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Executive Functions in ADHD in Adults, an Experimental Study

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Abstract

Objective: The current body of knowledge supports an association between ADHD (attention deficit hyperactivity disorder) and EF (executive functioning). The present study explores this relation by means of two methods, a questionnaire and the experimental method. Additional research into the relations between motivation and impulse control, EF and ADHD has been examined.

Method: We gathered a sample of 394 students. These students have been presented with two online questionnaires (Conners' Adult ADHD Rating Scales–Self-Report: Long Version (CAARS-S:L), EFI-Executive functioning Index scale) and filled in the questionnaire in correspondence with their schedule. In the next step, 40 students were invited to participate in an experiment to measure cognitive functions of motivation and inhibition.

Results: Regarding our hypotheses, we found evidence that replicates findings concerning the association between high ADHD symptomatology and poorer EF (moderate correlation of -.489 of high significance). Furthermore, higher levels of ADHD were associated with poorer inhibition but not with poorer motivational drive according to the EFI. Performance of the Go/No-Go task revealed that the group with higher levels of ADHD responded faster on the fast condition and slower on the slow condition, compared to the group with low levels of ADHD. This might suggest motivational problems, however students with high levels of ADHD did not show a problem in inhibition as is indicated by the percentage of errors during the task.

Conclusion: The findings underline the relationship between ADHD and EF in students. Based on the findings of the questionnaire, inhibition appears to be a more prominent factor compared to motivational drive, while the experiment suggests the opposite.

Keywords: attention deficit hyperactivity disorder, executive functioning, Go/No-Go task

Executive Functions in ADHD in Adults, an Experimental Study

Attention deficit hyperactivity disorder (ADHD) is one of the most prevalent psychiatric conditions and approximately 5% of children are affected, of which around 40% continue fulfilling diagnostic criteria in adulthood (Mendeley, 2010). Even though the prevalence of affected individuals in adulthood is still substantial, the perception by society and medical experts of ADHD as an inclusive childhood condition complicates the process of acquiring help and a proper diagnosis for adults. Existing differences between manifestations of symptoms in adulthood and childhood have led to long-term negligence of the topic of ADHD in adults from the side of researchers (Reimann-Höhn, 2016). This topic has been receiving progressively more attention in recent years.

According to DSM 5-TR diagnostic criteria for ADHD (American Psychiatric Association [APA], 2022), there are three recognized subtypes of ADHD, the inattentive subtype, the hyperactive-impulsive subtype, and the combined subtype. A shared feature of these subtypes is a persisting pattern of behavior that impacts development or functioning. To fulfill diagnostic criteria symptoms of an inattentive or hyperactive subtype of ADHD need to be manifested in at least two or more settings, e.g., school/work, relationships, and other activities. Other criteria are clinically significant manifestation for at least six months and symptoms need to occur before the age of twelve without being better explained by other diagnoses. If more medical conditions account for manifested symptoms, comorbid disorders are often diagnosed together with ADHD).

In order to fulfill the diagnostic criteria for ADHD in adulthood, at least five of the symptoms per subtype need to be present, while in childhood, six of the main symptoms per subtype are necessary. In the case of the combined subtype of ADHD, diagnostic criteria for both the inattentive subtype and the hyperactive-impulsive subtype need to be fulfilled (APA, 2022).

Examples of symptoms related to the inattentive subtype might be decreased attention to detail, the frequent tendency to get distracted by external stimuli, careless mistakes, and problems sustaining attention. These symptoms result in problems with organizing and finishing tasks and engagement in activities for which it is essential to sustain mental effort for a prolonged period of time. Symptoms related to the hyperactive-impulsive subtype might include the tendency to tap, fidget or squirm while being supposed to sit or stay still, which might also lead to a tendency to leave when remaining seated is required and trouble engaging in quiet leisure time activities. Furthermore, frequent tendencies of excessive talking, 'jumping into speech', and insufficient capacity to let others finish their talk are commonly present. Hyperactivity can be shortly described as an 'excessive restlessness', while impulsivity is a desire for a quick reward without full realization of potential consequences (APA, 2022).

Current literature suggests that problems with executive functioning (EF) are associated with ADHD (Cristofori, 2019; Barkley, 1997; van de Meere, 2005; Lace, 2020). Executive functioning can be defined as a goal-directed cognitive process that influences self-regulation and the achievement of future goals (Barkley, 1997). Specifically, executive functions are described as high-order cognitive abilities, which include inhibitory control, working memory, planning, reasoning, problem-solving and cognitive flexibility (Cristofori, 2019).

The extent to which EF plays a role in the nature of ADHD is still not fully understood. Importantly, the question at stake is whether executive function deficits can be considered to be a set of symptoms falling under the range of ADHD or whether they can be considered a consequence of ADHD symptoms. If EF is found to play a prominent role, sufficient to be considered symptomology of ADHD, it can help the development of new and more appropriate diagnostic criteria for adults.

One of the prominent theories about the association between EF and ADHD is the Inhibition theory (Barkley, 1997). Barkley recognized the deficit of inhibition as a core feature, which led to the development of the cognitive deficit-oriented theory about inhibition, known as Barkley's theory. Research attempting to support this theory has yielded inconsistent results. Studies suggested that EF, specifically the inhibitory factor of EF, plays an important role in the symptomatology of ADHD, but does not account for all the ADHD symptoms, implying it is probably not a core feature (Willcutt, 2005). For instance, a factor analysis study by Lace (2020) rather supported Barkley's theory. Another influential theory of ADHD is that motivation is involved in ADHD symptomatology. This point of view presents the psychophysiological model of the State regulation model. According to this model, the non-optimal energy regulation resulting in motivational deficits is a core issue underlying symptoms of ADHD (van de Meere, 2005).

University students present a special category of adults with ADHD. On one hand, young children in school settings receive a relatively large amount of attention from the side of research and attention of mainstream media and a much better general understanding from the side of society, coaches, professionals and teachers. On the other hand, adolescents and adults with ADHD received much less attention of this kind and a general understanding of their issues falls far behind the understanding of children (Reimann-Höhn, 2016). Also, university students with ADHD, who tend to struggle academically did not receive as much attention and support as pupils in primary schools with ADHD (Green, 2012). In general, university students with ADHD are known to experience less academic success, higher levels of psychological and emotional distress, lower levels of motivation toward academic duties and overcoming daily hustles and higher rates of abuse of alcohol and drugs (Green, 2012; Martin, 2012; Weyandt, 2006). In relation to EF, in particular motivation and organizational aspects appear to be the most impaired (Dvorsky, 2019).

Students generally tend to present a rather homogenous group regarding EF, because functioning in the university setting requires a rather high level of EF (Green, 2012; Martin, 2012; Weyandt, 2006). That means that deviations from expected EF levels might indicate profound issues they are forced to deal with.

The main goal of the study is to gain a better understanding of the symptoms of ADHD in relation to EF in adults. The application of the dimensional approach to ADHD symptomatology offered a new perspective to investigate the level of ADHD symptoms and EF deficits in the normal population sample. This approach presumes that these traits follow a continuum rather than distinct categories.

The more specific goal is to investigate students and the association between ADHD and EF in the sample. Scores from the Conners' Adult ADHD Rating Scales–Self-Report: Long Version (CAARS-S:L) and The Executive Functioning Scale (EFI) questionnaires would be used for investigating this research question. However, there are some recommendations related to the formulation of the CAARS questionnaire which will be addressed in the discussion.

Another way of investigating EF deficits in the present study is to assess the cognitive performance and the motivational drive traits of EF based on the performance of the students on Go/No-Go task. In Go/No-Go tasks participants respond to certain stimuli and ignore other stimuli. The experiment in the present study would present fast and slow conditions to assess the participant‘s performance. Based on prior research, subjects with high levels of ADHD tend to perform worse than subjects without ADHD. The response pattern of people with ADHD is in general characterized by faster responses and more mistakes, in situations when stimuli are presented quickly and rather slower responses when stimuli are presented slowly when compared with non-ADHD subjects (Metin, 2012; Bezdijan, 2009; Wright, 2014).

The first research question has two components. The first interest is to assess whether there is a general association between ADHD and EF. The second is to see precisely, how two factors of EF, the motivation drive and the impulse control relate to ADHD and to each other.

According to the current body of evidence, ADHD and EF are known to be correlated (Barkley, 1997**;** van de Meere, 2005**;** Lace, 2020), therefore it is expected that the total scores of EFI and CAARS-S:L questionnaires are correlated. That means that when assessed in a sample of students it is expected that students with lower levels of EF according to the EFI scale, will have more prominent symptoms of ADHD according to the CAARS scale.

Barkley (1997) theorized that inhibition is the core deficit underlying ADHD, while van de Meere (2005) theorized that motivation plays the most prominent role. For that reason, correlations between motivation drive and impulse control subscales of EFI would be separately correlated with the ADHD Index subscale, each other and the total EFI score.

The second research question examines whether students with high levels of ADHD respond faster on the fast part of the Go/No-Go task and slower on the slow part of the Go/No-Go task, compared to students with low ADHD symptomatology. This research question is in line with the impulsivity trait associated with ADHD and the known patterns of their responses on Go/No-Go task. (Metin, 2012; Bezdijan, 2009; Wright, 2014). This will serve as a measurement of the effect of over and under stimulation on motivation of the students participating in this task. It is expected that the pattern of responses of students high on ADHD traits will be marked with faster responses on the fast task and slower on the slow task of go-no go task.

The third research question concerns the percentage of errors students make in the Go/No-Go task. This will serve as a tool to see how well participants can inhibit their responses in order to perform the task to the best of their extent, thus measuring the executive

function of inhibition. Based on the current body of knowledge, students with high levels of ADHD are expected to make a larger amount of errors compared to their peers with low levels of ADHD on both parts of the task (Metin et al., 2012; Kooistra et al., 2010; Wright et al., 2014).

Methods

Participants

Subjects in our study represent a convenience sample gathered predominantly via a portal called SONA, which serves as a site where psychology students earn credits for a practical course. The SONA portal contains approximately 700 subjects. Regarding conditions, all subjects had to be university students between the ages of 17-31. The pool of participants consisted of 394 students with an average age of 20 (M = 20.14, SD = 2.12). In terms of sex, 296 were natal females (75.1%) and 98 natal males (24.9%), and 22 subjects have been officially diagnosed with ADHD.

Participants who completed the questionnaires and were invited via the SONA portal (n = 32) and participants who were acquaintances of the researchers and met the criteria mentioned above (n = 17). The final sample size consisted of 40 participants of ages 18 to 27 (M = 21.83, SD = 2.323). A total of 20 natal males (48.8%) and 21 natal females (51.2%) participated. Six participants reported having an official ADHD diagnosis. Written consent was provided by all participants. Furthermore, the study has been approved by the Ethical Committee of Psychology at the University of Groningen. Lastly, participants were split in groups based on their T-score on CAARS. An ADHD Index score of 60 or higher was considered high and an ADHD Index score lower than 60 was considered low (Vizgaitis et al., 2023).

Table 1

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
CAARS_TscoreADHDIndex	394	31,11	87,16	52,5716	10,68685
MD	394	7	20	14,45	2,641
IC	394	6	24	16,78	3,379
EFI_total	394	58	122	94,98	10,262
Valid N (listwise)	394				

Note. CAARS = Conners' Adult ADHD Rating Scale; EFI = Executive Function Index Scale; Impulse Control = IC; Motivational Drive = MD

Questionnaires

Conners' Adult ADHD Rating Scales–Self-Report: Long Version

Conners' Adult ADHD Rating Scales–Self-Report: Long Version (CAARS-S:L) is a self-report structured measurement of ADHD symptomatology in an adult population (Conners et al., 1999). The test is oriented at patients with suspected ADHD or related issues. The CAARS test has been developed by Keith Conners (Conners et al., 2002). The test exists in two variants- long and short, and for this study, we used the long version. Both versions of the test are considered to be reliable and cross-culturally valid measures of ADHD symptoms in adults (Christiansen et al., 2020). The test is suitable for assessing individuals' current functioning. Therefore, it does not include items questioning childhood onset of symptoms, which are necessary for a diagnosis and overall understanding of ADHD symptomatology within an individual (Conners, 2002).

CAARS-S:L is composed of eight subscales. These subscales are Inattention/Memory Problems, Hyperactivity/Restlessness, Impulsivity/Emotional Lability, Problems with Self-Concept, DSM-5: Inattentive Symptoms, DSM-5: Hyperactive-Impulsive Symptoms, DSM-5: Symptoms Total, which together contain 66 questions. Part of the scale are also specific

items, which are able to identify individuals who are at risk for having ADHD diagnosis. These specific items together create the ADHD Index subscale. All of the questions are organized on a Likert scale, ranging from option 0- 'Not at all, Never' to 3- 'Very much, Very frequently'. For this study, T-scores of each of all of the above-mentioned subscales and T-score of the overall score have been calculated. Overall score indicates levels of ADHD symptoms. In this case, high score indicates higher levels of ADHD symptoms and low score indicates low levels of ADHD symptoms (Conners et al., 2002). The scale that was used for the analysis is the T-score of the ADHD Index. For the analysis, the T-score of ADHD- Index has been relevant.

The Executive Functioning Scale

The Executive Functioning Scale (EFI) is a self-report structured measurement scale of executive functioning oriented at a non-clinical adult population, originally made for college students (Spinella, 2005). This scale is deemed to be highly reliable with found correlational support with other executive functioning tests and neuroimaging techniques. Moreover, it demonstrates good internal consistency with Cronbach's alpha ranging from .69 to .82.

EFI is composed of five subscales which are Motivational Drive (MD), Impulse Control (IC), Empathy (EM), Organization (ORG) and Strategic planning (SP). The subscales add up to 27 items further divided into questions. Questions are organized on a Likert scale ranging from option 1- 'not at all' to 5- 'very much'. Because the present study mainly tries to expand evidence for the motivation theory, its focus will lie on the results of MD and IC. Certain questions in the test are reversed based on the sentence structure, therefore some of the scores indicate lower instead of higher executive functioning. Reversed questions are Question four from Motivational Drive Subscale, all questions from Organization and

Impulse Control subscales and Question 12 from Empathy subscale. The EFI Total Score is calculated as the sum score of all subscales. For all scales, higher scores represent better EF performance. The scales that are used for the analysis are Impulse Control, Motivational Drive and EFI Total.

Go/No-Go Task

Materials and Apparatus

The experiment for our project was created using the Python programming language in Open Sesame (Mathot et al., 2011). It was conducted on a computer with a 1920 x 1080 mm HP display. The experiment ran in the laboratory owned by the University of Groningen and the data was first stored in the university computer, then sent through email and finally uploaded into the safe university drive where only the researchers of this study had access to in accordance with The General Data Protection Regulation (GDPR).

Task

To give their responses, participants had to either press “B” at the Go trials or withhold their response to press “B” at the No-Go trials (Figure 1). Failure to press “B” at a Go trial is an error of omission, while pressing “B” at a No-Go trial is an error of commission. In addition, our task consisted of two conditions (event rate manipulations; ER), as measured by the inter-stimulus-interval (ISI) duration of each trial (Metin, 2013). In the fast condition, the ER was 1.2s while in the slow condition, the ER was 7.2s. A 2-minute mandatory break was added between the two to counterbalance fatigue or primacy effects.

The fast condition started with one practice block consisting of six trials, five Go trials and one No-Go trial. This was preceded by one experimental block consisting of four Go trials and one No-Go trial that were repeated 20 times, resulting in a total of 100 trials. The

trials in each block were presented in a randomized order to decrease order effects. In the slow condition, there was one practice block and one experimental block. The practice block consisted of five trials, one Go trial and four No-Go trials. Proceeding this, there was one experimental block with four Go trials and one No Go trial that repeated 10 times and resulted in a total of 50 trials. As mentioned above, all trials were presented in random order to counterbalance order effect.

Trial

In the fast condition, the stimuli screen is always presented for 200 ms after a fixed ISI screen of 300 ms, and is followed by two identical screens of 700 s (350 ms each). The trials are preceded by one practice trial consisting of one trial sequence. In the slow condition, every trial starts with a fixed ISI of 5000 ms before the stimulus is presented. The stimuli is presented for 200 ms, followed by two identical screens of 1000 ms each. The trials in each condition were composed of a fixed ISI, the stimuli screen of 200 ms, and two identical screens in which participants' responses on each screen are recorded. The time between each trial depends on the response of the participant. If there was a keyboard response (keyboard press “B”) prior to the ending of the stimulus screen of 200 ms, the stimulus screen would end with the press.

Stimuli

All stimuli in the Impulsivity Experiment are shown against a white screen. Due to the possibility that a fixation dot would interfere with our experimental manipulations and to ensure that the stimuli will always be presented in the middle of the screen, there is no fixation dot on the screen before the start of each trial. Thus, at the beginning of each trial, a white empty screen with 32 x 32 px grid is presented, followed by the stimuli screen. For the purpose of our research, a Go/No-Go task with event-rate manipulations was used (Borger &

Van Der Meere, 2000). Therefore, our experiment has two types of stimuli, an O (the Go stimuli) and a Q (the No-Go stimuli). The letters were always presented in the middle of the screen and had a black color, HTML format and mono font, to contrast the white screen. Moreover, in the practice block as well as the experimental block, there were always 20% No-Go stimuli and 80% Go stimuli.

Reaction Time and Error Calculation

The reaction time was measured from the start of the stimulus until the button press. Only correct trials were considered valid reaction times. Mean reaction time and mean standard deviation were calculated of all correct responses. Correct responses shorter than 150 ms were considered as pre-emptive and were not used to calculate mean reaction time and mean standard deviation. To calculate the percentage of error, the number of commissions was divided by the total number of No-Go trials multiplied by 100.

Procedure

The participants filled in the questionnaires online, beginning with the CAARS-S:L and ending with the EFI. The first page of the CAARS-S:L was informational, followed by a consent page, where the participants had to agree in order to be included in this study. The next page asked for their SONA number. Then participants indicated their age, biological sex, job (if applicable), first language, diagnosis of a physical, psychiatric or neurological condition and whether they are taking medication with the option to mention which one(s). The next four pages contained the CAARS-S:L questionnaire where participants rated agreement to each item from 0- ‘Not at all, Never’ to 3-‘Very much, Very frequently’. The page after that asked for optional consent to process a student’s grades. There was one more page asking for the participants' student number and finally a page where participants could mention any comments or questions they had for the researchers.

The EFI questionnaire started with a page informing participants that they can now fill in the second questionnaire, followed by a page that asked for a consent. Then they were asked to provide their SONA number again. On the next page they filled in the EFI questionnaire, rating their agreement to each item on a scale from 1- ‘not at all’ to 5- ‘very much’. On the next page they could indicate possible comments they had.

For the experiment, we worked together with students from the Honours College who researched ADHD and inhibition. The results from the inhibition experiment will not be discussed in this paper, and we have no reason to suspect that the inhibition experiment influenced the results of the impulsivity experiment.

The participants were invited to the lab to carry out the Go/No-Go, which took about 15 minutes per participant, and inhibition experiment, which took about three minutes per participant. They sat behind a computer in a room without any distractions, where the lighting and the sounds were controlled for. Before starting the experiment, the participants had to read the information sheet about our experiment and sign a consent form (see Appendix A). After the consent form was signed, the participants were instructed to fill in their personal number at the beginning of the experiment. Furthermore, in order to counterbalance fatigue or primacy effects, the participants started with either the inhibition task or the Go/No-Go task, the order of which was randomly decided.

For the Go/No-Go task, the participants were first presented with a welcome screen, which is followed by a brief informed consent screen in which they have the possibility to opt not to participate. Next, an instruction screen appeared, where the participants were informed that either an ‘O’ or a ‘Q’ would appear on screen. Whenever the participant saw an ‘O’, they had to press the ‘B’ key. When a ‘Q’ appeared, they had to withhold their response. The main goal of the task was to react as fast and as accurately as possible. Following that, the participants were directed to the practice block to become acquainted with the task.

Afterwards, the participants were notified that the practice block ended and that the main experiment would begin, as well as reminded of the instructions. For the purposes of our experiment, the participants received no feedback once the practice and experimental blocks were completed. When the participant finished both experiments, they were asked about their experiences, and could leave. The experimenter would then send the questionnaires to the participant, depending on if the participant had already filled them out or not.

Data analysis

Questionnaires

For the CAARS we computed sum scores and T-scores, and for the EFI we created sum scores and a total score. For the analysis of the questionnaires, we used the T-scores of the ADHD Index (ADHD symptoms) and the DSM Total (ADHD DSM symptoms) from the CAARS and the sum scores of the Impulse Control (IC) and Motivational Drive (MD) scales, plus the Total score from the EFI (executive functions). The statistical software platform called SPSS (version 28) was used for doing the analysis.

Determining the distribution of the variables (T-scores of ADHD Index and DSM Total, and subscales IC, MD and EFI Total) is important for choosing the appropriate test. Therefore, the assumption of normality has been tested using the Shapiro-Wilk test. From the test we can conclude that the distribution of all analyzed variables is significantly deviated from a normal distribution. To test the linearity, we look at the Normal Q-Q plots of all analyzed variables and it can be concluded that all variables are approximately linear.

Since the data is not normally distributed, we make use of non-parametric tests to look at the relations between the variables. Therefore, to examine first component of the first research question, regarding whether there is a negative relationship between ADHD

symptoms and executive functions is tested through a Spearman correlation. For testing the second component of the first research question, whether ADHD is negatively related to IC and MD, another Spearman correlation was conducted.

Go/No-Go Task

Our experiment follows a mixed design with one between subject factor (i.e., ADHD level) and one within subject factor (i.e, event-rate [ER]). Thus, each participant with either high or low levels of ADHD was exposed to both the fast and the slow condition, which represent levels of the independent variable; event-rate. An ADHD Index score of 60 or higher was considered high and an ADHD Index score lower than 60 was considered low as scoring higher than 60 could require clinical attention (Vizgaitis et al., 2023). In the impulsivity task, responses to the letter Q were considered errors of commission (EOCs) while not responding to the letter O was considered an error of omission (EOO). To address the second research question, reaction times (RTs) in milliseconds were measured after each screen excluding the fixed ISI prior to the beginning of each trial. To answer the third research question, accuracy was also measured for each screen by the percentage of correct answers (correct = 1) to wrong answers (correct = 0). In total, there were three variables, percentage error (PE), mean reaction time for correct answers (MRTC), and the standard deviation of the reaction time for correct answers (SDC) divided into two conditions (fast and slow). Data analyses will be done using these six variables on two groups; high and low ADHD level.

The main statistics used for the experiment was repeated measures ANOVA and paired sample t-tests. This can be done since the q-q plots indicated that these variables are nearly normally distributed. The Shapiro-Wilk test has been used for checking the normality assumption. All variables except two (low ADHD group for both fast condition of PE (W(40)

= 0.916, p = .004) and slow condition of PE (W(40) = 0.906, p = .029) showed non-significant results, meaning that they had a normal distribution. Both the fast and slow condition of MRTC had non-significant results (F(1,38) = 0.064, p = .802 and F(1,38) = 0.282, p = .589, respectively). These non-significant results were also seen for the fast and slow condition of PE (F(1,38) = 1.971, p = .168 and F(1,38) = 0.352, p = .557, respectively).

Results

Association between ADHD and EF

Table 2

Correlations

Variable	CAARS_TscoreADHDIndex	EFI_total	IC	MD
1. CAARS_TscoreADHDIndex	-			
2. EFI_total	-.489**	-		
3. IC	-.353**	.602**	-	
4. MD	-.014	.253**	-.130**	-

**Correlation is significant at the .01 level (2-tailed).

Note 1. CAARS_TscoreADHDIndex = Conner's Adult ADHD Rating Scale- T-score of ADHD Index subscale; EFI = Executive Function Index Scale; IC = Impulse Control-subscale of EFI; MD = Motivational Drive -subscale of EFI

Addressing the first component of the first hypothesis, the correlations as displayed above in Table 2 depict the relation between how multiple subscales and an overall scale of EF (based on the EFI scale) relate to the ADHD Index (based on the CAARS scale) and all these correlations were significant except the correlation between the ADHD Index and MD. The correlation between the ADHD Index and overall EF total score was found to be moderate (r = -.489, p = <.001), supporting the first component of the first research question.

To interpret the results easier, note that a negative correlation indicates that higher levels of ADHD symptomatology are associated with lower levels of EF.

Associations between ADHD and specific subscales

Addressing the second component of the first hypothesis, the correlation between the ADHD Index and IC has been found to be moderate (r = -.353, p = < .001) while the correlation between MD subscale and ADHD was found to be insignificant from practical perspective (r = -.014, p = .782). These results (see Table 2) are in line with Barkley's theory (1997), because they display that the higher levels of ADHD symptomatology are related to worse ability of impulse inhibition. However, the results offer only minimal support to van de Meere's theory (2005), because the insignificant correlation between the ADHD Index and MD suggests that the level of ADHD is only weakly related to motivation. This finding is not in line with the expectation.

To get more insight in the specific correlations, the subscale IC and MD were correlated as additional analysis. These subscales are found to be weakly negatively correlated (r = -.130, p = .010), which means that worse IC is associated with higher MD and vice versa. However, due to the weak correlation, this finding might not be relevant in practice. This suggests different underlying mechanisms behind these two factors. Both subscales of MD and IC are correlated with the overall score of EFI, where MD is correlated weakly (r = .253, p = < .001) and IC moderately (r = .602, p = < .001). This means that lower scores on both of these scales are correlated with lower overall scores on EFI.

Experiment

Validation of the experiment

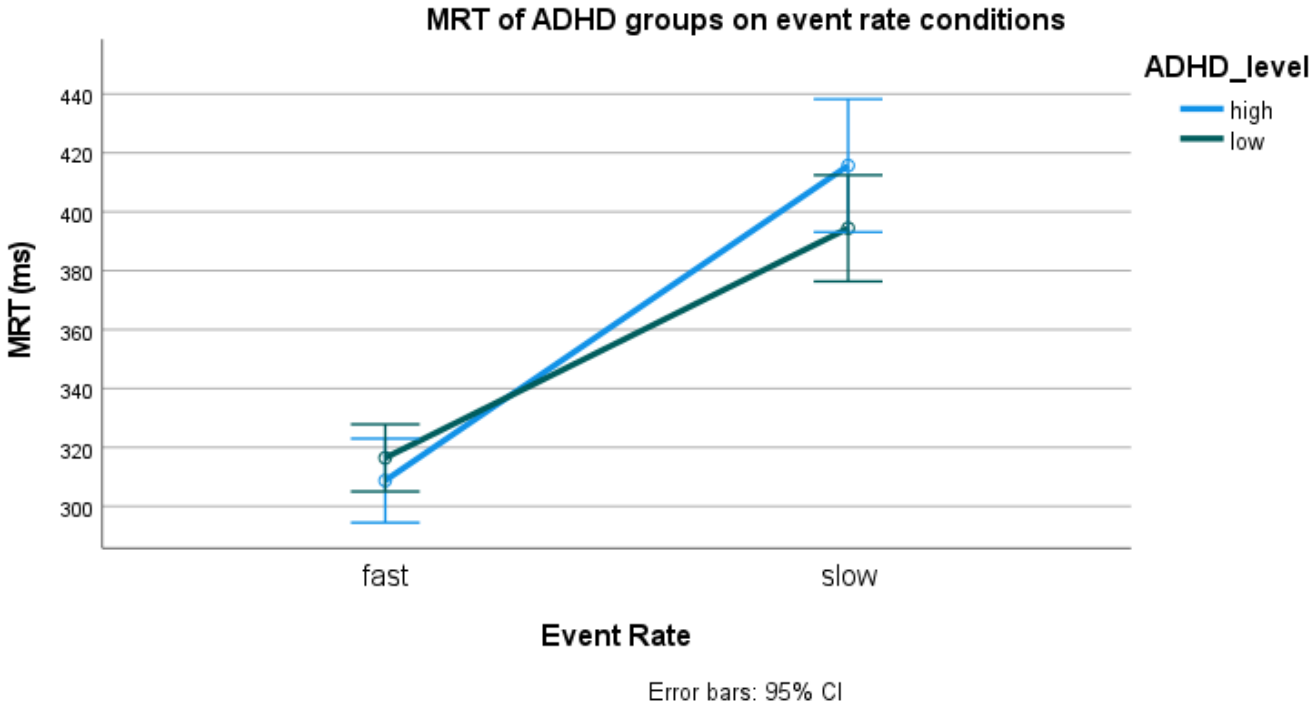
To validate the experiment, we seek a significant difference in MRTC and PE based on the fast and slow condition of the Go/No-Go task regardless of the group. For the fast

condition, the mean value of MRTC equaled M = 313.31ms and for the slow condition equaled M = 403.27ms. The mean value for the PE of the fast condition was found to be M = 31.87% and for the slow condition was found to be M = 24.5%. The usage of mixed ANOVA with repeated measures was used to assess the difference between event rate conditions without taking groups into account. This test revealed significant main effect of ER for MRTC ($F(1,38) = 236.4$, $p < .001$, $\eta_p^2 = .862$) and the significant main effect of ER for PE ($F(1,38) = 7.531$, $p < .009$, $\eta_p^2 = .165$). Later post hoc analysis of the variance of the MRTC has been conducted with the same test and revealed significant main effect of ER ($F(1,38) = 23.52$, $p < .001$, $\eta_p^2 = .382$). These results support the idea that there are significant differences between the fast and the slow version of the Go/No-Go task, meaning that the applied version of the task is a valid way to measure the values of interest. In other words, the significant main effect of MRTC on event rate means that reaction times of the fast condition were proved to be slower in the slow condition than in the fast condition of the task. The significant main effect of MRTC on event rate means that there were more errors in the fast condition than in the slow condition. And lastly the significant main effect of variance of the mean reaction times on event rate means that the variance of MRT distribution has been broader in the slow condition regardless of the group.

The Reaction Time performance of the groups

Figure 1

Profile plot of MRTC



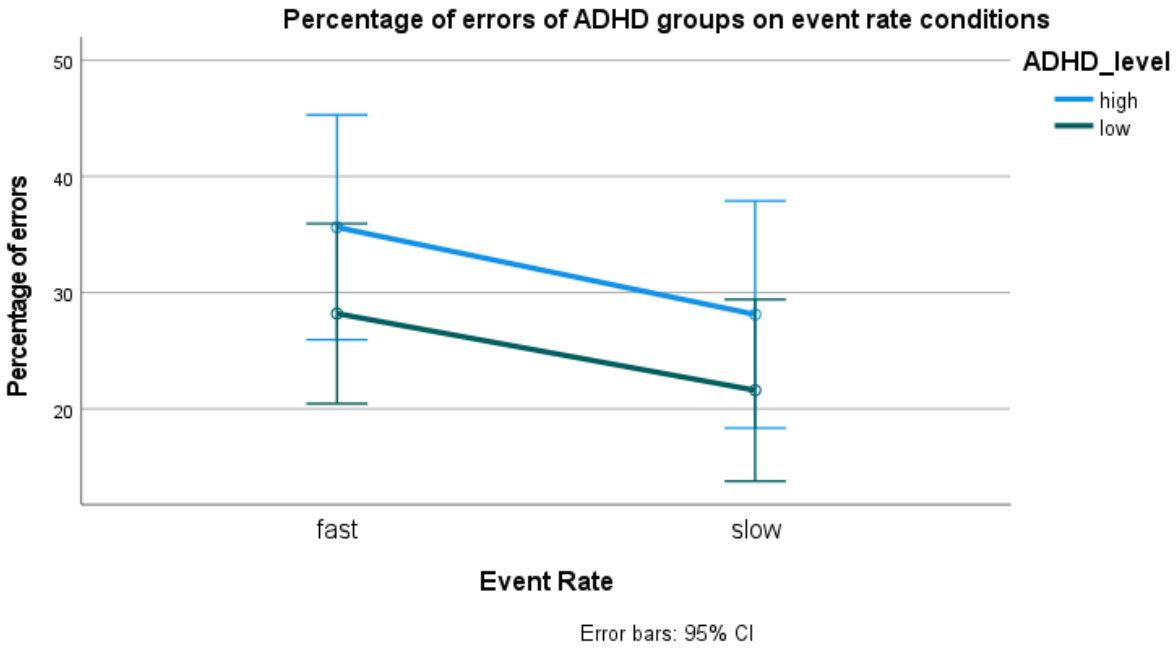
Note: ADHD = Attention deficit hyperactivity disorder; MRT= mean reaction time

The main effect of Group was not significant (F(1,38) = 0.386, p = .538, η_p^2 = .010) and revealed that the finding of faster responses in the fast condition and slower responses in the slow condition is the same for both groups. Moreover, as seen in Figure 1 above, comparison of the means of the groups in both conditions, fast and slow, revealed a significant interaction effect of Group by Event Rate for MRT **(**F**(**1,38**) =** 5,496, p = .024, η_p^2 = .126**)**, which means that the variable of ADHD influenced the speed of the response of the participants**.** In other words, participants with higher levels of ADHD in general responded faster in the fast condition and slower in the slow condition, when compared to participants with lower levels of ADHD**.** This finding supports the second hypothesis.

The Error performance of the groups

Figure 2

Profile plot of PE



Note: ADHD = Attention deficit hyperactivity disorder

Even though the percentage of errors (PE) had a non-normal distribution, the sample size of n = 40 was deemed sufficiently high for application of mixed ANOVA with repeated measures, which was also suggested by the Q-Q plots. The analysis showed a significant main effect of Group for PE ($F(1,38) = 7.531$, $p = .009$, $\eta_p^2 = .165$), meaning that both ADHD groups made an equal amount of errors in the fast condition compared to the slow condition. However, further analysis on the interaction effect between ADHD groups and PE for fast and slow condition revealed that ADHD group seemed not to play a role, which is concluded based on an insignificant interaction of Group by Event Rate for PE ($F(1,38) = 0.001$, $p = .969$, $\eta_p^2 = .000$). Thus, the group of students with high levels of ADHD symptomatology was found not to be equal to the group of students with lower levels of ADHD symptomatology in

terms of the number of errors they made in the fast and slow condition**.** This finding contradicts the expectation of the third research question (see Figure 2).

The post hoc analysis of interaction effect between ADHD and event rate

To better understand to what extent does factor of motivation play a role in number of errors, an additional post hoc analysis of the RT performance has been conducted. The assumption of this test is that students in the group with higher manifestation of ADHD symptomology would present with higher standards deviations of responses on both conditions than the control group. Firstly, the standard deviations of MRT between the fast (*M* = 65.04) and slow (*M* = 84.90) have been calculated. Significant main effect of event rate ($F(1,38) = 23.52$, $p < .001$, $\eta_p^2 = .382$) was found, which means that both groups exhibited more variability in their RT in the slow condition compared to the fast condition of the Go/No-go task. Further, main effect of the group on RT has been conducted, where a non-significant result ($F(1,38) = 3.656$, $p = .063$, $\eta_p^2 = .088$) has been found. This means that the groups did not significantly differ in MRT in neither of the conditions. However, the p-value of 0.063 shows a tendency for a main effect of ADHD on the PE. Moreover, the interaction of Group and Event Rate was not significant ($F(1,38) = 3.777$, $p = .059$, $\eta_p^2 = .090$), which suggests that ADHD group has no effect on the variance od responses when the two conditions are compared.

Discussion

Questionnaire

The present study first examined the relationship between ADHD symptomatology and EF. More specifically, it aimed at creating a better understanding of how ADHD symptoms relate to levels of EF impairments in students. The first component of the first research question, regarding the presence of a general association between ADHD and EF, has been supported. This, in practice, means that students with higher levels of ADHD symptomatology, indeed

seem to struggle with executive functioning more than their peers with lower levels of ADHD. This claim supports what is generally known about the

relationship between ADHD and EF (Barkley, 1997**;** van de Meere, 2005**;** Lace, 2020). To address the second component of the first hypothesis, certain subcategories of EFI, Impulse Control and Motivational Drive have been correlated to the overall EFI scale, with IC moderately to the overall scale and MD not correlated to the overall ADHD scale.

The meaning of these correlations, more precisely was to assess which deficit seemed to be more prevalent in this group of students. Moreover, post hoc analysis revealed that the MD and IC subscales have been uncorrelated to each other, supporting the idea that inattentive ADHD and hyperactive-impulsive ADHD have different underlying mechanisms and therefore different executive functions are affected. Thus it seems that motivation is more of an issue in the inattentive type of ADHD and the impulse control is expected to be more of an issue in the hyperactive-impulsive type of ADHD. This phenomenon is frequently referred to as the dual-pathway model (Daley, 2010). However, more data needs to be gathered to properly understand these mechanisms. Additionally, IC has been moderately associated with ADHD Index, while MD has been uncorrelated. This can mean IC might in general play a bigger role in the relationship between EF and ADHD than MD. Prominence of IC as a main impaired executive function is a finding in line with Barkley's theory (1997). However, it can also show this sample's symptomatology trend, which can be leaning towards rather hyperactive-impulsive symptom manifestation. The reason for this might be that being a university student requires high levels of motivation. In other words, in order for a person to claim a place in a high-ranked university, they need high levels of academic success for which high motivation drive is a necessity. Therefore, students with more severe manifestation of symptoms of inattentive ADHD might be underrepresented, because this subtype in general exhibits lower academic success (Daley, 2010). In order to better understand this, more

research can focus on distinguishing issues of clinical subjects diagnosed with predominantly inattentive type of ADHD, predominantly hyperactive-impulsive type of ADHD and combined form of ADHD to better understand different types of mechanisms underlying EF in more specific typologies of ADHD.

Experiment

The goal of the experimental part of study was to investigate particular executive functions of inhibition and motivation in students with consideration of their group based on their levels of ADHD symptomatology more closely. This has been done with the usage of the Go/No-Go task. Although the Go/No-Go task serves mostly as a test of impulsivity, usage of both the fast and slow condition can be used to measure motivation too.

The second research question examined how a group based on different levels of ADHD symptomatology affect reaction time of the students on the Go/No-Go task. We firstly validated the effect of event rate in the experiment. When assessing the effect of the levels of ADHD symptomatology, it was found that the group of students with relatively high ADHD scores were faster in the fast condition and slower in the slow condition compared to the group of students with low scores of ADHD symptoms. This is in line with the hypothesis. Found result has been expected as it suggests higher impulsivity in the process of deciding whether to respond to stimuli or not in the fast condition. The significantly slower response time can be potentially explained by lower motivation which is a frequent issue associated with ADHD (van de Meere, 2005). In this case it would suggest that under-stimulation created a situation in which these individuals became bored and therefore were distracted, which would cause them to answer slower. The other more positive explanation suggests, that the amount of effort put in the process of inhibiting their need to impulsively respond to any stimuli presented, made them inhibit themselves to extent that their reaction time became slower to assure higher accuracy. In other words, higher cognitive load made them answer

more slowly. This scenario would suggest high levels of motivation which supports a finding from the questionnaire regarding no association between MD and ADHD Index.

The third research question was whether students from the group with higher levels of ADHD symptomatology tend to make more errors than their peers from the group with lower levels of ADHD symptoms. This research question has been rejected, because levels of ADHD have been found to be insignificant in relation to the event rate.

Additional interest in interaction effects examined whether motivation plays the role in the variance of mean reaction times. The assumption has been rooted in an idea that students from the group with higher levels of ADHD will exhibit lower motivation, therefore the variance of reaction time would have been higher. The interaction effect between fast and slow condition in terms of MRT was insignificant. This suggests that the groups indeed did not differ that much in the variance of reaction time between the conditions. This might support the idea that students from the group with higher levels of ADHD apply compensation strategies which helps them to differ less than expected from their peers from the group with lower levels of ADHD. This result might differ if we used a sample group that is diagnosed with ADHD, rather than only having higher ADHD symptomatology. Another explanation is that the students with ADHD have adequate coping mechanisms connected to higher motivation drive, therefor representing a more specific group of adults with ADHD than expected, which can be explained by the fact that we used a convenience sample of university students, which might present a more high-functioning subgroup of adults with ADHD.

Limitations

The first limitation is assumed to be the usage of self-report checklist questionnaires in the first part of the study. This design allows students to assess themselves based on their

subjective perspective which cannot only differ from reality but also only provides a one-sided perspective of their symptoms and general struggles in their everyday lives. Therefore, it is up to a consideration whether these findings can be generalized to all subtypes of students with the official diagnosis of ADHD.

Another limitation is the fact that subjects have been picked from a convenience homogenous sample of predominantly psychology students from the same university who are expected to collect credits in order to pass one of their courses. In order to receive the credits, their performance and truthfulness on the test are not required or possible to assess, therefore there is a chance they did not put effort in their responses but instead fill the questionnaires out as quickly as possible. The necessity of their arrival at a special place for an experiment in the second part of the study under indirect supervision might have enhanced their dedication to properly concentrate on the experimental part, therefore decreasing the above-mentioned issue of reliability.

In the beginning of the questionnaire, subjects were asked about the use of prescribed medication, however, this question did not include the usage of drugs like alcohol and cigarettes. This factor might present possible effects on both their performance on certain tasks and their executive functioning. Illicit substance abuse might in some cases intervene with the executive functioning of the affected individuals, therefore influencing their responses about daily struggles with EF (Parada, 2012; Brunelle 2015). If the questionnaire or the experiment has been completed under the influence of almost any type of drug, responses can be also influenced (APA, 2022).

Moreover, even though the CAARS questionnaire is reported to have high validity, some of the items are formulated in an arguably unclear manner and their improvement can lead to a higher clarity and reliability of the test. Moreover, if the questions are not formulated in a sufficiently clear manner, people with high levels of ADHD traits can potentially get

frustrated and reply more carelessly, further obscuring the results. On top of this, unclear questions can lead to different interpretations when the test is retaken, leading to lower test-retest reliability. For example, one of the items ‘I get down on myself‘ can be interpreted in at least two different ways. First, in a sexual meaning, from the phrase ‘getting down on ...‘, which implies performing oral sex on someone, or it can refer to the phrase ‘feeling down‘, indicating feeling sad or disappointed. The second option is likely the correct interpretation in this case, however, the possibility of two entirely different interpretations can be confusing to the participant and can lead to frustration affecting further responses and different sets of answers for the particular question, based on the interpretation of a particular participant. Moreover, people with ADHD are not only known to experience higher ratings or feelings of disappointment, by themselves (Reimann-Höhn, 2016), as this might be one of the interpretations of the question, but also sex often plays a more prominent role in their lives, especially in those high on hyperactive-impulsive traits. Moreover, they tend to start their sexual lives much sooner than people without ADHD (Reimann-Höhn, 2016) and they often have in general higher rates of sexual desire and sexual thinking (Canu, 2003). For this reason, it can be assumed that participants high on hyperactive-impulsive traits might be more likely to understand this question in a sexual manner. Even if participants with ADHD will tend to show higher agreement with this option by either of these interpretations, the presence of an unclear question should be avoided to improve the face validity of the questionnaire. Moreover, people with ADHD tend to struggle more with understanding idioms (Reimann-Höhn, 2016), therefore usage of idioms might be intended to be avoided when assessing participants with issues of understanding metaphorical expressions.

Another rather unambiguous question in the CAARS questionnaire is ‘I can concentrate in groups of up to four persons, but I can’t follow conversations of more than four persons.’ This question is double-barreled, which in general is not a preferred practice in

questionnaires and can be unclear to understand. Rephrasing should be considered in a newer version of the CAARS questionnaire.

Another potential limitation is that present study compared students with high and low levels of ADHD. While this is an innovating approach because it focusses on the dimensional character of ADHD, future studies can concentrate on students diagnosed with ADHD and students without this diagnosis as a control group.

Future directions

In conclusion, the association between EF and ADHD cannot be doubted, therefore closer attention to EF deficits in adult patients either diagnosed with ADHD or in the process of acquiring a diagnosis might be beneficial. Also focus on ADHD deficits in the coaching programs oriented at adults and students with ADHD might serve as a good strategy to elevate their general distress and help them to function more efficiently in their everyday lives. If more research supports the relevance of the role of EF in ADHD, even changes of the DSM criteria and the ICD criteria might be a positive step for people with ADHD. Moreover, the present study focused on the role of inhibition and motivation in ADHD, future studies can focus on other executive functions and their role in this disorder. Also, further studies can focus on the differences between ADHD in students versus ADHD in the general adult population in terms of EF and the extend of inhibition and motivation. More research can be conducted in the way how strategies of overcoming ADHD can lead to benefits in the life of people with ADHD that others without this diagnosis do not experience.

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Appendix A

INFORMATION ABOUT THE RESEARCH

VERSION FOR PARTICIPANTS

"EXECUTIVE FUNCTIONS AND ADHD, AN EXPERIMENTAL STUDY"
PSY-2021-S0094

- **Why do I receive this information?**

You are being invited to participate in this bachelor thesis research that explores executive functioning in students scoring low or high on the symptoms of ADHD.
You are eligible to participate in this research when you have received an invitation email via the SONA-pool or when you have received a personal invitation. Also, to participate you need to be at least 18 years old.
Our research team consists of Dr. Nobert Börger, Daria Bacsin, Koen Busschers, Nidarshana Ganesan, Deniz Koerts and Nora Sippel. All members of the team are involved in data collection, analysis, retention, sharing and publication.

- **Do I have to participate in this research?**

Participation in the research is voluntary. However, your consent is needed.

Therefore, please read this information carefully.

Ask all the questions you might have in case you do not understand something. Only after these doubts are clarified to you, proceed with answering the questionnaires

If you decide **not to participate**, you do not need to explain why, and there will be no negative consequences. You have this right at all times, including after you have consented to participate in the research.

- **Why this research?**

The purpose of this research is to gain a better understanding of the role of executive functioning in adult ADHD. Specifically, we will focus on performances of two cognitive tasks measuring inhibition and motivation and on the two questionnaires, Conners' Adult ADHD Rating Scale (CAARS) and Executive Function Index (EFI).

- **What do we ask of you during the research?**

  - Before starting the research, you as a participant will be provided with necessary information about the study. Next, you will be asked for your consent to participate, and will have the liberty to make an informed decision. Your answers will and shall remain anonymous.
  - The research solely contains two cognitive tasks completed on a computer. You will first receive instructions on how to complete the first task and then be asked to complete the second task. After that, you will receive instructions for the second task and will then be asked

to complete the second task. You will also be asked to fill in some general information, like age and gender.
- In total, the study will take approximately 30 minutes (each task will take approx. 15 minutes).
- Participants that are in the first-year students SONA-pool will receive 1.5 Credits when completing the study. The participants who volunteer will receive a coffee after completing the tasks.

- **What are the consequences of participation?**

There are no negative consequences associated with the two cognitive tasks employed in this study.

- **How will we treat your data?**

Data processing will take place for educational purposes of the researchers who will use the data to write their bachelor thesis. The performance of the two cognitive tasks will be stored and shared only among the researchers involved in the project. The data stored is pseudonymised, meaning that the researchers involved can only see your SONA-number but not your name. If you wish to access, modify, or remove your personal data you can do so until 1 August 2023 by contacting the principal investigator via email (n.a.borger@rug.nl). Note that this will lead to your identification.

- **What else do you need to know?**

You may always ask questions about the research: now, during the research, and after the end of the research. You can do so by speaking with one of the researchers present right now or by emailing (d.bacsin@student.rug.nl, n.sippel@student.rug.nl, d.koerts@student.rug.nl, k.busschers@student.rug.nl, n.ganesan@student.rug.nl) one of the researchers involved.

Do you have questions/concerns about your rights as a research participant or about the conduct of the research? You may also contact the Ethics Committee of the Faculty of Behavioural and Social Sciences of the University of Groningen: ec-bss@rug.nl.

Do you have questions or concerns regarding the handling of your personal data? You may also contact the University of Groningen Data Protection Officer: privacy@rug.nl.

As a research participant, you have the right to a copy of this research information.

INFORMED CONSENT

"EXECUTIVE FUNCTIONS AND ADHD, AN EXPERIMENTAL STUDY"

PSY-2021-S0094

1. I have read the information about the research. I have had enough opportunities to ask questions about it.

☐ YES ☐ NO

2. I understand what the research is about, what is being asked of me, which consequences participation can have, how my data will be handled, and what my rights as a participant are.

☐ YES ☐ NO

3. I understand that participation in the research is voluntary. I myself choose to participate. I can stop participating at any moment. If I stop, I do not need to explain why. Stopping will have no negative consequences for me.

☐ YES ☐ NO

Below I indicate what I am consenting to.

Consent to participate in the research:

☐Yes,I consent to participate; this consent is valid until 01-08-2023

☐No, I do not consent to participate

Consent to processing my personal data:

☐Yes, I consent to the processing of my personal data as mentioned in the research information. I know that until 01-08-2023 I can ask to have my data withdrawn and erased. I can also ask for this if I decide to stop participating in the research.

☐No, I do not consent to the processing of my personal data.

The researcher declares that the participant has received extensive information about the research.

You have the right to a copy of this consent form.