, Aase, Meyer, & Sagvolden, 2002; Sagvolden, Johansen, Aase, & Russell, 2005; Tripp, & Wickens, 2008; Williams & Taylor, 2004). Dopamine hypofunctioning may, in most cases, be genetically determined while in other cases it may be induced by environmental factors such as drug abuse or pollutants (Johansen et al., 2002; Sagvolden et al., 2005).

The Dynamic Developmental Theory of Sagvolden et al., (2005) postulates that ADHD symptoms could be a result of altered dopamine functioning, which fail to appropriately modulate non-dopaminergic (primarily glutamate and GABA) signal transmission. This theory further postulates that the hypofunctioning dopamine branches give rise to primary individual predispositions, as they predict that behaviour and symptoms in ADHD result from an interplay between individual predispositions and the surroundings (Tripp & Wickens, 2009). The mesocortical branch connects the ventral tegmentum to the cerebral cortex, in particular, the frontal lobes. This branch is crucial to the normal cognitive function of the DLPFC, which is associated with behaviour planning, working memory and cognitive flexibility (Gendle, Young, & Romano, 2013; Oades et al., 2005; Sagvolden et al., 2005).

Baddeley's (2003) model views working memory as a multi-component system which consists of independent phonological and visuospatial subsystems. Working memory is comprised of the central executive which is primarily responsible for focusing and dividing controlled attention among concurrent tasks and independent phonological and visuospatial storage/rehearsal subsystems (Baddeley, 2007). Verbal and auditory information is temporarily stored and processed in the phonological loop. The phonological loop system stores and rehearses speech-based information and is necessary for language acquisition. The visuospatial sketchpad system manipulates memories of visual images and spatial information. The central executive is assumed to be an attention-control system which processes information from these two short term storage systems (Kokubo et al., 2012). It is involved in the organising, binding and integration of information, and it permits interfacing with long-term memory (Zillmer, Spiers, & Culbertson, 2008). The central executive also allows for the manipulation and storage of information in working memory by means of supervising and co-ordinating assistant systems (Repovš & Baddeley, 2006). It is a general, domain system that facilitates the ongoing interaction of domain-specific storage, that is phonological or visuospatial information (Kane, Conway, Miura, & Colflesh, 2007).

According to Gathercole, Pickering, Ambridge, and Wearing, (2004), central executive functions are associated with the frontal lobes and also some posterior (mainly parietal) areas. It has been suggested by Baddeley and Della Sala, (1996) that organising and encoding material occurs in the left frontal lobe and episodic retrieval in the right frontal lobe.

Working memory is the active maintenance of visual and auditory information used to serve the needs of ongoing tasks. This includes not only the part responsible for information maintenance, but also the central executive system, related to the active control process, which is closely related to the attention process (Aben, Stapert, & Blokland, 2012; Luck & Vogel, 2013). Working memory impairments in children with ADHD are likely to be affected by the attentional process.

Cognitive flexibility, which is also referred to as task switching or set-shifting, is the ability to shift strategies between multiple operations and mental states (Anderson, 2002; Diamond, 2013, Miyake et al., 2000; Monsell, 1996; Re, Lovero, Cornoldi, & Passolunghi, 2016). It is usually assumed that the ability to shift between tasks or mental sets is an essential aspect of executive control. Cognitive flexibility has been proposed as a component of EF. The shifting process involves the disengagement of an irrelevant task set and the subsequent active engagement of a relevant one (Monsell, 1996). In a changing environment, behaviour has to be adaptive and flexible (Kehagia, Murray, & Robbins, 2010). Children with ADHD can be slow at switching between stimuli or between sets of stimuli to control behaviour which is appropriate to changing situations (Oades & Christiansen, 2008).

The executive-oriented shifts may be regulated primarily by the frontal lobes, including the anterior cingulate or the "anterior attention network" (Miyake et al., 2000). One key symptom of frontal lobe impairment is perseveration or repetition of the same response repeatedly, even when it is no longer appropriate. It is often understood in terms of difficulty in shifting of mental sets (Ardila, 2008; Stuss et al., 1986). Lesions of the DLPFC impair the ability to shift attentional sets (Manes et al., 2002).

Individuals of all ages afflicted with ADHD have reported difficulty with set-shifting, that are related to abnormal activity of the PFC, a brain region that has been associated with cognitive flexibility (Dalley, Cardinal, & Robbins, 2004; Wood, Kohli, Malcolm, Allison, & Shoaib, 2016). Neurophysiological and neuroimaging studies report roles for the inferior frontal regions in switching between stimuli (Beck, Rees, Frith, & Lavie, 2001; Jemel, Achenbach, Müller, Röpcke, & Oades, 2002) and parts of the intraparietal sulcus in switching between plans contingent on set. Dopamine dysfunction plays a pivotal role in the neurobiology of cognitive flexibility, especially a hypofunctioning mesocortical dopamine branch, which supplies the prefrontal cortex (Johansen et al., 2002; Sagvolden et al., 2005; Tripp & Wickens, 2009). Dopamine neurotransmission in the medial striatum and PFC is critical for basic reinforcement learning and the integration of negative feedback during reversal learning, whilst orbitofrontal serotonin likely mediates the type of low level flexibility, by reducing interference from prominent stimuli (Kehagia, Murray & Robbins, 2010). Damage to different prefrontal areas (PFC) results in deficits in separate forms of cognitive flexibility. Damage to the orbitofrontal cortex (OFC) is thought to impair reversal learning but not attentional set-shifting (Boulougouris, Dalley, & Robbins, 2007; Hornak et al., 2004; McAlonan & Brown, 2003). Dopamine neurons are thought to be important for learning. The deficient functioning of the D1 and D2 receptors in the lateral PFC, impairs learning of new stimulus-response associations and cognitive flexibility (Klanker, Feenstra, & Denys, 2013).

The current study investigated working memory and cognitive flexibility deficits in children with ADHD using the Digit Span Test and Trail Making Test A and B.

Materials and Methods

Sample

One hundred and fifty-six children (76 boys and 80 girls), aged 7-14 years, were recruited from a school-based population in Limpopo, South Africa. A total number of 5480 children were screened for ADHD by means of the Disruptive Behaviour Rating Scale (DBD), (Pelham Jr, Gnagy, Greenslade, & Milich, 1992; Pillow, Pelham, Hoza, Molina, & Stultz, 1998). The questionnaire was completed by their teachers and parents, in order to identify symptoms of ADHD. The return rate for the DBD was 98.5%. Seventy-eight (78) children had ADHD criteria (ADHD group) and were matched with seventy-eight (78) children, for gender, age and home language who did not meet the criteria for ADHD (control group). Children with an IQ <80, a history of neurological or severe psychiatric problems (e.g. head injuries, epilepsy, cerebral palsy, cerebral malaria, autism spectrum disorder, etc.) were excluded from the study. None of the children were on psychostimulant medication at the time of testing.

Instruments

Disruptive Behaviour Rating Scale (DBD)

The DBD was used to screen for ADHD symptoms (Pelham et al., 1992). The scale assesses the presence and degree of ADHD-related symptoms; inattention and hyperactivity/impulsiveness, Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD) as formulated in the DSM-IV. The DBD has been translated into five South African languages (viz. Northern Sotho, Tshivenda, Afrikaans, Tsonga and Tswana) all of which are spoken in the Limpopo Province. Internal consistency and norms for each language group were established (Meyer, Eilertsen, Sundet, Tshifularo, &. Sagvolden, 2004). Cronbach's alpha computed was 0.92 for inattention and 0.90 for hyperactive/impulsiveness. Cut-off points for ADHD and the control group were based on the results from a previous study, in which more than 6000 children in Limpopo participated (Meyer et al., 2004). Children with scores of $\geq$18 on the hyperactive/impulsive sub-scale were classified as having ADHD hyperactive-impulsive presentation (ADHD-HI) and those participants with scores of $\geq$21 on the inattention sub-scale as having ADHD predominantly inattentive presentation (ADHD-PI). If participants met the criteria on both ADHD-HI and ADHD-PI, they were classified as having ADHD combined presentation (ADHD-C). The cut-off point for the control group was set at the $\leq 85^{th}$ percentile, in order to decrease the risk of false positives in this group

The Memory for digits (MFD) is a subtest of the Senior South African Individual Scales (SSAIS-R), (Cockcroft & Blackburn, 2008; Van Eeden & Visser, 1992). The test consists of two subtests of strings of digits read to the test taker. The test requires the concentration of the testee to be able to encode and recall the digits. The test determines the working memory, auditory sequencing and auditory attention of the participant (Van Eeden & Visser, 1992). Internal reliability ranges from 83 to 1.90 and construct validity from 0.1 to 0.5. (Cockcroft, 2013).

Digit Forward.

Digit Forward (DF*)* is a task of short-term auditory memory, focused attention, sequencing and simple verbal expression and a measure of the phonological loop of Baddeley (1992) model of working memory (Quinlan & Brown, 2003). It also requires the test taker to repeat a series of numbers which increase in length, after each success.

Digit Backward.

Digit backward (DB) is more sensitive to deficits in working memory. It involves the additional components of attention and executive processes (Quinlan & Brown, 2003). It requires the testee to repeat the numbers backwards.

The Trail Making Test (TMT) is a test of visual search, attention, mental flexibility and motor function (Spreen & Strauss, 1998). It has two parts; Part A is a measure of visual search, attention and mental tracking while Part B measures cognitive abilities, such as flexibility and the capacity to deal with more than one stimulus at a time (Kokubo et al., 2012). The TMT-B has been found to be sensitive to prefrontal lesions in ADHD (Shue, & Douglas, 1992). Children with ADHD take significantly longer to complete TMT-B when compared to controls (Johnson & Freker, 2001; Nigg et al., 2004; Pennington & Ozonoff, 1996; Rapport et al., 2009). Elosúa, Del Olmo, and Contreras, (2017) indicated that test-retest reliability for TMT was between 0.60 and 0.90.

Both parts of the TMT consists of 25 circles, which are distributed over a sheet of paper. In part A, the circles are numbered 1-25, and the participant is expected to draw the lines to connect the numbers in ascending order. In part B, they need to connect 13 numbers and 13 letters. These have to be alternately connected in both numerical and alphabetical order (Vaucher et al., 2014).

Procedure

The researcher instructed the children in their home language, namely, Tsonga and Sepedi. The assessments were conducted during school hours. The participants were assessed individually, in a quiet room.

Ethical Considerations

The Social Sciences Research Ethics Committee of the University of KwaZulu-Natal approved the study (approval number: HSS/1452/015D). The Department of Education, Limpopo Province and the school principals of the schools involved, gave permission for the study to be conducted. Participation was voluntary. The parents or legal guardians of the children gave informed consent. The children also assented to participate in the study.

Statistical Analysis

Multivariate analysis of variance (MANOVA) was used to investigate possible between-group differences, in the Memory for Digits subtests of the SSAIS-R (digits forward and digits backwards) and Trail making test A and B raw scores. The analysis was conducted by means of Statistica 10, (StatSoft, 2011). The results for each test were analysed with 4 x 2 x 3 (ADHD presentation x gender x age group) MANOVA's for independent variables. Bonferroni *post-hoc* test was used to establish within-group differences.

Results

No main or interacting effect for age or gender was found between the ADHD and control groups for digits forward, digits backwards, and TMT A and B Test (Table 1). Statistically significant differences were found in the performance on DF and DB) for the ADHD presentations, Wilks $\Lambda = 0.44$, $F= 25.34$, $p = < 0.001$, $\eta_p^2 = 0.34$. *Post-hoc* analysis (Bonferroni) revealed that the ADHD-PI ($p < 0.001$) and ADHD-C ($p = 0.03$) presentations performed poorer than the controls on the DF subtest, while the ADHD-HI, ADHD-PI and ADHD-C presentations performed significantly more poorly than the controls on the DB (all three presentations, $p < 0.001$).

Statistically significant differences in performance on the TMT A and B were found for the ADHD presentations, Wilks $\Lambda = 0.46$, $F= 23.50$, $p = < 0.001$, $\eta_p^2 = 0.32$. *Post-hoc* analysis (Bonferroni) showed that the ADHD-HI, ADHD-PI and ADHD-C presentations performed significantly more poorly than the controls, on the TMT-B Test only (all three presentations, $p < 0.001$). No statistical difference between the ADHD (all three presentations) and the control groups were found with regards to performance on the TMT-A. An effect size (partially eta squared, η_p^2) of 0.32 and 0.34 can be considered as large (Cohen, 1988)

Table 1 provides the descriptive statistics for the MFD and the TMT A and B, the MANOVA and *post-hoc* (Bonferroni) analysis for the DF, DB, TMT A and B.

Insert Table 1 here -

Discussion

The study attempted to establish deficiencies in working memory and cognitive flexibility in children screened for ADHD. Age and gender did not affect task performance on MFD on both DF and DB and on the TMT A & B. This finding is consistent with other studies which showed no gender and age effect on the MFD and TMT-A and B (Arcia & Conners, 1998; Parkin, Walter, & Hunkin, 1995; Rucklidge & Tannock, 2002; Shikwambana, 2006; Salthouse, Atkinson, & Berish, 2003; Seidman, Valera, & Makris, 2005).

Our study indicated that the ADHD-PI and ADHD-C presentations did encounter difficulties with the DF subtest, when compared with children without ADHD. The results are consistent with those of Martinussen, Hayden, Hogg-Johnson, and Tannock, (2005), Willcutt, Doyle, Nigg, Faraone, and Pennington, (2005) and Kofler, Rapport, Bolden, Sarver, and Raiker, (2010) who also found that children with ADHD-PI and ADHD-C encountered difficulties with the DF. Children with poor working memory are reported to be inattentive and have short attention spans (Alloway et al., 2009; Archibald et al., 2011; Gathercole et al., 2008). Both the ADHD-PI and ADHD-C presentations show deficiencies in sustained attention which is not observed in the ADHD-HI presentation. Therefore, the poorer performance of the participants with ADHD-PI and ADHD-C presentations, can be ascribed to the core symptom of inattention. Biederman et al., (2002) indicate that inattention is associated with numerous functional deficits, such as educational failures, poor school performance and school dropout. Children with ADHD-PI appear to display cognitive and interpersonal dynamic problems disparate from ADHD-HI children as they are socially withdrawn/introverted, cognitive, behavioural and orally sluggish, namely daydreamers rather than overly talkative and aggressive (Carlson & Mann, 2000; McBurnett, Pfiffner, & Frick, 2001; Milich, Balentine, & Lynam, 2001). Furthermore, children with inattention also encounter various other educational problems because of their short attention span, difficulty concentrating, inability to modulate attention in response to externally imposed demands and trouble selectively attending to relevant stimuli while filtering out unnecessary noise. The ADHD-PI presentation tends to be more impaired on tasks of selective attention and working memory, which is also according to Barkley (1997), who indicated that children with ADHD demonstrate weaknesses in working memory as they have difficulties supressing competing stimuli and are less likely to hold information in mind as they are more distractible.

Our study also showed that children with all three ADHD presentations performed significantly worse on the digit backwards test. Previous studies indicated that children with ADHD perform poorly on tasks of working memory, since they recall fewer digits than the controls (Gropper & Tannock, 2009; Hervey, Epstein, & Curry, 2004; Mariani & Barkley, 1997). Deficits on working memory may be best interpreted by a deficient phonological loop involved in holding verbal information and which has therefore limited capacity (Hervey et al., 2004; Pennington & Ozonoff, 1996; Repovš & Baddeley, 2006; Sergeant, Oosterlaan, & van der Meere, 1999; Sonuga-Barke, Dalen, Daley, & Remington, 2002).

In terms of the cognitive flexibility tasks, TMT A, our study results were similar to most other researchers', Pennington and Ozonoff, (1996); Elosua, Del Olmo and Contreras, (2017) and Houghton et al., (1999) who also found no statistically difference in the performance of participants, between all three ADHD presentations and the controls on the Trail Making Test A. However, the TMT-A provides an attentional baseline and does not demonstrate sensitivity and specificity for the identification of cognitive flexibility associated with ADHD (Nigg, Blaskey, Huang-Pollock, & Rappley, 2002).

The study results recognised that children with all three ADHD presentations performed significantly worse on the TMT-B tests, when compared to the control group, a finding which is consistent with other studies (Nigg, Blaskey, Stawicki, & Sachek, 2004; Pennington & Ozonoff 1996; Rapport, Kofler, Alderson, Timko & DuPaul, 2009 &

Rohlf, 2012). Children with ADHD made more errors in the test due to their impulsive responses. They are reported to perform inadequately on the TMT-B as they lack strategic flexibility and showed a more impulsive strategy, rather than a true planning problem. They also performed the task immediately, due to their aversion to delay (Sonuga-Barke, Taylor, Sembi, & Smith, 1992). They may be slow at switching between stimuli, or between sets of stimuli, and lack control behaviour appropriate to changing situations (Oades & Christiansen, 2008). fMRI findings show increased activity in the left dorsolateral prefrontal region of the brain during TMT-B performance. Therefore, dorsolateral frontal lobe dysfunction may produce poor performance on TMT-B (Chan et al., 2015). Oades and Christiansen (2008) revealed that not only the left DPFC, but also the precentral gyrus, cingulate gyrus and medial frontal gyrus are involved, suggesting both motor control and cognitive flexibility that are important for performance on part B of the TMT.

Children with ADHD are reported to have altered reinforcement processes (Sagvolden et al., 2005; Sonuga-Barke, 2005), deficient controlling effortful processes (Sergeant et al., 2003) and problems switching attention-related processes (Mason, Humphreys, & Kent, 2004; Pearson, Lane, & Swanson, 1991; White & Shah, 2006). According to Sonuga-Barke's dual pathway model (2002), children with ADHD display problems with set shifting and working memory because ADHD may not only pertain to dysregulation of the thought and action pathway, but also to the motivational style pathway. The first pathway (ADHD DTAP) is manifested in a primary, inhibitory dysfunction, that is mediated by secondary cognitive and behavioural dysfunctions, which in turn leads to faulty task engagement (deficits of set shifting and working memory) and to symptomatic behaviour (i.e inattentiveness and hyperactivity). The second pathway (ADHD MSP), is characterised by a dysregulation of reward mechanisms which leads to a higher preference for immediate rewards in children with ADHD (Sonuga-Barke. 2003).

The ability to shift set and the capacity of working memory are aspects of the cognitive control function that are important for children in their everyday life. Working memory has an important role for achievement at school and learning. Working memory actually, might be more predictive for school achievement than intelligence (Alloway & Alloway, 2010). Passolunghi and Siegel, (2004) showed that children with ADHD cannot adapt well to new situations and struggle especially with mathematical subjects.

They also indicated that children who experience difficulties in solving mathematical problems have a general deficit in central executive functioning. These children need constant reminders, because of their problems with working memory. They do not deal with contradictions well and cannot adapt to changes or changing situations easily. They do not shift easily, can get stuck on one routine, hyper-focus on one task and are rigid in their thinking (Hosenbocus & Chahal, 2012). Teachers have found that children who have problems with sustained attention usually have also WM problems (Alloway et al., 2009; Archibald et al., 2011; Gathercole et al., 2008). Beyond forgetfulness, WM also involves recall of what has just been read, heard or said. Short-term memory impairments may also contribute to other problematic behaviours which are recognised as symptoms of ADHD. Children with ADHD often do not follow through on instructions and fail to finish school work and chores and frequently lose equipment necessary for tasks or activities (Quinlan & Brown, 2003). Increasing awareness and understanding of deficiencies in EF, especially working memory and cognitive impulsiveness, can improve school performance for children with ADHD (Martinussen, Tannock, Chaban, McInnes, & Ferguson, 2006). Working memory training may improve performance and inattentiveness (Klingberg et al., 2005).

Some limitations in this research hinder generalisability of the results. The sample was limited to Sepedi and Xitsonga speaking children in a particular municipal area. Future studies should include all language groups. Another limitation was the small sample size of the ADHD-HI sub-group, which is usually under-represented in ADHD populations. A larger sample in future studies will help increase the number of ADHD-HI participants.

Children with ADHD have deficits in cognitive flexibility/mental set-shifting and working memory, as was demonstrated by the Memory for Digits subtest and Trail making test. They performed especially badly on the Digit Backwards and TMT-B, which indicates that they experience problems with set-shifting and working memory. These instruments constitute a valid tool to measure cognitive flexibility and working memory. Since they successfully distinguished between children with ADHD and neurotypical controls, in a non-Western population, the tests can be considered as culture-fair.

Declaration of conflicting interests

The authors declare that they have no financial or personal relationships which may have inappropriately influenced them, in the writing of this article.

Acknowledgements:

The authors acknowledge the following field workers:

Xichavo Lobyana

Khuliso Matidza

Penny Mafela

Rotakala Sadiki

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Table 1: MANOVA: Digit Span and Trail Making

	Subtypes			Control	Group Comparison DF (6, 296)				*Post-hoc* (Bonferroni)	
	ADHD-HI	ADHD-PI	ADHD-C		Wilks Λ	*F*	*p*	η_p^2		*p*
N	12 (7%)	30 (20%)	36 (23%)	78 (50%)						
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*						
Digits					0.44	25.34	< 0.001	0.34		
DF	7.00 (1.48)	6.90 (1.56)	7.36 (1.73)	8.27 (1.53)					PI < Control C < Control	< 0.001 0.03
DB	2.33 (0.78)	2.30 (0.97)	2.33 (0.76)	4.79 (1.54)					HI, PI, C < Control	<0.001
TMT					0.46	23.50	<0.001	0.32		
A	105.08 (58.80)	102.43 (46.14)	97.31 (42.95)	83.65 (27.82)						n/s
B	206.33 (71.06)	246.97 (83.68)	244.17 (43.89)	129.35 (37.73)					HI, PI, C > Control	< 0.001

4.4 Paper 4

The final paper investigated whether the commonly used EF neuropsychology assessments employed can predict the core symptoms of ADHD: Hyperactivity/impulsiveness and inattention.

Paper 4 was published in the African Journal of Psychological Assessment.

4.4.1 Reference

Boshomane, T. T., Pillay, B. J., & Meyer, A. (2021). Measures of executive functions predicting Attention-Deficit/ Hyperactivity Disorder core symptoms. *African Journal of Psychological Assessment*, *3*(0), a48. https://doi.org/10.4102/ ajopa.v3i0.48

African Journal of Psychological Assessment
ISSN: (Online) 2617-2798, (Print) 2707-1618

AOSIS

Measures of executive functions predicting Attention-Deficit/Hyperactivity Disorder core symptoms

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Dates:
Received: 01 Apr. 2021
Accepted: 19 Aug. 2021
Published: 22 Oct. 2021

How to cite this article:
Boshomane, T.T., Pillay, B., & Meyer, A. (2021). Measures of executive functions predicting Attention-Deficit/Hyperactivity Disorder core symptoms. *African Journal of Psychological Assessment, 3*(0), a48. https://doi.org/10.4102/ajopa.v3i0.48

Attention-deficit/hyperactivity disorder (ADHD) is a common childhood disorder, and in many children, ADHD is thought to be aggravated by a deficit in executive functions (EFs). This study tried to establish whether commonly used neuropsychological tests of EF also predicted the core symptoms of ADHD, namely hyperactivity/impulsiveness (H/I) and inattention, as well as total ADHD symptomatology, according to the *Diagnostic and Statistical Manual of Mental Disorders, 4th Edition, Text Revision* (DSM-IV-TR). The participants were children from the Limpopo province, South Africa, aged from 6 to 15 years (M = 11.7 years; SD = 1.7). One hundred and fifty-six children (51.3% girls) were assessed by neuropsychological tests of EFs: the Tower of London (ToL), Digits Forward and Digits Backward, Trails-A and Trails-B and Wisconsin Card Sorting Test (WCST). Forward stepwise regression analysis was employed to predict H/I and inattention, as well as total ADHD symptomatology, based on DSM-IV-TR criteria. All the tests, except Trails-A, were found to predict ADHD symptomatology. The WCST (total errors) was the best predictor of all the ADHD symptoms and also for H/I and inattention separately, followed by Trails-B and Digits Backwards, which were found to predict more symptoms of inattention than H/I. Perseverative errors on the WCST predicted more H/I symptomatology, whilst non-perseverating errors were more associated with inattention. The ToL and Digits Forward predicted fewer ADHD symptoms. The ToL seemed more sensitive to inattention, whilst Digits Forward showed a stronger association with H/I. The WCST, Digits Backwards and Trails-B may be used to measure EF to support the diagnosis of ADHD in a clinical setting and to indicate cognitive impairment.

Keywords: ADHD; executive functions; hyperactivity/impulsiveness; inattention; neuropsychological tests.

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is the most commonly diagnosed psychiatric disorder, affecting 5% – 7% of children and adolescents worldwide (Polanczyk, De Lima, Horta, Biederman, & Rohde, 2007) and 5.5% in the Limpopo province, South Africa (Meyer, Eilertsen, Sundet, Tshifularo, & Sagvolden, 2004). In about two-thirds of cases, ADHD continues into adulthood (Faraone, Biederman, & Mick, 2006). It is a neurodevelopmental disorder, characterised by the core symptoms of hyperactivity/impulsiveness (H/I), inattention or both (American Psychiatric Association, 2013). *Hyperactivity* manifests as greater than usual levels of movement and activity and an inability to remain still for a long time (Danielson et al., 2016), whilst *impulsiveness* is the tendency to act prematurely without anticipation or consideration of the consequences (Dalley, Everitt, & Robbins, 2011). *Inattention* can be described as the inability to focus, high levels of distractibility, forgetfulness and poor planning and organising abilities (Elisa, Balaguer-Balleester, & Paris, 2016). The *Diagnostic and Statistical Manual of Mental Disorders, 4th Edition, Text Revision* (DSM-IV-TR) (American Psychiatric Association, 2000) requires a child to meet six or more of H/I or six or more of inattention behaviours, for at least 6 months, before the age of 7 years. The DSM-IV criteria are mainly similar to those of *DSM-5*, except for the age of onset that changed from 7 to 12 years of age.

Executive functions and attention-deficit/hyperactivity disorder

Executive functions are an umbrella term that embraces a varied range of cognitive processes and abilities that facilitate goal-orientated behaviour and thought processes such as planning, insight, judgement, reasoning and cognitive flexibility (Ogilvie, Stewart, Chan, & Shum, 2011). The EFs involve the cognitive abilities necessary for controlling attention, timed organisation of responses, goal-directed planning of complex tasks, abilities to access and manage information in long-term memory and the monitoring of current internal and external states (Funahashi, 2001). The EFs measurements are generally designed to measure performance in experimental settings; however, in real-life settings, the demands on EF capacities are complex, multifaceted and involve multiple sub-tasks (Ogilvie et al., 2011). Most research on EFs focuses on the following: *Mental flexibility*, which refers to the ability to switch rapidly between established task sets (Van Holstein et al., 2011). Chiang and Gau (2014) indicated that *planning and problem-solving* be defined as the categorising and organising of the steps and elements required to carry out an intention, whilst *inhibition* refers to the ability to suppress irrelevant stimuli or behavioural impulses to enable goal-directed behaviour. *Working memory* is the cognitive ability to store limited amounts of information for a short period so that it can be manipulated to direct behaviour and to navigate the social world effectively (Diamond, 2013).

Attention-deficit/hyperactivity disorder is not only a behavioural disorder that is characterised by hyperactivity and inattention in children and excessive restlessness and impulsiveness in adults but also a cognitive disorder (Ciuluvica, Mitrofan, & Grilli, 2013). Children with ADHD show deficits in executive functions (EFs) (Barkley, 1997; Miyake et al., 2000; Nigg, 2017; Willcutt, Doyle, Nigg, & Faraone, 2005). Children with ADHD who do not present impairment in tasks in experimental settings may still face difficulties with everyday tasks that involve executive control (Sonuga-Barke, Dalen, Daley, & Remington, 2002; Sonuga-Barke, Dalen, & Remington, 2003; Thorell & Wåhlstedt, 2006).

All these processes and functions are complex and depend on multiple sub-processes and sub-functions (Ogilvie et al., 2011). Although children with ADHD have often exhibited poor EFs (Thorell & Wåhlstedt, 2006), these deficits are not present in all children with the disorder. Researchers in the area have repeatedly emphasised the need to take the heterogeneity of EFs into account when studying the symptomatology of ADHD (Sonuga-Barke et al., 2002, 2003; Thorell & Wåhlstedt, 2006). The work of several authors suggests that ADHD symptoms are the result of a primary flaw in a specific EF domain (e.g. response inhibition or working memory), or they arise from a more global difficulty with executive control (Barkley, 1997; Pennington & Ozonoff, 1996; Willcutt et al., 2005).

Because of the heterogeneity of EFs, they are difficult to measure (Miyake et al., 2000). Miyake and Friedman (2012) called this a *task-impurity* problem and maintain that any target EFs must be embedded within a specific task context. Therefore, any score obtained from an EFs task includes systematic non-EF variance and measurement error attributed to non-EF processes (Miyake & Friedman, 2012). For this reason, multiple tasks that appear different on the surface but still capture the targeting ability are often selected. If these tasks share little systematic non-EF variance, it is possible to statistically extract what is common across those tasks and use that 'pure' variable as the measurement of EF (Miyake & Friedman, 2012).

There are several theoretical explanations for ADHD and EF's relationship. Firstly, Barkley (1997) proposed that a deficit in behavioural inhibition is the core deficit of ADHD, which, in turn, creates disturbances in five neuropsychological functions: working memory; internalisation of speech; self-regulation of affect, motivation, and arousal; behaviour analysis and synthesis and motor control, fluency, and syntax. Barkley (1997) also suggested that difficulties with inhibition of behaviour may underlie some of the psychological and social difficulties linked with the other four EFs (Barkley, 1997). According to Barkley (1997), the configuration of deficits found in children with ADHD suggests the involvement of EFs including working memory. Therefore, EFs have been found to correspond with the symptoms of ADHD.

Secondly, the influential Baddeley, Logie, Bressi, Sala and Spinnler (1986) multi-component model of working memory includes three components (the phonological loop specialised for the maintenance of speech-based phonological information) and the visuospatial sketchpad (specialised for visual and spatial information). The model also includes a central control structure called the central executive, which controls and regulates the cognitive processes (EFs) and is frequently connected to frontal lobes functioning (Miyake et al., 2000).

Miyake et al. (2000) suggested a model that identifies three separable but partially correlated constructs: inhibiting prepotent responses (inhibition), shifting between tasks or mental sets (shifting) and updating of working memory representations (updating). ADHD-related working memory deficits were apparent across all three cognitive systems with deficits in the central executive. It also indicated that children with ADHD tend to perform poorly in a complex working memory task as they rely heavily on the central executive.

Lastly, according to Sonuga-Barke's dual pathway model (2002), children with ADHD display problems with set-shifting and working memory because ADHD may pertain not only to dysregulation of the thought and action pathway but also to the motivational style pathway. The first of these pathways is manifested in a primary, inhibitory dysfunction, that is mediated by secondary cognitive and behavioural dysfunctions, which in turn leads to faulty task engagement (deficits of set-shifting and working memory) and to symptomatic behaviour (i.e. hyperactivity and inattentiveness). The second pathway, in contrast, is involved in reward mechanisms (Sonuga-Barke et al., 2003). According to the delay aversion concept, children with ADHD experience higher sensitivity to delays than their peers. This leads to decisions that entail choosing a smaller-sooner reward over larger-later rewards on tasks designed to measure the relationship between impulsivity and delay aversion. Delay aversion is expressed as certain behaviour theorised to be motivated by the desire to escape or avoid delay. Children with ADHD act thoughtlessly because they avoid waiting. They may demonstrate elevated frustration when they feel annoyed owing to an unexpected delay during task performance and may show early detachment and inattention during long and tedious tasks. This leads to impulsive choices and perseverating responses.

Neuroanatomically, EF processes are primarily mediated through the frontal cortex, especially the prefrontal cortex (PFC). However, it is not clear how specific frontal areas are involved (Miyake & Friedman, 2012; Miyake et al., 2000). However, the integrity of the whole brain is necessary for the best performance of EF tasks (Funahashi, 2001). Koechlin (2016) indicated that damage to the PFC may result in impaired concentration, problem-solving ability, planning and judgement.

Studies amongst rural South African children (Mokobane, Pillay, & Meyer, 2020; Pila-Nemutandani & Meyer 2016) indicate that children with ADHD are significantly impaired on measures of planning behaviour and problem solving (as measured by the Tower of London [ToL]), showing that mainly the inattention component is involved. This was confirmed by Saydam, Ayvaşik and Alyanak (2015) and Oosterlaan, Scheres and Sergeant (2005).

Shikwambana (2006), also in a study amongst rural South African children, found that children with ADHD were impaired in working memory as measured by the Memory for Digits (MFD), especially the Digits Backwards (DB). Gropper and Tannock (2009) and Kofler, Rapport, Bolden, Sarver, & Raiker (2010) confirmed these results, but the latter also found that children with ADHD encountered difficulties with the Digits Forward (DF) test. Cockcroft (2011) in another SA study on working memory functioning in children with ADHD indicated that children with ADHD often experience working memory difficulties, as measured by DB test.

Pennington and Ozonoff (1996) found that Part A of the Trail Making Test (TMT) could not detect ADHD symptoms, whilst Kofler et al. (2010) found that children with ADHD performed worse than controls on the Trails-B, which measures cognitive flexibility, indicating the instrument's sensitivity to ADHD symptoms.

In another study amongst rural South African children, Mathivha (2005) showed that children with ADHD made more perseverative errors (PE) and non-perseverative errors (NPE), as measured by the Wisconsin Card Sorting Test (WCST), with especially the H/I component being affected. Geurts, Verté, Oosterlaan, Roeyers and Sergeant (2005) found poor performance on the WCST amongst children with ADHD, with both H/I and inattention affected. Tsuchiya, Oki, Yahara and Fujieda (2005) and Saydam et al. (2015) indicated that all ADHD presentations exhibited poor performance on the WCST as suggested by total errors (TE) and PE. Tsuchiya et al. (2005) also found that children with ADHD exhibited poorer performance on the WCST, as indicated by NPE.

It was, therefore, hypothesised that instruments used to measure EF performance (planning, working memory and set-shifting) would predict the core symptoms of ADHD, namely H/I and inattention as well as total ADHD symptomatology.

The purpose of the study was to examine whether commonly used neuropsychological EF tests, the ToL, MFD (DF and DB), Trails-A and Trails-B and WCST could predict the core symptoms of ADHD, namely H/I and inattention, as well as total ADHD symptomatology, as measured by a questionnaire (Appendix 1) based on the DSM-IV-TR criteria (American Psychiatric Association, 2000) in a South African population of primary school children.

Method

Participants

One hundred and fifty-six children between 6 and 15 years of age (M = 11.7 years; SD = 1.7) were recruited through a screening process from public primary schools around Tzaneen, in the Limpopo province of South Africa. The sample was obtained from Grade 1 to Grade 7 learners from six schools of a total 10 schools in the circuit; the learners were randomly selected. The home languages of the learners were Sepedi and Xitsonga. The exclusion criteria, based on the information provided by parents on the demographic questionnaire (Appendix 1) and school records, were academic problems at school, as reported by their teachers, a history of head injury, epilepsy, cerebral palsy, cerebral malaria, autism spectrum disorder or severe psychiatric disorders and children who did not return the consent forms. None of the recruited children were taking psychostimulant medication at the time of testing.

Instruments

Demographic questionnaire

The parent or guardian of each participant was requested to complete a demographic questionnaire (Appendix 1) which included biographical, socio-economic, developmental and medical history. They were recorded on an extensive database.

Disruptive Behaviour Rating Scale

The dependent variables comprised the total ADHD score, as well as the scores of the H/I and inattention subscales as measured on the DBD (Pelham, Gnagy, Greenslade, & Milich, 1992; Pillow, Pelham, Hoza, Molina, & Stultz, 1998). The DBD assesses the presence and the degree of ADHD-related symptoms (H/I and inattention), Oppositional Defiant Disorder and Conduct Disorder. In this study, only 18 ADHD items were used. Both the parents and teachers of the participants were asked to rate each item on a four-point scale of a paper and pencil rating scale: 'not at all' (0); 'just a little' (1); 'pretty much' (2) and 'very much' (3). For each scale (H/I and inattention), the minimum score was 0 and the maximum 27. Teachers' and parents' scores were averaged. Cut-off points were established at ≥ 17 on the H/I scale and at ≥ 20 on the inattention scale, based on the epidemiological study by Meyer et al. (2004). Raw scores were recorded.

The scale is standardised and normed for all languages and population groups in Limpopo province, South Africa (Meyer et al., 2004). This locally normed DBD has been shown in other studies to be valid and reliable for the population (Mokobane et al., 2020; Pila-Nemutandani & Meyer, 2016). The Cronbach α computed for the locally normed DBD was 0.90 for the H/I scale and 0.92 for the inattention scale (Meyer et al., 2004).

Tower of London

The ToL is a widely used instrument for assessing planning ability and consists of two tower boards, which contain three pegs of different lengths and three balls, usually coloured red, blue and green (Boccia et al., 2017). The test consists of 12 problems, of which the first two are a practice problem and 10 are test problems. The participants are shown two identical tower boards, one for the participants and one for the examiner. The examiner places the participants' beads in the start configuration and sets up the practice problem. In the practice problems, two steps are needed to reach a solution. The participants are asked to transform the start state into the goal state in a predetermined minimum number of moves whilst following three rules: (1) they have to move only one ball at a time; (2) a ball in the lower row cannot be moved when another ball was lying above it and (3) three balls may be placed on the tallest peg, two balls on the middle peg and one ball on the shortest peg.

From the start position, the participants are required to use the fewest steps to move the beads to the end position. The minimum number of moves required is seven. The number of moves required to reach the goal position and the time taken to complete the test are counted. Good planning is indicated by a lower total number of moves. The total number of moves and the time taken were manually recorded on a scoring sheet and scored. The scoring for moves depends on the minimum number of solutions moves of each test problem subtracted from the participants' actual move count to determine the move score. Raw scores were used. The time taken to complete the test was 10–15 min. The split-half reliability coefficient was r = 0.72 and internal consistency, Cronbach α = 0.69 (Kaller, Unterrainer, & Stahl, 2012). The Cronbach α for the present study was 0.62.

Memory for digits

Memory for Digits is a subtest of the Senior South African Individual Scales-Revised (SSAIS-R), an instrument that is used to measure general intelligence that was published in 1964 and revised in 1992 (Cockcroft & Blackburn, 2008; Van Eeden & Visser, 1992). The test also determines the participants' working memory, auditory sequencing and auditory attention ability (Van Eeden & Visser, 1992). The test requires the concentration of the participants to be able to encode and recall the digits. Although this test was originally standardised for mixed race, Indian and White children, the test has been successfully used amongst Black children by Shikwambana (2006), who found that the instrument distinguished between children with and without ADHD symptoms, the latter successfully repeating more digits, especially digits backward.

The test consists of two subtests of strings of digits that are read at a steady rate to the participant, who repeats the digits read to the researcher. In one subtest, DF, the two series of eight sets of digits are read to the participant, who is required to repeat them. In the second subtest, DB, two series of seven digits are read to the participant who is required to repeat them backwards. Each of the MFD tests (DF and DB) is discontinued after two consecutive items are incorrectly answered (Van Eeden & Visser, 1992). The scoring of 2 marks is awarded if the participant repeats the first series of an item correctly, 1 mark if the participant repeats only the second series of an item correctly and 0 if they repeat both series incorrectly. The total maximum score is 16. The internal reliability of the test ranges from 0.83 to 0.90 and construct validity ranges from 0.1 to 0.5 (Cockcroft, 2013). For the present study, the Cronbach α was 0.78.

Trail making test

The TMT has been used as an indicator of visual scanning, graphomotor speed, EF, working memory and inhibition (Lezak, Howieson, Loring, & Fischer, 2012) and is also a test of visual search, attention, mental flexibility and motor function. The TMT is a timed task, consisting of two subtests: Part A measures visual search, attention and mental tracking ability, whilst Part B measures cognitive abilities such as flexibility and the capacity to deal with more than one stimulus at a time (Kokubo et al., 2012).

Both parts of the TMT comprise 25 circles distributed over a sheet of paper. In Part A, the circles are numbered 1–25, and the participant is expected to draw lines to connect the numbers in ascending order. In Part B, the circles contain 13 numbers and 12 letters; participants need to connect circles, alternating both numerically and alphabetically, in increasing order. Any errors made by the participants are recorded. In both parts, a participant's performance (score) is the time taken to complete each trial correctly. The test-retest reliability for the TMT is between 0.60 and 0.90 (Wagner, Helmreich, Dahmen, Lieb, & Tadić, 2011). Cronbach α for the present sample was 0.67 and 0.72, for Parts A and B, respectively.

Wisconsin Card Sorting Test

The WCST consists of 128 cards that present sets of geometric designs that vary according to colour, form and number. In the computerised version of the WCST (CV4-Research edition), the stimulus cards remain at the top of the screen, and a single response card appears at the bottom of the screen. The participant is required, with the use of a computer mouse, to select a stimulus card that they believe to be correctly 'matched' to the response card. After each attempt, the computer provides positive or negative feedback by displaying the word 'right' or 'wrong' at the bottom of the screen (Williams & Jarrold, 2013). The purpose of the test is to measure mental flexibility. The classification rule changes after every 10 cards, which means that once the child has worked out the rule, they may begin to make a single mistake (or more) when the rule changes. In this study, the numbers of TE, PE, perseverative responses (PR) and NPE were used as the main scores to assess set shifting. The inter-rater reliability for the WCST is between 0.88 and 0.93 (Mitrushina, Boone, Razani, & D'Elia, 2005), with Cronbach α of 0.90. Cronbach α for the present study was 0.89.

Procedure

The Department of Education and principals of the schools gave permission to assess the participants at their school. The DBD questionnaires were distributed to both educators and parents of 5480 children to screen for ADHD symptoms. The final sample consisted of 78 children, who could be classified as ADHD and 78 with not enough symptoms to meet the criteria for ADHD, who were selected for further testing. The participants used were selected for other studies that required matched controls. They were matched according to gender, age and ethnicity with neurotypical controls.

The assessment procedures and instructions were conducted by the researcher and trained assistants in the participants' home language. The researcher and research assistants had a minimum of a bachelor's degree in psychology and were fluent in Sepedi and Xitsonga. The assessments were conducted individually with each participant, in a quiet room, during the morning school hours. The tests were administered in the following sequence: ToL, DF and DB, Trails-A and Trails-B and WCST. The assessment procedure for each child took ± 60 min.

Ethical considerations

The Ethics Committee of the University of KwaZulu-Natal (reference number: HSS/1452/015D) approved the study. Permission to conduct the tests was obtained from both the Department of Education of Limpopo province and the school principals of the identified schools. Participation was voluntary. Written, informed consent was obtained from the parents or legal guardians of the learners. The children themselves also had to agree to participate in the study.

The completed consent forms were submitted to the school principals, in sealed envelopes and locked in a safe until the researcher collected them.

The researchers read out the assent form to children in their home language and, after establishing that they understood the content, all participants assented to their participation in the study. The children's identity was coded on all questionnaires and the database to guarantee anonymity. All data were then stored securely in the researcher's office and entered onto the researcher's computer with a security code. Test protocols and answer sheets are securely stored in a locked cabinet for 5 years, after which they will be destroyed. Confidentiality was explained and assured to the participants. No risks were involved when assessing children. The parents were informed that the participants will be referred to the closest psychological services for the final diagnosis and treatment when the need arises.

Data analysis

During the evaluation of the participants, their scores were recorded on the score sheets by the researcher and research assistants and later transferred to a database for analysis. Depending on the tests, they were either manually or electronically scored. A multiple regression analysis was carried out on the raw scores to determine the capacity of the various EF measurements to predict the diagnostic criteria for ADHD, as well as for the core symptoms of H/I and inattention. The main goal was to establish whether the ToL (moves and time), MFD (DF and DB), Trails-A and Trails-B and WCST (TE, PE, PR, and NPE) correctly predicted ADHD symptoms. Consequently, the raw scores of measures were introduced in the analysis as predictor variables, whilst the DBD scores on the H/I and inattention scales, as well as the total ADHD score, were dependent variables. Outliers were only noted for a few tests investigated and were not removed for analysis. The forward stepwise multiple regression programme from Statistica-13 (Statistica, 2015) was employed.

Results

Descriptive statistics for all predictors (tests of EF) and dependent variables (H/I, inattention and ADHD total score) are presented in Table 1.

Table 2 illustrates the Pearson product-moment correlation coefficients between the measurement of EF and the DBD scores for H/I, inattention and total ADHD. The correlation coefficients between the tests of EF and the DBD scores ranged from 0.11 to 0.69. Alpha was adjusted for multiple comparisons with Bonferroni corrections. The correlation coefficient for Trails-A was not statistically significant and therefore did not form part of the regression analysis.

TABLE 1: Attention-deficit/hyperactivity disorder and executive function test results (N = 156).

Variable	Mean	Standard deviation	Min–Max
ADHD	26.65	18.03	0.00–64.00
Hyperactivity/impulsiveness	11.39	9.58	0.00–30.00
Inattention	15.24	9.89	0.00–34.00
ToL – moves	36.74	24.97	8.00–124.00
ToL – time taken	83.74	75.82	8.00–643.00
Digits Forward	7.70	1.67	4.00–12.00
Digits Backward	3.67	1.83	0.00–8.00
Trails-A	91.98	38.97	27.00–253.00
Trails-B	184.86	76.62	66.00–560.00
WCST TE	36.32	20.87	6.00–159.00
WCST PR	21.54	15.09	4.00–109.00
WCST PE	17.95	12.62	3.00–184.00
WCST NPE	18.42	12.56	2.00–75.00

ADHD, Attention-deficit/hyperactivity disorder; ToL, Tower of London; DF, Digits Forward; DB, Digits Backward; TMT, Trail Making Test; TMT-A and TMT-B, WCST, Wisconsin Card Sorting Test; TE, Total Errors; PE, Perseverative Errors, PR, Perseverative Responses; NPE, Non-Perseverative Errors; WCST, Wisconsin Card Sorting Test.

TABLE 2: Correlation between attention-deficit/hyperactivity disorder symptom domains and executive function measures.

Variable	ToL M	ToL T	DF	DB	Trail A	Trail B	WCST TE	WCST PR	WCST PE	WCST NPE
ADHD	0.41***	0.41***	-0.24*	-0.62***	0.11	0.63***	0.69***	0.48***	0.57***	0.55***
H/I	0.35***	0.35***	-0.19*	-0.54***	0.35	0.53***	0.64***	0.46***	0.57***	0.46***
Inattention	0.41**	0.42***	-0.26**	-0.61***	0.14	0.63***	0.64***	0.43***	0.49***	0.56***

*, p <0.05; **, p <0.001; ***, p <.0001.

ToL, Tower of London; M, Moves; T, Time; DF, Digits Forward; DB, Digits Backward; TMT, Trail Making Test; WCST, Wisconsin Card Sorting Test; TE, Total Errors; PE, Perseverative Errors; PR, Perseverative Responses; and NPE, Non-Perseverative Errors.

TABLE 3: Relationship between scores of tests for executive function and attention-deficit/hyperactivity disorder domains (DF = 2, 153).

EF Test	ADHD		Hyp/Imp		Inattention	
	β	R^2	β	R^2	β	R^2
ToL M	0.41*	0.17	0.35*	0.12	0.41*	0.17
ToL T	0.41*	0.17	0.35*	0.12	0.42*	0.18
Digit F	-0.24*	0.06	-0.19*	0.12	-0.26*	0.07
Digit B	-0.62**	0.39	-0.54**	0.30	-0.61**	0.37
Trail B	0.63**	0.39	0.53**	0.28	0.63**	0.40
WCST TE	0.69**	0.48	0.64**	0.40	0.64**	0.41
WCST PR	0.48**	0.23	0.46**	0.21	0.43*	0.19
WCST PE	0.57**	0.33	0.57**	0.32	0.05**	0.25
WCST NPE	0.55**	0.30	0.46**	0.21	0.56**	0.31

*, $p \leq 0.01$; **, $p \leq 0.001$.

ADHD, Attention-deficit/hyperactivity disorder; ToL, Tower of London; ToL- M, Moves, ToL-T, Time; DF, Digits Forward; DB, Digits Backward; TMT, Trail Making Test; TMT-A and TMT-B, ECST, Wisconsin Card Sorting Test; TE, Total Errors; PE, Perseverative Errors, PR, Perseverative Responses; NPE, Non-Perseverative Errors.

A multiple regression analysis was conducted where the nine remaining tests of EF were entered into a forward stepwise regression analysis to predict H/I, inattention and total ADHD criteria, as measured on the DBD scale (see Table 3).

Significant associations were found for all nine tests. The analysis revealed that TE on the WCST was the strongest predictor for total ADHD, which explained 48% of the variance. This was followed by DB and Trails-B, which each predicted 39% of the variance. The PE on the WCST explained 33% of the variance and NPE 30%. These were followed by the WCST PR, which predicted 23% of the variance, and the ToL, which predicted 17% of the variance for both moves and time taken. The DF test was revealed as the poorest predictor for ADHD symptomatology, as it explained only 6% of the total variance.

Total errors on the WCST were again found as the strongest predictor of H/I symptoms as they predicted 40% of the variance. This was followed by WCST PR, at 32% of the variance, DB at 30% of the variance, Trails-B at 28% of the variance and WCST NPE and PR, both at 21% of the variance. The ToL, both for moves and time taken, and the DF test were the poorest predictors of H/I symptoms, as each predicted 12% of the variance.

The strongest predictor for the inattention criteria was once again the total number of errors on the WCST, which explained 41% of the variance, followed closely by Trails-B and DB, at 40% and 37% of the variance, respectively. The NPE on the WCST explained 31% of the variance and could also be regarded as a satisfactory predictor of inattention symptoms. Wisconsin card sorting test PE and WCST PR explained 25% and 19% of the variance, respectively. The ToL moves and time taken were weak predictors of inattention criteria and predicted only 17% and 18% of the variance, respectively. The poorest predictor of inattention, however, was the DF, which only explained 7% of the variance.

Discussion

The results of the study support the hypothesis that commonly used clinical tests of EF predict the diagnostic criteria for ADHD, namely H/I and inattention, as well as total ADHD symptoms, according to the DSM-IV-TR criteria. All the tests investigated, except Trails-A, predicted ADHD symptomatology. Of the EFs measures analysed, the WCST (TE) was the best predictor, as it accounted for the largest variance, contributing to total ADHD symptoms and also to H/I and inattention separately. Trails-B and DB followed closely, as they both accounted equally for the variance of total ADHD symptoms, but they were found to predict more symptoms of inattention than H/I. The responses on the WCST indicated that PE predicted more H/I symptomatology, whilst NPE were largely associated with inattention. Although there was also an association between ADHD symptoms and the ToL and DF, their predictive power was much lower. However, the ToL seemed more sensitive to inattention symptoms, whilst the DF test showed a slightly stronger association with H/I than with inattention.

The significance of the WCST in predicting ADHD symptoms (both H/I and inattention) did not come as a surprise. Performance on the WCST measures not only cognitive flexibility (set-shifting) but also involves other EFs such as working memory and inhibition. The instrument measures higher cognitive abilities and requires attention, perseverance, abstract thinking, planning, organised search and use of feedback, all frontal lobe functions that are often deficient in ADHD candidates (Toplak, West, & Stanovich, 2013).

The results of the analysis showed that PE and TE of the WCST predicted more H/I symptoms than inattention symptoms. Saydam et al. (2015) also indicated that the WCST, especially in terms of PE and TE, showed that children with ADHD lack strategic problem solving because of a more impulsive strategy rather than thinking through the planning of the problem. Tsuchiya et al. (2005) also reported that the WCST is sensitive mainly to symptoms of impulsiveness.

The NPE of the WCST predicted more symptoms of inattention than those of H/I. Ahmadi, Mohammadi, Araghi and Zarafshan (2014) also reported that the NPE of the WCST are associated with more inattention symptoms in children with ADHD than PE. Because of their distractibility, children with ADHD fail to sustain attention and therefore display inefficient use of working memory strategies. Moreover, these children struggle to pay attention to maintain interest in a task; they frequently make careless errors and become distracted by external stimuli (Tripp & Wickens, 2009).

Trails-B and DB were also strong predictors of ADHD symptomatology. Trails-B predicted inattention (40% of the variance) better than H/I (28%) and DB predicted inattention (37% of the variance) slightly better than H/I (30%). Trails-B measures mental flexibility, working memory and attention (Sánchez-Cubillo et al., 2009). The DB test measures working memory (Cockcroft, 2011, 2013). Poor performance on the Trails-B and DB tests suggests that because of their inattentiveness, children with ADHD are slow to switch between stimuli or between sets of stimuli, in order to control and adapt their behaviour to adjust it appropriately for changing situations. Other research also indicated that ADHD symptoms of inattention are associated with poor performance on the Trails-B task (Oades & Christiansen, 2008; Pennington & Ozonoff' 1996; Willcutt et al., 2005) and also on DB (Gropper & Tannock, 2009; Kofler et al., 2010; Shikwambana, 2006). Barkley (1997) and Chhabildas, Pennington and Willcutt (2001) also indicated that inattention causes problems with executing working memory tasks. Barkley (1997) explained that children with ADHD show difficulties with working memory because they struggle to suppress competing stimuli, and their distractibility means they are less likely to retain information in mind.

The ToL, which measures behavioural planning, was not a strong predictor of ADHD symptomatology although it showed a slightly stronger association with inattention (18% of the variance in time taken and 17% of the moves) than with H/I (12% for each). Chhabildas et al. (2001) also indicated that the ToL had a stronger association with inattention symptoms than H/I. Mokobane et al. (2020), Pila-Nemutandani and Meyer (2016) and Saydam et al. (2015) also found that inattention was mainly involved, as especially children with ADHD-PI and ADHD-C's ability to plan strategies are negatively affected. Cornoldi et al. (2001) found that children with ADHD had difficulty with problem solving, as they tend to remember information that are less relevant or irrelevant. Kofman, Gidley Larson and Mostofsky (2008) also reported that children with ADHD struggled with competence on tasks needing strategic planning. According to Kaller et al. (2012), planning requires adequate control of impulses (the H/I component), as well as reasonably functioning memory (inattention).

Digits Forward was found to be a poor predictor of ADHD symptomatology. However, it showed a stronger association with H/I (12% of the variance), probably because of impulsive responses by the participants, than with inattention (7%), because the DF only measures short-term auditory memory. Rosenthal, Riccio, Gsanger and Jarratt (2006) found that the DF test very slightly predicted inattention and did not predict EF involvement.

The finding that Trails-A, which measures visual scanning, simple attention and motor speed but not EF, did not tap into ADHD symptoms was confirmed by Johnson et al. (2001).

Finally, the results of the current study indicated that most of the tests used to assess EFs predicted the core symptoms of ADHD: H/I and inattention. Barkley (1997), Miyake et al. (2000), Nigg (2017) and Willcutt et al. (2005) confirmed that EFs are actually an integral part of ADHD symptomatology. The detection of executive dysfunction will supply insight into cognitive difficulties that may contribute to scholastic and behavioural problems (Nigg, 2017). The results of our study suggest, therefore, that measures for EFs may detect ADHD symptomatology effectively and will supply valuable additional information for a successful diagnosis.

Implications

The results suggest that especially the WCST, Trails-B and DB tests could be effective complementary instruments to indicate cognitive impairment in children diagnosed with ADHD. The combined use of ADHD rating scales, parent interview and the abovementioned tests may provide valuable information on the functioning of children with ADHD in academic and social settings.

Limitations and future recommendations

The sample used in this study was fairly homogeneous, in that the participants all came from the same geographical area. The children were Sepedi and Xitsonga speaking. Therefore, it is not possible to generalise the results to children in other regions of South Africa. The study has yet a further limitation in that it did not test for comorbidities. Comorbid disorders should be carefully examined as they play a significant role in EF performance and in day to day. Children with ADHD may display more difficulties with EFs if they have comorbid disorders such as Oppositional Defiant Disorder, Conduct Disorder, Depression, or Reading Disorder (Willcutt, Pennington, Chhabildas, Friedman, & Alexander, 1999). Another limitation is that the sample size was limited. fMRI could be used to indicate frontal lobe dysfunction associated with EFs.

Conclusion

The study showed that the tests of the EFs investigated predicted the core symptoms of ADHD, except Trails-A. The tests predicted ADHD symptomatology to various degrees. The study showed that, whilst the WCST was the strongest predictor, both DB and Trails-B were also found to be strong predictors of ADHD. The WCST, DB and Trails-B could be used in clinical settings to successfully measure EFs to complement the diagnosis of ADHD.

Acknowledgements

The authors would like to acknowledge and thank the following field workers: Xichavo Hobyani, Khuliso Matidza, Penny Mafela and Rotakala Sadiki.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

T.T.B. made an extensive contribution to the concept and design of the article, collected data and drafted the article and finalised the version to be published. B.P. assisted with overseeing, made substantial remarks on the prepared articles and approved the final version to be published. A.M. provided the data analysis and tables, revised the article and approved the version to be published.

Funding information

This project was partially funded by the University of KwaZulu-Natal.

Data availability

Data will be available in the University of KwaZulu-Natal library, no data sharing.

Disclaimer

The views expressed in the submitted article are those of the authors and not an official position of the institution or funder.

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Appendix 1: Biographical Questionnaire

CHILD AND FAMILY INFORMATION

Number/code:	
Birth date:	
Age:	
Child's school:	
Child's grade:	

DEVELOPMENTAL AND MEDICAL HISTORY
PREGNANCY AND DELIVERY

A. Length of pregnancy (weeks)	
B. Length of delivery (number of hours from initial labour pains to birth	
C. Mother's age when child was born	
D. Child's birth weight	

E. Did any of the following conditions occur during pregnancy/delivery?

1. Bleeding	No	Yes
2. Excessive weight gain	No	Yes
3. Toxaemia/preeclampsia	No	Yes
4. Rh factor incompatibility	No	Yes
5. Frequent nausea or vomiting	No	Yes
6. Serious illness or injury	No	Yes
7. Took prescription medications *a. If yes, name of medication*	No	Yes
8. Took illegal drugs	No	Yes
9. Used alcoholic beverage *a. If yes, approximate number of drinks per week*	No	Yes
10. Smoked cigarettes *a. If yes, approximate number of cigarettes per day (e.g., ½ pack)*	No	Yes
11. Used snuff *a. If yes, how many times per day?*	No	Yes
12. Was given medication to ease labour pains. *a. If yes, name of medication*	No	Yes
13. Delivery was induced	No	Yes
14. Forceps were used during delivery	No	Yes
15. Had a breech delivery	No	Yes
16. Had a caesarean section delivery	No	Yes
17. Other problems – *please describe*	No	Yes

F. Did any of the following conditions affect your child, during delivery or within the first few days after birth?

1. Injured during delivery	No	Yes
2. Cardiopulmonary distress during delivery	No	Yes
3. Delivery with cord around neck	No	Yes
4. Had trouble breathing following delivery	No	Yes
5. Needed oxygen	No	Yes
6. Was cyanotic, turned blue	No	Yes
7. Was jaundiced, eyes turned yellow	No	Yes
8. Had an infection	No	Yes
9. Had seizures	No	Yes
10. Was given medications	No	Yes
11. Born with a congenital defect	No	Yes
12. Was in hospital more than 7 days	No	Yes

G. BREAST FEEDING

1. Did you breastfeed your child?	No	Yes
2. If you breastfed your baby, for how long?	No	Yes
3. At what age did you introduce solid food?	No	Yes
4. At what age was your child completely weaned from the breast?	No	Yes

CHAPTER 5

DISCUSSION

The objectives of this study were to assess EF deficiencies of behavioural planning, cognitive flexibility and working memory, in children with ADHD. The results of the study were presented in four separate papers (see Chapter 4). This chapter provides a discussion of the research findings, and the clinical, research, and theoretical implications of these findings for future research. As part of the conclusion, some research limitations and recommendations are included.

5.1 Behavioural Planning and ADHD

It was hypothesised that children with ADHD would show more deficiencies in tasks of behavioural planning than children without ADHD symptomatology. Our findings indicated that children with high levels of ADHD symptoms encountered significantly more problems on a task (ToL) that measures behaviour planning than neurotypical controls, especially among ADHD-PI and ADHD-C groups, which suggested that inattention is mainly responsible for deficiencies in behavioural planning. Other researchers, for example Chhabildas et al. (2001) and Cornoldi et al. (2001), also showed that inattention is responsible for poor behavioural planning. Our findings are also consistent with past research, which found that children with ADHD scored significantly lower on tests that measure planning and problem-solving than control groups (Chiang et al., 2013; Nigg et al., 2002; Tripp et al., 2002). Further, Kofman et al. (2008) indicated that children with ADHD display poor performance in tasks that need either planning or creating a proper strategy.

Further, as our results showed that deficits in planning were mainly in participants who presented with ADHD-C and ADHD-PI, this partly supports the work of Sarkis et al. (2005), who found that children who presented with ADHD-C performed worse than the other two-sub groups on the ToL. Mokobane et al. (2020), Pila-Nemutandani and Meyer (2016), Schmitz et al. (2002), and Solanto et al. (2007) also showed that children with ADHD-C demonstrate planning deficits, and that they face more difficulties in planning in comparison to children with the ADHD-HI and ADHD-PI presentations and children without ADHD. Saydam et al. (2015) and Nigg et al. (2002) found, contrary to our findings, that ADHD-PI children are equally affected and that the children with ADHD-C presentation had impaired planning strategies compared to the ADHD-PI presentation.

A possible reason for children with ADHD-C symptoms being more severely impaired may be because their impulsiveness may aggravate their performance, as they struggle to remember instructions and to plan new strategies in a different situation (Saydam et al., 2015). Children with ADHD-C encounter more problems carrying out tasks to their conclusion and paying attention to instructions. Further, they react quickly and in a disorderly manner when they plan their tasks, and their solutions are not well thought out. However, Brocki et al. (2010), Araujo Jiménez et al. (2014) and Mullane et al. (2011) indicated that children with ADHD-PI have more deficits in EF than children with ADHD-HI, as they do not pay attention to events that happen around them. They have no initiative to plan, organise and develop strategies to solve a problem.

Children with ADHD-PI are usually unable to finish tasks, organise and sustain efforts and are forgetful. Literature shows that they are poor problem-solvers, that is, they do not only select the most relevant information included in the problems and therefore they remember smaller amounts of relevant, and a greater amount of irrelevant, information when compared to neurotypically children (Cornoldi et al., 2001; Pasolunghi et al., 1999). The current study therefore demonstrated that children with high levels of ADHD symptoms, especially those with

ADHD-PI and ADHD- C presentations, show more deficiencies than neurotypical controls in behaviour planning, which contributes to their inattention and distractibility, and in the case of children with an ADHD- HI presentation, it is aggravated by their impulsive behaviour. These findings support the first hypothesis in the study that children with high levels of ADHD symptoms are more deficient in behaviour planning.

In contrast to our findings, Geurts et al. (2005) showed no deficiencies in children with ADHD-C on the ToL task. However, this difference may be due to the small sample utilised in their study.

The ability of children with ADHD-C and ADHD-PI presentations to learn are compromised in the classroom context at school, as it is difficult for them to adapt to the behaviours expected of them (Schwenck et al., 2009). Children with ADHD-C may face graver problems in executing academic tasks for which planning is essential, as inattention combined with impulsiveness will contribute to more severe impairment (Kofman et al., 2008). Kaller et al. (2012) indicated that good impulse control and reasonably working memory are necessary in planning, indicating that both inattention and impulsiveness affect performance.

The posterior parietal cortex is connected with the PFC and has been shown to represent neural correlates of decision-making and planning (Faraone, 2015). Optimal levels of dopamine in the brain, especially in the PFC, help in improving working memory and attention span (Ayano, 2016). The prefrontal areas seem to be dysfunctional in children with ADHD, probably because a hypofunctioning of the mesocortical dopamine branch will cause deficits in attention and poor behavioural organisation (Sagvolden et al., 2005). The deficiencies in behaviour planning in children with ADHD emphasise the need to strengthen planning strategies, as they are essential skills in the learning and social environments. The improvement of behaviour planning lessens the impact on academic performance and behaviour problems.

It is essential that teachers and parents recognise children with high levels of ADHD symptoms early so that they can provide appropriate and effective intervention. Thus, early referral to an occupational therapist on tasks of behaviour planning is essential. As the classroom is a setting where planning and learning processes are required, the training of teachers in the use of behaviour modification is important. They must be made aware that planning is needed in order to apply the new skills learned, as well as for improving learning ability at school (Pelham et al., 1998; Schwenck et al., 2009; Staff et al., 2021).

5.2 Mental Flexibility or Set-Shifting in Children with ADHD

It was hypothesised that children with high levels of ADHD symptoms would show more deficiencies in tasks of mental flexibility or set-shifting than children without ADHD, and that their predominant ADHD presentation, their age and their gender would affect their performance. Our study showed that all ADHD presentations (or subtypes) made significantly more total perseverative and non-perseverative errors and perseverative responses than the neurotypical control group. The results of our study were consistent with those of Aly et al. (2015), Romine et al. (2004) and Tsuchiya et al. (2005), who reported in their studies that all ADHD presentations exhibited poorer performance on the WCST, as suggested by the total errors and perseverative errors. This result is also supported in our study (see Paper 2) that children with high levels of ADHD symptoms make significantly more perseverative errors and total errors because they lack strategic flexibility, and their score reflects a more impulsive strategy rather than proper planning for the problem (Saydam et al., 2015). They also performed the task hastily due to their aversion to delay (Sonuga-Barke et al., 1992), which impaired their performance.

Our results also found that all children with high levels of ADHD symptoms, no matter the presentation, exhibited poorer performance on the WCST, as indicated by their non-perseverative errors; this is a result which is consistent with the study done by Tsuchiya et al. (2005). Oades and Christiansen (2008) indicated that children with ADHD are slow at switching between stimuli or between tasks. They are therefore unable to change behaviours or plans according to environmental demands, and they have difficulties in reorganising an alternate plan when presented with new situations or tasks. They do not shift between tasks easily; instead, they are hyper-focused on a specific task (Hosenbocus & Chahal, 2012). Reinforcement deficiencies may play a role in the differences in set-shifting. Children with ADHD do not learn from previous mistakes, and they need more frequent reinforcement. Children with ADHD having impaired performance on set-shifting tasks may be attributable to difficulties in preserving competing rule sets prior to shifting (Irwin et al., 2019).

In line with prior research, the current study supported the hypothesis that children with ADHD will show more deficiencies on tasks of mental flexibility/set-shifting compared to the neurotypical group and in their predominant presentation (Aly et al., 2015; Romine et al., 2004; Tsuchiya et al., 2005).

Our study failed to show age or gender differences. Our results contrast with other studies (Geurts et al., 2005; Klorman et al., 1999; Lawrence et al., 2004; O'Brien et al., 2010; Perchet et al., 2001; Sergeant et al., 2002; Toplak et al., 2008), which show significant differences in performance between the three ADHD presentations and the control groups. Hinshaw et al. (2002), Klorman et al. (1999), Nigg et al. (2002), and Solanto et al. (2007) showed that the ADHD-C presentation children performed worse than both the ADHD-PI presentations and neurotypical comparisons on task-switching. However, there are several studies that reported no differences between presentations and neurotypical groups (Rapport et al., 2001; Saydam et al., 2015; Solanto et al., 2007).

Children with ADHD exhibit impairment in set-shifting which is related to abnormal activity of the prefrontal cortex, a brain region that is associated with high-level executive processes, which are needed for goal-directed behaviour (Craig et al., 2016; Kaplan et al., 2006). Children with prefrontal damage cannot perform well on WCST tasks, as they are unable to display flexibility and adapt their behaviour to the regularly changing demands of the test. These children exhibit a relative dysfunction in the left anterior PFC and right dorsolateral PFC (Sergeant et al., 2002). Lesions of the dorsolateral PFC impair the person's ability to shift attentional set (Arnsten & Li, 2005; Manes et al., 2002).

Dopamine dysfunction is also considered to play a pivotal role in the neurobiology of cognitive flexibility, especially a hypo-functioning mesocortical dopamine branch, which supplies the prefrontal cortex (Johansen et al., 2002; Sagvolden et al., 2005; Tripp & Wickens, 2009). Reinforcement deficiencies also play a role, as children with ADHD have displayed altered responses to reinforcement (Sagvolden et al., 2005; Sonuga-Barke et al., 2003; Tripp & Wickens, 2008). Children with ADHD do not learn from their previous mistakes, and they therefore require more frequent reinforcements than their neurotypical peers. The outcome of the current study supports the DDT and Sonuga Barke's dual pathway model in relating mental flexibility/set-shifting with ADHD symptomology. The model indicates that reinforcement deficiencies play a role in differences in set-shifting; children with ADHD displayed altered reinforcement responses (Sagvolden et al., 2005; Sonuga Barke, 2003; Tripp & Wickens, 2008). As argued above, they do not learn from previous mistakes, they keep on making more errors (Lahey et al., 1998), they are slow to switch between stimuli, and they need more frequent reinforcement than their neurotypical peers.

Children with ADHD show deficiencies in set-shifting/mental flexibility which will affect their academic and social functioning (Biederman et al., 2004; Fenesy & Lee, 2018;

Lambek et al., 2010). The WCST, it would seem, can be used as an additional diagnostic instrument for assessing ADHD and appears to be useful in providing additional information on executive functioning, specifically, cognitive flexibility. The set-shifting deficiencies emphasise the need for early pharmacological and/or behavioural treatment. Further training for the teachers and parents on set-shifting techniques can decrease the severity and symptoms of ADHD. This will further improve academic performance and well-being.

5.3 Working Memory and Cognitive Flexibility in Children with ADHD

Our study also hypothesised that working memory and cognitive flexibility were impaired in children with high levels of ADHD symptoms, as indicated by their performance on the Digits Forward, Digits Backwards and Trial Making Test A and B. Our results showed that children with high levels of ADHD symptoms perform more poorly than controls on the Digits Backwards, a result supported by other studies (Cockcroft, 2011; Gropper & Tannock, 2009; Hervey et al., 2004; Kasper et al., 2012; Karatekin & Asarnow, 1998; Mariani & Barkley, 1997; Martinussen et al., 2005; Rapport et al., 2008; Rosenthal et al., 2006; Schulze et al., 2011; Willcutt et al., 2005); these authors all found that all ADHD presentations performed worse on the working memory task and that children with high levels of ADHD symptoms have deficits in working memory compared to neurotypical peers. Children with deficits in working memory often have difficulty remembering things, even for a few seconds, and they tend to lose track of what they are doing as they work (Stievano et al., 2017). They cannot hold information in mind and manipulate it, even for a brief period. Klingberg et al. (2002) also indicated that children with ADHD have working memory deficits, which are attributed to impaired frontal lobe functioning and expressed as inattention and short attention span (Alloway et al., 2009; Archibald et al., 2011; Gathercole et al., 2008).

However, our study results are in contrast with studies by Karatekin (2004) and Murphy et al. (2001), who did not find deficits in working memory in children with ADHD. The difference may be attributed to methodological aspects and the test measures used in the studies.

Our results showed deficits in cognitive flexibility applied to all three ADHD presentations; this is in keeping with the work of Nigg et al. (2004), Pennington and Ozonoff (1996), Rapport et al. (2009) and Rohlf et al. (2012), who also found that, for all three ADHD presentations, children performed more poorly than the neurotypical children on the TMT-B. Our results also support the hypothesis that children with high levels of ADHD symptoms make more errors in the test due to their impulsive responses, rather than this being a true planning problem. They perform the task immediately because of their aversion to delay (Sonuga-Barke et al., 1992).

In summary, cognitive flexibility refers to task-switching or set-shifting, which is the ability to shift strategies between multiple operations and mental states (Anderson et al., 2002; Diamond, 2013; Miyake et al., 2000; Monsell, 1996; Re et al., 2016). In a changing environment, behaviour must be adaptive and flexible, (Kehagia et al., 2010), and children with ADHD can be slow at switching between stimuli, or between sets of stimuli, to control behaviour which may be appropriate to changing situations (Oades & Christiansen, 2008).

Our findings support the hypothesis (see Paper 3) that children with have working memory and cognitive flexibility deficiencies compared to their neurotypical peers. Our findings are also in line with Barkley's (1997) theory on nonverbal memory and reconstitution, which allows a person to analyse their experiences in their working memory to synthesise new responses. Barkley's (1997) causal executive dysfunction theory of ADHD highlights the role of working memory as one of the main executive functions creating goal-directed behaviour and, further, allowing for effective self-regulation and adaptive functioning. In Barkley's model, working memory is held to be responsible not only for keeping stimuli in mind, but also for allowing goal-directed behaviour.

Baddeley et al.'s (1986) multicomponent model of working memory is used to clarify more precisely the storing and processing functions of working memory in children with ADHD. In his model, three elements are thought to be essential for working memory: maintenance of the speech-based phonological loop, the visuospatial sketchpad, and the central executive. The latter is considered responsible for the control and regulation of cognitive processes.

Baddeley and Hitch's (2000) theory also indicates that children with ADHD tend to perform poorly in complex working memory tasks that rely heavily on the central executive (Rosenthal et al., 2006; Swanson et al., 1999). Baddeley's theory supports our results, which indicate that children with ADHD performed worse on the Digits Backwards tests than their neurotypical peers.

Our findings may also be explained by Sonuga-Barke et al.'s (2002) dual pathway model. The first pathway dysregulation of thought and action pathway (ADHD DTAP) is manifested in a primary inhibitory dysfunction that is mediated by secondary cognitive and behavioural dysfunctions, which in turn lead to faulty task-engagement (deficits in set-shifting and working memory). Our findings also support the findings by Boonstra et al. (2005) and Rosenthal et al. (2006), who indicated that TMT-B and Digits Backwards are more sensitive to deficits in working memory.

The PFC is said to play a central role in working memory (Geurts et al., 2005; Tripp et al., 2002). PFC lesions impair the ability to sustain attention, particularly over long delays

(Voytek & Knight, 2010), resulting in symptoms such as forgetfulness, impulsiveness, distractibility and disorganisation (Arnsten & Li, 2005).

fMRI studies have identified functional abnormalities in working memory-related brain regions such as the bilateral dorsolateral prefrontal cortex, the right parieto-occipital area, the right inferior parietal lobe and the right caudate nucleus, as well as reduced functional connectivity between frontal and subcortical regions (Depue et al., 2010; Sheridan et al., 2007). According to (Küper et al., 2016) and Sheridan et al. (2007), greater working memory ability predicts increased activation of the left prefrontal cortex. The dorsolateral prefrontal cortex is linked to working memory (Faraone, 2015), and lesions in this area impair the ability to shift attentional set (Arnsten & Li, 2005; Manes et al., 2002).

Working memory is essential for the development of academic skills in developing children and for learning. Early training of teachers and parents to address working memory deficits in their children can improve school outcomes for children with ADHD (Holmes et al., 2010; Klingberg et al., 2005). Early screening of working memory in children with ADHD may help alleviate high risk for poor academic performance and cognitive dysfunction (Fried et al., 2016).

5.4 Measures of Executive functions Predicting ADHD Core Symptoms

The last objective of the study, that is to identify whether commonly used neuropsychological EF tests, the ToL, Memory for Digits (DF and DB), Trails-A, Trails-B, and WCST, could predict the core symptoms of ADHD, namely hyperactivity/impulsiveness and inattention, as well as total ADHD symptomatology, as measured by a questionnaire based on the DSM-IV-TR criteria (see paper 4). The study showed that the WCST (total errors) was the best predictor of ADHD, as it accounted for the largest variance, contributing to total

ADHD symptoms and to hyperactivity/impulsiveness and inattention separately. Trails-B and DB followed closely, since they both accounted equally for the variance of total ADHD symptoms, but they were found to predict more symptoms of inattention than hyperactivity/impulsiveness. The responses on the WCST indicated that perseverative errors predicted more hyperactivity/impulsiveness symptomatology, while non-perseverative errors were largely associated with inattention. Although there was also an association between ADHD symptoms and the ToL and DF, their predictive power was much lower. The ToL seemed more sensitive to inattention symptoms, while the DF test showed a slightly stronger association with hyperactivity/impulsiveness than with inattention. The deficits revealed by tests were independently related to symptoms of inattention and hyperactivity/ impulsivity.

Our findings on the WCST are consistent with past research that the WCST (total errors and perseverative errors) predicted more hyperactivity/impulsiveness symptoms than inattention symptoms (Reeve & Schandler, 2001; Saydam et al., 2015; Sergeant et al., 2002; Tsuchiya et al., 2005). However, the results are in contrast with other studies (Geurts et al., 2005; Romine et al., 2004; Scheres et al., 2004). Children with delay aversion are more likely to choose a smaller, more immediate reward rather than waiting for a larger reward in order to decrease the delay time between action and reward (Sonuga-Barke et al., 1992). The delay aversion theory was shown to hold more promise for problems related to hyperactivity/impulsiveness than inattention (Castellanos et al., 2006; Thorell, 2007).

Our findings on the WCST (non-perseverative errors) predicted more inattention than hyperactivity/impulsiveness and are consistent with previous research (Ahmadi et al., 2014; Döpfner et al., 2015; Klorman et al., 1999; Tsuchiya et al., 2005). Because of their distractibility, children with ADHD fail to sustain attention and therefore display inefficient use of working memory strategies. These children struggle to pay attention to maintain interest in a task, they frequently make careless errors and become distracted by external stimuli (Tripp & Wickens, 2009), although other studies (Gafoor, 2015; Krieger & Amador-Campos, 2018) show otherwise.

Trails-B and DB predicted more symptoms of inattention than hyperactivity/impulsiveness, findings consistent with the work of Gropper and Tannock (2009), Kofler et al. (2010), Oades and Christiansen (2008), Pennington and Ozonoff (1996), Shikwambana (2006) and Willcutt et al. (2005). Barkley (1997) explained that children with ADHD show difficulties with working memory because they struggle to suppress competing stimuli, and their distractibility means they are less likely to retain information in mind.

The ToL and Digit Forwards (DF) were the strongest predictors of ADHD symptomatology, although the ToL showed a slightly stronger association with inattention. This is consistent with the findings of Boshomane et al. (2020), Mokobane et al. (2020), Pila-Nemutandani and Meyer (2016), and Saydam et al. (2015). The reason for inattention significantly contributing to the difficulty with problem-solving in children with ADHD is that they remember information that is less relevant or is irrelevant (Cornoldi et al., 2001). According to Kaller et al. (2012), planning requires adequate control of impulses (the hyperactivity/impulsiveness component), as well as reasonably functioning memory (inattention component).

The DF showed a strong association with hyperactivity/impulsiveness, probably more because of impulsive responses than inattention (Rosenthal et al., 2006). The Trails-A did not detect ADHD symptoms, a finding that is consistent with other studies (Johnson et al., 2001; Pennington & Ozonoff, 1996). Whilst the WCST was found to be the strongest predictor, both DB and Trails-B are also good predictors of ADHD.

EF processes are primarily mediated through the frontal cortex, especially the prefrontal cortex (PFC). Koechlin (2016) indicated that damage to the PFC may result in impaired concentration, problem-solving ability, planning and judgement. There are preferred models for explanations for ADHD and EFs. The outcome of the current study is in keeping with Barkley's (1997) model and Sonuga-Barke et al.'s (2002) dual pathway model. Barkley’s model (1997) suggests that difficulties with inhibition of behaviour may underlie some of the psychological and social difficulties linked with EFs, namely: planning, cognitive flexibility, working memory and internalisation of speech. According to Barkley (1997), the configuration of deficits found in children with ADHD suggests the involvement of EFs, including working memory.

Sonuga-Barke’s (2002) dual pathway model states that children with ADHD display problems with set-shifting and working memory because ADHD may pertain not only to dysregulation of the thought and action pathway but also to the motivational style pathway. According to the delay aversion concept, children with ADHD experience higher sensitivity to delays than their peers. This leads to decisions that entail choosing a smaller-sooner reward over larger-later rewards on tasks designed to measure the relationship between impulsivity and delay aversion. Other researchers (Barkley, 1997; Miyake et al., 2000; Nigg, 2017; Willcutt et al., 2005) confirmed that EFs are an integral part of ADHD symptomatology.

Most of the tests used to assess EFs predicted the symptoms of ADHD-HI and ADHD-PI. The early detection of executive dysfunction by teachers and health professionals will provide insight into cognitive difficulties in children that may contribute to scholastic and behavioural problems (Nigg, 2017). The WCST, Trails-B and DB are effective complementary instruments to measure cognitive impairment in children who are diagnosed with ADHD.

5.5 Limitations

The study limitations were the small sample size, especially when the ADHD groups were separated according to the predominant presentations or sub-types, as the ADHD-HI group was very small.

Another limitation is that the research sample consisted of only rural primary school learners, who were Sepedi- and Xitsonga-speaking children from the same geographical area. The researcher and the research assistant were fluent in Sepedi and Xitsonga. The assessment procedures and instructions were conducted in the participants' home language. While the study is one of a few that is providing research findings on rural children, a significant dearth in the country, the results have to be generalised with caution.

A further limitation was that the study did not screen for comorbid disorders, as these can play a significant role in EF performance and in day-to-day function of the children. Children with ADHD may display more difficulties with EFs if they have comorbid disorders such as Oppositional Defiant Disorder, Conduct Disorder, depressive and anxiety disorders, or Reading Disorder (Willcutt et al., 1999). A final limitation of the study was that measurements of EFs were undertaken only at primary schools. Future research should include older children from secondary schools representing the various ethnic groups. The research should improve standard instructions to incorporate all language groups.

5.6 Recommendations for Future Research

The results of our study revealed that children with ADHD showed deficits in EFs such as planning, set-shifting and working memory. It is recommended that, when evaluating children for ADHD, these tests should be incorporated into the assessment battery as it has shown to be able to adequately assess planning, set-shifting and working memory differences between children with ADHD symptoms and a neurotypical group in a South African context. The WCST, DB and Trails-B may be used in clinical settings to successfully measure EFs to complement the diagnosis of ADHD. It is also recommended that a clinically relevant EF battery should be incorporated with the tests used in this study. Future research should employ larger samples, from rural and urban settings, and represent more of the ethnic groups in the country and a wider range of age groups. A comparison between age groups with ADHD would provide useful information on the presentation of deficits and whether these improve with age. A large sample in future studies will help increase the reliability and validity of results.

Further studies should also focus on EFs in terms of other comorbidities of ADHD, such as Oppositional Defiant Disorder, Conduct Disorder, depressive or anxiety disorders, and Reading Disorder. In this study, we only focused on ADHD symptoms, although literature suggests that children with ADHD display more difficulties with EFs if they have comorbid disorders (Willcutt et al., 1999).

5.7 Conclusion

The overall objective of the study was to investigate deficits in behavioural planning, set-shifting or cognitive flexibility and working memory in children with ADHD, with the use of specific neuropsychological tests, designed to measure deficiencies in the cortical areas of EFs, and compare this performance with a neurotypical control group. Children with ADHD showed deficits in behavioural planning, set-shifting and working memory. The study makes a valuable contribution to the existing knowledge of ADHD among Black rural children in South Africa and adds specific value for the people in the communities studied, particularly since there is a dearth of such knowledge. The WCST, DB and Trails-B can be used in clinical settings to successfully measure EFs and to improve the diagnosis of ADHD. The participants showed that they have independent problems with inattention, impulsivity or both combination which indicates that ADHD is a complex neuropsychologically condition which results in different educational and social impairment. Early detection of executive function deficits will help recognise children at risk, so that they may be identified early and referred timeously to an appropriate mental health worker for pharmacological treatment and/or behavioural intervention. All interventions must take into account the EFs deficits in ADHD, so that the child may be able to overcome the long-lasting consequences of the disorder and gain maximum functioning ability required for their optimum academic, social and occupational functioning.

Our study also supports that view that rural children with ADHD demonstrate deficits in planning, working memory and cognitive flexibility/ set-shifting similar to studies done in children from Western population. The tests used in our study were developed in Western countries (ToL, WCST and Trails A and B) and were found to predict deficits in planning, working memory and cognitive flexibility in the rural children participating in our study. While our study supports the use of these tests amongst rural children, it is important to note that when working in a multicultural context, appropriate norms and the reliability and validity of test must be established and considered by the examiner. These results lend support to the idea that ADHD is a common neuropsychological disorder worldwide.

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Appendix 1

Biographical Questionnaire

CHILD AND FAMILY INFORMATION

Number/ Code ____________________ Birth date ____________________ Age __________ Child's school ________________________________ Child's grade ________________________________

DEVELOPMENTAL AND MEDICAL HISTORY

PREGNANCY AND DELIVERY

A. Length of pregnancy (weeks) ______________

B. Length of delivery (number of hours from initial labour pains to birth ______________

C. Mother's age when child was born ______________

D. Child's birth weight ______________

E. Did any of the following conditions occur during pregnancy/delivery?

1. Bleeding	No	Yes
2. Excessive weight gain	No	Yes
3. Toxemia/pre-eclampsia	No	Yes
4. Rh factor incompatibility	No	Yes
5. Frequent nausea or vomiting	No	Yes
6. Serious illness or injury	No	Yes

7. Took prescription medications a. If yes, name of medication	No	Yes
8. Took illegal drugs	No	Yes
. Used alcoholic beverage a. If yes, approximate number of drinks per week	No	Yes
10. Smoked cigarettes a. If yes, approximate number of cigarettes per day (e.g., ½ pack)	No	Yes
11. Used snuff a. If yes, how many times per day?	No	Yes
12. Was given medication to ease labour pains. a. If yes, name of medication	No	Yes
13. Delivery was induced	No	Yes
14. Forceps were used during delivery	No	Yes
15. Had a breech delivery	No	Yes
16. Had a caesarean section delivery	No	Yes
17. Other problems - please describe	No	Yes

F. Did any of the following conditions affect your child, during delivery or within the first few days after birth?

1. Injured during delivery	No	Yes
2. Cardiopulmonary distress during delivery	No	Yes
3. Delivery with cord around neck	No	Yes
4. Had trouble breathing following delivery	No	Yes
5. Needed oxygen	No	Yes
6. Was cyanotic, turned blue	No	Yes
7. Was jaundiced, eyes turned yellow	No	Yes
8. Had an infection	No	Yes
9. Had seizures	No	Yes
10. Was given medications	No	Yes
11. Born with a congenital defect	No	Yes
12. Was in hospital more than 7 days	No	Yes

G. BREAST FEEDING Yes/No

1. Did you breastfeed your child? __________
2. If you breastfed your baby, for how long? __________
3. At what age did you introduce solid food? __________
4. At what age was your child completely weaned from the breast? __________

Appendix 2

Teacher/ Parent DBD rating scale

(English and Sepedi versions)

Teacher / Parent DBD Rating Scale (English version)

Child's name:________________________ Form completed by: ____________

Sex: M/F Age:_______ School: _____________________

Grade:___________________ Date Completed: __________

Home language: English / Afrikaans / N-Sotho / Xitsonga / Tshivenda /

Setswana / Sesotho isiZulu / Other: _____

Check the column that best describes this child. Please put a question mark next to any item for which you do not know the answer.

	Not at all (0)	**Just a little (1)**	**Pretty much (2)**	**Very much (3)**
1. Often interrupts or intrudes on others (e.g., butts into conversations or games)				
2. Has run away from home overnight at least twice while living in parental or parental surrogate home (or once without returning for a lengthy period)				
3. Often argues with adults				
4. Often lies to obtain goods or favours to avoid obligations (i.e., 'cons' others)				

5. Often initiates physical fights with other members of his or her household				
6. Has been physically cruel to people				
7. Often talks excessively				
8. Has stolen items of nontrivial value without confronting a victim (e.g. shoplifting, but without breaking and entering; forgery)				
9. Often easily distracted by extraneous stimuli				
10. Often truant from school, beginning before age 13 years				
11. Often fidgets with hands or feet or squirms in seat				
12. Often spiteful or vindictive				
13. Often blames others for his or her mistakes or misbehaviour				
14. Has deliberately destroyed others' property (other than by fire setting)				
15. Often actively defies or refuses to comply with adults' request or rules				
16. Often does not seem to listen when spoken to directly				
17. Often blurts out answers before questions have been completed				
18. Often initiates physical fights with others who do not live in his or her household (e.g. peers at school or in the neighbourhood)				
19. Often has difficulty playing or engaging in leisure activities quietly				
20. Often fails to give close attention to details or makes careless mistakes in schoolwork, work or other activities				
21. Often angry and resentful				
22. Often leaves seat in classroom or in other situations in which remaining seated is expected				
23. Often touchy or easily annoyed by others				
24. Often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace				

(not due to oppositional behaviour or failure to understand instructions)				
25. Often loses temper				
26. Often has difficulty sustaining attention in tasks or play activities				
27. Often has difficulty awaiting turn				
28. Has forced someone into sexual activity				
29. Often bullies, threatens, or intimidate others				
30. Is often "on the go" or often acts as "if driven by a motor"				
31. 31. Often loses things necessary for tasks or activities (e.g. toys, school assignments, pencils, books, or tools)				
32. Often runs about or climbs excessively in situations in which it is inappropriate				
33. Has been physically cruel to animals				
34. Often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (such as schoolwork or homework)				
35. Often stays out at night despite parental prohibitions, beginning before age 13 years				
36. Often deliberately annoys people				
37. Has stolen while confronting a victim (e.g. mugging, purse snatching, extortion, armed robbery)				
38. Has deliberately engaged in fire setting with the intention of causing serious damage				
39. Often has difficulty organising tasks and activities				
40. Has broken into someone else's house, building, or car				
41. Often forgetful in daily activities				
42. Has used a weapon that can cause serious physical harm to others (e.g. a bat, brick, broken bottle, knife, gun.				

Teacher / Parent DBD Rating Scale (Sepedi version)

Leina la ngwana………............Bong………… E tladitswe ke……………………………

Letsatsi leo e tladitswego ka lona…………………………Mengwaga………………..……

Polelo ya ka gae ……………………….
Mphato………………………………………………

Lebedisisa kholomo yeo e hlalosago ngwana wa gago gabotsebotse. Ngwala GT

mo o bonago o se na karabo ya maleba.

Ga ke tsebe-GT

	Le gatee (0)	**Gannyane** (1)	**Kudu** (2)	**Kudu kudu (go feta tekanyo)** (3)
1. O fela a tsenatsena babangwe ganong				
2. O kile a lala malalatle gabedi gomme a boa morago ga lebaka le letelele nakong ya ge a le ka fase ga tlhokomela ya bafepi (mohlokomedi yo mongwe)				
3. O rata go ngangisana le ba bagolo				
4. Gatsi o bolela maaka go rela lerato, go hwetsa seo a se nyakago goba go efoga maikarabelo				
5. Gantsi o fetla ntwa ka lapeng				
6. O kile a sorofatsa ba bangwe				
7. O bolela go feta tekanyo				
8. O kile a utswetsa yo mongwe thoto ye bohlokwa ntle le go ikopanya le motho yoo (mohlala, go utswa ka lebenkeleng ka ntlele go pshatla goba go tsena, go utswa ka bofora				
9. Gantshi sedi ya gagwe e tsewa ke tseo di sa mo amego				

10. Gantshi o ikamanya le ditiro tse kotsi ntle le go naganisisa ka ditlamorago tsa ditiro tseo (e se k age a katana le go ithabisa), mohlala, o kgona go tsena				
11. O na le moya wa botefeletso goba go gobatsa ba bangwe				
12. Gantsi o rogana goba o dirisa polelo ya go befa				
13. Gantsi o sola ba bangwe ka diphoso tsa gagwe				
14. O sentse dithoto tsa ba bangwe ka boomo				
15. Gantsi o tshela ditaelo goba a latola dikgopelo tsa ba bagolo				
16. Gantsi ga a bontshe a theeleditse ge babangwe ba bolela le yena				
17. O katana le go fetola motho pele				
18. Gantsi o kwana le go rumula bao bas a tswego thoko ya gabo, kudu sekolong le mo motseng				
19. Gantsi ga a kgone go bapala ka setu				
20. Gantsi o sitwa go fa mosomo sedi goba go dira diphoso tsa bosilo mosomong wa gagwe wa sekolo,ka gae le mabaleng a mangwe				
21. O dula a befetswe a ithumutse				
22. Gantsi o tlogela setulo sa gagwe le ge go nyakega gore a dule fase				
23. Ka mehla o befedisa ba bangwe				
24. Gantsi ga a kgone go latela ditaelo le go fetsa mosomo wa gagwe ka tshwanelo, e k aba ka gae, sekolong goba mosomong (e se k age a sa kwisise)				
25. Ga a kgone go itshwara, o befelwa ka pela				
26. Ga a kgone go fa mosomo sedi				
27. Ga a kgone go emela nako ya papadi yeo e mo lebanego				
28. O kile a gapeletsa go robalana le yo mongwe				
29. Gantsi o hlakisa ba bangwe, goba a ba tshosetsa				

30. O dula ale lebelong, goba o bonala a potlakile nke o a rakediswa				
31. Gantsi o timeditse dilo tse bohlokwa tseo di swanetsego go somiswa go phetha mosomo goba dikarolo (mohlala, dibapadisane tsa bana(diralokiswa), mesomo ya sekolo, diphentshele, dipuku didiriswa tse dingwe				
32. Gantsi o a kitima goba o namela le mo go sa nyakegego.(go merojana gob aba bagolo, se se ka hwetsago mabakeng a ge bas a iketla moyeng)				
33. O kile a sorofatsa diphoofolo				
34. Gantsi ga a nyake mosomo wo o mo gapeletsago go nagana bjalo ka mosomo wa sekolo				
35. Gantsi o thomile pele a eba le mengwaga e 13 go hlokomologa dikeletso tse batswadi bam o fago mabapi le go sepela boshego				
36. Gantsi o kgopisa batho ka boomo				
37. O kile a utswa ka go ikopanya le mothoyoo a mo utswetsago e ka ba go phamola dikanapa, go tseela motho				
38. O kile a tshuma hlaga ka maikemisetso a bosenyi				
39. Gantshi ga a kgone go beakanya mosomo wa gagwe ka tshwanelo				
40. O kile a pshatla le go tsena ntlong, moagong goba koloing ya o mongwe				
41. Gantsi o na le go lebala mesomo ya gagwe yeo a swanetsego go e dira letsatsi ka letsatsi				
42. O kile a dirisa sebetsa se se ka gobatsago ba bangwe bjalo ka mpheng, sethunya goba mphaka				

Appendix 3

Consent Form

I____, the

parent/guardian of__________________________________(name of

learner), of

___________________________primary school in __________________________

province, having understood the following aspects of the study.

1. That participation is voluntary.

2. Psychometric test and informal tasks will be used.

3. That my child may withdraw at any time with any reasons and without any adverse consequences to his/her academic record.

4. Results obtained in the study will be strictly confidential and not used for promotion purposes.

Hereby grant____________/ do not grant______________(tick whichever

is applicable) permission for my child to be a participant in this study.

______________________ ______________________

Signature of Parent/Guardian Date

Appendix 4

Learner Assent Form

I____, having understood the above, as explained by my parent/guardian, do agree/ ____disagree ______________ (tick whichever is applicable) to be part of this study.

____

(Signature of Learner)

____

(Date)

Appendix 5

University of KwaZulu-Natal (Humanities & Social Sciences Research Ethics Committee) Ethical clearance (HSS/1452/015D)

UNIVERSITY OF KWAZULU-NATAL™
INYUVESI YAKWAZULU-NATALI

1 March 2016

Mrs Tshikani T Boshomane 213574212
School of Nursing and Public Health
Howard College Campus

Dear Mrs Boshomane

Protocol reference number: HSS/1452/015D
Project Title: Testing deficits in behavioural planning and working memory of children with Attention Deficit Hyperactivity Disorder (ADHD)

Full Approval – Full Committee Reviewed Protocol

In response to your application received 9 October 2015, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol has been granted **FULL APPROVAL**.

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment /modification prior to its implementation. In case you have further queries, please quote the above reference number.

PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of 3 years from the date of issue. Thereafter Recertification must be applied for on an annual basis.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

[redacted]

....

Dr Shenuka Singh (Chair)
Humanitities & Social Scinces Research Ethics Committee

/pm

Cc Supervisor: Professor BJ Pillay and Professor A Meyer
Cc Academic Leader Research: Professor M Mars
Cc School Administrator: Ms Caroline Dhanraj

Humanities & Social Sciences Research Ethics Committee
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Appendix 6

Limpopo Department of Education Approval Letter

LIMPOPO
PROVINCIAL GOVERNMENT
REPUBLIC OF SOUTH AFRICA

DEPARTMENT OF
EDUCATION

Enquiries: MC Makola PhD, Tel No: 015 290 9448 .E-mail: MakolaMC@edu.limpopo.gov.za

UNIVERSITY OF KWAZULU-NATA
SCHOOL OF NURSING AND PUBLIC HEALTH
SCHOOL OF SCIENCES
PRIVATE BAG X10
DALBRIDGE
4041

BOSHOMANE TT

RE: Request for permission to Conduct Research

1. The above bears reference.
2. The Department wishes to inform you that your request to conduct research has been approved. Topic of the research proposal: **"TESTING DEFICITS IN BEHAVIOURAL PLANNING AND WORKING MEMORY IN CHILDREN WITH ATTENTION DEFICIT HYPERATIVITY DISORDER(ADHD)"**

3 The following conditions should be considered:

3.1 The research should not have any financial implications for Limpopo Department of Education.

3.2 Arrangements should be made with the Circuit Office and the schools concerned.

3.3 The conduct of research should not anyhow disrupt the academic programs at the schools.

3.4 The research should not be conducted during the time of Examinations especially the fourth term.

3.5 During the study, applicable research ethics should be adhered to; in particular the principle of voluntary participation (the people involved should be respected).

3.6 Upon completion of research study, the researcher shall share the final product of the research with the Department.

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The heartland of southern Africa - development is about people!

4 Furthermore, you are expected to produce this letter at Schools/ Offices where you intend conducting your research as an evidence that you are permitted to conduct the research.

5 The department appreciates the contribution that you wish to make and wishes you success in your investigation.

Best wishes.

[redacted]

07/08/2015

Mashaba KM **Date**

Acting Head of Department.