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

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

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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