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ADHD, Executive Function and the Core Executive Function Working Memory in Students

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Abstract

The symptoms of ADHD in adults are not fully known which may lead to underdiagnosis. This study examines Attention-Deficit/Hyperactivity Disorder (ADHD) symptoms, executive functioning, and the core executive function working memory in the population of university students. A sample of 523 university students completed the Conners' Adult ADHD Rating Scales (CAARS) and the Executive Function Index (EFI). From this sample, 26 participants were selected for further testing based on their CAARS scores, to comple an abstract shapes task designed to measure working memory where memory load was increased in the second part of the task. Students with higher levels of ADHD had more problems with overall executive functioning, specifically with the executive functions: Impulse Control (IC), Strategic Planning (SP), and Organization (ORG). The abstract shapes task manipulation successfully differentiated working memory load, but higher levels of ADHD were not related to working memory performance. These results support the idea that ADHD symptoms in adults are associated with executive function deficits overall, including some specific functions. However, the anticipated relationship between ADHD and the core executive function working memory was not observed. A possible explanation is that the core executive function inhibition plays a more important role than working memory, highlighting that more research into core executive functions (working memory, inhibition, and set-shifting) is needed.

Keywords: ADHD, executive function, working memory, students, abstract shapes task,

ADHD, Executive Function and the Core Executive Function Working Memory in Students

While Attention-Deficit/Hyperactivity Disorder (ADHD) used to be seen as a developmental disorder that is present exclusively in children, recently the diagnosis has been extended to adults. However, there are problems diagnosing adults with ADHD. One reason may be that their environmental circumstances differ substantially from children's. These different circumstances may lead to different symptom expression that make the diagnosis of adults more difficult leading to underdiagnosis of ADHD in the adult population. ADHD in adults is associated with executive function problems. These executive function problems may be additional symptoms of ADHD in adults.

Executive Functions

Executive functions are defined as cognitive processes that are used to complete goal-directed behaviour. The executive functions can be observed on the behavioural level, and according to Spinella (2005) they can be categorized into Motivational Drive, Organization, Impulse control, Empathy, and Strategic planning. People with ADHD who have impairments in these functions have higher rates of externalizing problems as well as lower academic achievement measured by lower grade averages and higher dropout rates (Gordon & Hinshaw, 2020).

Davidson et al. (2006) define three core underlying executive functions: inhibition, working memory, and set-shifting. Impairment of one of the functions might be a cause for more complex executive problems as well as ADHD symptoms (Antshel et al., 2014). Inhibition and working memory both play a role in set-shifting, which is defined as the ability to examine something from multiple perspectives as well as shift between thoughts and integrate different sources of information (Davidson et al., 2006). Inhibition can be seen on the cognitive level as the ability to ignore irrelevant information. Working memory is defined as the ability to hold in mind and modify information. Working memory is an interactive system consisting of the phonological loop, the visuospatial sketchpad, and the central executive system. The phonological loop is responsible for speech-related information, and the visuospatial sketchpad is for visual-spatial information. The central executive system coordinates the phonological loop and the visuospatial sketchpad controls attention, and monitors information (Ramos et al., 2020).

Inhibition and ADHD Symptoms

Barkley's Inhibition Deficit theory assumes that problems with the core executive function inhibition is an underlying cause of ADHD symptoms. Problems with inhibition may lead to dysregulation of executive functions like self-regulation and working memory as well as to ADHD symptoms (Antshel et al., 2014). In an addendum to his original theory, Barkley states that executive functions are impaired in their functionality not only through inhibitory difficulties but also through issues with, especially non-verbal, working memory. Barkley sees working memory as a core function essential for self-directed and future-oriented action. Impairments in working memory are seen by him as the underlying issues causing ADHD symptoms by impairing future-oriented actions (Antshel et al., 2014).

Davidson et al. (2006) found that, in a non-clinical population, inhibitory control is especially difficult for children and gets less effortful with age as it develops. Working memory relatively develops later and requires more effort than inhibition for young adults such as students (Davidson et al., 2006). Consequently, adults are assumed to have more problems with working memory than inhibition.

In children diagnosed with ADHD, working memory issues are more common and do not decrease from teenage to adulthood (Gordon & Hinshaw, 2020). Working memory issues in children and teenagers diagnosed with ADHD have been documented by Molitor et al. (2018), who found when comparing executive functions to each other working memory was consistently one of the most impaired functions. Additionally, Fosco et al. (2020) found that 67%-71% of the teenagers diagnosed with ADHD were impaired in at least one working memory domain.

With reaching adulthood people find themselves in a more complex and unstructured environment that requires more executive functioning. Working memory problems that are already present in children with ADHD may become more relevant with age, as working memory becomes more effortful to use (Davidson et al., 2006). In accordance with Barkley's Theory, core working memory problems may then lead to executive function difficulties as well as ADHD symptoms (Antshel et al., 2014).

The present study

The general goal is to get more insight into adult ADHD symptoms by investigating the relationship between ADHD symptoms and executive functions in adults as well as the underlying factor of working memory. My goal is to investigate the association of ADHD symptoms and executive functions and the core executive function working memory in a sample of psychology students.

ADHD will be measured through the Conners' Adult ADHD Rating Scales–Self-Report (CAARS) questionnaire (Conners et al., 1999). The CAARS takes a dimensional approach to characteristics associated with ADHD and was specifically designed for the adult population. Executive function will be assessed through the Executive Function Index Scale (EFI; Spinella, 2005). The EFI is a self-report measure that assesses executive functions in daily life. The questionnaire defines five executive functions: Motivational Drive, Organization, Impulse Control, Empathy, and Strategic Planning. The core executive function of working memory will be assessed through the abstract shapes reaction time task (Davidson et al., 2006). The task has two conditions to measure working memory, in the first condition (easy condition) participants are presented with two shapes, and in the second condition (difficult condition) they are presented with 6 shapes.

The first question (1a) is whether students with worse executive function scores have more ADHD symptoms. According to Loo et al. (2007), there is a clear relationship between the EFI and ADHD symptoms in adults. My expectation is higher ADHD symptoms as measured by the ADHD Index and the DSM Total scale will be associated with worse general executive functioning as measured by lower scores on the EFI Total scale.

The second part of question one (1b) is whether the specific executive functions are related to ADHD symptoms. According to Nigg et al. (2002), worse strategic planning is associated with higher ADHD scores and according to Krieger & Amador-Campos (2018), Organisation and Impulse Control is impaired in students with higher ADHD scores. I expect that higher levels of ADHD symptoms as measured by higher scores on the ADHD Index and DSM Total scales will be associated with worse Organisation, Impulse Control and Strategic planning as measured by lower scores on the ORG, IC and SP scales of the EFI respectively.

The first part of the second question (2a) is whether the manipulation of working memory of the task was successful. Davidson et al. (2006) found that the task conditions successfully manipulated working memory demands. The manipulation will be examined by exploring whether the reaction time and the accuracy differences between conditions are significant. It is expected that in the more difficult condition performance will be worse (as measured by reaction time and accuracy). This will be measured by looking at the differences in mean reaction time all, mean reaction time correct, mean reaction time error and percentage correct between the easy and difficult condition of the task.

The second part of the question (2b) is whether there is an association between ADHD symptoms and working memory. Studies done by Loo et al. (2007) and Kasper et al. (2012)

found worse working memory performance in people with an ADHD diagnosis compared to control groups. In line with the change in importance of working memory with age documented by Davidson et al. (2006) it is expected that the scores on the abstract shapes task will have a stronger correlation with the CAARS Index scale that specifically measures adult symptoms and a weaker correlation with the CAARS DSM total scale as it measures the DSM criteria. It is expected that the working memory performance on the abstract shapes task measured by the differences between easy and difficult conditions will be larger when students have more symptoms of ADHD as measured with the CAARS, specifically the ADHD Index and the DSM Total scale. This would mean that higher ADHD scores are associated with longer reaction time (slower response). The difference in accuracy between conditions is expected to be negatively correlated to both measures of ADHD. This would mean that worse accuracy between conditions would be related to higher symptom severely (making more errors in the difficult condition).

Methods

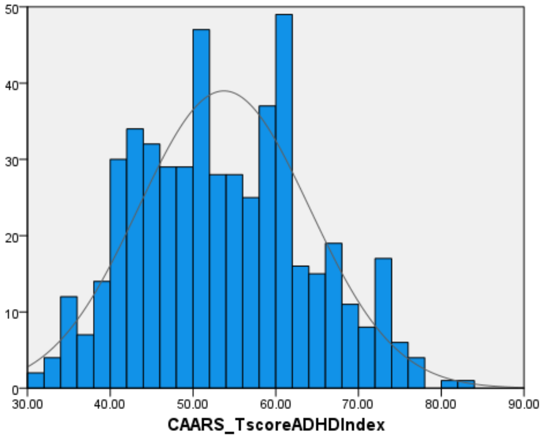
Participants

To recruit first-year students of the University Groningen, a portal called SONA was used. The students obtained SONA credits by participating in different studies. The sample of participants is a convenient sample that was selected based on participation in a previous study done online in which they filled out the CAARS and the EFI questionnaire. Based on analysis of the CAARS scale, participants that were among the 25% scoring either the highest or the lowest were invited for the experiment. In this study, two samples were used. Sample 1 consists of 523 participants between the ages of 16 to 35 with an average of 20 (M = 19.84, SD = 2.20), with 75.5 % (n = 385) identifying as female, 23.7% (n = 124) as male and 0.8% (n = 4) identified as other, while Sample 2 consist of 30 participants (10 males, 20 females) agreed to participate in the experimental task (Sample 2). Four participants did not complete the study and were excluded from the analysis. The final sample for the task consists of 26 participants, 34.6% (n = 9) male and 65.4% (n = 17) female, aged 18 to 26 years old (*N* = 26*; M* = 20.19; *SD* = 1.98). Sample 1 only completed the questionnaire while Sample 2 did the abstract shapes task in addition to the questionnaire.

The study was approved by the Ethical Committee of Psychology at the University of Groningen.

Figure 1

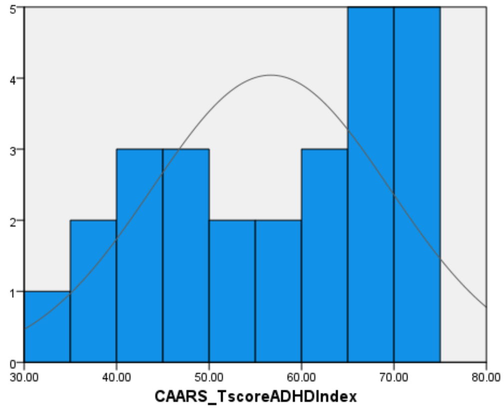
Histogram of ADHD Index score distribution in Sample 1



Note: This histogram shows the distribution of the ADHD Index in Sample 1 (*n* = 523).

Figure 2

Histogram of the ADHD Index distribution of Sample 2



Note: This histogram shows the distribution of the ADHD Index scale in Sample 2 (*n* = 26)

Measures

Adult ADHD symptoms

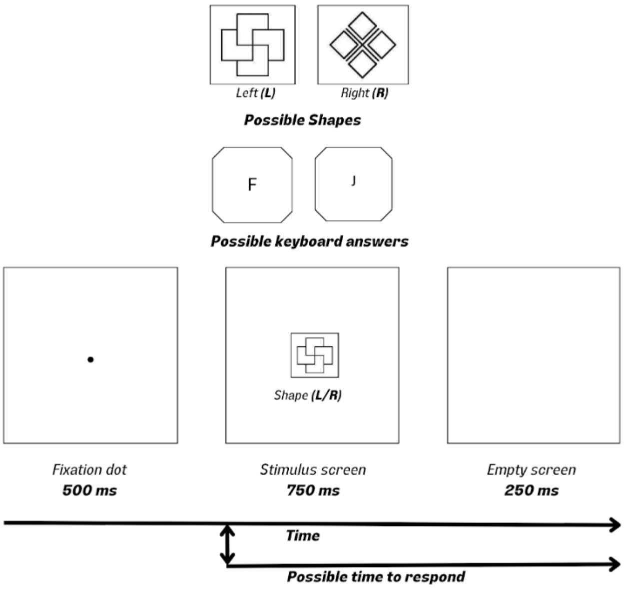
Conners' Adult ADHD Rating Scales–Self-Report: Long Version: Conners' Adult ADHD Rating Scales–Self-Report: Long Version (CAARS) was developed by Conners et al. to measure the current state of ADHD symptoms of adults through self-report (Conners et al., 1999). The test is available in both a long and a short version. While the test assesses current symptom strength it does not include all requirements for a diagnosis based on the DSM-5-TR (APA.,2022) and should therefore not be used as a diagnosis tool. The scale has 81 questions related to both behavioural (i.e., ‘I talk too much’), and cognitive (i.e., ‘I don’t plan ahead’) symptom manifestations, and it uses a 4-point measurement scale, ranging from 0 (Not at all, never) to 3 (Very much, very frequently). The CAARS provides two main scores: the ADHD-Index score and the DSM-Total score. The ADHD index contains items tailored to adults while the DSM Total scale is based only on DSM items. The raw CAARS scores are transferred into a T-score in order to compensate for gender and age. Higher scores on each scale indicate greater symptom severity. The CAARS has good reliability ($\alpha = 0.968$), high specificity and sensitivity, and is a valid cross-cultural measure (Christiansen et al., 2012). This study will use the DSM Total and the ADHD Index scale.

The Executive Functioning Scale: Executive functioning is measured using the Executive Function Index Scale (EFI; Spinella, 2005). Through self-report, the participant's executive functions are assessed in daily life. Specifically, it aims to capture individuals' ability to initiate and sustain goal-directed actions, maintain motivation, and regulate their behaviour to achieve desired outcomes. The scale consists of 27 items covering five factors namely: Motivational Drive (MD), Organization (ORG), Impulse Control (IC), Empathy (EM), and Strategic Planning (SP) as well as a Total Score (EFI Total). The participants were asked to rate themselves on a 5-point Likert scale, ranging from 1 (not at all) to 5 (very much). The EFI demonstrates good internal consistency with Cronbach's alpha values ranging from .69 to .82. This study uses the EFI Total, Organization, Impulse Control, and Strategic Planning scales. A higher score on each scale means better executive functioning.

The Abstract Shapes task: The abstract shapes task had two conditions. All shapes were presented in the middle of the screen. The first (easy) condition had two shapes and the second (difficult) had a total of six. In the easy condition for one shape key "f" has to be pressed and for the other shape key "j" (Figure 3a), in the difficult condition for three of the shapes key "f" has to be pressed and for the remaining three shapes the "j" key (Figure 3b). The measures of interest were accuracy in each condition as well as reaction time. Participants had 1500ms to respond to each trial, with a fixation dot shown for 500ms, the shape presented for up to 750ms (stimulus screen), and a 250ms blank screen (in case the participant did not respond during stimulus presentation). The first condition included 6 practice trials and 40 experimental trials, while the second condition included 6 practice trials and 42 experimental trials. The different amount of shapes per trial was used to manipulate memory load in accordance with Davidson et al. (2006).

Figure 3a

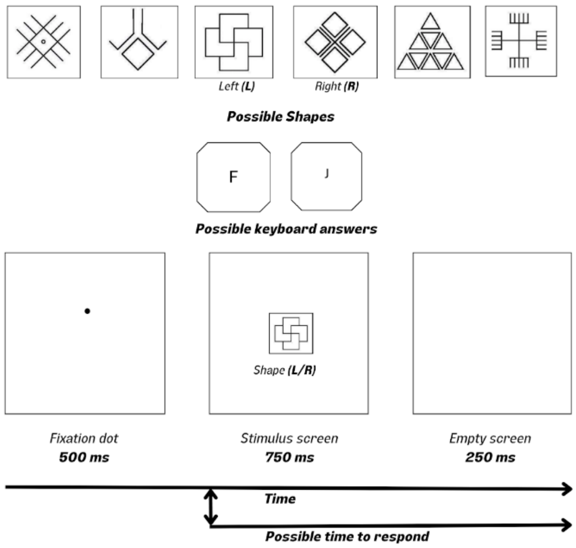
Abstract Shapes Task (Easy Condition)



Note: Figure 3a provides an example of the easy condition in the study. Initially, a screen with fixation dot is shown for 500ms. Then the shape is presentation for 750ms. Participants are told to press the "f" key when one shape appears on the screen and the "j" when the other one appears. The final blank screen lasts 250ms and severs as break between trials in case the participant does not respond to the stimuli.

Figure 3b

Abstract Shapes Task (Hard Condition)



Note: Figure 3b provides an example of the difficult condition in the study. Initially, a screen with fixation dot is shown for 500ms. Then the shape is presentation for 750ms. Participants are told to press the "f" key when one of the three shape appears on the screen and the "j" when one of the other three appears. The final blank screen lasts 250ms and severs as break between trials in case the participant does not respond to the stimuli.

Procedure

The study consists of two parts, in which the participation is voluntary, and the students could stop at any time. In the first part, the participants participated in the CAARS and the EFI through a questionnaire platform (i.e. Qualtrics) to acquire credits through a research platform (i.e. SONA) for a university course. The information about the study and its purpose was described shortly without deception and then participants checked the box for informed consent. The estimated time to complete the two questionnaires is 50 minutes. Based on the scores for the first part, the participants with the 25% lowest or highest CAARS scores were invited via email to the second part of the study. In the second part of the study, the participants participated in five experimental tasks through an experimental research program (i.e. OpenSesame) on a computer in a controlled environment (i.e. research lab). The tasks varied all in time, ranging from two to 20 minutes. Including two breaks of two minutes.

In the first part of the study, the students were first presented with information about the study. The goal of the study was explained, it was stressed that participation is completely voluntary, that they can quit at any time and ask questions if they want to. Then, demographic information was gathered (i.e. age, job, language, gender, and biological sex) and the students were asked whether they had received a formal diagnosis of ADHD and/or taking prescribed medication, after which the student was directed to the CAARS. Lastly, the student could leave a comment if preferred. In the EFI, it was first stressed again that the students could always email when there were questions and that they could quit at any time, after which informed consent was asked. The students started the EFI, afterwards they could leave a comment if preferred. The students that were invited to the second part of the study conducted the experiment. After a general introduction was given about the tasks, the students proceeded with a randomized sequence of the tasks. The informed consent was implemented in the inhibition task (i.e. Go/No-Go task).

Data analysis

Data preparation for the Abstract shapes

Mean reaction times for all responses (m_rt_all_easy, m_rt_all_difficult), correct responses (m_rt_corr_easy, m_rt_corr_difficult), and incorrect responses (m_rt_error_easy, m_rt_error_difficult) were computed. The percentage of correct responses was also calculated for each condition (%_corr_easy, %_corr_difficult). Differences in reaction time (diff_rt_62) and accuracy (diff_acc_62) between conditions were analysed.

Hypothesis 1 Executive Function and ADHD

The normality of ADHD and EFI scores was assessed using the Shapiro-Wilk test. As shown in Table A1 (Appendix A), non-normal distributions were found for all variables except the EFI Total scale and the Organization subscale. Thus, Spearman's correlations were used to examine relationships between ADHD Index, DSM Total, and EFI scales (Total, Strategic Planning, Organization, and Impulse Control).

Hypothesis 2 ADHD and working memory

Shapiro-Wilk tests indicated non-normality for mean reaction time errors in condition one (W (26) = .848, p = .001) and the percentage of correct responses in condition two (W (26) = .681, p < .001). Examining the Q-Q plots for the mean reaction time error in condition one (Figure 3) revealed that the deviation may be due to an outlier, however, due to the small sample size (n = 26), these deviations were considered significant. Therefore, the Wilcoxon Signed Ranks Test was used for hypothesis 2a to test condition differences. For hypothesis 2b, Spearman's correlations examined the relationship between ADHD Index, DSM Total, and differences in accuracy (diff_acc_62) and reaction time (diff_rt_62) between conditions.

Results

Descriptive Statistics

CAARS and EFI sample

Descriptive statistics for the CAARS and EFI in sample 2 can be found in Table 1.

Table 1.

Descriptive statistics for the CAARS and EFI

	N	Minimum	Maximum	Mean	Std. Deviation
EFI total score	523	66	121	95.40	8.978
Strategic planning	523	9	35	23.30	4.408
Empathy	523	11	30	26.09	3.086
Impulse control	523	6	25	16.72	3.545
Organisation	523	8	23	15.12	2.681
Motivational drive	523	5	20	14.17	2.735
CAARS_TscoreDSM_Total	505	30.00	97.43	57.4964	13.64115
CAARS_TscoreADHDIndex	505	31.80	83.81	53.7476	10.33842

Note: This table shows the descriptive statistics for sample 2 of *n* = 523 of both EFI scores and the CAARS scores ADHD Index and DSM Total

CAARS and Abstract Shapes task

Descriptive statistics for the CAARS scores of participants who completed the abstract shapes task in the second part of the study can be found in Table B1 (Appendix B). The mean reaction time in the easy condition was 410.75 milliseconds (ms) (M = 410.75, SD = 44.69) and the difficult condition was 521.03 ms (M = 521.03, SD = 38.97). The percentage correct in the easy condition was 92.05 (M = 92.05, SD = 4.57) and the difficult condition was 50.14 (M = 50.14, SD = 0.63). All values can be visualized in Table B2 (Appendix B).

Executive Function and ADHD Association

Question 1a:

The relationship between the ADHD Index and the DSM Total scale with the EFI Total scale was examined using Spearman's correlation (Table 2). The results indicated a significant negative correlation between the EFI Total scale and the DSM Total scale ($r(523) = -.509$, $p < .001$), as well as between the EFI Total scale and the ADHD Index ($r(523) = -.485$, $p < .001$). This suggests that individuals with higher ADHD symptom scores had lower overall executive functioning scores.

Table 2.

Spearman's rho correlations between the CAARS and the EFI Scales

			EFI Total	Strategic Planning	Empathy	Impulse control	Organisation	Motivational drive
Spearman's rho	CAARS_DSM_Total	Correlation Coefficient	-.509**	-.417**	.004	-.477**	-.596**	.196**
		Sig. (2-tailed)	<.001	<.001	.932	<.001	<.001	<.001
		N	523	523	523	523	523	523
	CAARS_ADHD_Index	Correlation Coefficient	-.485**	-.349**	.020	-.428**	-.542**	.054
		Sig. (2-tailed)	<.001	<.001	.646	<.001	<.001	.214
		N	523	523	523	523	523	523

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Note: This table shows the Spearman's correlations between the DSM Total, the ADHD Index, and the EFI scales. Two-sided significance levels were calculated for each correlation.

Question 1b:

Spearman’s correlations between the DSM Total, ADHD Index, and the EFI subscales are also presented in Table 2. The DSM Total scale showed significant moderate negative correlations with Impulse Control (IC; $r(523) = -.477$, $p < .001$) and Strategic Planning (SP; $r(523) = -.417$, $p < .001$), and a strong negative correlation with Organization (ORG; $r(523) = -.596$, $p < .001$). These results show that higher DSM Total scores are associated with lower scores in Organization, Impulse Control, and Strategic Planning. Similarly, the ADHD Index showed moderate negative correlations with Impulse Control (IC; $r(523) = -.428$, $p < .001$) and Strategic Planning (SP; $r(523) = -.349$, $p < .001$), and a strong negative correlation with Organization (ORG; $r(523) = -.542$, $p < .001$). This means that higher ADHD Index scores are associated with lower scores in Organization, Impulse Control, and Strategic Planning. These findings mean that more ADHD symptoms are related to worse Organization, Impulse Control and Strategic Planning.

ADHD and Working Memory

Question 2a:

The effectiveness of the task manipulation of working memory was assessed by examining the differences in reaction time measures between conditions using the Wilcoxon Signed Ranks Test (Table C1, Appendix C). The test showed significant differences in total reaction time, reaction time for correct responses, and reaction time for error responses between conditions ($Z = -4.457$, $p < .001$). Additionally, the difference in percentage correct between conditions was significant ($Z = -4.466$, $p < .001$). These results indicate that the task manipulation was successful in increasing working memory load in the second condition.

Question 2b:

The relationship between the ADHD Index, DSM Total, and the working memory measures (differences in reaction time and accuracy between conditions) was examined using Spearman's correlations (Table 3). None of the correlations between these variables were significant. However, the correlation between the DSM Total scale and the difference in reaction time between conditions (*r*(26) = .368, *p* = .064) approaches significance with a *p* value between .05 and .10. This means that there is a trend towards a relationship between more ADHD symptoms and worse working memory performance.

Table 3.

Spearman's rho correlations between CAARS scales and abstract shapes measures

			CAARS_TscoreDSM_Total	CAARS_TscoreADHDIndex
Spearman's rho	diff_rt_6-2	Correlation Coefficient	.368	.094
		Sig. (2-tailed)	.064	.647
		N	26	26
	diff_acc_6-2	Correlation Coefficient	.076	-.122
		Sig. (2-tailed)	.713	.552
		N	26	26

**. Correlation is significant at the 0.01 level (2-tailed).

Discussion

The general objective of this study was to investigate the relationship between ADHD and executive functioning as well as the core executive function working memory in students. Specifically, the study aimed to explore the connection between ADHD symptoms with executive functions and the core executive function working memory guided by Barkley's theory about executive functions (Antshel et al., 2014).

Consistent with Barkley's theory (Antshel et al., 2014), this study found that higher ADHD scores were associated with worse executive functioning overall. This was true for both ratings of the Total DSM score and the ADHD Index score. Contrary to expectations, the ADHD Index did not have a higher correlation with the Total EFI score. Instead, both scales demonstrated moderate correlations with the total executive function score. This relationship supports the idea that the current ADHD diagnostic criteria in the DSM could be improved by incorporating executive function problems as additional symptoms. The findings do not support the idea that the relationship between executive function difficulties and ADHD symptoms is different in adults as the general relationship aligns with findings in children and teenagers with ADHD (Loo et al., 2007).

Further analysis revealed that executive functions Impulse Control, Strategic Planning, and Organization were more impaired in students with higher scores on either the DSM Total or the ADHD Index scales. While both Impulse Control and Organization were more strongly related to high scores on the ADHD Index, Strategic Planning showed a stronger correlation with higher DSM Total scores. This suggests that, although both measures of ADHD symptoms are related to general executive functioning, the importance of specific executive functions related to ADHD may vary from the adult context to the DSM symptoms. Impairment in executive functions Impulse Control and Organizational, although not currently emphasized in the DSM, may play a crucial role in adult ADHD.

To study the core executive function working memory, the abstract shapes task was used, which involved two conditions: one with two shapes and one with six shapes. Reaction time and accuracy measures utilized to assess working memory. The task manipulation was successful, as evidenced by significant differences between the conditions, consistent with findings by Davidson et al. (2006).

However, the expected relationship between ADHD scores and working memory performance (i.e., differences in accuracy and reaction time between conditions) was not found. Instead, the tendency of worse working memory performance in students with more ADHD symptoms as measured by the DSM scale was present. This tendency requires follow-up studies. The nonsignificant relationship between impairment of core executive function working memory and more ADHD symptoms contrasts with the finding of impaired executive functions Impulse Control, Organization, and Strategic Planning in students with more ADHD symptoms as well as with Loo et al. (2007). He reported that 30% of individuals diagnosed with ADHD exhibit significantly impaired working memory. There are several possible explanations. One explanation may be that while Barkley sees deficits in the core executive function working memory as underlying factors of more complex executive impairment as well as ADHD symptoms, his theory additionally includes the core executive function inhibition (Antshel et al., 2014). As worse working memory performance was not significantly associated with more ADHD symptoms, the core executive function inhibition may be more important in explaining the impairment of the more complex executive functions (IC, SP, ORG) that were related to more ADHD symptoms in students. A second explanation may be that there are different parts of the core executive function working memory. That is the abstract shapes task taxes the visuospatial sketchpad while other tasks such as the digit span backwards tax the phonological loop. Fosco et al. (2020) found that worse impairment of the component central executive system was related to more ADHD symptoms. Additionally, a meta-analysis found that children and adolescents with ADHD were more impaired in their phonological loop (Ramos et al., 2020). Impairment of other components of working memory may lead to worse complex executive function performance in students with more ADHD symptoms.

Strengths and Implications

One notable strength of this study is its dimensional approach to assessing ADHD symptoms, this allows for a more detailed exploration of symptom severity beyond a categorization of ADHD. Furthermore, the presence of the relationship between ADHD symptoms and executive function problems in the student population adds to the existing research done in other age groups and lends support to the notion that executive problems may be generally associated with ADHD regardless of age.

Another strength lies in the controlled laboratory environment for the working memory task, ensuring equal conditions for all participants. This control enhances the reliability that the conditions of the task were successful in manipulating working memory load and offering the option for future research to replicate the conditions in different samples to compare results. Moreover, this approach is valuable as research has primarily found that higher levels of ADHD are associated with deficits in the phonological loop as measured by verbal working memory tasks (i.e. digit span backwards) (Stavro et al., 2007; Kasper et al., 2012; Ramos et al., 2020; Gordon & Hinshaw, 2020; Loo et al., 2007), and the use of a non-verbal working memory task (the abstract shapes task) broadens the scope of working memory components examined in association to ADHD.

The association between ADHD symptoms and executive function problems in students may be of use for clinicians to incorporate assessments of executive function deficits into their diagnostic processes for ADHD, particularly in adults. The connection of ADHD and executive problems in students found by this study could be useful for educational institutions to implement interventions to address specific executive function problems potentially improving academic performance and overall well-being of students with ADHD symptoms.

Limitations and Direction for Future Research

This study has several limitations. The sampling was done exclusively through a convenient sampling of first-year psychology students that may limit the generalizability of the findings as well as the external validity. The small sample size for the second part of the study and the predominance of female participants further limits the possible application and generalization of the findings. The predominantly female sample may be an issue as women with ADHD diagnosis typically have more inattention symptoms while men additionally have more hyperactivity symptoms. The different impairments may have different associations with executive functions (Nigg et al., 2002).

Additionally, the use of self-report measures like CAARS and EFI, while reliable, may introduce biases. There is evidence that people with higher ADHD scores may be impaired in their self-evaluation which may lead to inaccurate results on self-report measures (Loo et al., 2007, Antshel et al., 2014). The abstract shapes task, although effective in manipulating working memory load, may not capture the full complexity of working memory deficits in ADHD. As there are different working memory components that can be measured, this task only gives a small part of information about the working memory of participants. Additionally, due to the small sample size and the range of CAARS scores, it was not possible to get a clear picture of the difference in performance between high and low ADHD severity.

Future studies should aim to address these limitations by replicating these findings with larger, more diverse samples and consider longitudinal designs to examine how executive function and working memory deficits in ADHD evolve over time, especially in adults. Additionally, incorporating different tasks that tackle different parts of working memory may give a clearer picture of which aspects of working memory are impaired in students or adults with ADHD in general.

Further investigation into the subcomponents of the EFI and how they may relate to ADHD as measured by the DSM Scale, or the ADHD Index scale in a more adult context, may give insight into different mechanisms underlying executive function impairments in adults with ADHD.

Conclusion

The current study aimed to explore the relationship between ADHD symptoms, executive functioning, and core executive function working memory in a sample of university students. The findings of an association between worse executive function and more ADHD symptoms contribute to the growing body of evidence highlighting the significant association between ADHD and executive function deficits, particularly in impulse control, strategic planning, and organization. However, contrary to expectations and previous findings, there was no significant relationship between ADHD symptoms and working memory performance. The findings of this study could aid the development of improved diagnostic criteria for ADHD in different age groups

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Appendix A

Normality Testing

Table A1.

Test for Normality for CAARS and EFI Total and SP, ORG and IC

	Shapiro-Wilk		
	Statistic	df	Sig.
CAARS_TscoreADHDIndex	.987	505	<.001
CAARS_TscoreDSM_Total	.974	505	<.001
EFI total score	.996	505	.206
Strategic planning	.991	505	.004
Empathy	.897	505	<.001
Organisation	.983	505	<.001
Motivational drive	.982	505	<.001
Impulse control	.983	505	<.001

a. Lillefors Significance Correlation

Note: This table shows the results of the Shapiro-Wilk test. The p-value shows significant deviations from the normality of the CAARS scales, the ORG, and the IC subscales. The EFI Total and the Strategic Planning scale do not deviate significantly.

Table A2.

Test of Normality for each abstract shape measure

	Shapiro-Wilk		
	Statistic	df	Sig.
m_rt_all_easy	.979	26	.852
m_rt_corr_easy	.984	26	.950
m_rt_error_easy	.848	26	.001
%_corr_easy	.939	26	.126
m_rt_all_difficult	.976	26	.788
m_rt_corr_difficult	.964	26	.486
m_rt_error_difficult	.964	26	.479
%_corr_difficult	.691	26	<.001
diff_rt_6-2	.092	26	.200*
diff_acc_6-2	.135	26	.200*

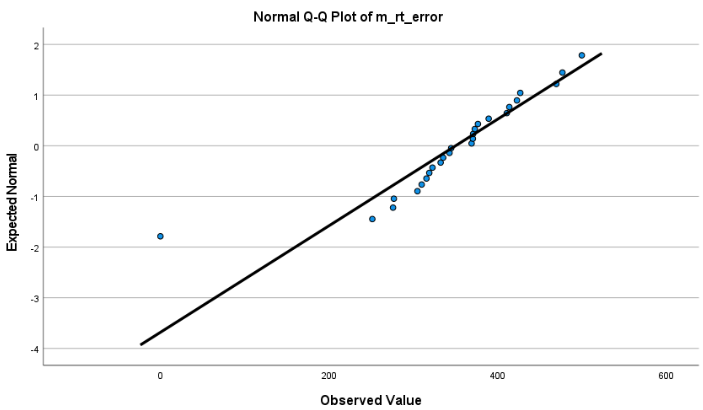
*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Note: This Table shows the results of the Shapiro-Wilk test of all measures of the abstract shapes task. The p-values of the mean reaction time error in the easy condition and the percentage of correct responses in the difficult condition deviate significantly from normality.

Figure A1.

Q-Q plot of the mean reaction time error in the difficult condition



Appendix B

Descriptive statistics

Table B1.

Descriptive statistics of the CAARS for the experimental sample

	N	Minimum	Maximum	Mean	Std. Deviation
CAARS_TscoreDSM_Total	26	44.58	81.85	61.4211	11.46961
CAARS_TscoreADHDIndex	26	32.72	73.74	56.6792	12.83157

Note: This table shows the descriptive statistics for the CAARS DSM Total and ADHD Index scales of the participants in sample 2 (*n* = 26).

Table B2.

Descriptive statistics for the abstract shapes measures

	N	Minimum	Maximum	Mean	Std. Deviation
m_rt_all_easy	26	314.948718	517.475000	410.75321419	44.692078876
m_rt_corr_easy	26	328.843750	517.475000	414.64405192	43.632745641
m_rt_error_easy	26	.000000	500.000000	350.18827838	95.122347049
%_corr_easy	26	82.0512821	100.0000000	92.048686804	4.5657268629
m_rt_all_difficult	26	450.000000	598.625000	521.03294700	38.973041595
m_rt_corr_difficult	26	453.428571	616.619048	523.57133704	38.510468654
m_rt_error_difficult	26	446.333333	604.550000	518.47051288	43.480212799
%_corr_difficult	26	48.7804878	51.2195122	50.140712946	.6291475686
diff_rt_6-2	26	46.24210530	160.95135100	108.9272850538	27.11326627142
diff_acc_6-2	26	-50.000000	-32.051282	-41.90797388	4.567898225

Note: This table shows the descriptive statistics all reaction time measures in both the easy and the difficult condition as well as the percentages correct.

Appendix C

Analytical statistics

Table C1.

Wilcoxon Signed Ranks Test for abstract shapes condition manipulation

	m_rt_all_easy - m_rt_all_difficult	m_rt_corr_easy- m_rt_corr_difficult	m_rt_error_easy - m_rt_error_difficult	%_corr_easy - %_corr_difficult
Z	-4.457[b]	-4.457[b]	-4.457[b]	-4.466[c]
Asymp. Sig. (2-tailed)	<.001	<.001	<.001	<.001

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

c. Based on positive ranks.