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Differences in executive functioning between adults with ADHD and those diagnosed with other psychiatric diagnoses: Utility of the CTMT and the WAIS-IV

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ABSTRACT

In this study, the utility of the Comprehensive Trail Making Test (CTMT) and WAIS-IV working memory (WMI) and processing speed (PSI) indices in assessment of ADHD were examined. Using retrospective analysis of data from two private practices, patients were classified as having ADHD, having another psychiatric disorder, or having comorbid ADHD and other psychiatric disorder. Results indicated that significant differences existed in performance across the three groups [$F(6, 246) = 3.38$, $p = .003$; Pillai's Trace = 0.152, partial $\eta^2 = 0.076$] on CTMT scores ($p < .05$), WMI scores ($p \leq .001$) and PSI scores ($p < .05$). Logistic regression analyses indicated WMI and CTMT trail 5 scores were individually useful indicators in identifying the presence of ADHD. Analysis also indicated minimal increase in correct classification of presence or absence of ADHD through combining CTMT, WMI, and PSI scores. Clinical implications for neuropsychological assessment and differential diagnosis of ADHD are discussed.

KEYWORDS

ADHD; CTMT; differential diagnosis; executive functioning; WAIS-IV

Individuals with attention-deficit hyperactivity disorder (ADHD) often have impairments in various executive functions (e.g., planning, prioritizing tasks, organizing and sequencing information to solve problems; Barkley, 2018, 2020). Such deficits are often observable on standardized tests of executive functioning and are more pronounced among those with neurocognitive disorders like ADHD and traumatic brain injury than those with other psychiatric conditions (Radomski et al., 2018). As such, assessment of executive functioning is an important component of neuropsychological assessments meant to aid in differential diagnosis.

A diagnosis of ADHD does not require a psychological evaluation and that the use of behavioral checklists has been endorsed by the American Academy of Pediatrics (Felt et al., 2014) and prominent scholars in the field (Barkley, 2018). However, several scholars have reasoned that a description of the underlying cognitive processes associated with ADHD is helpful in designing a remediation plan other than the use of medication (Gioia et al., 2002; Mapou, 2019). Adults are also required to furnish recent testing in order to obtain accommodations on standardized college entrance exams (College Board, 2022), thereby necessitating understanding of how performance on neuropsychological measures aligns with diagnostic pictures.

Experts have repeatedly reported that trail making tests have utility as measures of executive functioning and are thus an important component of neuropsychological batteries (Atkinson et al., 2011; Strauss et al., 2006). For example, trail making tests can aid in increasing diagnostic clarity of adults with traumatic brain injuries (Radomski et al., 2018; Riccio et al., 2013; Strauss et al., 2006). One available trail making test is the Comprehensive Trail Making Test (CTMT; Reynolds, 2002). However, very little research has been generated to test the relationship between performance on the CTMT among adults diagnosed with ADHD and other psychiatric disorders. In this study, we sought to assess the utility of the CTMT in differentiating adults diagnosed with ADHD, other psychiatric disorders, and ADHD comorbid with other psychiatric disorders (ADHD + OPD). Additionally, we assessed the relative incremental validity of the CTMT in diagnosis of ADHD within the context of performance on the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV) Working Memory Index (WMI) and WAIS-IV Processing Speed Index (PSI).

Development & description of the CTMT

Partington and Leiter (1949) were the first to recognize the utility of trail making tasks as a measure of divided attention. Building on Partington and Leiter's work, Reitan (1956, 1958) and later Reitan and Wolfson (1993) developed the two-item Trail Making Test (TMT). To complete the first trail (Trail A), the test taker must scan a page of 25 encircled numbers and, with a pencil, connect them in numeric order. On the second item (Trail B), 25 circles containing either a number or letter are randomly placed on the page. To complete the trail, the test taker is required to alternate between numbers and letters in sequential order

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(i.e., by drawing a continuous line connecting 1 to A to 2 to B and so on). Although the TMT improved upon Partington and Leiter's work, concerns regarding psychometric properties of the TMT persisted (Reynolds, 2002). The CTMT (Reynolds, 2002) was designed to remedy the weaknesses found in the TMT.

To develop the CTMT, Reynolds completed a number of modifications to the TMT, including: updating the normative comparison group, converting the raw scores to standard scores and percentiles by age group, expanding the number of trails, and adding distractors to the stimuli to increase the difficulty of the task. Moreover, the CTMT was designed to focus on specific cognitive skills: set shifting, visual search and selection, alternating cognitive focus between two well-learned concepts, and sustained attentional skills (Moses, 2004, Reynolds, 2002, Strauss et al., 2006). As such, review of similarities and differences between the TMT and CTMT is warranted.

Similar to Trail A on the TMT, Trail 1 of the CTMT requires recruitment of sustained attention, visuospatial/selective attention skills, and visual sequencing and visuomotor skills to complete the task. Trails 2 and 3 of the CTMT add different types of distractor targets, thereby requiring greater selective attention and discrimination skills. Trail 4 adds another level of complexity by requiring attention to target stimuli composed of a mixture of Arabic numbers (1, 2, 3) and written numbers (One, Two, Three) and thus recruiting from language areas of the brain. CTMT Trail 5 is similar to TMT Trail B; however, Trail 5 has 15 empty "distractor" circles which adds to the challenge of the task. Adding to the complexity and demand of the CTMT, in Trail 4 and 5, the placement of the targets/spatial array is more complex and multi-directional when compared to the original TMT (Moses, 2004, Strauss et al., 2006).

Improvements in interpretability of results was facilitated by the creation of a new scoring system. Inclusion of age-specific norms for each trail allowed for the calculation of two summary scores and a Composite Score. The Simple Sequencing score is calculated by summing the T-scores from Trails 1, 2, and 3 and the Complex Sequencing score is calculated by summing the T-scores from Trail 4 and 5 (Reynolds, 2002). A Composite Score can subsequently be derived from the two summary scores. Riccio et al. (2013) verified the validity of the two factor structure reflected by the Simple Sequencing and Complex Sequencing summary scores. Factor 1, which aligned with the Simple Sequencing score, measured attention-sequencing while Factor 2 measured set shifting and inhibition. This factor structure is reflected in the updated CTMT2 (Reynolds, 2020).

Trail making tests in neuropsychological assessment

Ample literature outlines the use of the TMT as part of both adult and youth neuropsychological batteries (Atkinson et al., 2011; Atkinson & Ryan, 2008; Murphy, 2002; Smith et al., 2008). More recently, the CTMT has been used with a variety of clinical groups and ages to help make a differential diagnosis. For example, the CTMT is used in evaluating youth who suffer from traumatic brain injury and concussion (Allen et al., 2012; Bauman Johnson et al., 2010; Ringdahl et al., 2019); to evaluate cognitive changes in attention and set shifting in persons with neurological disorders (Beratis et al., 2018; Garcia et al., 2015); and to help with differential diagnosis with youth with ADHD (Classen et al., 2013). In comparison to use of the CTMT to detect traumatic brain injury in adults (Radomski et al., 2018; Smith et al., 2008; Strauss et al., 2006) little research has addressed the possible utility of using the CTMT in detection of ADHD.

In a recent Delphi consensus study assessing frequently used neuropsychological instruments in the assessment of adults with ADHD, Fuermaier et al. (2019) indicated that the TMT was rated 13th of 16 frequently used instruments. However, the superior psychometric properties of the CTMT over the TMT suggest that this more advanced trail making task may serve as a viable component of neuropsychological assessment of adults with ADHD. In addition to the relative psychometric strength of the CTMT over the TMT, the CTMT allows for assessment of relatively discrete abilities (e.g., inhibitory control and set-shifting) that are likely associated with functioning in the frontoparietal and dorsal and ventral attentional network (Koziol et al., 2013).Overall, literature addressing the use of the CTMT as part of a neuropsychological battery to assess the presence of ADHD in adults is sparse (Bain, 2018; Murphy, 2002; Radomski et al., 2018), but the potential for CTMT performance to inform diagnostic work by measuring unique aspects of executive functioning is promising and deserves further study.

Differential diagnosis of ADHD in adults

In clinical practice, adult patients who present for ADHD evaluation often exhibit a complex symptomology. Referral questions are frequently directed at ruling out psychiatric symptoms and/or the presence of comorbid psychiatric disorders as possible reasons for symptom presentation; most often, variations of anxiety and depression disorders (Bain, 2018; Fuermaier et al., 2015; Guo et al., 2021; Holst & Thorell, 2020 May-Jun; Pettersson et al., 2018). According to the DSM-5 (American Psychiatric Association, 2013) comorbid anxiety and depression are found at higher levels with persons diagnosed with ADHD than in the general population. Barkley's (2018, 2020) executive functioning model of ADHD may help explain the association between anxiety/depression and ADHD. Individuals with ADHD frequently have poor regulatory control of both inhibition and activation. Poor attention and affect regulation can lead to an increased focus on negative or harmful stimuli and decreased regulation of the accompanying emotional response (Barkley, 2018, 2020).

The professional literature offers inconsistent findings regarding the role of comorbid anxiety and depression on executive functioning among adults with and without ADHD (Boonstra et al., 2005; Fuermaier et al., 2019; Holst & Thorell, 2017; Wiig & Nielsen, 2012). Theiling and Petermann (2016) found that adults with ADHD performed significantly lower on

working memory and processing speed tasks of the WAIS-IV. The authors concluded that the WAIS-IV reliably differentiated between controls and individuals with ADHD and that deficits in those with ADHD were robust. Building on such findings, Bain (2018) found that working memory functioning, as measured by the WAIS-IV (WMI was more impaired among adults with ADHD and comorbid anxiety, or depression compared to adults with only an ADHD diagnosis. This means that the WMI score was useful in distinguishing adults with ADHD alone from adults with ADHD and comorbid anxiety or depression. Bain (2018) also noted that TMT Trail A was significant in differentiating persons with ADHD from persons with ADHD and comorbid anxiety or depression. Bain (2018) did not find significant discrepancies in WAIS-IV PSI scores between adults diagnosed with ADHD and adults diagnosed with ADHD and comorbid anxiety or depression. However, others have observed that adults with ADHD have significantly lower PSI scores than their peers (Brown et al., 2009; Theiling & Petermann, 2016). While the WAIS-IV WMI and, to a lesser extent, PSI scores have discriminative ability that can be useful in differentiating those with ADHD from those who do not have ADHD (Theiling & Petermann, 2016), questions regarding specificity remain. Specifically, impairments in working memory and processing speed are also common indicators of learning disorder (Moll et al., 2016), anxiety (Moran, 2016), traumatic brain injury (Carlozzi et al., 2015) and more. Thus, identifying ways to increase diagnostic accuracy via the inclusion of another measure, such as the CTMT, in diagnostic batteries is desirable. The current study extends understanding of the relative contributions of the WAIS-IV WMI, the WAIS-IV PSI, and the CTMT in differentiating adults with ADHD alone, other psychiatric disorderss (OPD) from those with ADHD and a comorbid OPD. Based on past literature, the following hypotheses were formulated:

Hypotheses

H1: Adults with OPD would perform significantly better on the CTMT than adults with ADHD and adults with ADHD would perform significantly better on the CTMT than adults with comorbid ADHD and OPD.

H2: Adults with OPD would perform significantly better on the WAIS-IV WMI than adults with ADHD and adults with ADHD would perform significantly better on the WAIS-IV WMI than adults with comorbid ADHD and OPD.

H3: Adults with OPD would perform significantly better on the WAIS-IV PSI than adults with ADHD and adults with ADHD would perform significantly better on the WAIS-IV PSI than adults with comorbid ADHD and OPD.

H4: WAIS-IV WMI and WAIS-IV PSI scores will each significantly contribute to predicting ADHD diagnosis and addition of CTMT trail scores will significantly improve predictive validity of ADHD diagnosis.

Methods

Participants

Data were collected from patient files from two private practices. A significant majority of clients referred to these practices for testing are referred to aid in differential diagnosis of possible problems with attention, learning, or other psychiatric disorders (e.g., anxiety). As a result, the CTMT was often administered as part of the base battery used in both practices. To be retained for analysis, the patient had to be 18:0 or older at the time of the evaluation and had to have been administered the CTMT as part of a broader diagnostic battery between 2016 and 2020. In total, assessment results were retained from 140 adult patients (mean age = 37.95, SD = 16.65). Notably, only 127 patients from the sample had also completed the WAIS-IV. The sample was composed of 69 men (mean age = 37.22, SD = 16.68), 70 women (mean age = 38.82, SD = 16.65), and one self-identified transgender patient (age = 26.83). Patients identified their race as White ($n = 119$), Black ($n = 5$), Middle Eastern ($n = 2$), Albanian ($n = 2$), biracial ($n = 1$), Jamaican ($n = 1$), Korean ($n = 1$), and Latino ($n = 1$); racial identity was not recorded for eight participants. A total of 61 patients were diagnosed as having ADHD (17 as having only ADHD and 44 as having ADHD and at least one OPD, such as a mood, anxiety, or learning disorder) and 79 were diagnosed with a mood, anxiety, or other psychiatric disorder in the absence of ADHD. Diagnoses were determined using a comprehensive approach that included review of diagnostic criteria, patient interview data, informant and self-rating scales, and performance on standardized tests. All or nearly all patients had private insurance; few to no patients were covered by Medicaid. Educational status and income were not systematically collected given that data were derived from clinical practice and not originated as a research study.

Procedures

As noted earlier, data were collected from patient files from two private psychology practices. The first practice was a small practice operated by a doctoral level, fully-licensed clinical psychologist with respecialization training in neuropsychological assessment and who has more than 40 years of clinical experience. The practice is located in the suburbs of a Midwestern urban city. Typical referrals for evaluation are generated by primary care physicians, therapists, or self-referral. The initial assessment was conducted by the doctoral level clinical psychologist. Tests to be used and domains of functioning to be assessed were determined following this initial assessment. Administration of tests was completed by a master's level psychologist with over 20 years of test administration experience. Review of relevant reports, interpretation of the test data including writing of the report and patient feedback was completed by the doctoral level psychologist.

The second practice is a group practice with approximately 16 clinicians located in a Midwest suburb of a major city. The practice is managed by a doctoral level psychologist with nine years of post-graduate experience. Typical referrals were generated from psychiatrist, primary care physician, or therapist referral. All aspects of testing,

Table 1. Pearson bivariate correlations (one-tailed) among predictor variables.

	M	SD	1	2	3	4	5	6	7
1. WMI	92.24	13.71							
2. PSI	94.66	15.57	0.41						
3. Trail 1	42.70	10.84	0.40	0.54					
4. Trail 2	42.61	11.58	0.33	0.40	0.65				
5. Trail 3	40.09	10.26	0.42	0.52	0.66	0.65			
6. Trail 4	43.41	11.27	0.45	0.54	0.60	0.58	0.66		
7. Trail 5	41.07	11.53	0.53	0.56	0.61	0.48	0.66	0.69	
8. CTMT Composite	40.81	10.07	0.53	0.61	0.83	0.77	0.86	0.85	0.84

Note: $p < .001$ for all reported relationships in the table; Table reflects pairwise relationships based on 140 patients' CTMT score profiles and 127 WAIS-IV scores profiles. WMI: WAIS-IV WMI; PSI: WAIS-IV PSI score; Trails 1–5 are the respective CTMT trails 1–5. M and SD for WMI and PSI are standard scores; M and SD for CTMT scores are T-scores.

including the initial interviews, test selection, test administration, and interpretation were typically completed by the psychologist; however, in a minority of cases, a doctoral student administered the testing battery prescribed by the psychologist. Review of relevant reports, interpretation of the test data including writing of the report and patient feedback was completed by the doctoral level psychologist.

Following IRB approval, data were extracted from patient files by a team of graduate student research assistants under the supervision of the authors. Procedures were put in place to ensure patient privacy and to verify that data were accurately recorded.

Measures

CTMT

The CTMT (Reynolds, 2002) is a brief measure of executive functioning. In the task, which usually takes less than seven minutes to complete, patients are asked to complete a series of trails; practice items are provided to ensure comprehension of the task. In the first three trails, functions associated with posterior attentional processes (e.g., attending, visual scanning, filtering visual distractions) are emphasized while processes associated with anterior attentional processes (e.g., set-shifting, alternating attention) are emphasized in the fourth and fifth trails.

WAIS-IV

The WAIS-IV (Wechsler, 2008) is among the most commonly used intelligence tests used in psychological assessment. Based on a patient's performance on 10 subtests, a full scale IQ score and four index scores can be calculated. The four index scores, which are calculated based on the patient's performance on 10 subtests, represent verbal comprehension, perceptual reasoning, working memory, and processing speed abilities.

Plan of analysis

In order to test hypotheses 1–3, patient data were assigned to one of three diagnostic groups: (1) those diagnosed with OPD alone; (2) those diagnosed with ADHD alone; and (3) those with comorbid ADHD and OPD diagnoses, or ADHD + OPD. Additionally, because of the focus on the CTMT in this investigation, MANOVA results for the individual CTMT trails were also completed. The ADHD only group composition was 76.47% White, 52.94% male, and had a mean age of 35.31 (SD = 14.18 years). The OPD group composition was 86.08% White, 53.16% male, and had a mean age of 42.35 (SD = 18.24 years). The ADHD + OPD group composition was 86.36% White, 40.9% male, and had a mean age of 31.05 (SD = 11.15 years).

A somewhat different approach was adopted in testing hypothesis 4, i.e., that WAIS-IV WMI and WAIS-IV PSI scores would each significantly contribute to predicting ADHD diagnosis and addition of CTMT trail scores would significantly improve predictive validity of ADHD diagnosis Because no significant differences in CTMT composite score, WMI score, or PSI score were observed between the ADHD and ADHD + OPD groups, they were subsequently combined into one larger ADHD/ADHD + OPD group. Combining these two groups allowed for higher statistical power in testing hypothesis 4. To test hypothesis 4, a bivariate logistical e regression was conducted. We opted to include each CTMT trail as a predictor rather than using the CTMT composite score. This method facilitated further understanding of possible unique predictive relationships of the individual CTMT trails in diagnosis of ADHD. We chose to not include the CTMT composite score in the analysis for two reasons. First, the CTMT composite score does not adequately address the bivariate factor structure inherent in the CTMT trails (Riccio et al., 2013) and second, the moderate to high degree of correlation across trail and the composite scores raises concerns about possible multicollinearity (Table 1).

Results

Data were analyzed using IBM SPSS Statistics for Windows, version 27. Pearson bivariate, one-tailed correlations were conducted to examine the intercorrelation among the performance variables. One-tailed analysis was chosen over two-tailed given that all seven variables are measures of executive functioning and thus would be expected to rise or fall together. Preliminary review of Table 1 indicated that, as anticipated, WMI and PSI scores often shared medium sized relationships with CTMT trail scores and with one another. Similarly, medium sized relationships were observed among CTMT trail scores. Large correlations ($r = 0.77$-0.85) were observed between the CTMT composite score and each of the trail scores. This final observation further supported our analytic approach in that the CTMT composite scores was significantly dependent on the underlying scores (i.e., multicollinearity).

Hypotheses 1, 2, and 3 were tested using MANOVA. Results indicated that significant differences existed in performance across the three groups, [$F(6, 246) = 3.38$, $p = .003$; Pillai's Trace = 0.152, partial $\eta^2 = 0.076$] on CTMT

Table 2. Between group comparison of CTMT T-scores and WAIS-IV standard scores; means and standard deviations.

		Total		ADHD/ADHD + OPD		OPD			
		M	SD	M	SD	M	SD	*F*	*p*
$n = 140$	Trail 1	42.70	10.84	39.72	10.78	45.00	10.38	8.61	.004
ADHD/ADHD + OPD = 61; OPD = 79	Trail 2	42.61	11.59	41.64	13.52	43.37	9.87	.76	.384
	Trail 3	40.09	10.26	37.92	10.94	41.76	9.44	4.96	.028
	Trail 4	43.41	11.27	41.07	10.54	45.23	11.55	4.82	.030
	Trail 5	41.07	11.53	36.51	10.85	44.59	10.84	19.15	.000
	CTMT Composite	40.81	10.07	38.02	10.18	42.97	9.49	8.82	.004
$n = 127$	VCI	100.24	14.44	98.87	13.71	101.46	15.06	1.02	.314
ADHD/ADHD + OPD = 60; OPD = 67	PRI	97.21	13.95	95.10	12.89	99.10	14.68	2.64	.107
	WMI	92.24	13.71	87.30	12.83	96.66	13.02	16.57	.000
	PSI	94.67	15.57	90.90	14.06	98.03	16.18	6.95	.009
	FSIQ	95.69	14.04	91.98	12.59	99.00	14.53	8.37	.005

Note. *p*-values indicate level of significance between ADHD/ADHD + OPD and OPD groups. Trails 1–5 are the respective CTMT trail T-scores. VCI: WAIS-IV verbal comprehension index standard score; PRI: WAIS-IV perceptual reasoning index standard score; WMI: WAIS-IV working memory index standard score; PSI: WAIS-IV processing speed index standard score; FSIQ: WAIS-IV Full Scale intelligence quotient score standard score.

scores ($p < .05$), WMI scores ($p \leq .001$) and PSI scores ($p < .05$). Tukey's *post hoc* analysis of CTMT performance indicated that the OPD group (M = 43.03, SD = 9.30) performed significantly better ($p = .05$) than the ADHD only group (M = 36.31, SD = 12.00) and the ADHD + OPD group (M = 38.50, SD = 9.61, $p < .05$). No significant differences in CTMT composite score were observed between the ADHD only and ADHD + OPD group.

Tukey's *post hoc* analysis of WMI performance indicated that the OPD group (M = 96.66, SD = 13.02) performed significantly better ($p \leq .001$) than the ADHD + OPD group (M = 86.32, SD = 12.15). No significant differences in WMI performance were observed between the ADHD group (M = 90.00, SD = 14.62) and the OPD group or between the ADHD group and the ADHD + OPD group. Tukey's post hoc analysis of PSI performance indicated that no significant differences existed between the OPD group (M = 98.03, SD = 16.18), the ADHD group (M = 89.31, SD = 15.49), and the ADHD + OPD group (M = 91.48, SD = 13.64). Results partially supported hypotheses 1, 2, and 3 in that significant differences were found based on the presence of ADHD; however, comorbid diagnosis of OPD and ADHD did not consistently result in greater impairment in executive functioning than ADHD alone.

To further understand CTMT performance across the three diagnostic groups an additional post-hoc analysis was conducted. *Post hoc* MANOVA results indicated that significant differences existed in CTMT performance across the three groups, F(12, 266) = 2.73, $p = .002$; Pillai's Trace = 0.219, partial $\eta^2 = 0.109$. Tukey's *post hoc* analysis indicated that, on CTMT Trail 1, those in the OPD group (M = 45.00, SD = 10.38) performed significantly better ($p < .05$) than those in the ADHD + OPD group (M = 40.14, SD = 10.78). Additionally, on CTMT Trail 1, differences between the OPD group and ADHD group (M = 38.65, M = 11.05) approached, but did not reach, conventional criteria for significance ($p = .067$). No significant differences between groups were observed in Trail 2, Trail 3, or Trail 4 performance.

On CTMT Trail 5 those in the OPD group (M = 44.60, SD = 10.84) performed significantly better ($p = .005$) than those in the ADHD group (M = 35.35, SD = 12.93) and significantly better ($p = .001$) than those in the ADHD + OPD group (M = 36.95, SD = 10.06). No significant differences on CTMT Trail 5 scores were observed between the ADHD only and ADHD + OPD groups. CTMT Composite Scores for those in the OPD group (M = 42.97, SD = 9.49) were significantly higher ($p = .050$) than those in the ADHD group (M = 36.76, SD = 11.77) and significantly higher ($p = .044$) than those in the ADHD + OPD group (M = 38.50, SD = 9.61). No significant differences on CTMT Composite Scores were observed between the ADHD only group and the ADHD + OPD group.

Because no significant differences on the CTMT were observed between the ADHD only and ADHD + OPD groups, the two groups were combined into one group to facilitate post hoc analyses. Results indicated that significant differences in CTMT scores existed between the ADHD/ADHD + OPD group and the OPD group, $F(6, 133) = 4.20$, $p < .001$; Pillai's Trace = 0.159, partial $\eta^2 = 0.159$ and on WAIS-IV scores, $F(5, 121) = 5.41$, $p < .001$; Pillai's Trace = 0.183, partial $\eta^2 = 0.183$. Specifically, significant differences were observed on 4 of the 5 CTMT trail scores, the CTMT composite score, WAIS-IV WMI scores, and WAIS-IV PSI scores. Review of Table 2 further indicated that both the OPD group and the ADHD/ADHD + OPD group had similar levels of reasoning ability as assessed by WAIS-IV Verbal Comprehension Index (VCI) and WAIS-IV PRI scores. While significant differences in Composite FSIQ scores were observed between groups, this observation is attributable to the role the WMI and PSI scores have in calculating the FSIQ score.

Hypothesis 4 was aimed at assessing the extent to which the addition of the CTMT might enhance explanation of variance in ADHD diagnosis, beyond the contributions of the WAIS-IV WMI and PSI scores. To assess this concern, a bivariate logistic regression analysis was completed using data from the 127 patients who had completed the WAIS-IV and the CTMT during their evaluations. The criterion variable was dummy coded such that those who had been diagnosed with ADHD (including both those diagnosed only with ADHD or with ADHD and comorbid psychiatric disorder) were coded as "1" and those who had been diagnosed with OPD were coded as "2." Resultantly, low scores on predictor variables (scores indicating relatively more impairment) would be interpreted as positively indicative of

Table 3. Logistic regression results for identifying ADHD.

	Variable	β	SE β	Wald t	df	Sig.	Exp (B)	95% CI Lower	95% CI Upper
Model 1 ($n = 127$)	Constant	−6.045	1.671	13.093	1	<0.001	0.002	–	–
	WMI	0.051	0.017	9.175	1	0.002	1.052	1.018	1.088
	PSI	0.016	0.013	1.334	1	0.248	1.016	0.989	1.043
Model 2 ($n = 127$)	Constant	−2.600	0.949	7.509	1	0.006	0.074	–	–
	Trail 1	0.059	0.029	4.131	1	0.042	1.060	1.002	1.122
	Trail 2	−0.035	0.025	1.844	1	0.174	0.966	0.919	1.015
	Trail 3	−0.007	0.030	.060	1	0.806	0.993	0.936	1.053
	Trail 4	−0.032	0.028	1.296	1	0.255	0.969	0.917	1.023
	Trail 5	0.082	0.027	9.043	1	0.003	1.086	1.029	1.146
Model 3 ($n = 127$)	Constant	−5.3558	1.698	9.954	1	0.002	0.005	–	–
	WMI	0.041	0.018	5.133	1	0.023	1.042	1.006	1.080
	PSI	0.002	0.017	0.018	1	0.893	1.002	0.970	1.036
	Trail 1	0.057	0.031	3.413	1	0.065	1.059	0.997	1.125
	Trail 2	−0.037	0.027	1.952	1	0.162	0.964	0.915	1.015
	Trail 3	−0.013	0.031	0.180	1	0.671	0.987	0.929	1.049
	Trail 4	−0.038	0.029	1.691	1	0.194	0.63	0.910	1.019
	Trail 5	0.068	0.029	5.630	1	0.018	1.070	1.012	1.132

Note: OR: odds ratio; 95% CI: lower and upper bound of 95% confidence interval; WMI: WAIS-IV WMI; PSI: WAIS-IV PSI score; Trails 1–5 are the respective CTMT trails 1–5.

ADHD diagnosis while high scores (indicating better performance) would be positively associated with OPD rather than ADHD.

Three logistic regressions (Table 3) were completed to (1) determine sensitivity of WAIS-IV WMI and PSI scores in classifying ADHD, (2) determine sensitivity of CTMT scores in classifying ADHD, and (3) determine whether increased sensitivity might be achieved by conjointly considering WMI, PSI, and CTMT scores. In Model 1, WMI and PSI scores were entered as predictors and ADHD status (1 = yes, 2 = no) was entered as the criterion. Review of the Hosmer and Lemeshow statistic indicated the model was a good fit. The model was significant ($X^2 = 17.30$, $df = 2$, $p < .001$) and accounted for 12.7% (Cox and Snelll R^2) to 17.0% (Nagelkerke R^2) of the variance. However, only WMI score made a significant contribution ($p = .002$). The sensitivity (i.e., true positives) of the model in predicting ADHD was 65% percent. The specificity in identifying those without ADHD as not having ADHD (i.e., accurate falses) was 74.6%; overall percentage of correct classification was 70.1%.

In Model 2, the five CTMT trail scores were entered as predictors and ADHD status (1 = yes, 2 = no) was entered as the criterion. Review of the Hosmer and Lemeshow statistic indicated the model was a good fit. The model was significant ($X^2 = 22.09$, $df = 5$, $p = .001$) and accounted for 14.6% (Cox and Snelll R^2) to 19.6% (Nagelkerke R^2) of the variance. However, only CTMT trail 5 score made a significant contribution ($p = .002$). The sensitivity of the model in predicting ADHD was 49.2% percent. The specificity in identifying those without ADHD as not having ADHD was 77.2%; overall percentage of correct classification was 65%.

In Model 3, WMI, PSI and five CTMT trail scores were entered as predictors and ADHD status (1 = yes, 2 = no) was entered as the criterion. Review of the Hosmer and Lemeshow statistic indicated the model was a good fit. The model was significant ($X^2 = 28.73$, $df = 8$, $p \leq .001$) and accounted for 20.2% (Cox and Snelll R^2) to 27.0% (Nagelkerke R^2) of the variance. WMI, and CTMT trail 5 scores each made a significant contribution ($p < .05$). The sensitivity of the model in predicting ADHD was 66.7% percent. The specificity in identifying those without ADHD as not having ADHD was 79.12%; overall percentage of correct classification was 73.2%.

ROC analysis indicated Establishing a standard score cutoff for WMI at 90.5 would result in a sensitivity of 66.7% and a 1- specificity (i.e., false positive) of 34.3% while a cutoff of 93.5 would result in a sensitivity of 71.7% and a 1- specificity (i.e., false positive) of 40.3%. Establishing T-score cutoffs for CTMT trail 5 at 43.5 would result in a sensitivity of 73.3% and a 1- specificity (i.e., false positive) of 41.8% while a cutoff score of 45.5 would result in a sensitivity of 78.3% and a 1- specificity (i.e., false positive) of 49.3% (Figure 1 and Table 4).

Discussion

In this study, we tested the differential diagnostic utility of scores on the WAIS-IV WMI and PSI and CTMT trails. A key reason for conducting this study was to help further understanding of inconsistencies reported in the extant literature regarding the role of OPD on executive functioning among adults with and without ADHD (Boonstra et al., 2005; Fuermaier et al., 2019; Holst & Thorell, 2017; Wiig & Nielsen, 2012). In comparing a sample of adults with ADHD, most of whom had comorbid OPD, to a control group, Theiling and Petermann (2016) found adults with ADHD produced significantly lower WMI and PSI scores. Bain (2018) documented relatively lower WMI scores for adults diagnosed with ADHD and adults with ADHD and a comorbid anxiety or depression diagnosis. While researchers have attended to differences in WMI and PSI scores, few have addressed whether differences in trail making test performance may meaningfully add to the diagnostic picture.

Researchers have observed a two-factor structure within the CTMT that provides insight into inhibitory control and set-shifting (e.g., Riccio et al., 2013). The relative thoroughness of the CTMT, current norms, and stable factor structure make the CTMT a better option for assessing aspects of attention than other trail making tests (Reynolds, 2002). This study adds to the discussion regarding the utility of

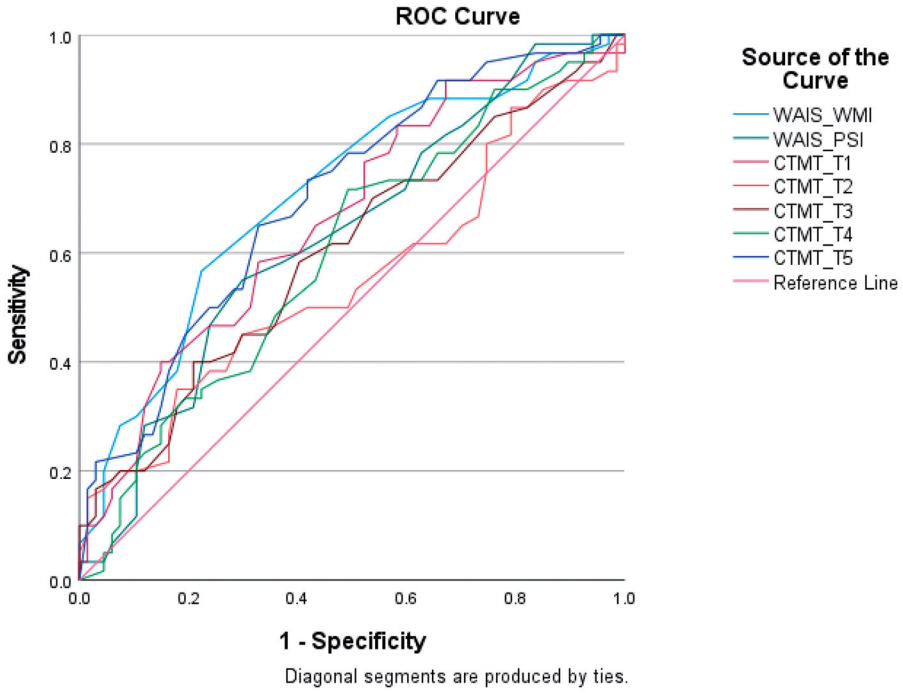

Figure 1. ROC analysis of predictor variables.

Table 4. ROC analysis of WMI, PSI, and CTMT trails.

	AUC	Asymptotic *p*-value
WMI	0.708	<.001
PSI	0.632	.010
Trail 1	0.665	.001
Trail 2	0.553	.303
Trail 3	0.603	.046
Trail 4	0.607	.049
Trail 5	0.701	<.001

WMI: WAIS-IV WMI; PSI: WAIS-IV PSI score; Trails 1–5 are the respective CTMT trails 1–5.

using the WAIS-IV and the CTMT in the differential diagnosis of ADHD, ADHD + OPD, and OPD alone.

In this study, data from a clinically derived sample of adults was assessed. Like Theiling and Petermann (2016), we found significant differences in WMI and PSI scores based on the presence of ADHD. However, unlike Bain (2018) who observed three statistically discrete levels of performance on WMI scores, in this study, significant differences were observed between those with ADHD and OPD and between the ADHD + OPD and OPD group, but not between the ADHD and ADHD + OPD group. Findings indicated that while the presence of ADHD is associated with significantly less working memory capacity, comorbid diagnosis of an OPD does not appear to significantly exacerbate this existing deficit. Like Bain (2018), we did not find significant discrepancies in PSI scores between adults diagnosed with ADHD and adults diagnosed with ADHD + OPD. Additionally, consistent with conceptualization of ADHD as a neuro-cognitive and not an intellectual disorder (Barkley, 2018, 2020), no significant differences in reasoning ability (as assessed by VCI and PRI scores) were observed. Generally, results support continued use of the WAIS-IV as a valuable part of neuropsychological batteries aimed at detecting ADHD.

Although past authors have demonstrated the utility of the CTMT as a diagnostic tool in identifying traumatic brain injury (ARMSTRONG et al., 2008, Radomski et al., 2018; Smith et al., 2008) this study is among the few to assess the utility of the CTMT as a diagnostically relevant tool in the diagnosis of ADHD. Furthermore, past studies (e.g., Allen et al., 2012; Kahn et al., 2012) have focused almost exclusively on children. Results from the current study indicated that adults diagnosed with ADHD and ADHD + OPD performed similarly to one another, but worse than adults with OPD on the CTMT composite score. Adults with ADHD/ADHD + OPD performed significantly worse than adults with OPD alone on four of five CTMT trails and subsequently had significantly lower CTMT Composite Scores than adults with OPD alone. The lack of difference between the ADHD and ADHD + OPD groups refutes the idea of additive impairment due to comorbidity, suggesting ADHD is the driving force behind deficits in executive functioning and CTMT performance. Overall, although the CTMT appears to hold little value in differentiating between adults with ADHD and adults with comorbid ADHD + OPD diagnosis, it appears to be a good indicator of overall presence of ADHD and the related underlying neurocognitive functioning.

A final goal of this study was to determine whether considering the CTMT and WAIS-IV together results in better prediction of ADHD diagnosis. Logistic regression results indicated that WMI and PSI scores alone (with only WMI having unique significant predictive value) resulted in correct classification of 70.1% of cases. By contrast the CTMT trail scores correctly classified only 65% of cases. When combined WMI, PSI, and the five CTMT trail scores resulted in a marginal gain for a total of 73.25 correct classification. Results thus suggest a modest gain in predictive

value by including the CTMT along with the WAIS-IV in neuropsychological evaluation of ADHD.

Implications for practice

Mirsky et al.'s (1991) analysis and assessment of attention has been influential in clinical diagnosis of ADHD. Unlike others, Mirsky et al. defined key aspects of attention *and* provided guidance on how these constructs could be evaluated via neuropsychological assessment. Key structures Mirsky et al. identified included focus, which may be measured by performance on a trail making test, Wechsler's Digit Span and Arithmetic subtests (i.e., the subtests that inform WMI scores), or a cancelation or coding test (which is similar to components of PSI scores), among others. Building on Mirsky et al.'s model, Koziol et al. (2014) offered support through revalidation of the Mirsky et al. model and added to the understanding of brain systems and functionality.

Findings from the present study align with Mirsky et al. (1991) and Koziol et al. (2014). These previous works predict deficits in the anticipated domains of functioning as evidenced by relatively impaired performance on tests of attention, working memory, and processing speed. While a single low test score on one of these measures may indicate intraindividual variability, a pattern of low performance across measures implies deficits in functions that align with Mirsky et al.'s model of attention. Low scores on neuropsychological tests are at best, correlative with ADHD diagnosis and do not uniquely predict a diagnosis of ADHD due to attention problems being common among a number of psychiatric disorders (e.g., schizophrenia, TBI). Whereas neuropsychological assessment is designed to elucidate brain-behavior relationships and point to a person's functional limitations, DSM-5 diagnosis of ADHD is categorical in nature and not dependent on brain-behavior relationships (Koziol et al., 2013). Nonetheless, identification of associations between neuropsychological tests and diagnostic categories can be informative.

In the present study, a prototypic profile built on CTMT, WMI, and PSI performance emerges in a manner anticipated by Mirsky's model. Notably, consideration of performance on the CTMT alongside performance on the WAIS-IV informs a more stable conceptualization by more completely assessing various aspects of attention. As such, we echo Smith et al. (2008) who concluded that "the CTMT may be a useful addition to a multifaceted neuropsychological test battery" (p. 507).

Results indicated that in addition to WMI scores, CTMT trail 5 scores were particularly important in differentiating the presence of ADHD. Notably, the CTMT manual (Reynolds, 2002, p. 41) offers prototypic profile data for special populations, including two diagnostic groups (i.e., those with learning disorder and those recovering from a cerebrovascular accident). Our findings extend understanding of prototypic performance by adults with ADHD on the CTMT and suggest guidance related to interpretation of WMI and CTMT trail 5 scores. Findings indicate that a cut point of $T = 43.5$ on trail 5 may balance competing needs for sensitivity and specificity; however, this observation is quite tentative and requires verification before it should be routinely employed in clinical decision making. Instead, we suggest that consideration of the overall CTMT profile alongside WMI scores and information obtained from clinical interview and other checklist data may be advisable.

Findings derived from this study may be particularly useful in describing the role of three measures of executive functioning in formal assessment of adults with ADHD. In this sample, compared to those with OPD, those with ADHD (i.e., ADHD or ADHD + OPD) scored about 10 standard score points lower on WMI, about 8 standard score points lower on the PSI, and about 5 t-score points lower on the CTMT Composite Score. Importantly, this means compared to the mean (SS = 100, T-score = 50) that those with ADHD (i.e., ADHD or ADHD + OPD) scored about 13 standard score points lower on WMI, about 9 standard score points lower on the PSI, and about 12 t-score points lower on the CTMT Composite Score. Additionally, those diagnosed with ADHD scored about 4 or 5 t-score points lower on Trail 1, 3, and 4, and about 8 points lower on Trail 5 compared to those with OPD alone. Generally, those diagnosed with ADHD exhibited performance that could be classified as in the "low average" range (despite "average" performance on verbal and perceptual reasoning indices). Results further point to the identification of a prototypic neuropsychological profile for adults with ADHD. Clinicians are encouraged to consider this profile in formulating diagnostic impressions.

Limitations & future research

Using a clinical sample, we demonstrated that relative to those with OPD, adults with ADHD evidence relative (and, in some instances, normative) deficits in attentional functioning. However, because data were derived from two practices that tend to use different testing batteries, additional assessment data (e.g., NAB Mazes, Wisconsin Card Sort, CPT-3, Gordon Diagnostic System) could not be included in the models while also retaining an adequate sample size for analysis. Future research that builds on these findings should seek to include additional assessment data to further assess the value of including the CTMT as part of a comprehensive evaluation for ADHD. Specifically, investigation into which aspects of the Mirsky model are most reliably implicated in the presentation of ADHD and thus are most readily assessable are needed. Better understanding the relative contributions of different measures of attention that align with the Mirsky model will expand the current findings by illuminating the relative contribution of tests that assess impairment in key constructs associated with the presence of ADHD.

The diagnosis of ADHD and other comorbid groups was made on a clinical interview using the DSM-5 criteria. This limitation may explain why the current findings diverge from previously reported findings, such as those detailed in Bain (2018). Psychometric assessment of OPD would have allowed for clearer understanding as to whether severity of

OPD moderates the relationship between performance on measures of executive functioning and ADHD diagnosis.

Summarizing others, Katzman et al. (2017) noted that "As many as 80% of adults with ADHD have at least one coexisting psychiatric disorder" (p. 1). This may explain the relatively small group of ADHD-only patients in our study and suggests that our study has good ecological validity. However, the diagnostic heterogeneity in OPD in our study nonetheless precludes the ability to make fine grained distinctions as to how those with ADHD perform on the measures of interest compared to specific homogeneous diagnostic groups (e.g., adults with anxiety vs. those with learning disorders). Attention to clinical presentation of ADHD (i.e., combined vs. predominantly inattentive) in future studies may also help clarify diagnostic profiles and the divergence of the current findings from past research.

Conclusion

The current study meaningfully contributes to consideration of the CTMT in differential diagnosis of ADHD in adults. Findings are derived from a real-world clinical sample and replicate past reports of impeded executive functioning among those with ADHD. Filling in a gap in the original CTMT manual, a prototypic profile for ADHD is reported and analysis of how this profile differs from those with OPD is provided. This study is also the first to assess the potential for incremental increase in diagnostic accuracy by supplementing WAIS-IV scores with the CTMT. Findings reported in this study provide a rationale for continued research into the use of the CTMT and identify needs for future research that can be used to inform clinical work.

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