Modern Psychological Studies

Volume 24 | Number 1

November 2018

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Abstract

It is infrequently recognized that healthy individuals occasionally obtain impaired scores on neuropsychological measures. This research was conducted to determine how often healthy undergraduate research participants obtain impaired scores on popular measures of executive functioning. Specifically, performance on the Delis-Kaplan Executive Function System (D-KEFS) Trail Making and Color-Word Interference subtests was investigated in a sample of 335 undergraduate research participants. Rates of impaired performance varied across subtests and ranged from 11% (Color-Word Interference Word Reading) to 3% (Trail Making Test Motor Speed). In general, individuals with greater intellectual functioning had higher scores and fewer impaired scores. Findings are consistent with a broad literature describing the psychometric properties of neuropsychological measures. Researchers should recognize that it is relatively common to observe impaired scores in healthy research participants when interpreting research and clinical data.

Rates of executive dysfunction in undergraduate research participants

Neuropsychological tests are frequently used by clinicians and researchers to evaluate the cognitive functioning of an individual. These measures assess a broad range of cognitive constructs such as memory, attention, and executive function, and are beneficial to consider when determining whether a cognitive disorder is present. Although these measures are commonly used in clinical settings, most are derived from experimental research, with minimal consideration given to documenting and evaluating psychometric properties (Strauss, Sherman, & Spreen, 2006). Thus, neuropsychological tests can greatly differ, not just in terms of what constructs they evaluate, but also with respect to psychometric properties (e.g., sensitivity and specificity to a condition of interest; test-retest reliability; internal consistency). Not all neuropsychological measures are valid and reliable (Retzlaff & Gibertini, 2000), and it is problematic if a clinician uses a tool with unknown psychometric properties because it would be impossible to attach meaning to an observed score.

Measuring Executive Function

The present research primarily focuses on the utility of executive functioning measures. Though aspects of the definition are still debated, a consensus is that executive function involves an individual’s ability to work towards a goal using planning, self-monitoring, and purposeful behaviors (Lezak, 1995). Given that executive function as a construct is relatively abstract and broad, many researchers find it difficult to developmeasures to directly and comprehensively assess it, and instead develop tests to identify narrower and specific aspects. However, each measure of executive function faces scrutiny and debate related to whether it is a valid assessment of the construct (Kramer & Quitania, 2007).

In terms of brain functioning, executive function is largely associated with activation of the prefrontal cortex and continues to develop into late adolescence and early adulthood. In fact, Barkley (2015) posited that the prefrontal cortex directs executive function (Barkley, 2012). While the prefrontal cortex largely mediates executive function, it is important to consider which areas (or more importantly, which pathways) are specifically responsible for the different aspects of executive function. The lateral prefrontal cortex (LPFC), for example, has been recognized as being involved in planning, monitoring, switching, and inhibiting (Stuss, 2007), while working memory has been associated with ventral and dorsal lateral prefrontal cortex (Muller & Knight 2006). While these findings are significant, there is still debate regarding which neural networks are involved with different aspects of executive function.

Current Study

There is significant variability in how healthy individuals complete neuropsychological measures within and across cognitive domains (Brooks, Strauss, Sherman, & Iverson, 2009). It is infrequently recognized by clinicians and researchers that healthy individuals can obtain impaired scores on neuropsychological measures (Axelrod & Wall, 2007; Crawford, Garthwaite, & Gault, 2007). This is related to many issues including the psychometric properties of tests and characteristics of the individual being evaluated. As a notable example, Crawford and colleagues (2007) reported that over 34% of the normative sample would exhibit at least one Index score below a Scaled Score of 85 (i.e., lower than or equal to one standard deviation below the mean) on a gold-standard intelligence test. The significance of this issue can be debated. One might argue that a test that “detects” impairment (i.e., a false positive score) in a healthy functioning individual is flawed. On the other hand, understanding the likelihood of a healthy individual obtaining an impaired score supports responsible interpretation of neuropsychological tests (i.e., it decreases the probability of over-pathologizing an individual).

The current study evaluates how often undergraduate students participating in research obtain impaired scores on common measures of executive functioning. It is documented that healthy individuals commonly obtain low scores on Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) tasks, especially if the individual has lower intelligence and/or has had limited educational experiences (Karr, Garcia-Barrera, Holdnack, & Iverson, 2017). Specifically, 53.6% of participants with 9-11 years of education had a score at or below the fifth percentile, while 22.3% of participants with 16 or more years of education obtained a score at or below the fifth percentile. The purpose of the present study was to assess how frequently healthy individuals obtain low scores on two commonly used measures, the D-KEFS Trail Making Test and Color-Word Interference Test. It was hypothesized that undergraduate students with high average or greater intelligence will obtain "impaired" scores across tasks at a lower rate than students with average or lower intelligence.

Methodology

The present study included 335 students from a private midwestern university. Data were collected across two studies that investigated the psychometric properties of neuropsychological measures. Word reading ability (Wechsler Test of Adult Reading; Holdnack, 2001) was used to estimate intellectual functioning. The sample was divided into two groups based on word reading ability: Group AB (AB = Average and below intelligence; n = 161) had an estimated Full Scale IQ $\leq$ 110; Group HA (HA = High Average and above intelligence; n = 174) had an estimated Full Scale IQ > 110. The groups were similar in age (Group AB m_{age} = 19.37, Group HA m_{age} = 18.96) and years of education (Group AB m_{years} = 12.96, Group HA m_{years} = 12.66), and GPA AB m_{gpa} =

3.3, Group HA m_{gpa} = 3.4). As expected, Group HA had a mean Full Scale IQ that was significantly greater than Group AB (Group AB m_{IQ} = 103.69, Group HA m_{IQ} = 115.72; t = -21.375, $p < .000$). Participants were compensated with credit in their psychology courses. A summary of demographic information for each group is included in Table 1.

Measures

Wechsler Test of Adult Reading

This word reading task was used to estimate premorbid intellectual functioning. The participant is asked to read increasingly difficult words aloud. This task tests an individual's ability to apply logic and knowledge about word pronunciation. Word reading is strongly correlated with Full Scale IQ (r = .73; Strauss, Sherman, & Spreen, 2006). Intelligence was used as the grouping variable for analyses based on previous research that established a relationship between performance on executive function measures and intellectual functioning (Brooks et al., 2009).

Trail Making Test

The D-KEFS Trail Making Test is intended to measure an individual's cognitive flexibility, as well as letter/digit sequencing, attention, and motor speed (Kramer & Quitania, 2007). It is derived from "Parington's Pathways," also referred to as the "Divided Attention Test" (Partington & Leiter, 1949). The Trail Making Test is one of the most commonly administered tests in neuropsychological assessment, especially when evaluating attention (Strauss et al., 2006).

In the visual scanning condition (Condition 1), the participant scans the protocol and marks a specific digit. In the number sequencing condition (Condition 2), the participant connects digits in ascending order. In the letter sequencing condition (Condition 3), the participant connects letters in ascending order. In the number-letter switching condition (Condition 4), the participant alternates between connecting digits and letters in ascending order. In the motor speed task

(Condition 5), the participant traces a line as quickly as possible. All conditions instruct participants to complete the task as quickly and accurately as possible.

The fourth condition of the Trail Making Test shows differential brain activation depending on whether the individual performs slowly or quickly (Richards, 2009). Slower completion of the task showed greater activation of the left dorsal lateral prefrontal cortex and left inferior medial prefrontal cortex. Additionally, when compared to the easier portion, the more difficult part of the task results in greater activation in the left dorsal lateral prefrontal cortex and the bilateral superior parietal lobes. Richards (2009) also demonstrated differential frontal lobe activation based on whether the participant was completing easy or more challenging aspects of the task (i.e., 2-B-3-C-4 versus 5-E-6-F-7).

Color-Word Interference Test

The D-KEFS Color-Word Interference Test is a Stroop Task that measures cognitive flexibility and the ability of an individual to inhibit an overlearned response of reading. In condition one, the participants name color patches presented. In condition two, the participant reads color names printed in black ink. In condition three, the participant names the ink color and inhibits reading the color words. In other words, the interference task requires an individual to inhibit the learned response to read a word, and instead requires color identification. In condition four, the participant switches between naming ink colors and reading the conflicting word. The Stroop Task is sensitive to frontal lobe damage, more so than some tasks in the Trail Making Test; in fact, it was the only task able to differentiate between lateralized left and right frontal lobe dysfunction (Demakis, 2004).

Adleman and colleagues (2002) conducted a fMRI study to investigate activation differences between different age groups while completing the Stroop Task. By adolescence (12-

18 years), the parietal cortex shows significant activation during the Stroop Task, while prefrontal cortex activation continues to develop and become increasingly pronounced into young adulthood (18-22 years). Specifically, young adults demonstrated significant activation of the inferior and middle frontal gyri, left anterior cingulate, and bilateral inferior and superior parietal lobes. Thus, as individuals age, they show increased activation of the prefrontal cortex and perform better on the task.

Results

Independent-samples t-tests were conducted to compare groups across each Trail Making and Color-Word Interference condition. As hypothesized, Group AB performed significantly lower on nearly all conditions. Notably, there was no significant group performance differences on Trial Making Test Visual Scanning (Condition 1). The results and effect sizes are summarized in Table 2. In general effect size differences were larger for the Color-Word Interference task.

Next, rates of impaired performance were investigated and is reported in Figure 1. Impairment was defined as a scaled score < 5, which corresponds with performance below the 5th percentile in relation to a representative normative sample. For the total sample, rates of impaired performance varied from 11% (Color-Word Interference Word Reading) to 3% (Trail Making Test Motor Speed) across the respective conditions. A chi-square test of independence was performed to examine if rates of impaired performance differed between the two groups (see Table 3). Rates of impairment differed between groups for the following Color Word Interference trials: Color Naming (X^2(1), N = 332) = 7.61, *p* = .04), Word Reading (X^2(1), N = 332) = 7.61, *p* = .006), and Interference/Switching (X^2(1), N = 331) = 6.71, *p* = .008). On these aspects of the Color-Word Interference Test, individuals in the AB group were more likely to obtain impaired scores (Color Naming 12.60% versus 5.80%; Word Reading 15.00% versus 5.70%; Interference/Switching

8.80% versus 2.30%). Similar rates of impaired scores were observed for the Color Word Interference task. (see Figure 1). With respect to the Trail Making Test, there was no difference in observing rates of impaired scores between groups across the respective conditions.

Discussion

Many clinicians and researchers interpret an impaired performance on a neuropsychological measure as an indication that the patient or research participant has neurocognitive dysfunction. In contrast, emerging literature documents that it is relatively common for healthy individuals to obtain impaired scores that do not necessarily reflect anything more than normal performance variability. The present study was conducted to investigate how frequently undergraduate research volunteers would obtain impaired scores on measures of executive functioning. This is a unique sample to consider given that frontal lobes continue to develop into young adulthood and college students as a whole are relatively intelligent.

It was common to observe impaired scores across conditions. In the total sample, rates of impairment were greater on Color-Word Interference subtests relative to the Trail Making Test and varied from 11% (Color-Word Interference Word Reading) to 3% (Trail Making Test Motor Speed) across conditions. To better understand who might be likely to obtain an impaired score, we considered performances differences between a group of participants with Average and below intelligence (AB Group) relative to a group of participants with High Average and above intelligence (HA Group). The decision to divide the groups based on IQ stemmed from previous literature that found relationships between IQ and executive function (Karr et al., 2017).

Intelligence group analyses revealed that most task performances were significantly different between the IQ groups, with participants in the HA group obtaining higher scores. Notably, group mean level differences were more pronounced on the Color-Word Interference task relative to the Trail Making Test. Considering percentages of impaired performances across groups, the HA group was less likely to obtain impaired scores on many Color-Word Interference conditions, whereas rates of impaired performance on the Trail Making Test were similar across groups. It is reasonable to believe that IQ may be less related to abstract, difficult-to-train executive functions, such as visuospatial reasoning on the Trail Making Test, and may be associated more so with executive functions dependent on academically-acquired skills (i.e. switching in reading), as measured in the Color-Word Interference test.

Researchers and clinicians should consider these findings and related studies when interpreting neuropsychological performances. Despite this sample being composed of healthy individuals, nevertheless, many participants obtained impaired scores. It is important to recognize that administering several tests assessing the same domain increases the probability of an individual scoring within a low range (Binder et al., 2009; Brooks et al., 2009). Thus, during clinical evaluations with a large battery, clinicians must be mindful of misinterpreting low scores (Karr et al., 2017). By including multiple tests for a particular domain, a clinician should take a more holistic approach to interpretation, rather than focusing on an isolated and potentially misleading low score.

Although the present study focuses specifically on two D-KEFS subtests, it is also important to consider high and low scores across different tests within a testing battery (Crawford, Garthwaite, & Gault, 2007). Furthermore, one must consider the probability of a participant scoring in the below average or impaired range on one measure and much higher on another task that is theoretically related to the same construct. While this may seem tedious and cumbersome to consider while interpreting testing data, computer programs are freely available that compute probabilities of impairment (or unusual deviations in performance) using multiple tests, thus providing clinicians a useful tool for more accurate interpretation of test data (Crawford et al., 2007).

Limitations and future considerations

Low scores often vary due to demographic characteristics, such as age, education, race/ethnicity, and sex (Brooks et al., 2009). While the present study was largely homogenous in terms of age and education, the sample did not account for differences in sex and race/ethnicity. Additionally, given that the sample included only university students, there were no participants in the borderline or impaired range of intelligence. Thus, the limited range in IQ may have influenced the analyses. We anticipate the findings may change if more distinctively different IQ groups were included. Future studies should attempt to include participants with a broad range of IQ scores to replicate and extend the current study.

Conclusion

The present study focused on two subtests within the D-KEFS, the Color-Word Inhibition and Trail Making tasks. These tasks and similar versions are regularly administered during neuropsychological evaluations. This project makes clear that healthy individuals with some regularity obtain impaired scores on measures of executive functioning. It also appears that an individual's intellectual functioning may be related to the likelihood of obtaining a potentially erroneous impaired score. Future research should examine other measures of executive functioning given that they are minimally correlated with one another (Delis et al., 2001). A greater understanding of these tasks and other measures will foster more accurate interpretation of test data, which will ultimately improve research and clinical practice.

Appendix

Table 1. Group demographics and intellectual level

	Group AB	Group HA
Age	19.37(1.24)	18.96 (1.01)
Years of Education	12.96 (1.08)	12.66 (.87)
GPA	3.34 (.41)	3.45 (.38)
Estimated FSIQ	103.69(5.88)	115.72(4.37)

Note. AB = Average and below intellectual functioning; HA = High Average and above intellectual functioning; GPA = Grade point average (self-reported); FSIQ = Full Scale Intelligence Quotient.

Table 2

Group differences and rates of impaired performance

Task	Mean AB Score	AB % Impaired	Mean HA Score	HA % Impaired	Cohen's *d*
Color Word Interference					
CWI 1***	9.33 (3.42)	12.6%	10.80 (3.72)	5.8%	.41
CWI 2 ***	9.46 (3.60)	15.0%	11.45 (3.20)	5.8%	.58
CWI 3 ***	10.45 (3.16)	7.5%	12.15 (5.39)	4.7%	.38
CWI 4 ***	10.31 (3.36)	8.8%	12.17 (5.71)	2.3%	.40
Trail Making Test					
TMT 1	10.52 (3.40)	10.2%	10.99 (2.81)	6.4%	.15
TMT 2 **	10.47 (2.93)	7.6%	11.42 (2.87)	5.2%	.32
TMT 3 **	10.51 (3.20)	8.3%	11.36 (3.13)	6.9%	.27
TMT 4 **	9.55 (2.89)	8.2%	10.47 (2.80)	8.1%	.32
TMT 5*	10.99 (2.51)	3.9%	11.52 (2.06)	2.4%	.23

Note. AB = Average and below intellectual functioning; HA = High Average and above intellectual functioning; CWI = Color Word Interference; TMT = Trail Making Test.

*** denotes $p < .001$, ** denotes $p < .01$, * denotes $p < .05$

Table 3. Group differences in rates of impaired performance

Task	Chi Square	p value
CWI 1	4.52	0.036
CWI 2	7.61	0.006
CWI 3	1.22	0.19
CWI 4	6.75	0.008
TMT 1	1.61	0.14
TMT 2	0.77	0.26
TMT 3	0.21	0.40
TMT 4	0.002	0.56
TMT 5	0.613	0.32

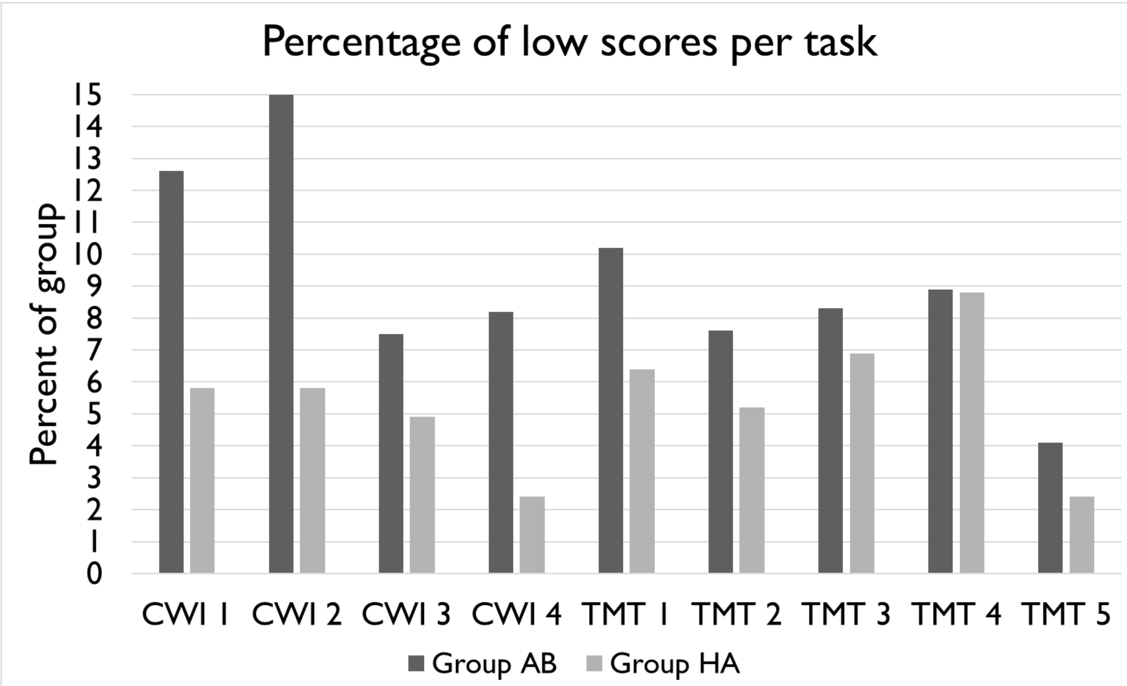

Figure 1. Percentage of impaired scores (SS < 5) across conditions and groups

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