Linking Effort Allocation, Cognitive Control, and ADHD Symptomology in University Students

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Abstract

Prior research regarding attention deficit/hyperactivity disorder (ADHD) indicates neurocognitive deficits. The state regulation model (SRM) accounts for this deficit in terms of an insufficiency in allocating effort in suboptimal conditions to perform at an optimal level. The dual mechanisms framework of cognitive control accounts for these deficits in terms of differences in use of proactive (preparatory) and reactive (responsive) cognitive control. Cognitive control can be linked to the lower levels of information processing in the SRM. The current study investigated interactions between cognitive control, effort allocation, and how levels of ADHD may affect these systems. 49 university students completed the CAARS and Task-Switching Paradigm. T-CAARS ADHD index and mean RTs were administered. Using the dimensional approach for ADHD symptoms, RM-ANOVAs and RM-ANCOVA were computed to test the interactions. Effort allocation was manipulated through event rate (fast, medium, slow) and cognitive control through cue informativeness (informative, alerting, no cue). Results indicated a significant effect for the interaction between “cognitive control” (cue level) and “effort allocation” (event rate; p <.001) and a tendency between “ADHD levels” and “effort allocation” (p = .082). No effects were found for the interaction between “cognitive control” and “ADHD levels” and for the three-way interaction. The significant result and the tendency can be explained in terms of the SRM. The non-significant effects are explained inability to distinguish between proactive and reactive cognitive control. Future research should use more complex tasks, include a larger sample size, and distinguish between proactive and reactive cognitive control.

Keywords: ADHD, Attention Deficit/Hyperactivity Disorder, State Regulation Model, Effort Allocation, Dual Mechanisms Framework, Proactive Cognitive Control, Reactive Cognitive Control, Task-Switching Paradigm, University Students, Dimensional Approach

Linking Effort Allocation, Cognitive Control, and ADHD Symptomology in University Students

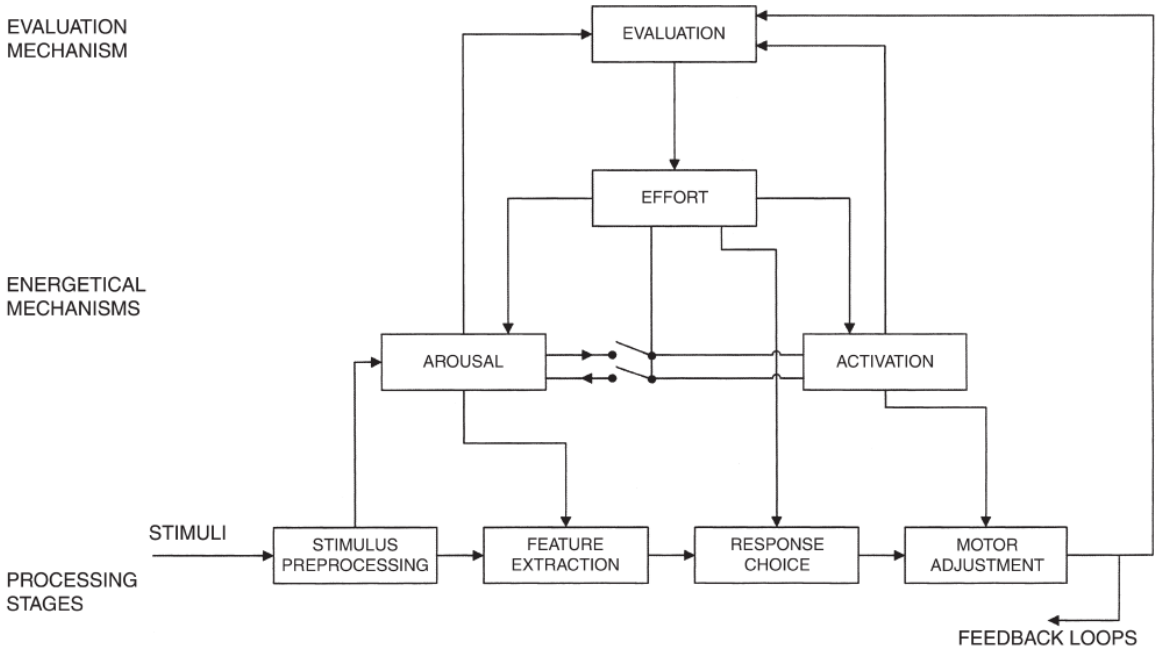
Attention Deficit Hyperactivity Disorder (ADHD) is a common neurodevelopmental disorder that affects around 5% of the population worldwide (Polanczyk et al., 2007). The core symptoms are inattentiveness, hyperactivity, and impulsivity are the core symptoms (American Psychiatric Association, 2013). ADHD diagnoses are most profound during childhood, with an estimated prevalence of 5% to 7% (Willcutt, 2012), but ADHD symptoms are also present in 2.5% of the adult population (Song et al., 2021; Weyandt & DuPaul, 2006; Willcutt, 2012). Within the college student population, the prevalence of ADHD is estimated between 2% to 8% (Weyandt & DuPaul, 2006) . ADHD symptoms have been linked to poorer academic performance, social and emotional functioning impairments, higher risk for other psychiatric problems (e.g., anxiety disorders), a worse quality of life and occupational difficulties (DuPaul et al., 2009; Faraone et al., 2021; King et al., 2007; Lee et al., 2016; O'Rourke et al., 2020; Wolf, 2001). As to minimise these adverse outcomes, it is crucial to understand the underlying mechanisms associated with ADHD in order to formulate appropriate interventions. Both adults and children frequently report deficits in neurocognitive mechanisms (Luo et al., 2019; Wolf, 2001), and it is speculated that some neurocognitive deficits are a core symptom of ADHD (Moffit et al., 2015). One method used to measure these deficits measures response times (RT) and error rates in neurocognitive performance tasks. An example of such task is the task-switching paradigm (TSP), which tests participants on their ability to flexibly adapt to changing situations by having to switch between one of two relatively simple tasks for across (Arabaci & Parris, 2019; Kiesel et al., 2010; Monsell, 2013). Many theories try to explain neurocognitive deficits, such as the Delay Aversion (Sonuga-Barke et al., 1992) and the Response Inhibition Hypothesis (Barkley, 1997), both of which focus on executive function deficits. Contrarily, the current study focuses on two different accounts. The first model, State Regulation Model (SRM), tries to explain the deficits in terms of difficulties in regulating energetic resources (i.e., effort allocation; Sergeant., 2005). The second account, the Dual Mechanisms Framework of Cognitive Control (DMC), focuses on the lower order of information processing, instead of higher order executive functions. The DMC focuses on two distinct modes of information processing that are used to maintain optimal performance (i.e., cognitive control; Braver, 2012).

State Regulation Model (SRM)

Based upon Sanders cognitive energetic model (1983; See Figure 1), the state regulation model (SRM) centralises around the notion that suboptimal conditions alter a person’s energetic state. The SRM postulates that task efficiency is controlled by a system that detects stimulation, evaluates internal activity levels, and tries to compensate when suboptimal activation levels are detected, in order to elicit optimal motor activation to perform certain tasks (Metin et al., 2017; Sergeant, 2005). The model comprises three levels. The first level consists of sequential cognitive information processing stages (i.e., stimulus encoding, feature extraction, response choice and motor adjustment; Sergeant, 2000; van der Meer, 2005). This basic process is influenced by the second level energetics pools: arousal, activation, and effort. Arousal is the time-locked phasic physiological response to information from incoming stimuli, whereas activation is involved in maintaining preparedness for motor activation (Mohamed et al., 2016; Sergeant, 2005; van der Meere, 2005). Arousal and activation can be affected by several internal and external factors (e.g., environmental stimulation, motivation, task complexity (Metin, 2013). Effort is defined as the system that regulates the energetic state in order to meet task demands by exciting and/or inhibiting arousal and activation (Sergeant, 2005; Sonuga-Barke, 2010). The energetic pool has a limited capacity and optimal performance depends upon appropriate allocation of this energetic source towards either the arousal or activity pool. The evaluation system that comprises the third level of the SRM and control effort. It monitors the discrepancies between the required activation state and the current arousal and activation levels. When a suboptimal state is detected, effort is allocated towards either the arousal or activation pool to shift towards the required state, defined as state regulation (van der Meere, 2005).

Figure 1

The Cognitive Energetic Model (Sanders, 1983)



Cognitive deficits in ADHD have been linked to executive functioning like inhibition difficulties (Barkley, 1997; Sergeant, 2005). However, deficits are also found in tasks that barely require executive functioning (Rommelse et al., 2007). Alternatively, the SRM of ADHD suggests that deficits may arise from a dysfunction in energetic state regulation (Sergeant, 2005). According to this model, deficits in effort allocation in ADHD will arise when the condition is suboptimal leading to under/or overaction and hence people with ADHD are unable to compensate by allocating more effort, causing a decrease in task performance (Metin et al., 2012). This can be tested by manipulating the inter-stimulus interval (ISI; i.e., the time in between trials), synonymous with the event rate (ER; Benikos &

Johnstone, 2009). A fast presentation rate is proposed to cause overactivation, whereas a slow presentation rate induces underactivation (Metin, 2013; Sergeant 2000; Sergeant, 2005). In order to maintain optimal performance and compensate for these altered energetic states, effort allocation is needed regulate motor activation (Metin et al., 2012; Mohamed et al., 2016). Numerous studies have indicated an increase in RT in the slow condition (Metin et al., 2012; Mohamed et al., 2016) or general slowing in the TSP (Wu et al., 2006). Another study found that the nonoptimal states can be influenced by the use of stimulant medication, improving performance under the slow ER, but further impairing performance in the fast ER (van der Meere et al., 2009). According to the SRM, fast event rates induce overactivation, that triggers fast (compared to slow condition) but inaccurate responding (Sergeant, 2005; van der Meere, 2005). The slow condition causes underactivation, increasing RTs. As the disproportionate slowing of RT in the slow condition has been most consistently found, the current study will focus on mean RT (Metin et al., 2012; Mohamed et al., 2016; Sidlauskaite et al., 2020; Wu et al., 2006).

Dual Mechanisms Framework of Cognitive Control

Another cognitive model that is used in explaining cognitive deficits in ADHD is the dual mechanisms of control (DMC) framework by Braver (2012), which focuses on cognitive control. Cognitive control can be defined as the ability to regulate thoughts and actions in accordance with a current goal in order to optimise performance (Braver, 2012). Unique of this model is that it distinguishes between two modes of cognitive control: proactive and reactive. Proactive cognitive control (PCC) is the preparatory mode that enables optimal cognitive performance over a sustained period of time (Mäki-Marttunen et al., 2019; Sidlauskaite et al., 2020). It involves top-down information processes of activating and retaining goal-relevant information before onset of an event in order to optimally prepare for an upcoming task. (Braver, 2012; Sidlauskaite et al., 2020). Reactive cognitive control (RCC) states that bottom-up control process of performance activate goal-relevant information after the onset of a target stimulus, after the adapt response behaviour accordingly. It also detects and resolves task interfering information to optimize performance. The two control mechanisms can be activated simultaneously, however task demands and individual characteristics can influence the preference of engaging in one mode over the other (Braver, 2012). Braver (2012) found that when the cognitive load is high, participants tend to rely more on the RCC, as PCC in itself is already more cognitively loading. Proactive and reactive cognitive control can be linked to the first level of the SRM, as they both involve information processing mechanism.

PCC and RCC can be tested by manipulating the informativeness of cues during cued task-switching tasks (King et al., 2007; Sidlauskaite et al., 2020). Informative cues give information about the upcoming task, providing advance preparation which is related to PCC (Sidlauskaite et al., 2020). Non-informative (alerting) cues signal that a target stimulus is coming up, without any preparatory information about the specific task. Alerting cues have several functions. Firstly, it serves as a control condition between the informative cue condition and trials preceded without any cue (no cue), in order to index PCC. As any cue also evokes general arousal, the alerting cue can be used to distinguish between the general arousing effect of the informative cue and added benefit from receiving preparatory information about an upcoming task (i.e., using proactive cognitive control; Sidlauskaite, 2020). Second, the alerting cue can also be used to index reactive cognitive control. As alerting cues provoke general arousal but do not contain information regarding the upcoming task, they can only react by being more aware a task is coming up (Sidlauskaite, 2020). A reduced mean RT on the alerting cue, compared to the no cue condition, would therefore indicate a reaction to the alerting cue (i.e., reactive cognitive control). RCC can be measured by calculating the difference in mean RT on alerting trials and the no cue trials. Thirdly, alerting conditions can be linked to the arousal phase of the SRM (Sergeant, 2005; Söderlund et al., 2007; Sonuga-Barke et al., 2010). The alerting acts as an external source of stimulation that increases arousal (Söderlund et al., 2007), as found in research linking background white noise to improved performance in children high on inattentiveness but impedes performance in the control group (Söderlund et al., 2007). In line with the SRM, the alerting condition may compensate for the underactivation in people with ADHD.

Cognitive deficits in ADHD may be linked to PCC or RCC. For example, Sidlauskaite et al. (2020) found that adults with ADHD make less use of informative cues than controls, indicating abnormalities in PCC. Arabaci and Parris (2019) also found something similar. When executing the TSP, participants high on inattentiveness tended to rely more on RCC, neglecting PCC. However, Grane et al. (2016) did not find such impairment and argue that proactive cognitive control is intact in adults with ADHD. These contrasting findings may suggest that impairment is not at the level of cognitive control, but rather at the higher order level of effort allocation, as theorized by the SRM (Sergeant, 2000; King et al., 2007; Benikos & Johnstone, 2008; Grane et al., 2016; Sidlauskaite et al., 2020). Indeed, research suggests a general slowing across task conditions (Kuntsi et al., 2001; King et al., 2007; Grane et al., 2016). Additionally, as the use of cognitive control strategies seem to rely on cognitive load (Braver, 2012), it may be that across different activation phases, the use of these strategies change. Little research has looked into the interaction between effort allocation and cognitive control but seems to be a valuable area of research.

The Present Study

The aim of the study is to explore the interaction between effort allocation and cognitive control, and whether levels of self-reported ADHD symptoms influence these processes. This is studied by examining the interaction between cue levels and event rates on mean RT in the task-switching paradigm (Sidlauskaite, 2020). To investigate the interactions of cognitive control and effort allocation with ADHD levels(separately and together), ADHD is entered as a covariance. This poses several hypotheses.

The Interaction between Effort Allocation and ADHD Levels

The first question is whether ADHD and effort allocation interact with one another. If the results are in line with previous research, it is expected that participants with higher levels of ADHD symptoms (highADHD) and will perform worse (increased mean RT) on the slow rate task due to underactivation, compared to participants with lower levels of ADHD (lowADHD; Metin et al., 2012; Mohamed et al., 2016; Sergeant, 2005; Wiersema et al., 2006).

The Interaction between Cognitive Control and ADHD Symptoms

The second question investigates whether an interaction exists between cognitive control ADHD symptoms. If participants use the informative cue appropriately, thus engaging in proactive cognitive control, a larger decrease in mean RT will be seen compared to alerting and no cue. Alternatively, if highADHD shows a deficit in the use of proactive cognitive control, no significant difference between the mean RT on the informative cue tasks and the alerting conditions is expected.

The Interaction between Effort Allocation and Cognitive Control

As the direct interaction between cognitive control and effort allocation has not been explored abundantly, there are no specific outcome expectancies. Suggestively, informative or alerting cues that are presented to test cognitive control may influence the activation state (i.e., effort allocation). These cues may compensate for the underactivation that is caused by the slow event rate, decreasing the RTs.

Furthermore, engaging in proactive cognitive control also requires extra effort and sustained attention (Braver, 2012). Consequently, if the task at hand is already cognitively demanding (i.e., underactivation in the slow event rate), participants may rely more on RCC by using the alerting condition as a source of arousal to compensate for the underactivation (Metin, 2016; Söderlund et al., 2007). A larger difference is expected in mean RT between the alerting condition and the no cue condition in the slow condition, compared to the medium and fast condition.

The Interaction between Effort Allocation, Cognitive Control, and ADHD Symptoms

Lastly, the interaction between effort allocation, cognitive control, and ADHD symptoms are investigated. Again, due to insufficient previous research on this topic, no specific outcomes are expected, and the question holds an exploratory purpose.

Method

Participants

The current sample consists of 49 (29 females) first year psychology students between the age of 18 to 27 (*M* = 19.9; *SD* = 2.1). They were recruited through the first year's research practicum pool (i.e., SONA studies). Participation in the study was compensated by receiving study credits. Several participants indicated having a diagnosis of ADHD (*N* = 3), attention deficits disorder (ADD; *N* = 1), depression (*N* = 8), anxiety (*N* = 7), a stress related disorder (*N* = 8), dyslexia or any reading disorder(*N* = 5), and/or a motor disorder (*N* = 1). As the study involves self-reported levels of ADHD symptoms within a non-clinical population, the dimensional approach of studying ADHD symptomology is adopted (Salum et al., 2014).

The Ethical Committee of Psychology (ECP) has carefully reviewed and approved the conduct of this study. The study was conducted in accordance with the National Code of Ethics for Research in the Social and Behavioural Sciences involving Human Participants as formulated by the National Ethics Council for Social and Behavioural Sciences (The Ethics Committee of Behavioural and Social Sciences, 2021).

Measures

Note: As this research was part of a larger study, a larger body of data was collected then was used for this particular research. This includes measures of the Weiss Functional Impairment Rating Scale (WFIRS), the Barkley Deficits in Executive Functioning Scale (BDEFS), and the Stroop Task.

The Conners' Adult ADHD Rating Scale (CAARS)

The CAARS is a self-report questionnaire tests the level of ADHD and consists of 66 questions and centralising around 4 main categories of ADHD symptoms (i.e., hyperactivity, impulsivity, inattentiveness, self-concept) and 3 subscales based on de DSM-IV (i.e., hyperactivity, inattentiveness, and impulsivity; APA, 1994). It also provides a total DSM index score and total ADHD index score. The CAARS is a 4-point Likert scale in which the participants indicated the frequency of experiencing the statements (0 = "not at all/never"; 3 = "very much/frequently"). Qualtrics software was used for administration of the responses. For the purpose of the study the CAARS total ADHD index score is used, as it was found to be a reliable measure of ADHD symptomology in adult life.

The CAARS total AHDH index was found to have high internal reliability ($\alpha > 0.85$) and interrater reliability ranged van .83 to .87 (Adler et al., 2008). Erhardt et al. (1999) found excellent test-retest reliability ($r = .89$) for CAARS subscales, and an overall diagnostic efficiency of 85%.

Task-Switching Paradigm (TSP)

Using OpenSesame (version 3.2), an adapted version of the task switching test was designed to test effort allocation and cognitive control (King et al., 2007). Jatos was used as the host-server in order to present the experiment to the subjects and collect the response data.

The complete task consisted of 208 fast event rate trials, 110 medium event rate trials, and 60 slow event rate trials. Each trial started with a cue presentation, lasting 800ms. The informative cue provides information about the upcoming task (i.e., "shape" or "colour"), the alerting cue consists of four hashtags (i.e., ####), and in the no cue condition, the screen remained black. After the cue presentation, the target stimulus was shown for 2200ms. The target stimulus had either the shape of a circle or a triangle and had the colour blue or yellow. The participants had to indicate on the keyboard either the shape (m = triangle, z = circle) or the colour (m = blue, z = yellow) of the target stimulus, according to the displayed task indicator presented above the target (i.e., the word “shape” or “colour”). The participants were instructed to react as quick as possible. Trials were excluded if the response time was longer than 2200 ms. For each trial, the RT and the error rate were measured. Following the response target, a black screen appeared. Depending on the event rate, the black screen was shown for 200ms (fast), 3000ms (medium), or 8000ms (slow). Between the event rate blocks of trials, the participant received breaks of 5 minutes in order to prevent fatigue. Including the breaks, this task lasted for about 45 minutes in total. The test included both mixed and unmixed blocks (spread equally across trials). Mixed blocks included randomized task switches or repetition, whereas the unmixed blocks existed of an equal amount of repetition of both tasks, switching once halfway. For this study, the mean RTs from the unmixed trials were investigated as controls for set-shifting, another cognitive ability that was not at interest of this study.

Effort allocation was manipulated by using different inter stimulus intervals (i.e., event rate): fast (200ms), medium (3000ms) and slow (8000ms), as seen in previous studies (Sanders, 1983; Wiersema et al, 2006; Sonuga-Barke et al., 2010). Cognitive control was manipulated through the use of different cue conditions (i.e., informative cue, alerting cue, and no-cue), in accordance with previous studies (King et al., 2007; Sidlauskaite et al., 2020). The trials containing the informative cue are used to test proactive cognitive control.

Because this is an adapted version of the well-established task-switching paradigm, sufficient validity can be expected (King et al., 2007; Monsell, 2003; Sidlauskaite et al., 2020). Research on a different adaptation of the task also indicated excellent internal consistency (*r* = 0.92) and good test-retest reliabilities between .78 and .82 (Eckart et al., 2021).

Procedure

The tests were administered online in the participants’ preferred environment and test administration was spread over two sessions. During the first session, participants first received an informed consent sheet, in which they were informed about the purpose of the study, confidentiality and the possibility of discontinuing the study at any time. After the participants agreed to the informed consent terms, they filled in the CAARS, the WFIRS, and the BDEFS. This took about 45 minutes. In the following session, the Stroop Task and the TSP were administered. They both lasted for about 45 minutes, including 5-minute breaks between every block of trials and between the tasks. First the Stroop task was completed. When starting the TSP, the key instructions were given first. The keys with the corresponding meaning were indicated and were displayed throughout the task. The task started with 14 practice trials, so participants became familiar with the task. They received feedback after the practice trials. After completing the practice trials, participants continued with the experimental trials, in which no feedback was given.

Data Analysis

First, assumptions of Repeated-Measures ANOVA were tested and corrected for if violated (see Appendix A). The mean and the standard deviation of the reaction time (ms) of the cue conditions and ER were calculated. Task effects on the task switching paradigm were calculated through RM-ANOVAs, to make sure cue level and event rate manipulation are sufficient to test cognitive control and effort allocation, respectively. The task effect of the task type (colour vs. shape) indicated high comparability between task types. For testing the effect of (ER), slow, medium, and fast were entered as within-subjects factors. For cue manipulation, informative, alerting, and no cue were entered as the within-subject factors. For the purpose of this study, T-CAARS ADHD index score was entered as a covariate.

To test the interaction between effort allocation and ADHD symptoms, a RM-ANCOVA was computed entering ER and ADHD index. For the interaction between cognitive control and ADHD level, the same analysis was computed, but entering cue levels instead of ER. To explore the interaction between cognitive control and effort allocation an RM-ANOVA was computed entering cue levels and ER. Lastly, in order to explore whether the interaction between cue levels and event rate is influenced by levels of ADHD symptoms, a three-way interaction between the three levels of event-rate, the three levels of cue informativeness and ADHD index was computed using a RM-ANCOVA. Effect sizes using partial eta squared and observed power using $\alpha = .05$ were also calculated.

Results

Data Screening and Preliminary Analysis

Three participants failed to complete the CAARS and hence are therefore not included when analysing interactions with regarding the ADHD analyses ($N = 46$, $M = 19.7$, $SD = 1.9$). The total sample for the other analyses remained $N = 49$. The T-CAARS ADHD index scores appears to be normally distributed (Figure 2). Mean RT and standard deviations from the ER conditions and cue conditions are presented in table 1.

Figure 2

Histogram with Normal Curve of ADHD Index Scores

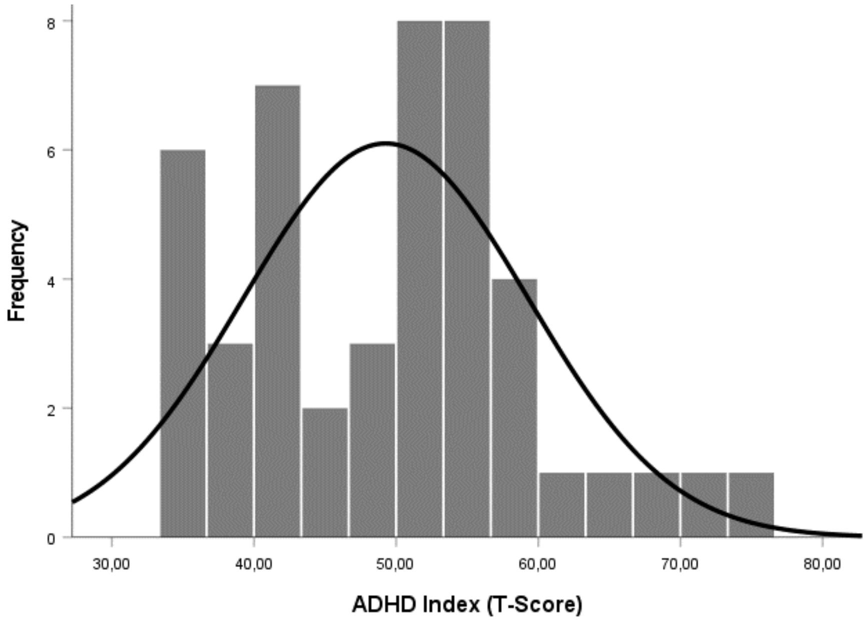


Table 1

Mean Reaction Time and Standard Deviation for Event Rate and Cue Level

Variable	*M*	*SD*
Event rate		
Fast	723.286	192.725
Medium	848.914	219.773
Slow	930.345	233.132
Cue level		
Alerting	867.354	175.141
Informative	697.924	209.051
No cue	937.267	182.198

Task Effects in the Task-Switching Paradigm

Task Type

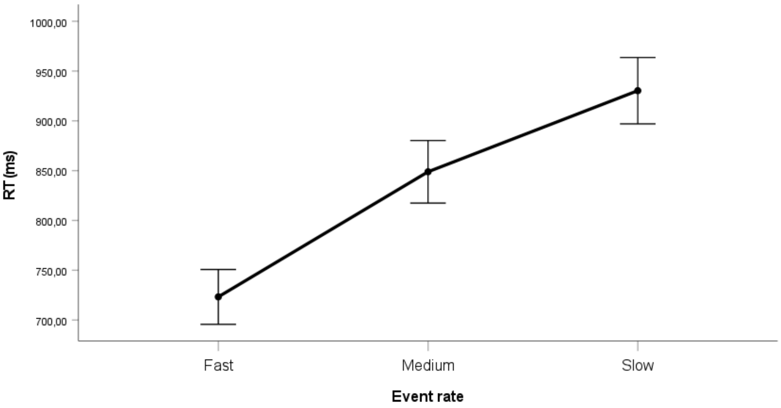
No significant differences were found between the task types, $F(1, 44) = 0.248$, $p = .621$, $\eta_p^2 = .006$, $1-\beta = .078$.

Event Rate

RM-ANOVA with a Huynh-Feldt correction revealed a significant difference for mean RT of the event rates, $F(1.848, 88.693) = 26.461$, $p < .001$, $\eta_p^2 = .355$, $1-\beta = 1$. Participants were fastest in the fast condition and slowest in the slow condition (Figure 3). For an overview of mean RTs and standard deviations, see table 1.

Figure 3

Line Graph of Mean Response Time of Event Rate



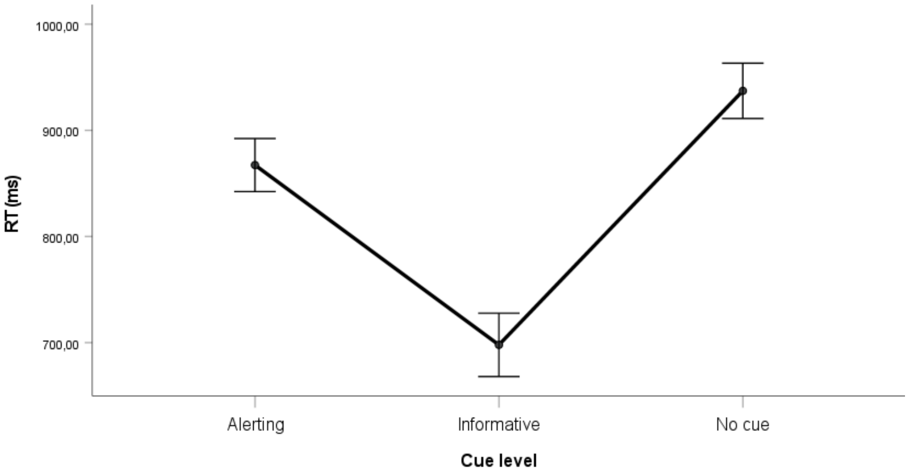
Note. Error bars Indicate +/- 1 Standard Error

Cue Level

RM-ANOVA with a Huynh-Feldt correction indicated a significant difference between the mean RT for cue levels, $F(1.653, 79.355) = 183.776$, $p < .001$, $\eta_p^2 = .793$, $1-\beta = 1$. The participants were fastest in the informative condition and slowest in the no cue condition (Figure 4). For an overview of mean RTs and standard deviations, see table 1.

Figure 4

Line Graph of Mean Reaction Time of Cue Level



Note. Error Bars Indicate +/- 1 Standard Error

Hypothesis Testing

Effort Allocation and Level of ADHD Symptoms

RM-ANCOVA found that ER tends to interact with ADHD index scores on RT, $F(2, 88) = 2.573$, $p < .082$, $\eta_p^2 = .055$, 1-β = .501. Further exploration by constructing scatterplots revealed a slight negative relationship for both medium and fast event rate between mean RT and ADHD-index scores ($R^2 = 0.034$, $R^2 = 0.023$). For the slow condition, a slight positive relationship between mean RT and ADHD index scores was found ($R^2 = 0.009$). See appendix B for scatterplots.

Cognitive Control and Level of ADHD Symptoms

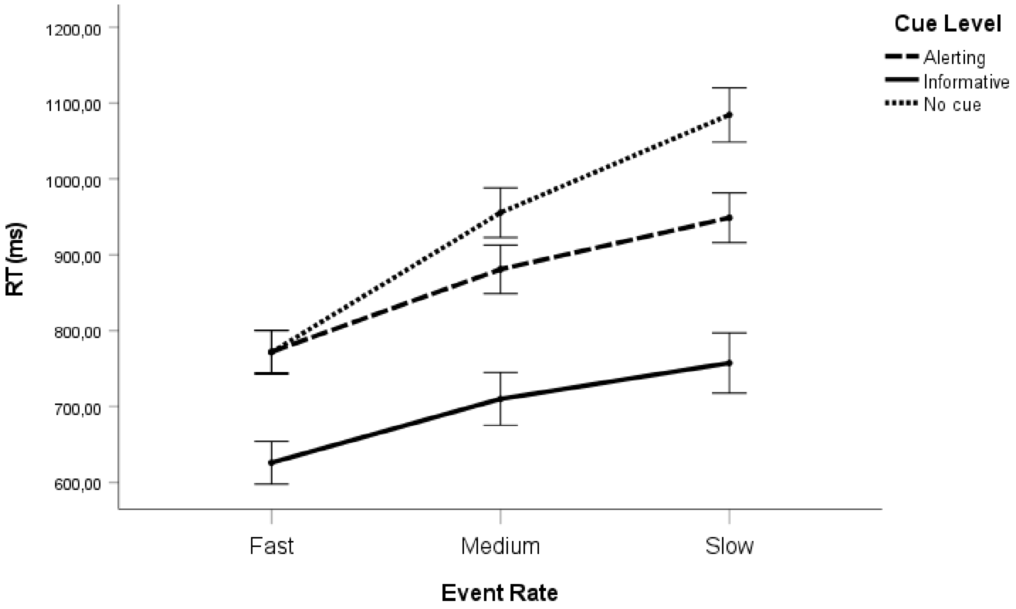
RM-ANCOVA using a Huynh-Feldt correction indicated no significant interaction between cue level and ADHD index on mean RTs, $F(1.675, 73.684) = 2.049$, $p = .144$, $\eta_p^2 = .045$, 1-β = .374.

Effort Allocation and Cognitive Control

RM-ANOVA with a Huynh-Feldt correction revealed an interaction between cue levels and event rate on mean RT, $F(3.621, 173.825) = 14.845$, $p < .001$, $\eta_p^2 = .236$, 1-β = 1 (see Figure 5). The informative cue condition shows significantly lower mean RTs on every ER. In the fast condition, the alerting and no cue are not significantly different, in the medium condition this difference becomes significant and in the slow condition, this difference is even bigger. For a pairwise comparison with the mean differences and significance levels between the conditions, the reader is referred to appendix C.

Figure 5

Line Graph of the Interaction Between Event Rate and Cue Level



Note. Error Bars Indicate +/- 1 Standard Error

Effort Allocation, Cognitive Control, and Level of ADHD Symptoms

RM-ANCOVA with a Huynh-Feldt correction indicated no significant three-way interaction between event rate, cue level and ADHD index on mean RT, $F(3.761, 165.495)$, $p = 0.117$, $\eta_p^2 = .041$, $1-\beta = .548$.

Discussion

The current study investigated the interaction between cognitive control, effort allocation and levels of self-reported ADHD symptoms in the student population. The research has investigated the direct link between these concepts, and will help to better understand how these effort allocation and cognitive control affect cognitive performance in people with lower and higher levels of ADHD symptoms. Consequently, this will be additive to the body of knowledge regarding cognitive deficits shown in ADHD, especially within a non-clinical university population. The latter point differs from prior research that mainly centralises around the comparison between clinical participants and control groups. However, accumulating evidence calls for the use of a more dimensional approach towards ADHD symptomology (Coghill & Sonuga-Barke, 2012; Salum et al., 2014). Taking the dimensional approach enables research of ADHD symptomology in subclinical and general population. The results show an interaction between cognitive control and effort allocation and a tendency between effort allocation and ADHD. No significant results were found regarding the interaction between cognitive control and ADHD and the three-way interaction between cognitive control, effort allocation and ADHD.

Effort Allocation and Levels of ADHD Symptoms

The first question discussed the interaction between ADHD symptoms and effort allocation. The tendency between ADHD symptoms and event rate indicate that indeed may be an effect of ADHD on effort allocation. It should be noted that due to the relatively small sample size, the power was rather low. For now, the interpretation must be held with caution. The effect shows that higher levels of ADHD symptoms have a different effect on the event rate, compared to participants with lower levels of ADHD. In the fast and medium event rate, highADHD are related to slightly faster responses, but slight worse performance in the slow event rate. This is in line with the SRM (Sergeant, 2005) . The slow ER is proposed to induce underactivation, for which participants have to compensate by allocating enough effort towards the activation pool to regulate motor activation (Metin et al., 2013). However, it seems that highADHD are not as able to compensate for the underactivation compared to lowADHD, indicating a dysfunction in effort allocation (van der Meere, 2005).

Alternative explanations may also account for this tendency. First, the task may not be sensitive enough. As the unmixed block is much easier as it mostly involves repetitions, unlike the mixed task that includes both switches and repetitions. Regulation activation may therefore also become easier. A more complex task (such as the mixed block) may be more sensitive in finding a significant effect. Future research should take task complexity into account when designing a study. Furthermore, university students are also among the higher functioning people within the general population (Wolf, 2001). Therefore, they may be able to compensate better for underactivation than people from the general population. The tendency would then suggest the true effect within this specific population. Further research should also look more into the effects within the general adult population compared to the university population and test whether this effect is true.

Cognitive Control and Level of ADHD Symptoms

No significant interaction was found between cognitive control and ADHD symptoms. Several explanations may account for this finding. First, this finding supports the notion the deficits are not at the level of first order information processing, but at the higher level of effort allocation, as proposed by the SRM (Sergeant, 2005; van der Meere, 2005). Second, as all the cues were entered simultaneously into the calculation, one cannot distinguish properly between the effects of ADHD on proactive and reactive cognitive control, separately. Hypothetically, ADHD symptoms may interact differently with the proactive and reactive cognitive control, and causes a cancelling out effect as demonstratedthe current analysis. For example, highADHD may engage in less PCC and more in RCC, compared to lowADHD. Post-hoc analyses may provide insight into this, but due to need for maintaining simplicity in the current study, it was decided against it. It is highly recommended that further research add post-hoc analyses or study reactive and proactive cognitive control separately with regards to ADHD symptomology.

Effort Allocation and Cognitive Control

The interaction between cognitive control and effort allocation indicates that across different event rates, differences scores between the mean RT between the cue levels alter (see Appendix C). Across all event rate conditions, significantly lower RTs are found for the informative cue condition, compared to the alerting condition. This indicating that participants do not only use the cue as external stimuli for general arousal, but also extract information from the stimuli to prepare for the upcoming task, indicating engagement with proactive cognitive control (Braver, 2012). Across the event rates, a general slowing can be spotted for the informative cue condition. RTs are fastest for the fast condition, medium for the medium condition and slowest for the slow condition. This effect can be explained through Braver's DMC (2012) and Sander's CEM (1983). According to Braver, the use of proactive cognitive control is linked to the cognitive load. PCC already requires more cognitive resources, and the slow event rate is also found to increase cognitive demands required to maintain optimal performance (Braver, 2012; Metin et al., 2012; Sonuga-Barke, 2010). This interaction may explain why mean RT for the informative cue increases during the slow condition compared to the fast condition.

Pairwise comparisons between cue levels on the event rates indicate that the mean RT differences between alerting cue and no cue increase from the fast to slow condition. This can be explained through effort allocation. The fast presentation rate in the fast condition in itself is already vastly alerting and a non-informative (alerting) cue will therefore not induce an additional effect. For the slow condition, the task itself is not alerting. The decrease in mean RT on the alerting condition in the slow condition shows a reaction to the alerting cue, indicating reactive cognitive control (Braver, 2012; Sidlauskaite, 2020). This is also in line with the finding that when the task demands become higher, RCC is more engaged (Braver, 2012). This is also evidence for the alerting cue being used in the arousal phase of the SRM (Sergeant, 2005; Söderlund et al., 2007; Metin et al., 2016). The alerting cue is used as an external source for increasing arousal, so more energetic resources are allocated towards motor activation, compensating for the underactivation (Söderlund et al., 2007; Metin et al., 2016). Future research could look into this by manipulating the external tools that can be used for arousal and manipulating activation levels (e.g., manipulating ER).

Effort Allocation, Cognitive Control, and Levels of ADHD Symptoms

No three-way interaction was found between effort allocation, cognitive control, and ADHD symptoms. Several reasons may explain this finding. First, it may be that this non-significant effect is true, meaning levels of ADHD do not influence the interaction between cognitive control and effort allocation, or that this interaction is not present in subclinical levels of ADHD. Research using clinical samples could provide insight in this. Alternatively, it may be that the deficit in ADHD is only present in one of these cognitive mechanisms, for example in effort allocation (King et al., 2007; Sidlauskaite, 2020, Wu et al., 2006). As aforementioned, task simplicity and higher functioning characteristics of the university population also have influenced these findings, by being able to compensate better. Lastly, it may also be the case that a distinction must be made regarding proactive and reactive cognitive control in order to find a three-way interaction, as mentioned earlier.

Limitations

The current study also consists of several limitations. The first limitation involves the relatively small sample size. Due to the small sample size, the variance in levels of ADHD was limited and the power was low. Future research should aim for larger samples to increase power and add more variability in levels of ADHD, making it more representative of the population. Convenience sampling was used to recruit the participants, which only consisted of university students. This poses problems regarding external validity. However, as university students may differ from the general population (Wolf, 2001), but are still at risk of aversive outcomes due to ADHD symptomology (DuPaul et al., 2009; Weyandt & DuPaul, 2006), they may be an appropriate target population. Research on university students with ADHD may provide more insight into how compensatory mechanisms and differences to both general and non-clinical populations (Wolf, 2001). Additionally, the homogeneity within the student population naturally controls for potential confounding factors such as age, IQ, and other demographic variables (Mohamed et al., 2016).

Another limitation of the study is the online administration of the tasks. This setting induced some problems regarding experimental control. Participants could have behaved in different ways during the tasks (e.g., taking longer breaks, playing background music). Different internet connections or wiring within the devices may influence the outcome, as the results depend on milliseconds in reaction time. Future research should ideally use in-person testing to control for environmental influences.

Although self-reports are susceptible to under- or overevaluating symptoms severity and depends on recall of past experiences, which has a modest reliability (Bellezza, 1984), the psychometric properties of the CAARS indicated good internal consistency, good internal and inter-rater reliability, and sufficient predictive power (Adler et al., 2008). The CAARS also enables testing ADHD symptomology in the general adult population.

Lastly, task used may not have been complex enough. The unmixed condition is easier than the mixed cognition, which much higher in cognitive load (Monsell, 2003). Therefore, the current test may not have been sensitive enough to find effects. Future research using more complex tasks may provide more insight into these cognitive processes.

Conclusion

The current study is early in directly testing the interaction between cognitive control and effort allocation, and the influence of ADHD symptomology. The results suggest an interaction between cognitive control and effort allocation. Participants engaged in proactive cognitive control, regardless of ADHD symptoms. Furthermore, results indicate that participants engage more in reactive cognitive control in slow condition to increase arousal and enable more effort allocation towards the motor activation, to compensate for underactivation. The tendency between effort allocation and ADHD may provide evidence for the SRM of ADHD, and that highADHD have more difficulties compensating for underactivation. Research using larger sample sizes should explore this tendency further. Lastly, no interaction between cognitive control and levels of ADHD (and effort allocation) were found. Further research should look into the interaction of effort allocation with proactive and reactive cognitive control separately.

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Appendix A

Assumptions Check for RM AN(C)OVA

First the data was check for outliers. Using Cook’s Distance, 2 outliers were found. However, as they do not seem to affect the data significantly, they were not removed.

The first assumption of RM ANOVA is the independence of observations. As all participants completed this task on their own, it can be assumed that this assumptions are not violated.

The second assumption of RM ANOVA is that the data should be approximately normal. The distribution of the CAARS index was found to be approximately. Furthermore, as posed by the Central Limit Theorem, sample sizes larger than 30 are theorised to be sufficiently large for using RM ANOVAs (Agresti, 2009). Furthermore, transforming results that would normally be done after violation of normality has been detect offer no more power (Schramm & Rouder, 2019). There the current data was found the be appropriate for data analysis without need for transformation.

The third assumption of RM ANOVA is sphericity (i.e., the standard deviation of the distribution of the difference between two paired observations is identical for each pair of groups; Agresti, 2009). For most measures the sphericity appeared to be violated (p <.05), as indicated by Mauchly's Test of Sphericity. All measures that violated the sphericity assumptions indicated ε > .75, for which Huynh-Feldt corrections are used. If a measure violation the assumptions, this was indicated by adding “correction with a Huynh-Feldt” in the results. If this is not stated, sphericity was not violated and the “sphericity assumed” was used.

Appendix B

Figure B1

Scatterplot of Correlation of Mean Reaction Times in the Fast Condition and ADHD Index Score

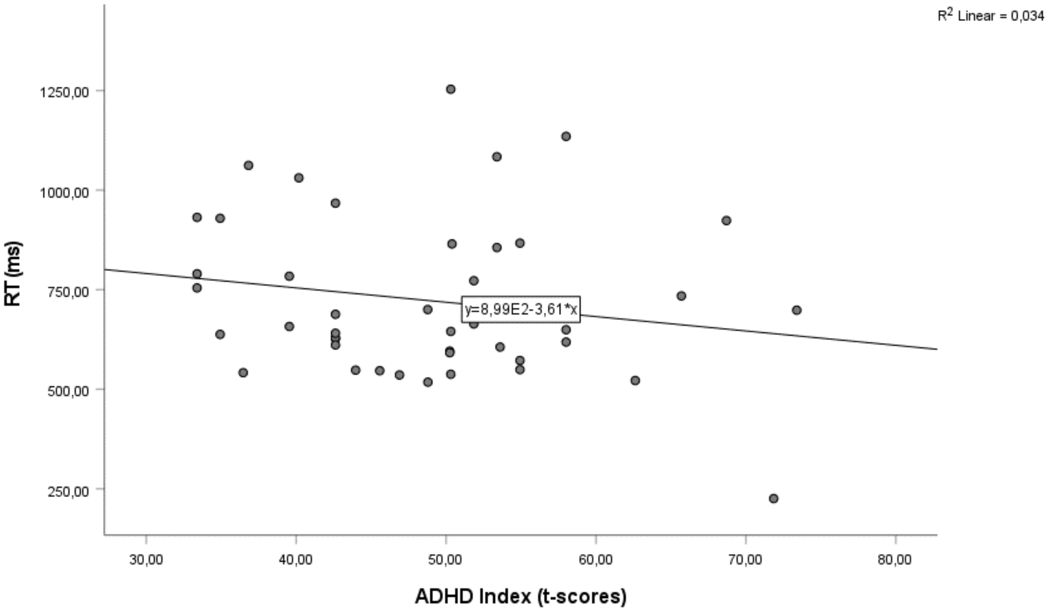


Figure B2

Scatterplot of Correlation of Mean Reaction Times in the Medium Condition and ADHD Index Score

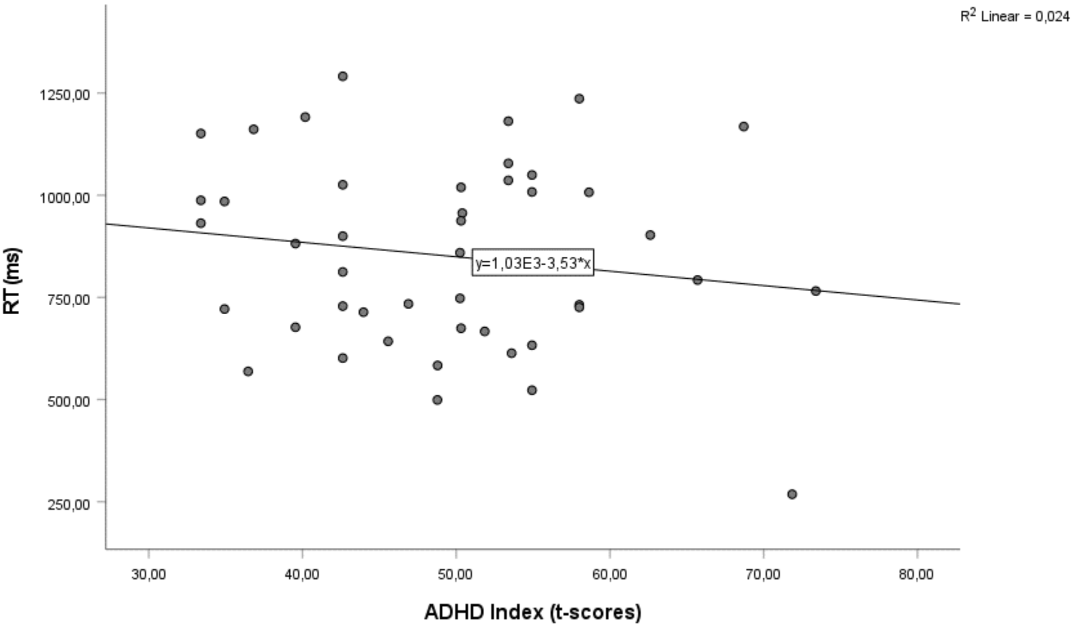
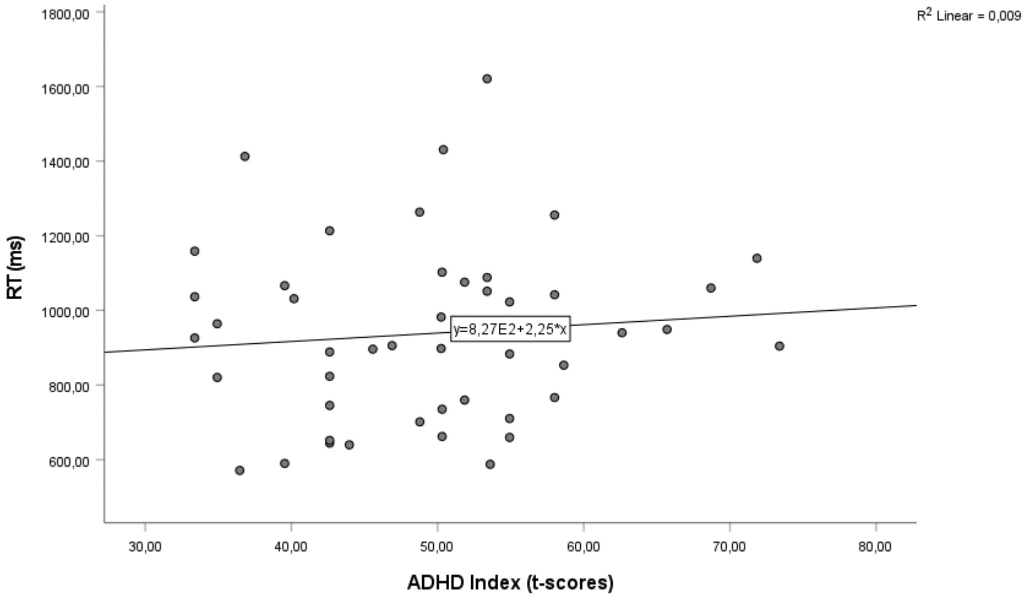


Figure B3

Scatterplot of Correlation of Mean Reaction Times in the Slow Condition and ADHD Index Score



Appendix C

Table C1

Pairwise Comparison of Mean RTs of Interaction Effect between Event Rates and Cue Levels

Event Rate	Cue Level	*Mean Difference*	*SE*	P^a
Fast	Alerting – informative	146.003*	11.201	<.001
	Alerting – no cue	0.649	10.685	1.000
	Informative – no cue	-145.345*	13.679	<.001
Medium	Alerting – informative	170.831*	21.722	<.001
	Alerting – No cue	-74.680*	13.433	<.001
	Informative – no cue	-245.511*	19.754	<.001
Slow	Alerting – informative	191.457*	22.461	<.001
	Alerting – no cue	-135.707*	23.781	<.001
	Informative – no cue	-327.164*	27.525	<.001

Note: Based on estimated marginal means.

SE = Standard Error

a. Adjustment for multiple comparisons using Bonferroni.

*The mean difference is significant at the .05 level.