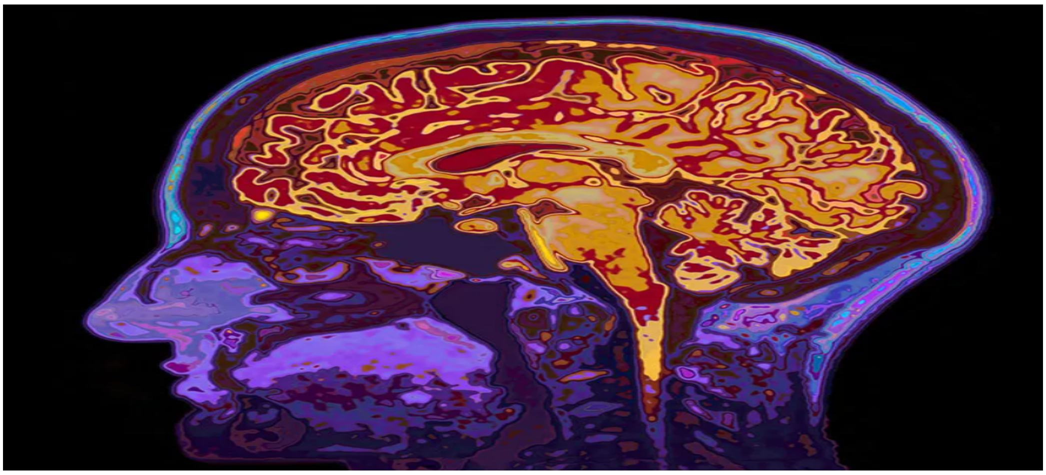
faculty of behavioural and social sciences

An Experimental Study on the Role Executive Functions plays in the manifestation of ADHD in Adults



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Abstract

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder as defined by the DSM-5-TR. The diagnosis poses significant challenges, particularly in adults. The diagnosis and management of ADHD remain complex and multifaceted, with an ongoing need for reliable diagnostic tools and tailored interventions. This paper aims to explore the relationship between Executive Functioning (EF) and the levels of ADHD in students, specifically, whether individuals with more ADHD symptoms have more difficulty with the cognitive process of inhibition. Inhibition is an important underlying factor in Executive Functions along with working memory and cognitive flexibility. To measure the level of ADHD and executive functioning, participants were required to fill out the Conners' Adult ADHD Rating Scale (CAARS) and the Executive Functions Index (EFI). 325 participants filled out the questionnaires, of those, 42 participants were invited to take part in the reaction time tasks experiment to measure inhibition. Inhibition was assessed by dividing participants into low-ADHD and high-ADHD groups. It was measured using the congruent and incongruent stimuli in the Hearts and Flowers task (mixed condition) and the Arrows task, both requiring a high demand of inhibitory control. Results showed that students with more ADHD symptoms had greater executive functioning difficulties. However, both groups performed similarly on inhibition tasks, suggesting no impairment with their cognitive function of inhibition. One possible explanation is that, as the brain matures, adults with ADHD may compensate for suboptimal inhibitory control by leveraging other cognitive skills, allowing them to perform well on inhibition tasks despite underlying challenges. Alternatively, it may be that students with ADHD do not specifically struggle with cognitive inhibition processes but may experience difficulties in other cognitive domains.

Keywords: Attention-Deficit/Hyperactivity Disorder, Executive functioning, Inhibition, Congruent, Incongruent

An Experimental Study on the Role Executive Functions plays in the manifestation of ADHD in Adults

The Attention-deficit/hyperactivity disorder (ADHD) diagnosis poses several obstacles when diagnosing adults. A significant obstacle in diagnosing ADHD in adults is that the diagnosis relies heavily on an individual's subjective experience and recollection of the symptoms. ADHD is most prevalent in children, yet many individuals do not get diagnosed until later in their adulthood, because of this, the clinician must trust the patient's recollection of symptoms that were apparent in their childhood and currently (Bordoff, 2017). A diagnosis may be harder to obtain in adults, as clinicians also face challenges in diagnosing due to receiving a lack of substantial information regarding how to screen for ADHD patients who have gone most of their lives untreated and undiagnosed. Clinicians generally consult parents and teachers to fully understand the client's behaviour in various settings, but as undiagnosed individuals grow, they may have adjusted to their symptoms making it difficult to identify. Such challenges, like the subjectivity of memory and the masking of symptoms, affect the ability for an accurate diagnosis.

The challenges with diagnosing ADHD in adults generate questions on how the symptoms of ADHD progressed over time. ADHD is a disorder that is most diagnosed during childhood to adolescence and was originally thought to resolve as the brain gradually develops from childhood to adulthood. Due to this, before the DSM-5, the criteria focused on diagnosing children. Now, it is believed that ADHD can persist into adulthood and the utility of the previous criteria in diagnosing adults was heavily questioned (Rivas-Vazquez et al., 2023).

ADHD is classified as a Neurodevelopmental disorder in the DSM-5-TR (American Psychiatric Association, 2022). The core symptoms in the DSM for ADHD are inattention and/or hyperactivity/impulsivity. Inattention symptoms include difficulty paying attention to detail, sustaining focus, listening when spoken to and following through with tasks or instructions etc. Symptoms for hyperactivity/impulsivity are characterized by frequent fidgeting, inability to remain seated, inappropriate running or movement, difficulty engaging in quiet activities, and difficulty in waiting their turn or interruptions. Criteria B in the DSM highlights that the symptoms were present prior to age 12. Criteria C says the symptoms are present in two or more settings. Criteria D states the symptoms clearly interfere with quality of life, and criteria D highlights that the symptoms are not due to another disorder.

More research needs to be conducted regarding the diagnosis of ADHD in adults and what other aspects clinicians should consider, such as executive functioning. Past research has shown that individuals with ADHD often exhibit problems with their executive functioning. Cognitive functions such as working memory, mental flexibility, and self-control underly Executive Functions (*Executive Function & Self-Regulation*, 2020). Executive functions manifest in behaviours through the way people shift and sustain their attention for different demands, the skills regarding memory, intimate and sustain goal-directed behaviour, etc. (Rivas-Vazquez et al., 2023). Impairment in inhibition and working memory is often seen in individuals with ADHD (Swanson, 2003). This impairment can be seen in the diagnostic criteria where symptoms such as impulsivity and inattention are highlighted.

The goal of the present study is to further investigate the association between ADHD and EF in students, and the impact the level of ADHD symptoms has on inhibition control. The results of this study can contribute to an exploration of the relevancy of EF impairment in diagnostic practices and intervention strategies. Identifying the extent to which Executive Function impairments correlate with ADHD could contribute to the development of more objective diagnostic tools and patient-centred treatment.

The Relationship Between the Level of ADHD Symptoms and EF

ADHD will be investigated through the Conners' Adult ADHD Rating Scales (CAARS) questionnaire which is considered a diagnostic and evaluative tool. Executive functioning will be investigated through the Executive Function Index (EFI) which is a self-reported evaluative tool.

The first research question is, "Is there a relationship between ADHD and Executive functioning?". It is hypothesized that more symptoms of ADHD mean an increase in executive functioning impairments. The underdiagnosis of ADHD in students could be because individuals experience more issues with executive symptoms rather than impulsive symptoms, for example. The level of ADHD symptoms will be measured by the CAARS ADHD index, which will be evaluated along with the total score of the EFI.

The Validation of the Task Manipulation of Inhibition

A select number of participants will be invited to take part in several experimental tasks called the diamond tasks. While participants will complete all five diamond tasks, Animals, Shapes, Hearts and Flowers, Arrows and Impulsivity, only the Hearts and Flowers and Arrows task results will be investigated. These tasks will more specifically measure cognitive inhibition by comparing reaction times.

This leads to the second research question, "Do the diamond tasks accurately measure inhibition?". The goal of this question is to measure the task effects and ensure validity that the manipulation of the diamond tasks is successful by comparing the congruent and incongruent conditions. Incongruent conditions in the task refer to when the participants receive the stimulus on the opposite side that their required response takes place, similarly, congruent conditions is when the participant receives the stimulus on the same side where their required response takes place. It is hypothesized that the reaction times will be slower, and accuracy will decrease for incongruent trials than the congruent trials.

Inhibition Differences Among ADHD Groups

Lower inhibition is reflected through more errors and longer reaction time while higher inhibition is indicated by fewer errors and faster response times. The experiment aspect of the study could only be explored once a relationship is established between ADHD symptoms and Executive functioning.

This leads to the final research question which is, “Do participants with more ADHD symptoms have more issues with their inhibition than participants with less ADHD symptoms?”. Based on the ADHD Index in the CAARS questionnaire, a distinction is made between two groups, high-scoring ADHD and low-scoring ADHD individuals, which would be compared to their results of the experiment. It is hypothesized that individuals in the High ADHD group experience more problems with inhibition than individuals in the Low ADHD group.

Method

Participants

Participants were recruited through the first-year SONA pool at the RUG to take part in a two-part study consisting of two online questionnaires and an experiment. The questionnaires and the experiment were approved by the ethics committee of the Faculty of Behavioural and Social Sciences (GMW) at the RUG. Participants received study credits for their participation. All participants were at least eighteen years old.

The first part of the study consisted of online questionnaires (the CAARS and the EFI) administered via the online survey tool Qualtrics. A total of 341 participants participated in the CAARS and the EFI questionnaire, of which 15 participants had not completed the EFI and 16 participants had not completed the CAARS in full. These participants were therefore also not included in the analysis. The final sample size comprised 325 students. The mean age of the questionnaire participants was 19.48 (SD = 1.92, min = 17 years, max = 33 years). Of the questionnaire participants, 18.5% were male, 80.4% female and 1.1% other.

For the second part of the study, namely the Diamond tasks (reaction time tasks), participants who fully completed both questionnaires were invited. 44 people participated in the reaction time tasks. Of these, two participants had incomplete data and were not included in the analysis. The final sample consisted of 42 participants. Based on the T-scores on the ADHD Index scale of the CAARS, participants were split into two groups. A score of 65 or higher was considered high, as scores above 65 can be considered clinically significant (Conners et al., 1999). Scores lower than 65 were considered low scores. The mean age of participants in the reaction time tasks was 19.74 (SD = 1.94, min = 17 years, max = 26 years). Of the participants in the reaction time tasks, 22.7% were male, 72.7% female and 4.6% other.

Table 1
Sociodemographic characteristics of the participants in the questionnaire

	N	%	M	SD	Min	Max
Total Participants						
Gender						
Male	61	18.5				
Female	262	80.4				
Other	2	1.1				
Age			19.48	1.92	17	33

Table 2
Sociodemographic characteristics of participants (experiment)

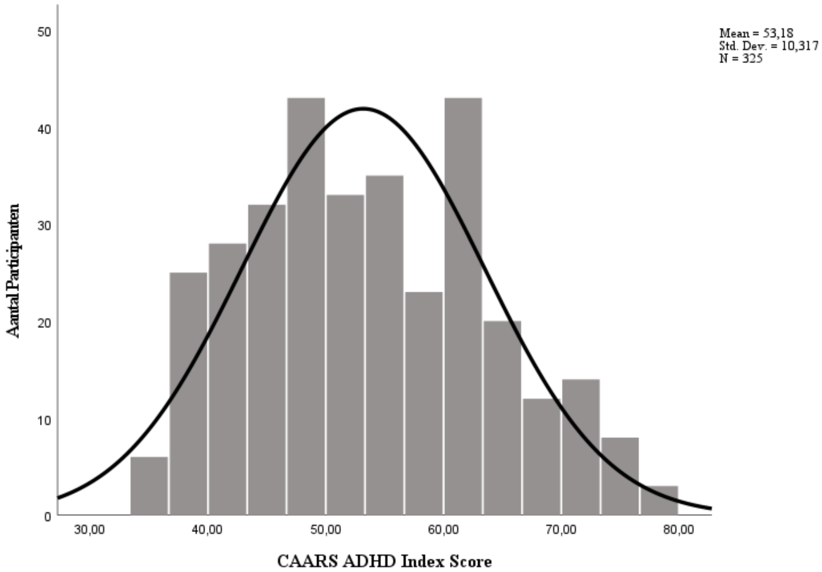
	N	%	M	SD	Min	Max
Total participants						
Gender						
Male	9	22.7				
Female	31	72.7				
Other	2	4.6				
Age			19.74	1.94	17	26

Figure 1 shows the distribution of the T-scores of the ADHD Index scale of the CAARS. The graph has a slightly longer tail on the right side, indicating a right-skewed distribution. This means that in the current sample, fewer people with a high score on the

ADHD Index scale of the CAARS participated than those with a low score on the ADHD Index scale of the CAARS.

Figure 1

Frequency distribution of ADHD Index Scores from the CAARS



Note. N=325

Measuring instruments

Conners' Adult ADHD Rating Scales

In this study, the Conners' Adult ADHD Rating Scales (CAARS, Conners et al., 1999) was used to measure the degree of ADHD symptoms on a dimensional scale in students. This is a diagnostic instrument consisting of 66 items rated on a 4-point Likert scale from 0 = not at all/never to 3 = very often. Participants independently filled in which answer best suited them. This survey took about 30 minutes. The CAARS comprises 9 subscales. The first four, determined through factor analysis, focus specifically on ADHD symptoms in adults and measure inattention/memory problems, hyperactivity/restlessness, impulsivity/emotional lability and self-concept problems. In addition, the CAARS contains three subscales corresponding to the ADHD criteria in the DSM-5: inattention, hyperactivity/impulsivity and total ADHD symptoms. The last two subscales are the ADHD Index, which gives an overall impression of ADHD, and the Inconsistency Index, which checks whether responses have been completed consistently (Conners et al., 1999).

To control for age and gender, the raw scores were converted to T-scores. T-scores above 65 were considered clinically significant and may indicate the presence of ADHD symptoms in adults without previously identified problems (Conners et al., 1999). The T-score of the ADHD DSM Total scale and the T-score of the ADHD Index scale were used for the analyses of this study. In general, higher scores indicate more symptoms of ADHD.

The instrument has high reliability: internal consistency, measured via Cronbach's alpha, ranges from .49 to .91 in women and from .64 to .91 in men (Macey, 2003). Test-retest reliability ranged from .88 to .91, indicating very high reliability and consistency on repeated measures. Moreover, the first four subscales have high sensitivity and specificity, and the construct validity of the CAARS is rated as good (Erhardt, Conners & Sparrow, 1999; Christiansen & Leong, 2012). This makes the CAARS a valuable instrument for the reliable and valid measurement of ADHD symptoms in adults.

Executive Function Index

In this study, the Executive Function Index (EFI) was used to measure executive functions in students (Mohamed et al., 2020; Spinella, 2005). The questionnaire was tested and developed on a general population and can be used to measure executive functions in adults.

The EFI consists of 27 different items measured by five subscales. The scales are Motivational Drive (MD), Organisation (ORG), Impulse Control (IC), Empathy (EM) and Strategic Planning (SP). The items of the Motivational Drive subscale measure behavioural drive, interest, activity level and keeping things in mind. The Organisation scale measures the ability to multitask, sequencing (performing actions in a logical order) and holding thoughts. The Impulse Control subscale identifies levels of risk-taking, self-inhibition and substance abuse. Empathy focuses on a person's concern for the welfare of others, tendency to display prosocial behaviour and the extent to which a person demonstrates a cooperative attitude. Finally, the Strategic Planning subscale assesses the extent to which students think ahead and anticipate consequences, use strategies and save money.

The Motivational Drive and Impulse Control scales contain four items. Empathy and Organisation both contain 6 items, and the Strategic Planning subscale contains seven items. Participants rate themselves on a 5-point Likert scale (from 1 = not at all to 5 = very much). Examples of items are: ‘’When doing several things in a row, I mix up the sequence ‘’ (Organisation) and ‘’I take other people's feelings into account when I do something‘’ (Empathy).

Thirteen items from the Motivational Drive, Organisation, Impulse Control and Empathy subscales were scored inversely. This was done to reduce possible response tendencies, increase reliability and detect inconsistency in responses.

To equalise the scales, the scores for the 13 items were inverted so that score 1 on all scales indicates ‘very much’ and score 5 indicates ‘not at all’ Inverting these items was necessary so that a higher score on the EFI indicates fewer problems with Executive Functions. The sum of all items is the total score of the EFI. This score was used for the analyses in this study. The rule is, the higher the score, the better the executive functioning.

The EFI has good internal consistency, the Cronbach's alpha ranging from .69 to .82. Thereby, the EFI correlates strongly with other questionnaires designed to measure Executive Function problems (Spinella, 2005).

Diamond tasks

Diamond and colleagues compiled five separate computer tasks to measure executive functions. Specifically, the three main components: inhibition, working memory and cognitive flexibility (Davidson et al., 2006; Diamond, 2013). In this study, participants performed all five tasks, but in this thesis, only the spatial incompatibility component of the Hearts and Flowers task (HF) and the Arrow task will be analysed. These tasks were used to measure inhibition.

In both the Hearts & Flowers task and the Arrow task, a stimulus is presented on the screen, with participants instructed to respond to the stimulus as quickly and accurately as possible by pressing the appropriate button. In both tasks, each trial started by showing a fixation point in the centre of the screen for 500 ms. A stimulus was then presented and remained on the screen until the subject made a response, or until the time limit of 750 ms was reached. Each trial ended with a blank screen that remained visible for 250 ms. In both tasks, speed was measured in terms of reaction time and accuracy was measured in the percentage of correct answers. Only participants' reaction times between 200 and 750 milliseconds were included in the results. A reaction time below 200 milliseconds, also called an anticipatory response, cannot be considered a ‘’real‘’ response to the stimuli. These responses are too fast for the brain to process the stimuli. There are two possible explanations for the occurrence of anticipatory responses. First, these reactions may occur due to the inability to release the key after the previous stimulus. Another explanation may be that the inability to wait for the next stimulus leads to pressing the key too quickly. Similarly, reaction times higher than 750 milliseconds are not possible. This is because, after 750 milliseconds, the next stimulus follows. When calculating reaction time and accuracy, only responses between 200 and 750 milliseconds were included. Accuracy was then calculated by dividing the number of valid correct responses by the total number of correct responses.

Hearts and Flowers task. The HF task, which was used to measure the degree of inhibition, consists of three conditions: (1) congruent, (2) incongruent, and (3) mixed. The first two conditions start with instruction, followed by a practice block. In the latter condition, there is only an explanation of how to perform the task and there will be no practice block. In the congruent part of the task, participants must key in the key on the side of the projection of the heart. In the centre of the screen, participants will see a fixation cross, from which the heart will appear to the left or right. During the incongruent part, participants should press the key on the other side where the flower appears. Again, this can be either on the left or right side of the cross. In the mixed block, the conditions of the congruent and incongruent parts are alternated in a random order. Both the heart and the flower can be projected on the screen. The incongruent condition measures inhibition by response accuracy and reaction time, where the dominant response to click the key on the same side of the projection is expected to be suppressed.

Faster reaction time and lower accuracy mean less inhibition (Davidson et al., 2006). This is measured by comparing scores on different conditions. For measuring inhibition by reaction times, the mean reaction time on incongruent trials is subtracted from the mean reaction time on congruent trials. To measure inhibition by accuracy, the percentage of errors on congruent trials was subtracted from the percentage of errors on incongruent trials. Inhibition = Percentage of errors in congruent trials - percentage of errors in incongruent trials. In a person with few inhibition problems, slower responses and more errors are expected on the incongruent trials than on the congruent trials. This is also true for the Arrow task. For the HF task, the mixed condition is also expected to have even slower reaction times and more errors than on the congruent condition and the incongruent condition. If someone deviates from this pattern, it may indicate inhibition problems.

Arrow task. The Arrow task, also used to measure inhibition, consists of a single condition in which congruent and incongruent trials are randomly alternated. Participants receive an instruction prior to the task, followed by a short practice block. During the task, a large arrow appears on the left or right side of the screen. In congruent trials, the arrow points straight down to the key on the same side of the arrow. In these trials, participants have to press the key on the same side of the arrow. In incongruent trials, the arrow points diagonally to the other side at a 45-degree angle. The participant is asked to press the key where the arrow is pointing. This is therefore on the opposite side to where the arrow appears.

The task requires participants to suppress the automatic response to press the key on the same side of the screen when the arrow points diagonally to the opposite side. An advantage of the Arrow task is that it requires little or no working memory, as the arrow points directly to the correct response key in all trials. This makes the Arrow task suitable for measuring Inhibition.

Procedure

The CAARS and EFI questionnaires were administered through the Qualtrics programme. Students were recruited through SONA and accessed the link to Qualtrics through SONA. In the SONA system, students are presented with different studies, this particular study was under the title 'PSY-2122-S-0006 ADHD and Executive functions in university 2024-2025'. Before completing the questionnaires and again before participating in the experiment, informed consent had been obtained from all participants.

In the first phase of the study, participants completed two questionnaires. The CAARS questionnaire that took 45 minutes and the EFI questionnaire that took 20 minutes. For both questionnaires, participants were first presented with a consent form that stated how their data would be handled, details about their privacy and rights and general information about the study, followed by the option of giving or not giving informed consent.

The CAARS questionnaire measured ADHD symptoms using 66 items, in which participants were asked to indicate whether they agreed or disagreed on a 4-point Likert scale. In the second questionnaire, the EFI, which measures executive functions, participants were again given 27 items and asked to indicate the extent to which they agreed or disagreed on a five-point Likert scale.

The second phase of the study had an experimental design. From the sample of participants completing the questionnaire, a subset of participants were sent an invitation to complete the experiment, as well as a code to sign up. The experiment consisted of five Diamond tasks, each lasting about five to 10 minutes per task.

Data Analysis

The statistical program SPSS Statistics (version 28) was used to analyse the data. T-scores were calculated from the ADHD Index Total Score and the DSM Total Score from the CAARS and the EFI Total Score for the correlational analyses.

To test the assumption normality of the data, the Shapiro-Wilk test was performed, where the null hypothesis is that the data is normally distributed (see Tables A1, A2). The analysis showed that of the questionnaires, both the ADHD Index and the DSM Total scale of the CAARS are not normally distributed. The EFI Total scale, however, is normally distributed. For the reaction time tasks, the variables also differ in normality. Among the reaction time variables of the mixed condition HF task, both the congruent and incongruent trials are normally distributed. Among the variables measuring accuracy, the compatible and incompatible trials are not normally distributed. Similarly, among the reaction time variables of the Arrow task, the compatible and incompatible trials are normally distributed and the variables measuring accuracy are not normally distributed.

To draw valid conclusions from the results, various underlying assumptions besides normality were checked. The first assumption assessed was of linearity, evaluated through a residuals plot (see Figure A1). The depicted scatter plot reveals no discernible pattern between the standardized predicted and residual values, confirming that the linearity assumption has not been violated. Lastly, a box plot was created for all three variables to assess any outliers or influential observations in the data (see Figures A3, A5, A6). A few outliers were identified in all plots; however, the outliers do not impact the previous assumptions and should not be removed without good cause.

Additionally, Levene's test for equality of variances was conducted for reaction time and accuracy across both the Hearts and Flowers task and the Arrows task. The results indicated that for most conditions, the assumption of homogeneity of variance was met (see Tables A3, A4 and A6). However, significant violations were observed for accuracy in the incongruent condition of the Arrows task, $F(1,40) = 6.91, p = .012$, as well as for accuracy in both the congruent, $F(1,40) = 5.12, p = .029$, and incongruent conditions of the Hearts and Flowers task, $F(1,40) = 4.71, p = .036$. These findings indicate that the assumption of equality of variances was not met for these specific conditions, although the ANOVA is robust, results should be interpreted with caution.

The first research question is whether there is an association between the number of symptoms of ADHD measured by the CAARS and problems with Executive Functions measured by the EFI. Since the T-scores of the ADHD Index scale and the DSM Total scale of the CAARS are not normally distributed, non-parametric Spearman's Rho correlations were used to test this association (see Table 3).

The second and third questions regarding inhibition and ADHD were analysed by conducting a repeated measure MANOVA. For the analysis, the mean reaction time and mean accuracy per stimulus type (congruent and incongruent trials) and per task (Hearts and Flowers mixed condition task and the Arrows task) were used. In the mixed condition of the HF task and the Arrow task, condition (congruent or incongruent) is the between-subjects independent variable (High and Low ADHD groups) and reaction time, and accuracy are the within-subject dependent variables.

Results

The present study explores the relationship between ADHD symptoms and executive functioning. This section reports the results of the statistical analysis conducted for this study.

The relationship between the level of ADHD and Executive Functioning

The analysis conducted for our first hypothesis assess whether there is a relationship between ADHD and EF through the CAARS and EFI questionnaires. To test our first hypothesis, the spearman's non-parametric correlation for all three variables were evaluated to establish whether there is a relationship, several significant correlations were found.

Table 3
Correlations statistics of CAARS ADHD Index, CAARS DSM Total & EFI total

	N	1	2	3
1. CAARS T score ADHD Index	325	1	0.800**	-0.573**
2. CARRS T score DSM Total	325	0.800**	1	-0.622**
3. EFI Total	310	-0.573**	–0.622**	1

***Correlation significant at p<0.01 (2-tailed)*

As seen in the table above, a significant, negative correlation of moderate strength for EFI and ADHD index, $r = -0.573$ was found. As well as significant, moderately negative correlation for EFI and DSM total, $r = -0.622$, slightly stronger than the correlation between EFI and the T scores for ADHD Index. These correlations suggest that as participants obtain a high DSM total or ADHD index total score, their EFI score will be lower indicating more issues experienced with their executive functioning. This analysis results confirms our first hypothesis.

The validation of the task manipulation of inhibition

The second analysis assessed our second hypothesis regarding slower reaction times and accuracy on incongruent conditions rather than congruent conditions. To evaluate the second hypothesis, a repeated measures analysis of variance (ANOVA) was conducted to verify that the experiments indeed measure inhibition, observing the tests of Within-Subjects Contrasts values.

The main effect of Congruency for reaction time in the Arrows task was significant, *($F(1,40) = 15.269, p<.001$)* and the effect of Congruency for accuracy in the Arrows task was, *($F(1,40) = 17.451, p<.001$).* The F statistic shows whether there was a significant difference between the two conditions, due to the significant p-value, this indicates a strong main effect of congruency. This means that participants responded slower and less accurate in incongruent trials than in congruent trials, indicating that the task measured inhibition.

The profile plots (see Figures A19, A11) for reaction time and accuracy for the Arrows task showed slower reaction time and decreased accuracy in the incongruent condition than the congruent condition.

The main effect of Congruency for reaction time in the Hearts and Flowers was not significant, *($F(1,40) = 0.156, p = 0.695$)* and the effect of Congruency for accuracy in the Hearts and Flowers task was, *($F(1,40) = 20.065, p < 0.001$)* which was significant. This means that participants' reaction times were not significantly different between the congruent and incongruent conditions. However, the significant main effect of congruency on accuracy shows that participants performed better in one condition in comparison to the other.

The profile plots for reaction time (see Figure A9) for the Hearts and Flowers task illustrates the lack of difference between the two conditions, the profile plot for accuracy illustrated participants doing better in the incongruent condition than the congruent condition (see Figure A8).

Inhibition differences among ADHD groups

The last analysis assed our third hypothesis regarding that individuals with more symptoms experience greater impairment in their inhibition, the analysis was conducted using the same MANOVA for the previous hypothesis.

The Main effect of Group for reaction time for the Hearts and Flower task was not significant *($F(1,40) = 0.633$, $p = 0.431$)* and the interaction effect of Group x Congruency in the Hearts and Flowers task was not significant *($F(1,40) = 0.093$, $p = 0.763$)*. This means that there was no significant interaction between congruency and ADHD group, ADHD levels do not significantly influence the difference in reaction time between congruent and incongruent conditions. The Main effect of Group for accuracy for the Hearts and Flower task was not significant *($F(1,40) = .911$, $p = 0.346$)* and the interaction effect of Group x Congruency for accuracy was not significant *($F(1,40) = 3.369$, $p = 0.074$)*. This means that the difference in accuracy between the congruent and incongruent conditions does not depend on whether the participant has high or low level of ADHD symptoms for this task.

Summarising the results for the Hearts and Flowers task, the output indicates that there were no significant differences between the high and low ADHD symptoms groups in terms of reaction time and accuracy. The main effects of group for reaction time and accuracy were not significant and there was no significant interaction between Congruency and Group. This suggests that the groups in the Hearts and Flowers task were equally good in inhibition as measured by the hearts and flowers task. These results do not support the third hypothesis which proposed that individuals with more ADHD symptoms would show greater impairment in inhibition.

The main effect of Group for reaction time for the Arrows task was not significant *($F(1,40) = 0.116$, $p = 0.735$)* and the interaction effect of Group x Congruency for reaction time was not significant *($F(1,40) = 0.000$, $p = 0.990$)*. This means that there was no significant interaction between congruency and ADHD group, the effect of congruency does not differ between groups as both low and high ADHD groups show similar differences. The Main effect of Group for accuracy for the Arrows task was not significant *($F(1,40) = 3.223$, $p = 0.080$)* and the interaction effect of Group x Congruency for accuracy was not significant *($F(1,40) = 0.862$, $p = 0.359$)*. This indicates that the difference in accuracy between the congruent and incongruent conditions is not influenced by whether the participant has a high or low level of ADHD symptoms.

Similarly to the Hearts and Flowers task, the results of the Arrows task showed no significant differences between high and low ADHD symptoms groups in terms of reaction time or accuracy. The main effects of Group for both reaction time and accuracy were not significant, furthermore, no significant interaction effects were found. The groups in the arrows task are equally good in measuring inhibition. These results do not support the third hypothesis which proposed that individuals with more ADHD symptoms would show greater impairment in inhibition.

Discussion

The aim of this study was to investigate the relationship between ADHD and executive functioning, particularly focusing on whether the level of ADHD symptoms in students affects their executive functioning (inhibition). To address these objectives, three research questions were formulated: 1. Is there a relationship between the level of ADHD symptoms and executive functioning? 2a. Do the diamond tasks accurately measure inhibition? 2b. Do participants with more ADHD symptoms have less issues with their inhibition than participants with less ADHD symptoms?

It was hypothesized that as ADHD symptom severity increases, difficulties with executive functioning would also increase. Furthermore, it was expected that higher levels of ADHD symptoms would be associated with greater difficulties in inhibition. The results supported the first two hypotheses, indicating a significant relationship between ADHD symptom severity and executive functioning, as well as validating the inhibition manipulation. However, the findings for the third research question were not supported.

The Relationship Between the Level of ADHD Symptoms and Executive Functioning, and the Theoretical Implications

The aim of the thesis focuses on investigating the relationship between core executive functions and ADHD symptoms in university students. Furthermore, the aim is to establish whether there is a relationship between inhibition and the number of ADHD symptoms. It was necessary for our research to establish a relationship with ADHD and Executive Functioning to further explore the dynamic between the two variables within the experimental phase of the conducted study. Through our correlational analysis the hypothesis was supported as a moderately negative correlation between ADHD symptoms and problems with Executive functioning was found. This negative correlation implies that students who experience higher symptoms with ADHD will also experience more impairments in their key executive functioning.

These findings are supported by previous research, which influenced our initial hypothesis. Previous research highlights that executive function difficulties are underrepresented due to the diagnosis being established for children and adolescents. Hence why it is a focus of research for several papers. Mohamed et al. (2020) emphasised a correlation between ADHD and EF, it was found that when controlling EF while conducting a correlational analysis on ADHD and mood symptoms, the correlation decreased. This implies that ADHD and EF are correlated, and that executive functioning may act as a moderator on the relationship between ADHD and mood symptoms. Weyandt et al. (2013) conducted a study examining the academic, psychological and neurological functioning in a sample of university students. Their findings showed that students with ADHD rated significantly more executive functioning difficulties than those who are un-diagnosed (Dvorsky & Langberg, 2014). While some research has shown that adults are able to compensate non-optimal executive functioning through increasing experience and education, both previous research and the present study emphasize executive dysfunction as a difficulty with ADHD students (Ceroni et al., 2022). The significant correlation highlights the need for further contributions of viewing executive dysfunction as an important part of the clinical profile for the syndrome.

The Validation of the Task Manipulation of Inhibition, Inhibition Differences Among ADHD Groups, and the Theoretical Implications

This established relationship allowed for a deeper exploration of functional impairment in university students with ADHD. The relationship between the two variables may go through the inhibition aspects of executive functioning. The second hypothesis which acted as a manipulation and validity check and was supported meaning the experiments conducted successfully measured inhibition. As the first hypothesis was founded on prior research suggesting a relationship with executive functioning factors and ADHD symptoms, the third hypothesis worked in taking the analysis a step further through exploring the relationship ADHD symptoms had with specific executive functioning, inhibition.

Using prior research, it was hypothesized that individuals with high ADHD symptoms would exhibit more issues with their inhibition than students with low level of ADHD symptoms. This hypothesis was not supported due to inconsistent results in correlation. While this does not necessarily mean there is no correlation between the two variables, more research needs to be conducted. There is prior research that both supports and rejects the idea of inhibition control. Schachar et al. (1993) found results showing the ADHD group indicated deficient inhibitory control compared to normal controls. Dorr and Armstrong (2018), used children and adolescents to demonstrate that when controlled for ADHD symptoms, executive functioning is related to multiple domains of impairment. However, this specific paper argues the functional impairment may mainly go through motivation aspects. This is contradictive to the chosen direction of this study's research which is issues experienced with inhibition, however, this highlights the potential idea that there are more aspects of underlying cognitive executive functions that could be included to make, for example, the diagnosis more optimal.

Limitations of the Study

Generalizability

A limitation of this study is the use of a convenience sample, which was recruited through the SONA system. This program allows first-year psychology students to participate in research studies in exchange for course credits. Since generalizability refers to the applicability of study findings across different contexts, the restriction of the sample to psychology students may affect the study's external validity. Consequently, the results may be less generalizable to a broader population. For example, including students from various academic disciplines, rather than limiting the sample to psychology students, could enhance the representativeness of the sample and improve the generalizability of the findings.

Validity

The EFI questionnaire and the Diamond tasks measure executive functioning through distinct aspects. The EFI measures a higher order of executive function and its manifestation in real-world situations and long-term contexts. Whereas the Diamond tasks focus on and measures fundamental cognitive executive functions in a controlled environment. The manipulation successfully ensured that congruency effects were observable in the reaction time task, demonstrating that higher stimulus-response congruency interfered with strong inhibitory capacities. However, is important to acknowledge that the experiment measures only a single aspect of inhibition, specifically through congruency and incongruency. It could be beneficial to investigate other tasks such as the emotional Stroop task which tests an individual's ability to name the colour of a word regardless of the emotional meaning behind the word (Ben-Haim et al., 2016). Furthermore, due to the controlled laboratory setting of the experiment, ecological validity is low, reducing the ability to translate the findings to real-world contexts

Reliability

A further limitation would be the location of the self-report questionnaires. As the questionnaire was distributed through an online link, participants were able to fill out the questions in various settings. It is possible that the external environment (distraction) could impact the way in which they answered as well as the state they took the questionnaire in.

This may result in a lack of reliability due to the variability in patients' accuracy in symptom reporting (Bordoff, B., 2017). It may be beneficial to administer the questionnaires in a controlled yet neutral setting, such as a library, to minimize external distractions while maintaining a comfortable environment for participants. In addition, when conducting the experiments, at times participants would be required to be in the same room. This could result in a third variable such as the external environment impacting the reliability of the reaction time tasks. Furthermore, there was a violation of the homogeneity of variance assumption. While the repeated measures ANOVA is robust to violations in larger, balanced samples, future studies should consider using corrective statistical methods such as Welch's ANOVA.

Conclusion and Future Directions

Succinctly, the study highlights an association between ADHD symptoms and Executive functioning challenges. Simultaneously highlighting the need for a more nuanced approach to better understand inhibition in ADHD. Sonuga-Barke (2002), suggested that executive deficits contribute primarily to symptoms of inattention and organization, and issues regarding rewards and response contribute primarily to the symptoms of hyperactivity and impulsivity in ADHD. It may be interesting to separate the ADHD groups into those who experience more issues with inattention and organization and those who struggle with hyperactivity-impulsivity. Furthermore, as mentioned previously, diagnosing individuals with ADHD becomes more difficult in their adulthood as they may have grown accustomed to their symptoms and found ways to work with them, and hyperactive-impulsive behaviours tend to become less prominent. It may be beneficial to develop three groups within the ADHD symptom variables. The three groups could be a control group, individuals who were diagnosed with ADHD in childhood, and individuals diagnosed with ADHD in adulthood.

The separation within the ADHD symptom variable may allow for more clear comparisons and results to be drawn.

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Appendix A

This section presents the SPSS output for the assumption checks and repeated measures ANOVA analysis.

Figure A1.

Linearity and homoscedasticity assumption check

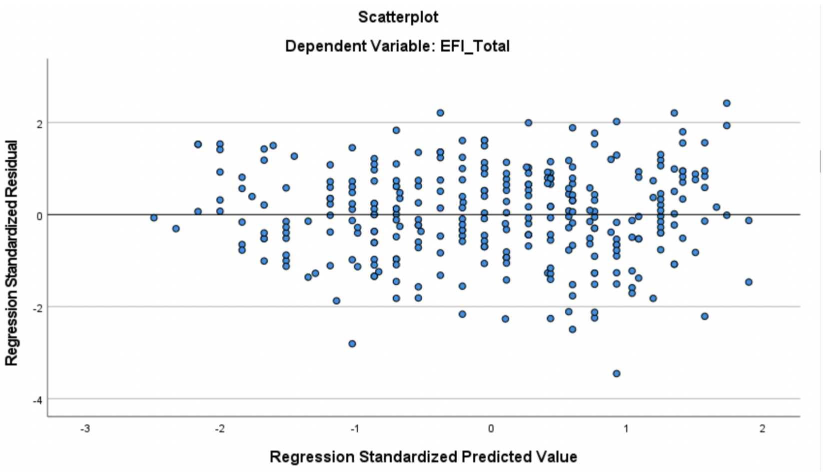

Table A1.

Shapiro Wilks normality test for EFI

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
EFI_Total	,037	326	,200*	,996	326	,492

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

a. Lilliefors Significance Correction

Figure A2.

Normality Q-Q plot

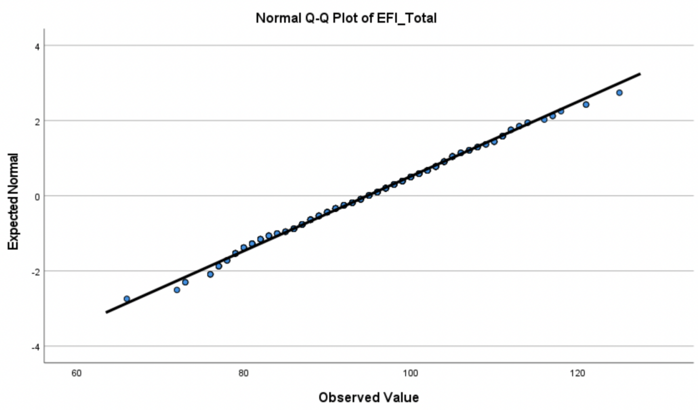

Figure A3.

Boxplot showing outliers

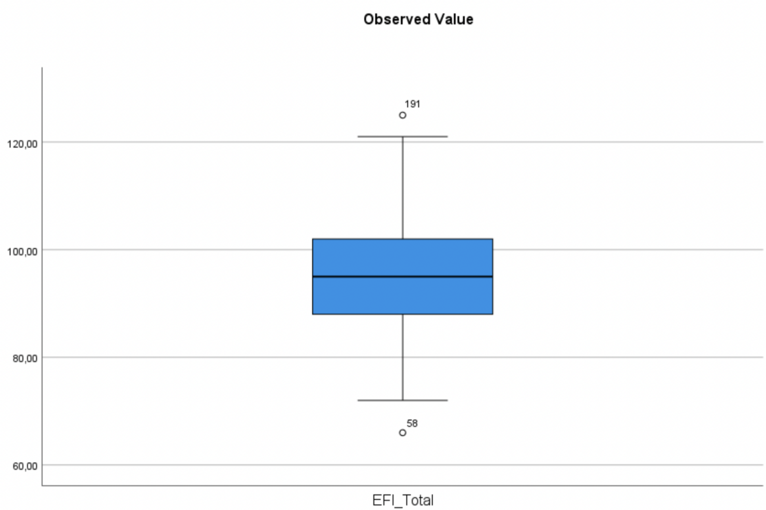

Table A2.

Shapiro Wilks normality test for CAARS

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
CAARS_TscoreADHDIndex	,077	325	<,001	,976	325	<,001
CAARS_TscoreDSM_Total	,070	325	<,001	,970	325	<,001

a. Lilliefors Significance Correction

Figure A4.

Normality Q-Q plot

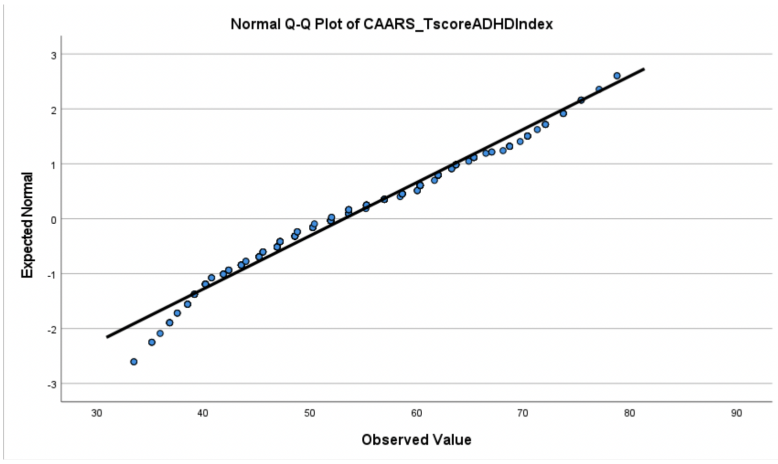

Figure A5.

Boxplot showing outliers

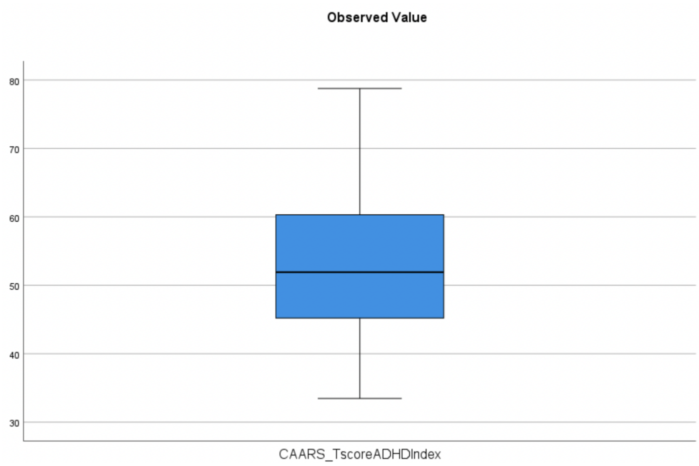

Figure A6.

Boxplot showing outliers

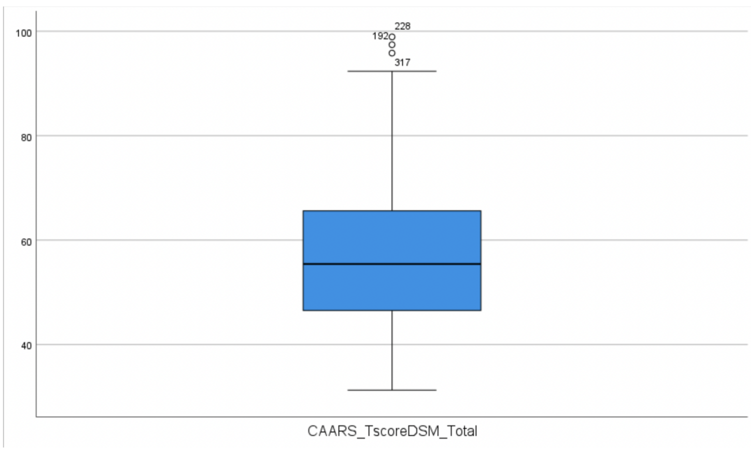

Figure A7.

Normality Q-Q plot

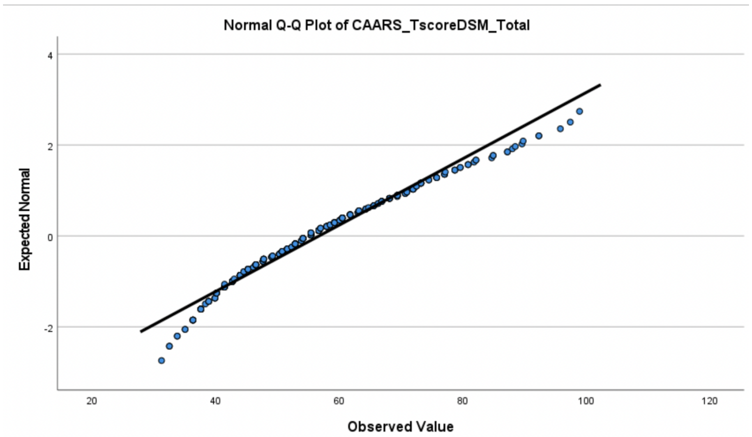

Table A3.

Levene's Test for Arrows Task – Reaction Time

Levene's Test of Equality of Error Variances[a]

		Levene Statistic	df1	df2	Sig.
A_m_rt_comp	Based on Mean	1,147	1	40	,291
	Based on Median	1,046	1	40	,312
	Based on Median and with adjusted df	1,046	1	38,218	,313
	Based on trimmed mean	1,162	1	40	,287
A_m_rt_incomp	Based on Mean	2,009	1	40	,164
	Based on Median	1,812	1	40	,186
	Based on Median and with adjusted df	1,812	1	38,134	,186
	Based on trimmed mean	2,032	1	40	,162

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Group
Within Subjects Design: Congruency

Table A4.

Levene's Test for Arrows Task – Accuracy

Levene's Test of Equality of Error Variances[a]

		Levene Statistic	df1	df2	Sig.
A_acc_comp	Based on Mean	,156	1	40	,695
	Based on Median	,539	1	40	,467
	Based on Median and with adjusted df	,539	1	34,167	,468
	Based on trimmed mean	,267	1	40	,608
A_acc_incomp	Based on Mean	6,905	1	40	,012
	Based on Median	3,821	1	40	,058
	Based on Median and with adjusted df	3,821	1	25,426	,062
	Based on trimmed mean	4,913	1	40	,032

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Group
Within Subjects Design: Congruency

Table A5.

Levene's Test for Hearts and Flowers Task – Reaction Time

Levene's Test of Equality of Error Variances[a]

		Levene Statistic	df1	df2	Sig.
HF_HF_%_comp	Based on Mean	5,121	1	40	,029
	Based on Median	3,395	1	40	,073
	Based on Median and with adjusted df	3,395	1	33,186	,074
	Based on trimmed mean	4,707	1	40	,036
HF_HF_%_incomp	Based on Mean	,866	1	40	,358
	Based on Median	,863	1	40	,358
	Based on Median and with adjusted df	,863	1	37,589	,359
	Based on trimmed mean	,977	1	40	,329

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Group
Within Subjects Design: Congruency

Table A6.

Levene's Test for Hearts and Flowers Task– Accuracy

Levene's Test of Equality of Error Variances[a]

		Levene Statistic	df1	df2	Sig.
HF_HF_m_rt_comp	Based on Mean	,839	1	40	,365
	Based on Median	,563	1	40	,458
	Based on Median and with adjusted df	,563	1	39,975	,458
	Based on trimmed mean	,842	1	40	,364
HF_HF_m_rt_incomp	Based on Mean	,877	1	40	,355
	Based on Median	,959	1	40	,333
	Based on Median and with adjusted df	,959	1	39,682	,333
	Based on trimmed mean	1,014	1	40	,320

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Group
Within Subjects Design: Congruency

Figure A8.

Profile Plot for the Hearts and Flowers Task - Accuracy

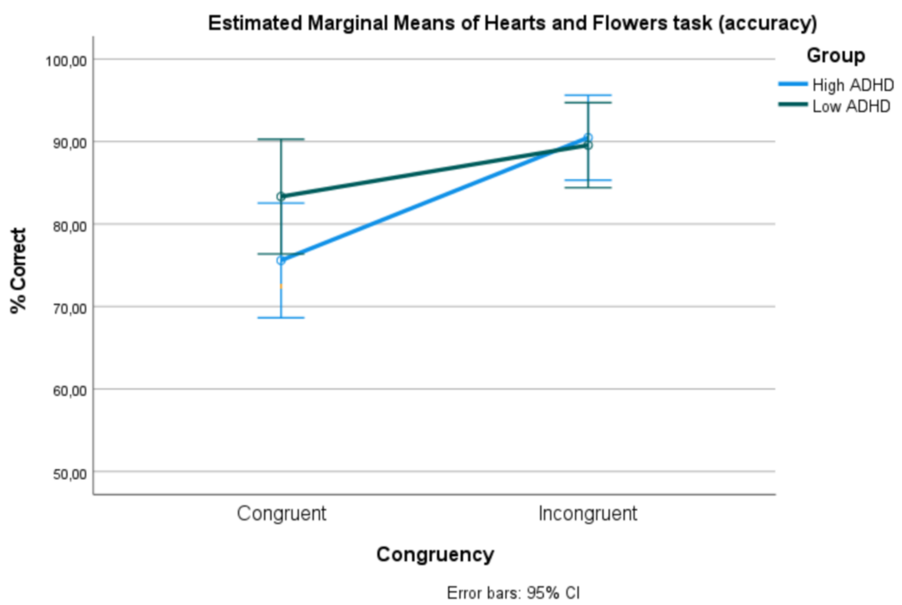

Figure A9.

Profile Plot for the Hearts and Flowers Task – Reaction Time

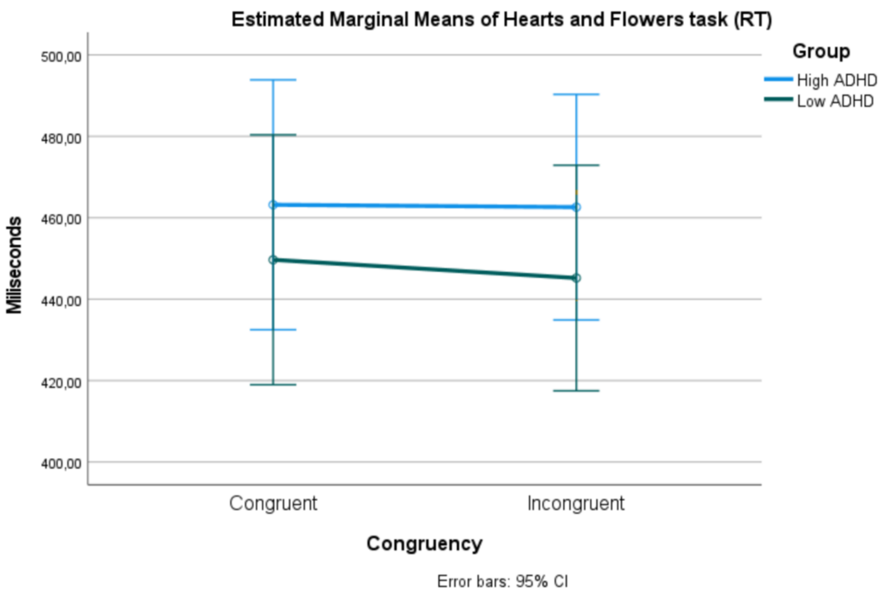

Figure A10.

Profile Plot for the Arrows Task - Accuracy

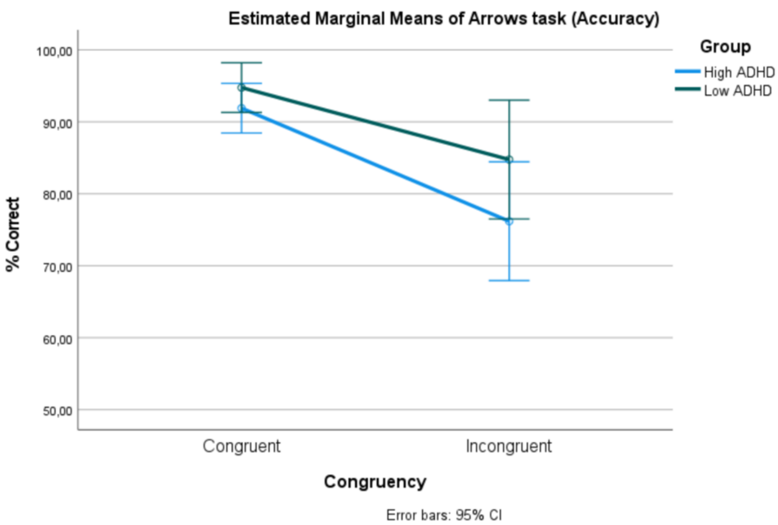

Figure A11.

Profile Plot for the Arrows Task – Reaction time

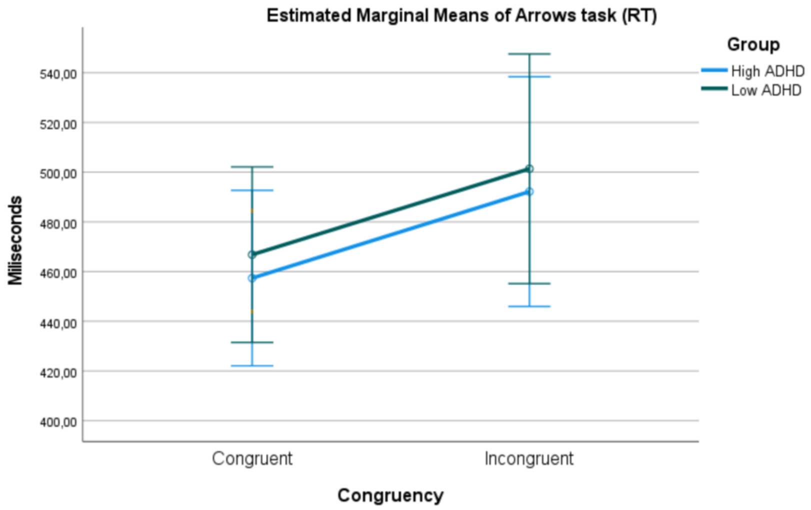

Table A7.

Repeated Measures ANOVA, Test of Within-Subject Contrasts – Hearts and Flowers Accuracy

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Congruency	Type III Sum of Squares	df	Mean Square	F	Sig.
Congruency	Linear	2339,815	1	2339,815	20,065	<,001
Congruency * Group	Linear	392,890	1	392,890	3,369	,074
Error(Congruency)	Linear	4664,517	40	116,613		

Table A8.

Repeated Measures ANOVA, Test of Between-Subject Effects– Hearts and Flowers Accuracy

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	603222,255	1	603222,255	2247,123	<,001
Group	244,577	1	244,577	,911	,346
Error	10737,682	40	268,442		

Table A9.

Repeated Measures ANOVA, Test of Within-Subject Contrasts – Hearts and Flowers Reaction Time

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Congruency	Type III Sum of Squares	df	Mean Square	F	Sig.
Congruency	Linear	134,022	1	134,022	,156	,695
Congruency * Group	Linear	79,697	1	79,697	,093	,763
Error(Congruency)	Linear	34460,322	40	861,508		

Table A10.

Repeated Measures ANOVA, Test of Between-Subject Effects– Hearts and Flowers Reaction time

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	17403574,401	1	17403574,401	2195,319	<,001
Group	5017,095	1	5017,095	,633	,431
Error	317103,276	40	7927,582		

Table A11.

Repeated Measures ANOVA, Test of Within-Subject Contrasts – Arrows Accuracy

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Congruency	Type III Sum of Squares	df	Mean Square	F	Sig.
Congruency	Linear	3471,429	1	3471,429	17,451	<,001
Congruency * Group	Linear	171,429	1	171,429	,862	,359
Error(Congruency)	Linear	7957,143	40	198,929		

Table A12.

Repeated Measures ANOVA, Test of Between-Subject Effects – Arrows Accuracy

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	634404,762	1	634404,762	2982,093	<,001
Group	685,714	1	685,714	3,223	,080
Error	8509,524	40	212,738		

Table A13.

Repeated Measures ANOVA, Test of Within-Subject Contrasts – Arrows Reaction Time

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Congruency	Type III Sum of Squares	df	Mean Square	F	Sig.
Congruency	Linear	25246,441	1	25246,441	15,269	<,001
Congruency * Group	Linear	,280	1	,280	,000	,990
Error(Congruency)	Linear	66136,355	40	1653,409		

Table A14.

Repeated Measures ANOVA, Test of Between-Subject Effects – Arrows Reaction Time

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	19309067,171	1	19309067,171	1227,696	<,001
Group	1822,665	1	1822,665	,116	,735
Error	629115,831	40	15727,896		