The Impact of Increasing ADHD Symptomatology on the Process of Proactive Cognitive Control

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Abstract

Cognitive control (CC) plays a major role in our daily functioning. According to recent research, individuals with attention-deficit and hyperactivity disorder (ADHD) indicate altered processes of proactive CC, which represent the ability to perceive and act according to contextual cues in our environment. The present study follows a dimensional approach to investigate the relationship between varying severity levels of adult ADHD, measured with the Conners' Adult ADHD Rating Scale Self-Report, and the impact on proactive CC in a convenience university sample. Proactive control is measured through reaction time on the informative-cued trials of the Stroop Task compared to alerting-cue trials. Post analysis include the differences in performance of the proactive CC process between gender. Our findings are inconclusive regarding the impact of proactive CC processes, due to the insignificance of our cue manipulation, despite varying levels of ADHD. No significant difference between gender was found. Overall, findings contradict research of previous clinical studies, which observed a significant difference in reaction time when implementing informative cues for both, healthy and ADHD groups. Nevertheless, varying levels of severity of ADHD symptoms presented a possible meaningful relationship in regards to the performance of the Stroop Task, which needs further investigation.

Keywords: ADHD, Stroop Task, Proactive Cognitive Control, CAARS

The Impact of Increasing ADHD Symptomatology on the Process of Proactive Cognitive Control

Attention-deficit and hyperactivity disorder (ADHD) is currently conceptualized as a heterogenous neurocognitive disorder characterized by dimensional symptoms of hyperactivity, inattention, and impulsivity (American Psychiatric Association [APA], 2013). Those cognitive and behavioral impairments can be explained by the delay of the development of the present prefrontal cortex (PFC) (Shaw et al., 2007; Zamorano et al., 2020). ADHD was thought to occur only in children until more studies considered the continuation of ADHD symptoms into adulthood, suggesting a change in symptomatology (Willoughby, 2003). Rates of inattention tend to be more persistent than hyperactivity and impulsivity (Biederman et al., 2000), whereas hyperactivity changes possibly into restlessness (APA, 2013). The current approximated prevalence is estimated to be 2.5% (APA, 2013) to 4.4% (Kessler et al., 2006) within adults and around 2% to 8% (DuPaul et al., 2009) within college students. ADHD is often assessed by a clinical interview in combination with the Conner's Adult Attention-Deficit/Hyperactivity Rating Scale (CAARS; Conners et al., 1999) self-report questionnaire, measuring the presence and severity of ADHD symptoms. The CAARS has proven to be a beneficial measurement (Conners et al., 1999; Erhardt et al., 1999; Van Voorhees et al., 2011) and is part of the present study.

Cognitive Control

An important consequence of ADHD symptomatology can be altered processes in the application of Cognitive control (CC). Cognitive control is a fundamental ability that aids individuals to adjust attention and decision-making regarding current goals flexibly, and is beneficial for overcoming habitual responses (Alexander & Brown, 2010).

The Dual Mechanism of Control Model

Braver (2012) proposed the Dual Mechanism of Control (DMC) theory, indicating that CC can be divided into two distinct but complementary cognitive processes: proactive and reactive control. Proactive control is the ability to process contextual cues of the environment to prepare for maintaining and pursuing goal-focused actions. It is characterized as a top-down process within the lateral PFC. The proactive control process enables optimal cognitive performance through a narrower focus of attention, action systems and perception (Braver, 2012). In contrast, reactive control involves bottom-up processes. Instead of contextual cues, the process represents responding flexibly to a changing environment at the moment of the detection of a target stimuli, wherefore reactive control is more transient and stimulus-driven. Further research on the DMC supported the theory of two independent cognitive processes (Braver et al., 2008; Gonthier et al., 2016; Yang et al., 2019).

Measuring Cognitive Control. Most experiments measuring CC include interactive reaction time tasks, where participants are presented with a series of trials and are required to respond quickly to a specific stimulus, but inhibit their response to a similar and slightly different presentation, like the Stroop Task. CC is measured through accuracy, reaction time and experimental manipulations, for instance by implementing informative cues or manipulating cue-probe conditional probabilities by increasing the frequency of a target stimuli. Both manipulations affect predictive validity and the prepotency of the target response to the stimuli. For example, participants in an informative cue experiment show more accuracy and faster reaction time when applying proactive CC by using the previously shown information on the following trial. On the other hand, individuals who apply reactive CC have no disadvantages in experimental manipulation, where no environmental cue is present due to them not preparing for a particular stimulus to appear (Redick, 2014). Therefore, CC is flexible, and its external expression depends on the subtle balance between reactive and proactive processes (Yang et al., 2019), and its optimal control may vary depending on the situation (Braver et al., 2008; Braver et al., 2009).

Cognitive Control in Adults with ADHD

Longitudinal research associated continuation of ADHD into adulthood with greater impairments of attention, behavioral inhibition, memory and planning (Biederman et al., 2010; DuPaul et al., 2021; Frazier et al., 2007; Hervey et al., 2004; Weyandt & DuPaul, 2008; Riccio, 2005), which are currently associated with altered processes of CC. Researchers suggest that adults with ADHD possibly engage in different or more inefficient mechanisms of CC (Sidlauskaite et al., 2020). The use of proactive CC in an effective way relies on the expectation, prevention and suppression of interference before the occurrence of high cognitive demand (Geng, 2014) and on the maturity of the PFC, which activation reflects active maintenance of task goals (Braver, 2012). In ADHD, the developmental delay of the PFC (Shaw et al., 2007; Zamorano et al., 2020) could interfere with the effective use of attention, behavioral inhibition and proactive processes (Hervey et al., 2004). The theory of impaired executive functioning was further validated by evidence showing that participants with ADHD tend to show less accuracy and speed during reaction time experiments than the control groups (King et al., 2007; Nigg et al., 2005). The underlying reason for the poorer cognitive performance of ADHD groups was the inefficient application of proactive control, reactive control, or both. When measuring CC in experiments, recent EEG studies showed that individuals with ADHD present altered proactive control processes, whereas reactive CC not affected (Grane et al., 2016; Sidlauskaite et al., 2020; Zamorano et al., 2020).

Zamorano et al. (2020) applied the manipulation of conditional probabilities and observed no significant difference in reactive cognitive control. When the probability of a stimulus occurring increased, children with ADHD did not make use of the contextual cues, whereas typically developing children did. This led to a higher error rate for children with

ADHD and could possibly indicate a lack of engagement in proactive control. Similarly, a continuation of this impairment into adulthood is present. Sidlauskaite et al. (2020) applied informative cues to a reaction time task and detected no difference between the ADHD- and control group for the no-cue trials, indicating similar engagement in reactive control processes. The ADHD group made significantly less use of the informative cues, indicating possible altered proactive CC. Studies focusing on future directions of ADHD research highlight the need for exploring possible deficits as altered proactive CC, to improve the understanding of the consequences and differences of ADHD symptomatology, and to develop preventive measures to face possible deficits (DuPaul et al., 2009).

Proactive and Reactive ADHD Performance on the Stroop Task

The Stroop Task is an exceptionally beneficial experiment to differentiate between proactive and reactive CC processes and to investigate underlying cognitive function deficits. In the classic color-naming Stroop Task (Stroop, 1935), the participant reacts to a written color, either displayed in a matching color, representing a congruent trial or presented written in a different color, representing an incongruent trial. The incongruent trial produces interference and is associated with slower average performance, which is called the Stroop congruency effect (CE) (King et al., 2007). CC is necessary to overcome the interference and selectively narrow the attention towards the required feature. The CE is reasoned in the cognitive conflict of relevant and irrelevant stimulus cues requiring additional attentional demands (Cohen et al., 1990). In a trial period, reaction time increases if incongruent trials follow incongruent trials, whereas the appearance of a congruent trial slows the reaction time down due to the focus on the task-relevant stimulus features (Gratton et al., 1992). These congruency sequence effects (CSE) represent cognitive processes of attention and memory, wherefore the Stroop Task is beneficial to investigate underlying cognitive processes due to its involvement of recent interaction and cues of the environment. Homack's (2004) meta-analysis indicated that the Stroop Task demonstrates sensitivity to executive function deficits like ADHD, expressed by lower scores of the ADHD groups compared to control groups, indicating a possible underlying neurological disorder.

According to Gonthier et al. (2016), the Stroop Task is a convenient measure to reflect the independent mechanisms of proactive and reactive CC. Several strategies to manipulate the Stroop Task to capture the process of proactive control were successfully applied, for example above mentioned manipulations regarding probabilities by increasing the frequency of incongruent trials within the trials (Gonthier et al., 2016; Zamorano et al., 2020) or applying informative cues about the nature of the upcoming trial (Aarts et al., 2008; Sidlauskaite et al., 2020). While manipulating probabilities requires the participant to learn that a certain stimulus's frequency increases over time, cue manipulations control for this learning effect. Wherefore the manipulation is less confounded by participant's slower adapting (Egner, 2010), and more likely to measure more accurately proactive CC. The present study follows the example of Aarts et al.(2008) by using informative cues, implementing in the experimental trials the words "same "for congruent and "different "for incongruent trials before stimulus presentation. Previous studies showed (Aarts et al., 2008; Sidlauskaite et al., 2020) that presenting those informative cues beforehand should evoke a faster reaction time for the following stimuli than trials without such information. Therefore, reaction times on the informative cued trials represent the application of proactive CC processes. According to previous findings of symptomatology and deficits individuals with ADHD experience, we expect that underlying proactive CC processes are altered (Sidlauskaite et al., 2020). Therefore, our study attempts to measure proactive CC by manipulating cues within the Stroop Task trials.

Gender Differences in ADHD and Cognitive Control

An essential but often neglected field of research is the analysis of gender differences in ADHD. Studies of children with ADHD highlight that girls are more likely to express the inattentive type of ADHD than boys, who are most likely to display the combined type of inattention, hyperactivity and impulsivity (APA, 2013; Biederman et al., 2002). Therefore, it is crucial to investigate if this difference in symptomatology also affects CC. Recent research suggested that women tend to make more use of proactive CC and men more of reactive CC (Bianco et al., 2020). Moreover, in the Stroop Task performed by nonclinical adults, women performed slightly better than male participants (Sjoberg & Cole, 2014). Our research investigates whether women with ADHD still perform better than men with ADHD and engage more in proactive CC processes due to their slight difference in emphasis of ADHD symptomatology and differences in brain responses in cognition (Xin et al., 2019). This topic is relevant for understanding cognitive differences between gender better and to potentially improve treatment for individuals if females and males are not equally affected by altered proactive control.

The Present Study

The relationship between individuals with ADHD and possible executive impairments is not fully explained and understood until today. More research is required to comprehend the disorder fully with its consequences, especially in adults (Boonstra et al., 2005; DuPaul et al., 2009). The present research attempts to explore the independent contributions of proactive CC in cognitive task performance of individuals with differing severity of ADHD. It expects to gather further information to identify specific relationships between clinical symptomatology, cognitive deficits, and neurobiological mechanisms.

Dimensional Study Approach

The study follows a dimensional rather than categorical diagnostic approach due to the conceptualization of ADHD symptoms as continuous and dimensional (APA, 2013) and due to studies promoting evidence for the dimensionality of the disorder (Shaw et al., 2011). The utilization of the CAARS enables us to use a dimensional approach by quantifying the degree of ADHD symptom severity and comparing individuals on a continuum of high and low ADHD symptom severity. Therefore, the study does not exclusively include adults diagnosed with ADHD. The research expands the focus on a subclinical group of individuals who do not meet the full DSM-IV criteria for ADHD but might be at risk of developing ADHD and experiencing greater behavioral and social difficulties than non-risk groups (Mcgarragle, 2013). Due to our diverse participant sample and dimensional approach, the study covers a variety of ADHD levels, attempting to highlight the impact of severity of ADHD and its consequences. Therefore, detecting a deficit in processes of proactive control in nonclinical adults with high ADHD symptoms on scales of the CAARS would contribute to a new direction of research about another subclinical group or possible risk group, which might need support or additional aids in university or work settings.

Influence of ADHD Severity on Proactive Cognitive Control. Given the relatively unexplored research field of altered proactive control concerning ADHD, our research question focuses on what impact increasing ADHD symptom severity has on the performance on the Stroop Task regarding proactive control.

According to previous research (Aarts et al., 2008; Sidlauskaite et al., 2020), we hypothesize that individuals with higher ADHD severity scores will perform significantly worse than the lower ADHD scored individuals on the information-cue trials of the Stroop Task due to altered use of the contextual cues, which represent proactive CC processes.

Despite the CAARS scores, we expect a similar performance of the groups on the alerting-cue trials due to studies suggesting reactive control not to be influenced by ADHD (Grane et al., 2016; Sidlauskaite et al., 2020; Zamorano et al., 2020). We expect individuals with low ADHD severity scores to apply proactive CC, observed through a significant difference in reaction time between the informative and alerting cued trials. In contrast, individuals with higher scores do not differ significantly between the alerting and informative cued trials in reaction time. We expect a relationship between decreasing effective applied proactive control with increasing severity of ADHD symptoms.

The hypothesis is tested by comparing the performances of the cued trials of the Stroop Task between participants with low, medium and high scores on the CAARS scales to observe, if their performances and application of proactive CC is dependent on previously achieved ADHD severity scores on the CAARS.

Gender Differences in Proactive Cognitive Control. This research strives to achieve further insight into the often-neglected topic of gender differences in ADHD symptoms and the impact of ADHD on neurocognitive processes. Thus, we want to include gender differences in our study by exploring whether there is a possible significant difference in applied proactive CC. Due to previous findings of symptomatology differences and performance of women on the Stroop Task (Biederman et al., 2002; Sjoberg & Cole, 2014), we want to explore and hypothesize if males perform significantly poorer than women with similar scores on the CAARS for the informative cued conditions due to women applying more proactive CC compared to man (Bianco et al., 2020). We also expect better performances of females on the alerting-cued condition due to previous findings of faster reaction time at the Stroop Task (Sjoberg & Cole, 2014).

Methods

Participants

A total of 49 students participated in this experiment as part of a convenience sample pooled from the SONA research program of the University of Groningen. The collected sample consisted of 20 males and 29 females with an average age of 20 (*M* = 20, *SD* = 2.13).

Female participants scored *M* = 48.1(*SD* = 9.4) and male participants *M* = 51.3(*SD* = 11) on the questionnaire of the CAARS. Of three students, one female and two male participants had a self-reported ADHD diagnosis, 14 participants reported either suffering from anxiety, depression or stress disorder, three stated dyslexia, and one person reported having a motor disorder. After further investigation, the participant's diagnosis of motor disorder was disregarded due to inconsistencies in the self-report of mental disorders. Two participants reported currently taking Methylphenidate and Sertraline. Of our sample, 31 participants did not indicate a prior clinical diagnosis. Visual impairments, like far-sightedness, were not accounted for in the experiment. Participation was voluntary, and participants were compensated for participating in this experiment by being awarded SONA points, necessary to pass the first year of Bachelor of Science in Psychology.

Apparatus

The participants completed the study online using a device of their choice and opened the link to the experiment through a web browser of their own choice. The participants were required to have internet access to participate in the reaction time task. OpenSesame Version 3.2 was used to create the online format of the experiment. Jatos was used to create a host server for the experiment. The specific online version of the CAARS questionnaire was created in Qualtrics in a previous study on ADHD in university students.

Measures

Conners' Adult ADHD Rating Scale Self-Report Long Form

The participants were instructed to complete the Conners' Adult ADHD Rating Scale Self-Report Long Form (CAARS-S:L), a questionnaire relating to the severity of ADHD symptoms. The CAARS is a popular measure to assess ADHD, with an acceptable test-retest reliability and moderate to high sensitivity and specificity to distinguish between individuals with ADHD from control groups (Conners et al., 1999; Erhardt et al., 1999; Van Voorhees et al., 2011). The questionnaire includes 66 items in numerical answer keys (0= not at all, 1= a little, 2= pretty much, 3= very much) and is divided into six sub-categories about statements relating to behavior or tendencies of the participants daily life. The sub-categories include DSM-IV: Hyperactive-Impulsive Symptoms, DSM-IV: Inattentive Symptom, Hyperactivity/Restlessness, Impulsivity/Emotional Lability, Inattention/Memory Problems and Problems with Self-Concept, reflecting ADHD symptoms. Higher scores of the CAARS indicate increasing symptom severity. Values around 50 (*SD* +/- 10) suggest that a participant is in the average range (Conners et al., 1999).

The DSM-IV: ADHD Symptoms Total Scale represents if the individual behaves in a manner consistent with the DSM-IV diagnostic criteria for the combined type of ADHD. The ADHD Index indicates individuals at risk for ADHD. In our analysis, the T-scores of the ADHD Index subscale were used, since the scale provides information about the risk and severity of ADHD symptomatology and indicates possible subclinical individuals who are at the risk of developing ADHD. This is more beneficial than the ADHD Symptom Total Scale, because we only have two individuals diagnosed with ADHD in our sample. Observing the risk of developing ADHD is more beneficial in the present research to differentiate between the performance of different risk groups of ADHD.

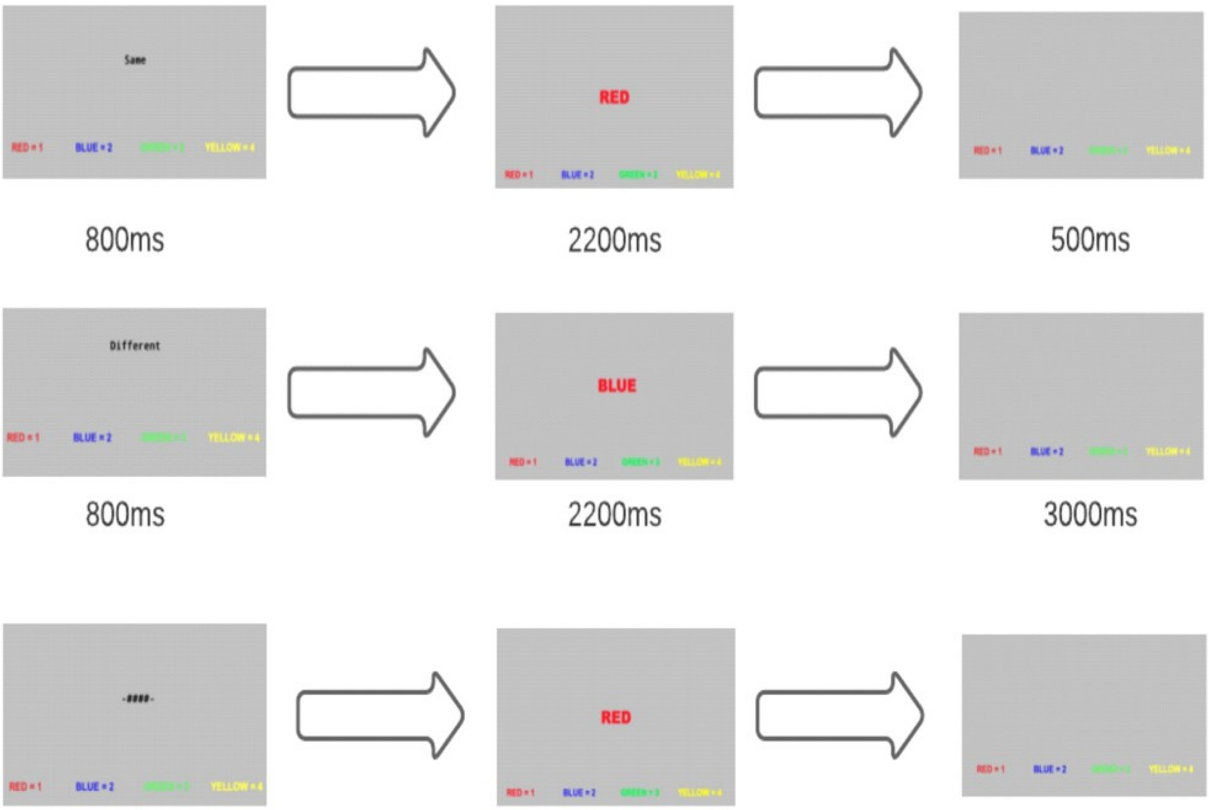
The Stroop Task. In the Stroop Task, the participants were presented with a color name either written in the same ink, like green written with green ink, or different, for example, green written with red ink (Figure 1). Participants were required only to react when the ink and the word were corresponding and to indicate the color of the word shown on the screen, using one of four keys on their computer (1 = red, 2 = blue, 3 = green, 4 = yellow). In this experiment, it was differentiated between three cued-trials, in which the stimulus was presented (Figure 1). The first condition showed the stimuli with no prior information or warning that the stimulus would occur, which can be seen in the third blank picture of Figure

1. We will refer to this condition as the no-cue condition, representative of measuring reactive control. The second condition, the alerting condition, warns the participant before the presentation of the stimulus with the image of four hashtags (-####-), that the stimulus will occur. The third condition reflects the measure of proactive control by including an informed-cue before the trial, informing the participant about the nature of the upcoming trial. The participant will be informed before the upcoming trial if the following trial will be a congruent(-same-) or incongruent(-different-) trial. Every cue condition appeared 800ms before the upcoming trial. After that 800 ms, the participants had 2200 ms to decide whether the trial was incongruent or congruent. Additionally, the conditions were presented at three different event rates, each with different time periods between the presentation of the stimulus. The three conditions were slow (8000 ms seconds between each interval), medium (3000 ms seconds between each interval) and fast (500 ms seconds between each interval). The slow condition included 60 trials, the medium trial included 110 trials and in the fast condition, 208 trials were presented, making the time needed to complete the slow and medium condition 11 minutes and the time needed for the fast condition 12 minutes.

The experiment was performed by the participants within two separate sessions. Previous to the experiment, a practice round of 14 randomized trials, including six non-cue trials, three alerting and five information-cued trials, was absolved. In the practice trial, the alerting and informational cues occurred 800ms, followed by the stimulus for 2000ms with received feedback on their performance for 2000ms. The experiment consisted of 24 trials in a randomized order, which were repeated in the slow condition for 60 trials, in the medium condition for 110 trials and in the fast condition 208 trials. In total, there were data recorded of 342 trials for the experiment.

Figure 1

Example of Presentation and Timeline of the Congruence, different Cues and Even Rate. From above to below. Presentation of the Slow Condition Timeline with Informative Cue(-Same-) indicating a following Congruent stimulus (red written in red). Presentation of the Medium Condition Timeline with Informative cue(-Different-) indicating a following Incongruent stimulus (blue written in red). Presentation of the Timeline of the Fast Condition with Alerting Cue (-####-) indicating a following appears soon.



Testing Procedure and Research Design

Before participating in the experiment, participants were given an information sheet containing general information about their participation in the experiment, after which they filled out an informed consent form. In the first session, participants were assigned to fill out scales measuring ADHD-related problems, namely the CAARS, the Weiss Functional Impairment Rating Scale (WFIRS) and the Barkley Deficits in Executive Functioning Scale (BDEFS). Data from the WFIRS and BDEFS are not applied in our research due to not every participant answering the questionnaires, resulting in a lack of data and some of the data not being linked with our research goals. The students participating indicated their SONA numbers as means of identification. For identity and privacy protection, these SONA numbers were translated into specific codes. The participants were able to decide whether to begin with the Stroop Task- or a Task-Switching experiment. Data from the Task-Switching was not analyzed in the present study. Between each of the three event rate conditions, the participants had the option to take a break of five minutes, to decrease the risk of fatigue. For each trial, accuracy and reaction were measured. The Stroop Task, including breaks, took approximately 45 minutes to complete. Afterward, the participants were briefed about the purpose of the experiment.

Data Analysis

The reaction times on the Stroop Task of three participants were excluded from the analysis due to missing scores on the CAARS questionnaire, which are essential for our main analysis, comparing varying scores of the CAARS to the performance of the Stroop Task.

To distinguish varying levels of ADHD, we applied tertiles to statistically create ADHD severity groups by separating the T-scores of the CAARS DSM Total into low, medium and high severity groups. The lowest tertile includes 16 participants with a CAARS score range of 33.4 – 42.63, the medium and high tertiles include 15 participants from the range 45.58 – 53.4 and 53.4 – 73.4. Three participants were difficult to separate into tertiles because they all had the same overall score on the CAARS Total. Therefore, we looked at the Hyperactivity and Inattention scores of those three participants and assigned the one with the highest scores on those scales to the upper tertile and the other two to the middle tertile.

Statistical Assumptions

The assumption of homoscedasticity tested with the Levene's test for equality of variances was met ($p > .05$). Normality was found to be partly violated, as tested with the Shapiro-Wilk test ($p < .05$). Adding the event rate manipulation in our analysis violated the assumption of homoscedasticity ($p < .05$). To reassure more accuracy of our results and to focus on proactive CC and ADHD severity levels, the event rate was excluded from our analysis.

Despite the violations of normality in our sample, we decided to use parametric tests instead of nonparametric tests since Repeated Measures Analysis of Variance (RM-ANOVA) has been shown to be resistant to non-normality in the past (Blanca et al., 2017). We also decided against using a log-transformation, as transforming the data would impair our ability to compare it to other reaction time studies since the transformed data does not represent the actual reaction time performance of the participants. Furthermore, the transformation would unlikely cause better type-one error reduction and higher statistical power in our data analysis (Schramm & Rouder, 2019).

Testing Study Hypotheses. In order to test the two main hypotheses, two RM-ANOVAS of the reaction times were performed. The first hypothesis will be tested with an RM-ANOVA by considering the three differing CAARS levels (low, medium, high) as between-subject factor and Congruence (congruent vs. incongruent) with Cues (alerting vs. informative) as within-subject-factors in the analysis. Furthermore, for post-hoc analysis, the RM-ANOVA is conducted again with an exclusion of the medium CAARS severity group to investigate the differences in scores and their consequences. We will focus on the main effects of the CAARS levels to see if different severity levels result in differences in performance and the main effect of Cues, to observe if participants applied proactive CC processes. Additionally, the main effect of Congruence will be observed to see if the general Stroop Task manipulation worked. It will also be investigated for an interaction effect between ADHD levels and Cues.

The second hypothesis is tested with an RM-ANOVA, using the same within-subjects variable mentioned above, but with the additional between-subject factor of Gender, indicated by participants as male or female. We will look at the main effect of Gender and Cues, to investigate possible gender differences and at the interaction of Gender with Cues and Gender, Cues and CAARS levels to look further into applied CC processes regarding Gender and ADHD.

Results

Descriptives

Table 1

Descriptive Statistics of the Mean Reaction Time (Standard Deviation) in Milliseconds of Congruent (Con) and Incongruent(Inc) Trials of the Stroop Task for Low, Medium and High Scores on the CAARS for the Alerting- and the Information-Cued Trials.

Cues	Scores	Alerting		Informative	
		Con	Inc	Con	Inc
Low	38.7(3.8)	742.3 (215.2)	797.6 (258)	734.6 (205)	802.7 (238.7)
Medium	49.8 (2.6)	666.8 (139.5)	709.2 (156.3)	655.1 (131.5)	734.5 (173)
High	60.1 (6.7)	647.3 (104.4)	698.4 (119)	624.5 (112.9)	689.7 (116.4)

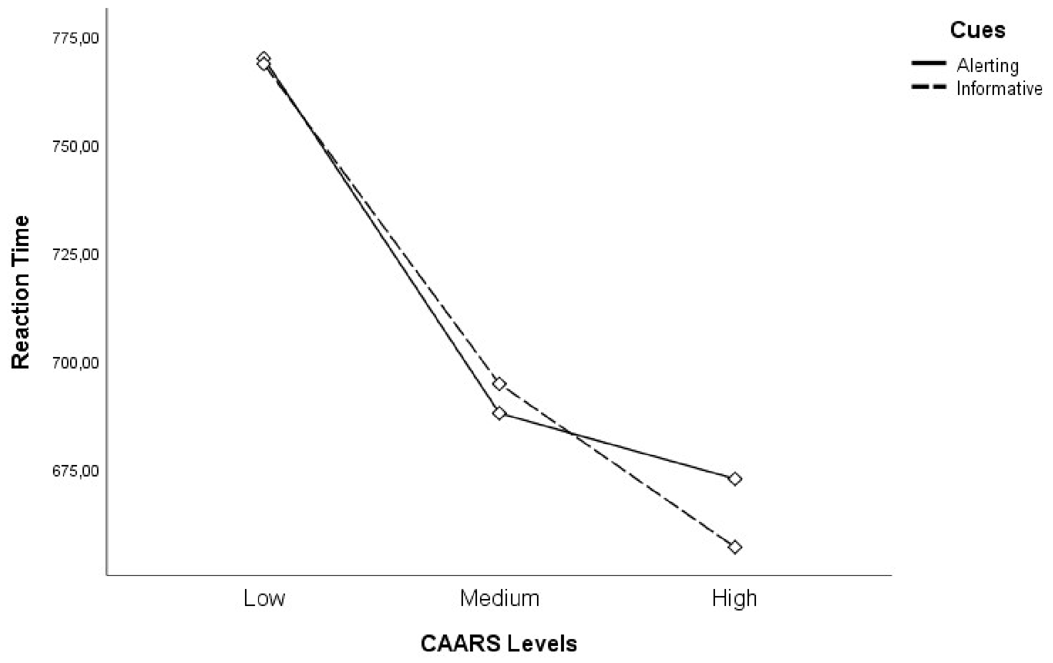
Note. Low $N = 16$, Medium $N = 15$, High $N = 15$

Performance of Differing Degrees of ADHD Symptomatology on the Stroop Task

The outcome for testing our first hypothesis indicated that the between subject-factor, the CAARS severity levels are not significant ($F(2, 43) = 2.8$, $p > .05$), but show a medium effect size in our analysis (*η2* = .056) with an observed power of 52.2%. There seems to be no significant difference between the within-subject factor of the Cues (*F*(1, 43) = 0.43, *p* > .05) with no observed effect size (*η2* = .000) with a minimal observed power of 9.8%. The results of our statistical analysis show that Congruence (*F*(1, 43) = 45.1, *p* < .001) seems to indicate the greatest significant difference in our experimental trial with a high observed power of 100% and with a close to medium effect size (*η2* = .046). There is no interaction effect between ADHD Levels and Cues (*F*(2, 43) = 1.57, *p* > .05) with a small effect size (*η2* = . 001) with an observed power of 31.5%.

Figure 2

Performance of differing ADHD Severity Levels (Low, Medium, High) on the Alerting- and Information-cued Trials of the Stroop Task, indicated by Estimated Marginal Means of Reaction Time in Milliseconds (ms).



Further post-hoc analysis, excluding the medium level group of the CAARS, indicated a significant difference in reaction time between high and low levels of the CAARS ($F(1,29) = 4.95$, $p = .034$) with a medium effect size ($\eta 2 = 0.072$).

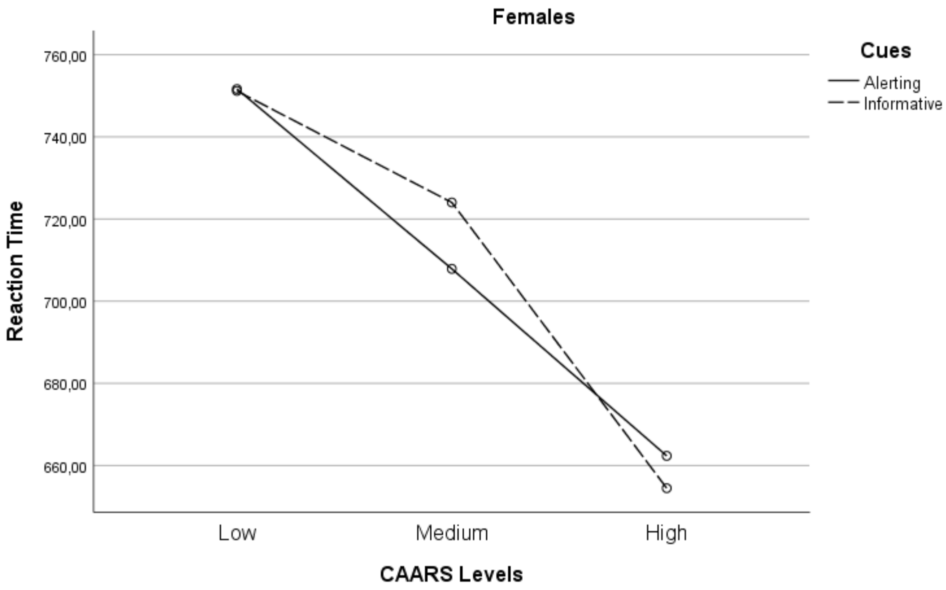
Analysis of Performances of Gender

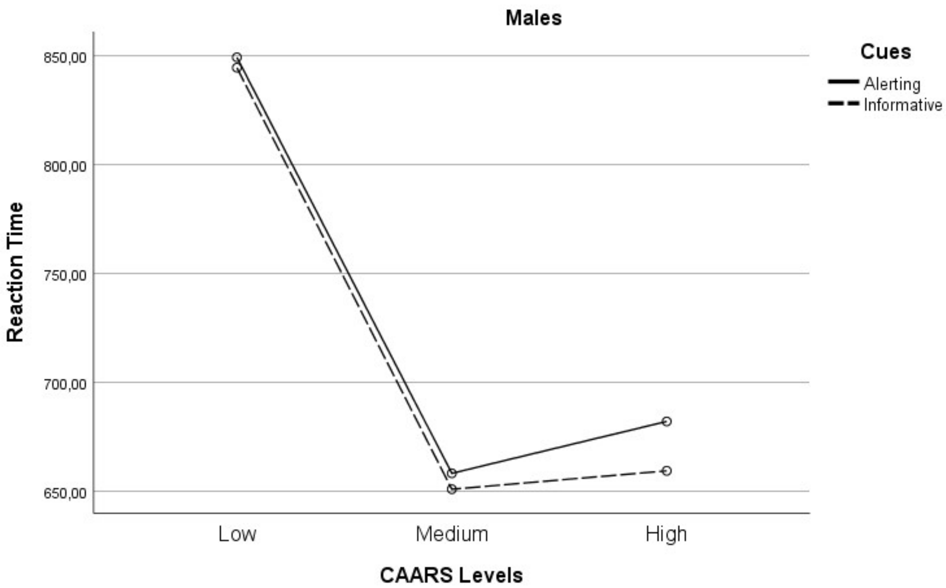
The overall reaction times for the Alerting- and Information-cue trials of the Stroop experiment were previously established being for women $M = 747.5$ ($SD = 156.2$, $n = 17$) and men $M = 736.9$ ($SD = 142.6$, $n = 29$).

The results of the analysis to test our second hypothesis present no significant difference between Genders (($F(1, 40) = 0.13$, $p > .05$) with a small effect size ($\eta 2 = .001$) with 6.5% observed power. The main effect of Cues ($F(1, 40) = 0.6$) seem to be not significant ($p > .05$) and presents again no effect size ($\eta 2 = .000$) with a observed power of 9.8%. The interaction effects of Gender with Cues are observed to be not significant ($p > .05$), as well as the interaction with Gender, Cues and CAARS Levels.

Figure 3

Performance of Females and Males with differing ADHD Severity Levels (Low, Medium, High) on the Alerting- and Information-cued Trials of the Stroop Task, indicated by Estimated Marginal Means of Reaction Time in Milliseconds (ms).





Discussion

Proactive CC application and processes play a major role in our general- and goal-directed behavior and influence the actions of our daily life. The present research aims to deepen the understanding of proactive CC and observe the application of those processes through performance on the Stroop Task and investigate if differences in ADHD levels impact this performance.

The Impact of Scores of the CAARS on Proactive Cognitive Control

We hypothesized that increasing ADHD scores on the CAARS would affect the performance on the Stroop Task by observing decreasing effective applied proactive control. Our hypothesis that higher severity scores of ADHD symptoms result in significantly poorer performance on the information-cued trials of the Stroop Task, due to less use of contextual cues, compared to individuals achieving low scores on the CAARS was not met. Already observed in the descriptives (Table 1) and later confirmed in our analysis, the average reaction time for all three CAARS severity groups did not differ when comparing their alerting-and informative-cued trials. The results align with our expectation that all severity levels showed no significant difference on the alerting-cue trials due to studies suggesting reactive control not to be influenced by ADHD (Grane et al., 2016; Sidlauskaite et al., 2020; Zamorano et al., 2020). Nevertheless, we observed that individuals with low ADHD severity scores did not perform significantly better on informative than on alerting cued trials, contradicting our expectations. The indifference between the experimental cues suggests that all groups did not use the contextual cues given in the informative trials (Figure 2).

Interestingly, this is the first study to demonstrate no significant difference in reaction time between alerting and informative cued trials. These findings contradict previous studies, where control groups or healthy participants did show a significant difference in reaction time between alerting-and informative trials (Aarts et al., 2008; Sidlauskaite et al., 2020). Neither the high, medium or low group of the CAARS made use of the contextual cues of the information-cued trials, wherefore we were not able to measure proactive CC processes in our sample or distinguish proactive from reactive CC.

Therefore, no evidence was found for a relationship between decreasing effective applied proactive control with increasing severity of ADHD symptoms. We did find indications for a meaningful and possibly significant difference of performances on the Stroop Task when applying the dimensional approach, especially when observing only the low and high scores. Although, in our sample, this significant difference in performance contradicted our expectation that high scores individuals would be observed to have the slowest reaction time (Nigg et al., 2005; King et al., 2007). In the present sample, increasing severity of ADHD symptoms resulted in a faster reaction time on the Stroop Task, whereas the group with the lowest scores on the CAARS had the slowest reaction time (Figure 2). The effect size of the CAARS level itself indicates that with a larger sample size, a significant difference between all three groups could be present.

The main effect of cues and CAARS levels in our first analysis are insignificant, except congruence being significant. Therefore, the manipulation of congruence in the Stroop task succeeded, and the Stroop congruency effect (CE) was observed. The success of the congruence manipulation does not account for the contradictory results we found regarding the cues and the ADHD levels.

There seems to be no significant interaction between the cues and CAARS levels, wherefore only the performance of individuals in different severity levels of the CAARS seems important in our sample.

Gender Difference of Performance on the Stroop Task

The second hypothesis that there would be a significantly different reaction time between gender due to proactive CC was not found in this study either. As mentioned before, no significant difference between the two cued conditions was found ($p > .05$), wherefore we could not investigate a possible gender difference of use of proactive CC processes properly. Thus, we found no indication whether severe ADHD symptomatology differs between gender regarding proactive CC. Previous findings that women tend to make more use of proactive CC than males (Bianco et al., 2020) could not be observed from our data (Figure 3). Our expectation that females are slightly faster than males in the alerting cue due to outcomes of previous studies (Sjoberg & Cole, 2014) was contradicted. Overall, there was no significant difference between the performance between gender found in our RM-ANOVA.

Limitations

Possible limitation and an alternative explanation for observing decreasing reaction time with increasing severity score levels of the CAARS could be due to the majority of our sample consisting of participants who scored an average range on the CAARS (Table 1). Therefore, the sample did not represent severe ADHD symptomatology. This could explain why participants considered in our study as high CAARS severity have the fastest reaction time. Van Voorhees et al. (2011) observed in their research that the CAARS provides valid information about attention problems in adults but does not distinguish perfectly between other psychiatric disorders such as mood- or anxiety disorder and ADHD. As we have many comorbidity disorders in our sample, the participants in the high CAARS group could have potentially achieved higher scores on the CAARS due to other disorders which do not affect proactive CC and the Stroop Task results as much as individuals with the actual risk of developing ADHD or having ADHD would.

Comorbidity

The sample consists of 17 participants with a self-reported mental health diagnosis, whereas 31 participants did not indicate or absolved the questionnaire. We did not control for comorbidity in our experiment due to our small sample size and consequently lower power in the research. The reported disorders included depression, anxiety, and stress disorder, all potentially affecting attention and reaction time. Also indicated pharmacological treatment with Seraltine could explain a slower reaction time of the low CAARS level group. Three participants indicated to be dyslexic, which is associated with more impaired or low working memory than the average person (Redick, 2014) and could contribute to not picking up on environmental cues. A participant indicated to treat ADHD currently with Methylphenidate, and another one indicated that ADHD was diagnosed in childhood. Both could potentially know how to treat their ADHD due to the period of diagnosis and the pharmacological aspect, which could influence their performance compared to untreated adults with ADHD. Therefore, both of those participants could have scores similar to the control group of low symptoms of ADHD, instead of showing a similar performance in studies with participants with ADHD on a similar task (Sidlauskaite et al., 2020). In addition, the meta-analysis of Homack (2004) indicates that the Stroop Task demonstrates sensitivity to executive function deficits like ADHD, autism and anxiety disorders but might not be able to discriminate between ADHD and other clinical groups consistently. The Stroop Task not differentiating between comorbidity and individuals with high ADHD scores could lead to similar slower reaction times by the low and medium CAARS severity group due to comorbidity influencing their performance.

Sample Size. The results in our study present small to no effect sizes with observed deficient power, indicating that the relationships between most of our variables were not meaningful and are limited in practical applications. The medium to large effect sizes for

ADHD levels is promising and could indicate a greater relationship between the CAARS severity levels and reaction time. No significant findings with a moderate effect size as in our first analysis of the CAARS levels could indicate that our sample is not large enough to reach statistical significance for the observed effect.

The variety and size of our study were very limited and small because our sample consists only of first-year university bachelor psychology students. Therefore, it is always suggested to replicate a study with a non-student sample (Peterson, 2001) to reassure external validity.

Categorical vs. Dimensional Approach

Despite a significant finding for cue manipulation, previous studies also found a significant finding between reaction times of participants with ADHD and healthy participants (King et al., 2007; Nigg et al., 2005). In contrast, in our research those with low severity scores have the slowest reaction time. The present study follows no categorical approach as the studies contradict our findings (Nigg et al., 2005; King et al., 2007; Sidlauskaite et al., 2020). Due to our study applying a dimensional approach, other results are expected due to the lack of a clear distinguishable clinical and healthy group.

Limitation in Methodology

Even though our sample consisted of participants, who were mostly not impaired by ADHD symptoms, Aarts et al.(2008) used in their study healthy participants to test proactive CC and found a significant difference for their cue manipulation. This different finding from our results can alternatively be explained by the difference in research design, the small sample size of the study, the low statistical power and the study's environment.

Research Design

Proactive thinking could not be captured in this study. Due to the lack of difference in alerting and informative cues, the participants in our study could have used reactive cognitive processes. Alternatively, we captured readiness as a process due to the structure of our Stroop Task. Experiments that found a significant difference in applying informative and alerting cues (Aarts et al., 2008; Sidlauskaite et al., 2020) required participants to press only two different buttons. In the present experiment, participants received a hint of whether the following stimulus would be congruent or incongruent but no information about the color. Therefore, they only knew if they had to react or not, but not which of the four buttons to press. In this case, readiness rather than proactive processes could have been recorded. The difference in experimental structure would explain why the current study found no significant difference between the cued conditions. Possibly if the informative cue contained additional information about the upcoming color, there would have been a difference in reaction time and more obvious proactive CC processes.

Experimental Manipulation. The manipulation of event rate in the Stroop Task for other research purposes could have potentially influenced the measurement of proactive CC. The manipulation increased the length of the study, and it was not possible to observe whether the five-minute break had been skipped by participants, which could impact the attention span of some individuals. After a visual investigation of the data set, it is noticeable that the effort of most participants was not kept consistent throughout the experiment, which is also observed in the standard deviations (Table 1), indicating fatigue or motivational deficits to absolve the experiment. Possible results for the alerting and informative cue might have been observed with only one trial focusing on measuring proactive CC without manipulating event rate due to shorter duration of the task, decreased data fluctuation, and improved focus of participants.

Differences in Study Environment. It has to be highlighted that contradicting studies (Aarts et al., 2008; Nigg et al., 2005; King et al., 2007; Sidlauskaite et al., 2020) were conducted in a controlled environment, unlike the present study, which took place in an online environment, due to COVID-19. The environment may explain some fluctuation of the reaction time data. In a laboratory environment, it can be controlled for distraction from noise, the outside, the time of the day when the experiment is done, homogeneity in devices like keyboards and internet connection. These lurking variables made it harder to reliably compare our results and potentially influenced the participants' performance.

Future Studies

For a future replication of the current studies to investigate the validity of our collected data, some minor adjustments should be made regarding sample size to lower the noise in standard deviation and possibly meet the assumption of normality. To capture proactive CC processes better, the Stroop Task should be adjusted. The participant could react to congruent trials with a left button and incongruent trials with a right button instead of clicking four different buttons to decrease thinking about which number is related to which color and increase the use of previous informative cues. Furthermore, the manipulation of event rate should be excluded to focus on the manipulation of cues solely. Then a difference between alerting and information-cued conditions should be expected. If the circumstances allow, future studies should not be held online to validate our results. At least a tertile of the sample should consist of individuals diagnosed with ADHD to fully capture varying levels of ADHD, and a fully or partly non-student sample should be considered (Peterson, 2001). Replications with larger samples size need to be conducted to investigate the validity of the insignificant findings and to increase the observed deficient power for the main effects of cues and gender.

Future studies of proactive CC processes are critical because if our sample with contradictory results is misleading, we will ignore the possibility of getting more insight into a possible sub-clinical group of ADHD who may have difficulties applying proactive CC. Further research of the degree of altered proactive thinking in adults with ADHD, sub-clinical ADHD, or low working memory (Redick, 2014) is very important since it could help with identifying and improving difficulties in applying proactive control. The PFC plays a significant role in academic, social and economic settings, which are all negatively impacted when proactive CC processes are altered (Billeke et al., 2014; Gonzalez-Gadea et al., 2016; Sidlauskaite et al., 2020). Therefore, further research is necessary to gain more knowledge into the CC processes to investigate the prevention of negative consequences and promotion of aids.

Conclusion

Due to our results being limited and observing contradictory data compared to previous research findings, no valid conclusion can be drawn. Why previous literature contradicts our results is questionable and could be based on a difference in methodology of the study environment, the dimensional approach or the experimental task design. In our study, reaction time increased with decreasing severity levels of ADHD. Additionally, men seemed to perform better than women, rejecting our hypothesis of females performing better than males. Overall, both hypotheses cannot be confirmed because proactive CC could not be captured in this study. Therefore, it remains inconclusive whether the application of proactive CC processes varies significantly for differing levels of ADHD severity and for different gender. From our study outcome, we can conclude that there is a possible association regarding different levels of ADHD severity and performance in the form of reaction time at the Stroop Task, but the direction is questionable and needs further investigation. Further research is necessary to shine a light on the relationship of proactive CC in varying severity levels of ADHD.

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