ADHD Symptomatology in Students and Executive Functions, an Experimental Study

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Abstract

Until recently, Attention-Deficit/Hyperactivity Disorder (ADHD) was considered a temporary childhood condition. This gap in knowledge has led to misdiagnosis in adults. Executive functions, which are complex neuropsychological processes, are known to be connected to ADHD. However, the nature of their link is yet unclear. Two relevant theories underline the importance of inhibition and motivation as key deficits to the disorders' symptoms. The aim of this study was to investigate the association between ADHD and executive functions. Particularly of interest was whether specific executive functions played a role in ADHD symptomatology. To test this, Conners' Adult ADHD Rating Scales (CAARS) and Executive Functioning Index Scale (EFI) were administered to 394 students. Further, an adapted Go/No-Go task with fast and slow event rates was employed to 41 participants. Students with more ADHD symptoms reported higher levels of daily executive dysfunction and more problems with inhibition, but no issues with motivational drive, as indicated by the questionnaires. Significant differences in speed and variability of responding were found between ADHD groups, indicating key deficits in motivation. Accuracy was similar throughout groups, which suggested that students did not have problems with impulsivity. No congruency was found between the results of task performance and questionnaires. Future studies should focus on motivational deficits in adult ADHD and more ecologically valid assessment measures of executive functions.

Keywords: ADHD, executive functions, Go/No-Go task, students, state regulation, motivation, inhibition

ADHD Symptomatology in Students and Executive Functions, an Experimental Study

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder considered to be a temporary childhood condition until the last decades (Canela et al., 2017). Whereas recently, it was found that around 65-85% of children previously diagnosed with ADHD will continue to experience symptoms as adults (Bordoff, 2017). Most importantly, unless ADHD is detected early on, most adults go undiagnosed. The diagnostic criteria for ADHD, according to the DSM-5, specify that a persistent pattern of inattention and/or hyperactivity and impulsivity that interferes with functioning or development must be present for a six-month period and that the onset of symptoms characteristic to the disorder should be prior to the age of 12 (American Psychiatric Association [APA], 2020). Moreover, the symptoms must be observed in two or more settings (such as at home, school, work, or during other activities), while these visibly reduce the quality of functioning in social, academic, or occupational settings. Finally, equally important in the DSM-5 is that symptoms should not appear exclusively during schizophrenia or related psychotic disorders and should not be more adequately explained by other conditions such as mood or anxiety-related disorders.

Problems with ADHD diagnosis in adults

Undoubtedly, there are numerous issues with adult ADHD diagnosis, despite the criteria of the DSM-5 being universally recognized by clinical experts. A well-known problem is the comorbidity with other disorders such as depression and anxiety, whose symptoms overlap with those of ADHD (e.g., Anastopoulos et al., 2018; Drake et al., 2019; Bordoff, 2017). Since the ADHD diagnosis was originally designed for children, the inattentiveness symptoms of ADHD may appear coincidentally along mood and affective disorders that have late adolescent or adult onset (Barkley et al., 2010). For instance, in their study about comorbidity among first-year students with well-defined ADHD, Anastopoulos et al., (2018) found that 55 % of those diagnosed had at least one current comorbid diagnosis, while 32% had two or more (Anastopoulos et al., 2018).

Further, identifying ADHD symptoms in adults is especially challenging as their brains mature, because they acquire coping strategies and normalize their symptoms to compensate for their shortcomings (Drake et al., 2019). Adults may potentially become aware of their symptoms only when confronted with a more demanding environment, such as when they follow a university program (Ramsay & Rostain, 2007; Bordoff, 2017). Another problem is the onset age of 12 required for the diagnosis of adults. Compared to children, accessing information from others about the onset of symptoms may not be viable, and parent or observer reports do not exclude the possibility of distorted responses either. This is true especially in university students, even though observer- or parent-reported symptoms would provide multi-source as well as multi-setting information which can be used for diagnosis (Drake et al., 2019).

Dimensional Approach to ADHD

Despite advances in diagnosing and understanding ADHD, researchers are still far from developing a full etiological model of the condition (Marcus & Barry, 2011). Applying the traditional categorical method of diagnosis, an individual who enters the clinic with symptoms of ADHD may be given a diagnosis or not depending on whether their behavioral symptoms fit the categories of the DSM-5. However, ADHD is constantly referred to in the literature as a heterogeneous disorder due to different presentations of the combination of symptoms described in the criteria of the DSM-5 and the type of neurocognitive deficiencies that vary greatly from an individual to another (Luo et al., 2019; Nigg, 2005; Ory, 2017). There are both advantages and disadvantages for investigating ADHD as a discrete or continuous entity (Marcus & Barry, 2011). The dimensional approach to psychopathology is when individual symptoms of the disorder are considered to exist on a continuum of normal human behavior. In a taxometric analysis conducted by Marcus and Barry (2011), symptoms of inattention, hyperactivity/ impulsivity, and ADHD were found to have a dimensional latent structure. Later, due to the inconsistencies in the findings of neurobiological studies of ADHD, The National Institute of Mental Health released their Research Domain Criteria in which a switch toward symptom-level ADHD research is recommended (Ory, 2017). Considering these findings and the growing interest in cognitive level research of ADHD, supplementing the traditional yes or no approach with the dimensional approach might be useful.

In fact, Conners et al. (1999) designed a multi-dimensional assessment of adult ADHD. Conners' Adult ADHD Rating Scales (CAARS) is a valid test for assessing current adult ADHD symptoms across cultures (Mohamed et al., 2021) and includes both DSM-5 symptoms subscales (inattention, hyperactivity/impulsivity, ADHD) and related symptoms subscales (inattention/ memory problems, hyperactivity/ restlessness, impulsivity/ emotional lability, and problems with self-concept). Because there is limited research done on ADHD as a multi-dimensional disorder, CAARS will be used in the present study.

ADHD and Executive Functions in children and adolescents

In the past decades, the idea that executive functions are closely related to ADHD has received considerable attention in clinical neuropsychological research (Crosbie et al., 2008). In fact, it has been demonstrated repeatedly that children with ADHD perform poorly on tasks that measure some aspect of their executive functions (Matthews et al., 2014). Yet, it is still unclear how the two are associated, and more specifically, which executive function characteristics observed in people with ADHD can be linked to the behavioral symptomatology they experience (Arellano-Virto et al., 2021). The term "executive function" (EF) is presented in most journal articles as the neuropsychological process needed to sustain complex problem-solving toward the completion of a future goal (Barkley, 2010; Willcutt et al., 2005). The recent prominent taxonomy of Hofmann et al., (2012) identified three basic EFs: working memory operations (ability to store information in an active, easily retrievable state), inhibition (capacity to purposefully suppress dominant, reflexive, or predominant reactions when needed) and mental set shifting (capacity to transition between several tasks).

Several researchers who investigated the association between ADHD and EFs believe that specific EF deficits exist in people with ADHD (Barkley, 1997). However, the extent to which these are a primary deficit has been difficult to establish due to the heterogeneity of the ADHD population, its subtypes, and the psychometric quality of neurocognitive tasks (Willcutt et al., 2005). In a meta-analysis conducted by Willcutt et.al., 2005, involving studies using response inhibition, working memory, and set-shifting tasks, researchers found that most correlations between ADHD symptomology and EF deficits were significant but small to medium in strength. Results show that although EF deficits appear to be one of the most significant shortcomings in the overall neuropsychological etiology of ADHD, they are not the primary issues. In fact, it is further emphasized that the neuropsychology behind many developmental psychopathologies is complex and multivariate, and a single sufficient cause is highly unlikely for most disorders.

Executive functions in students with ADHD

Although studies of ADHD and EF in student populations are limited, research in this area has high implications on academic performance issues in adults with ADHD as well as the higher risk of mood disorders associated with this period of life (APA, 2013). Although the number of people with ADHD who finish university has been growing in the past decade (Weyandt et al., 2013), Dvorsky and Langberg (2019) found that university students with ADHD have much lower grade point averages (GPAs) compared to their peers, are more likely to be put in probationary status, and are less likely to receive a bachelor’s diploma. In this study, students diagnosed with ADHD had an overall semester GPA of 2.30, while 21% had faced academic probation, and 29% had dropped out of at least one course.

The completion of a university degree brings about contextual changes that necessitate individuals with ADHD to effectively apply complex EF skills, including self-regulation, planning, and behavior organization (Dvorsky & Langberg, 2019). These skills are not only vital during educational activities but also in the day-to-day tasks associated with living away from caregivers (e.g., planning meals, cleaning, studying for exams, and completing assignments). It is well-established that students must autonomously handle a variety of tasks that demand goal-directed activity and organizational abilities (Mohamed et al., 2021). Consequently, researchers investigated the role of EF in relation to ADHD symptoms and academic achievement, employing both cognitive tasks and self-reported measures (Barkley & Murphy, 2010).

To demonstrate, Dvorsky and Langberg (2019) recently found in their longitudinal study that the organization and motivational features of EF seem to be especially significant in predicting the academic and general impairment of college students with ADHD. In another relevant study, when compared to the control group, students with ADHD reported substantially greater levels of executive dysfunction in the areas of inhibition, shift, emotional regulation, self-monitoring, initiating, working memory, planning, task management, and material organization (Weyandt et al., 2013). Interestingly, when the same students were tested on computer-based measures of sustained attention and behavioral inhibition such as Continuous Performance Tasks (CPTs), only a few differences in task performance were found. This discrepancy in findings will be addressed in the present study, as students with different levels of ADHD will be tested both behaviourally, using a questionnaire, and cognitively, using a cognitive performance task.

Lastly, Mohamed et al. (2021) studied the association between ADHD symptomatology and mood disorders in university students in the context of EF and daily life impairments through self-reports. EFs were measured through Executive Functions Index Scales (EFI), a highly used questionnaire created for both clinical and non-clinical populations that captures EF such as Motivational Drive, Organization, Impulse Control, Empathy, and Strategic Planning. Their results showed that when EF and daily life functional deficiencies were controlled for, the association between ADHD and mood symptoms was diminished dramatically. These findings suggest that investigating EF in students with ADHD symptoms could bring to light new knowledge involving models and theories of ADHD that emerged in the past years.

Theories of ADHD

Despite numerous endeavors to clarify the connection between executive functions (EFs) and symptoms of ADHD, researchers were unable to come to a consensus on whether EF deficits are a consequence, antecedent or an additional symptom of ADHD. This lack of agreement hinders our understanding of the interplay between EFs and ADHD. Two theories are particularly important in this case. The theory of Barkley (executive dysfunction theory, 1997; self-regulation theory, 2010) postulates that inhibition and executive functioning are the core issues in ADHD, while the theory of Van der Meere (the state regulation deficit model, 2005) assumes that motivation is the main problem in ADHD.

Inhibition and Executive Dysfunction Theory

Barkley (1997) concluded, in his efforts to unify existing literature on core processes involved in ADHD driven by the lack of a standard, large-scale theory, that response inhibition deficiencies, such as suboptimal behavioral inhibition, were the underlying cause of the disorder's symptoms, which in turn impaired four distinct EFs (working memory, self-regulation of affect- motivation- arousal, internalization of speech and reconstruction) and has received considerable recognition in the literature (Ory, 2017). Inhibition or inhibitory control covers a variety of behavioral and cognitive skills (e.g., controlling urges and distractions) and it promotes self-regulation even in challenging circumstances (Malagoli et al., 2022). Even in the most recent version of the DSM, it is stated that reduced behavioral inhibition, effortful control, and negative emotionality are linked to ADHD symptoms (APA, 2013). Furthermore, *impulsivity*, which is a loss of behavioral inhibition and a significant feature of ADHD, impacts many aspects of decision-making processes in both young children and adults (Leontyev et al., 2018).

Executive Functions and Self-regulation Theory

Later, Barkley (2010) proposed that ADHD is a disorder of self-regulation and that sufferers have deficiencies in self-directed actions that are commonly used to increase the likelihood of attainment of long-term goals. For example, EFs such as inhibition would be considered self-restraint, and self-awareness could be regarded as self-directed attention. Notably, is the notion that individuals with ADHD often develop “temporal myopia”, in which the person's behavior is more heavily influenced than usual by events that are happening right now or within the current context, as opposed to being influenced by internal knowledge about longer-term, future consequences (Barkley, 2010, p. 4). This in turn drives sufferers to maximize their immediate rewards and escape difficult aversive consequences along with a loss of awareness to delayed ones. The dopaminergic and noradrenergic neurons of the prefrontal cortex's anterior cingulate gyrus are thought to be involved in these deficits (Ory, 2017). The author further mentions that in adults, these problems in self-directed action are hardly visible to people around them, which further leads to diagnosis problems. Barkley's self-regulation hypothesis has been shared widely in the literature, although meta-analysis results remain unclear. Researchers have claimed that the problem is not with the theory, but with the methodology employed to evaluate EFs in the literature (Ory, 2017).

According to the theory of Barkley (1997), cognitive deficits in ADHD are mainly due to the executive function inhibition. However, it was found that children with ADHD show basic information-processing issues in tasks that do not only require executive functions (Rommelse et al., 2007). Moreover, despite earlier being assumed to be the primary weakness, executive function deficiencies are observed in just a small proportion of people with ADHD (Metin et al., 2012). Along with executive function deficits which involve a top-down approach to understanding ADHD symptom manifestations, problems in basic information processes might be involved in ADHD (i.e., bottom-up approach) (Metin, 2013). For that reason, psychophysiological models of information processing such as the Cognitive Energetic Model of Sanders (1983) were used to develop an explanation of ADHD that better describes what is seen in children who undergo neurocognitive tasks.

Motivation and State Regulation Deficit Model

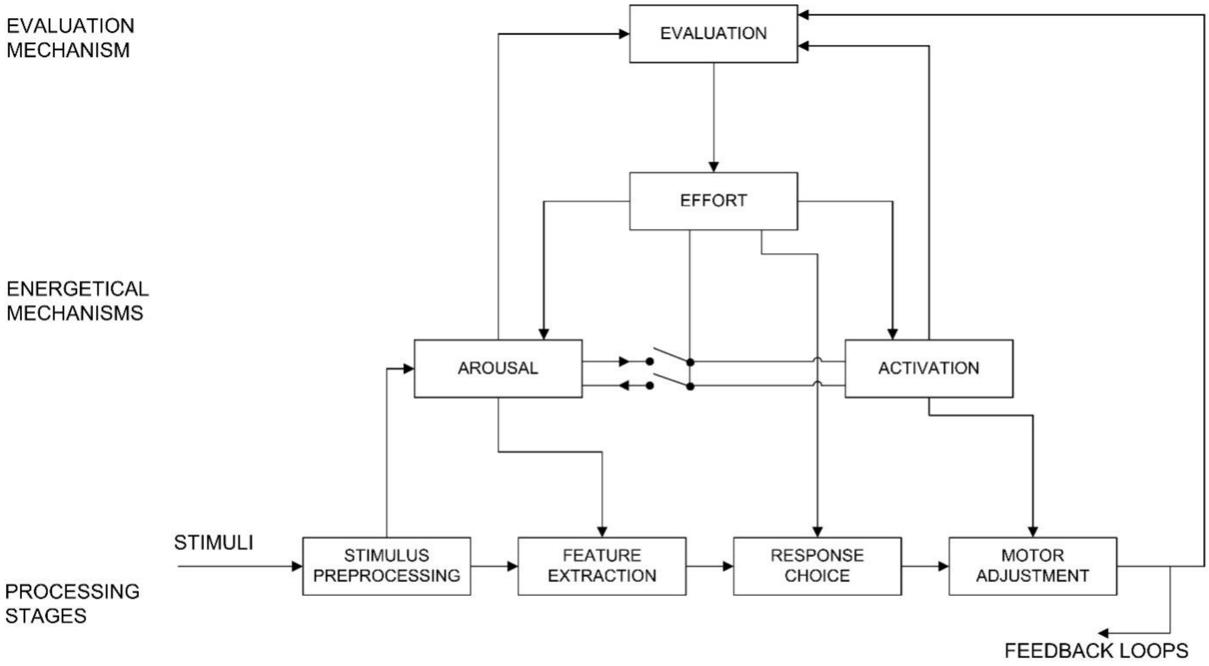
The State Regulation Deficit Model (SRDM) of ADHD was introduced and reviewed by several researchers (Borger & Van Der Meere, 2000; Sergeant, 2000; Nigg, 2001; Nigg et al., 2005; Van Der Meere et al., 2010; Shiels & Hawk, 2010; Metin et al., 2012). The model builds on the fundamental information processing framework by proposing that inhibitory control is moderated by the energetic states of a child, which are affected by suboptimal contingencies (Van der Meere, 2005; Metin et al., 2012). Furthermore, this model of ADHD emphasizes that a primary deficit in ADHD lies in state regulation (Metin et al., 2012). *State regulation* is described as the preservation of performance in the presence of stressors (i.e., stimulus presentation rates) by the allocation of extra effort, also referred to as *motivation* (Wiersema et al., 2006d).

Based on the Cognitive-Energetic Model (Sanders, 1983), the SRMD assumes three levels (see Figure 1). The first level represents basic cognitive processing stages that operate sequentially during the completion of a task and are known to be involved in executive functioning (i.e., stimulus processing, feature extraction, response choice, and motor adjustment; Van Der Meere et al., 2010; Sanders, 1983). In turn, the optimal performance of cognitive functions is controlled by levels two and three. Level two involves energetical mechanisms such as the arousal and activation of the participant. Arousal refers to the phasic physiological response to input, while activation refers to the tonic, long-lasting readiness for action (Van Der Meere et al., 2010). Level three consists of evaluation mechanisms that are in control of the effort system, which scans the states of arousal and activation to determine if they deviate from optimal states and to ensure optimal motor adjustment. When the current energetic state of the individual does not match the state necessary to accomplish the task, extra effort is required (Sargent, 2004). As mentioned above, effort is closely related to motivation. The effort system compensates for a suboptimal state of arousal and/or activation by triggering or restricting the arousal and/or activation resources (Van Der Meere et al., 2010). Because the effort resources are limited, effective effort allocation to either the activation or the arousal pool is crucial for optimal performance.

Moreover, state control is required to prevent a decline in performance. *State control* is a top-down ability to regulate how energy is mobilized by shifting from a sub-optimal condition to a desired target state (Van Der Meere et al., 2010). Nigg (2001) found that in children with ADHD, there is a deficiency of effective allocation of their effort to properly regulate activation states. To summarize, state regulation is influenced by how rewarding the task at hand is. If a task is long and boring, motivation to perform it decreases while if the task is fast and exciting, it has an adverse effect on motivation.

Figure 1

Cognitive Energetic Model



Note: Figure 1 depicts the Cognitive Energetic Model of Sanders (1983) in which different levels of cognition (processing stages, energetical mechanisms, evaluation mechanisms) interact for an optimal performance on a task. In ADHD, there is a deficiency in effort allocation to regulate activation states. By Van der Meere (2005). *The Cognitive Energetic Model,* (see reference list).

The Go/No-Go task

The *Go/No-Go task* is an impulsivity task that has been frequently used in the ADHD population to investigate SRDM. In a Go/No-Go task, individuals must respond to go signals while choosing to withhold automatic responses to no-go ones (Marzinzik et al., 2008; Zheng et al., 2008). The task was originally designed to test behavioural inhibition, as the rate of go to no-go stimuli makes it difficult to suppress a prepotent reaction (Young et al., 2017). Yet, it was found that the pace at which Go/No Go stimuli are shown (*event rate* [ER]) during neurocognitive tasks had an impact on test subjects' psychophysiological states by either enhancing or reducing the quality of their EF. ER effects are established by inter-stimulus intervals (ISI) manipulations (Metin et.al, 2012). According to the Cognitive Energetic Model (Sanders, 1983), there ought to be an inverted-U shape relationship between cognitive energetic components and performance, with both over-activation (related to fast ER) and under-activation (related to slow ER) having negative impacts on performance if not effectively allocated. In line with SRDM, this relationship is more pronounced in children with ADHD. Lastly, performance measures in the Go/No Go task are often determined by mean reaction time (MRT), mean standard deviation of mean reaction times (SDMRT), Errors of Commission (i.e., responding to the no-go stimuli; [EOC]).

The SRDM has been widely investigated in children and adolescents, but only scarcely in adults, using neuroimaging methods such as fMRI and EEG (e.g., Kooistra et al., 2010; Metin et al., 2016; Metin et al., 2012; Talati & Hirsch, 2005; Van der Meere, 2005; Wiersema et al., 2006). For children, there is consistent evidence of state regulation deficits in ADHD, as shown by the difficulty in attaining motor activation levels suitable for the task requirements. To demonstrate, Kooistra et al., (2010) found differences in frontostriatal activity between the ADHD and control groups which is associated with motor activation levels required to cope with task demands. Alternatively, in adults, Wiersema et al., 2006 found that when the event rate was manipulated, the ADHD group performed less consistently under both conditions and worse in terms of response time and the proportion of errors committed compared to the control group due to reduced parietal P300 amplitude and increased heart rate variability associated with insufficient effort allocation.

However, recent studies have shown significant differences in adults with ADHD compared to children in brain areas known to be involved in inhibitory control tested in the Go/No-Go task (Davis et al., 2003; Rahman et al., 2017). In addition, the development of inhibitory control has been found to improve from childhood to adulthood (Davis et al., 2003), as shown by differences in manifestations of impulsivity (APA, 2013). These differences have further been attributed to the prefrontal cortex maturity (Davis et al., 2003). Moreover, following the identification of distinct developmental trajectories of state regulation in younger children (specifically, seven- to eight-year-olds) compared to older children (i.e., 11- to 12-year-olds), Van der Meere (1999) highlighted the necessity to investigate a group of adults for more crucial conclusions. Consequently, this gap in knowledge will be addressed by investigating the Go/No-Go task in adults.

The present study

Few studies have examined the link between ADHD symptom manifestations and executive functions in adults. Limited research in this area has implications in today's adult ADHD misdiagnosis and a lack of individualized treatments. The aim of this study is to investigate the association between executive functions and ADHD in a sample of students with different levels of ADHD using both questionnaires and a simple impulsivity task. Symptoms of ADHD will be assessed dimensionally with CAARS, and the level of executive functions, inhibition, and motivation, will be assessed behaviorally with the EFI and its subscales, Impulse Control (IC) and Motivational Drive (MD). Moreover, performance measures on an adapted Go/No-Go task with a fast and slow stimuli presentation rates will be used to further investigate this association on a cognitive level.

The first research question (1a) is whether there is a general association between ADHD symptomatology and executive functions in students. It is well-known in the literature of ADHD that self-reported deficits in executive functions are linked to the manifestation of ADHD symptoms and this topic has been widely investigated since Barkley (1997) wrote about the association between the two (Green & Rabiner, 2012; Ory, 2017; Weyandt et al., 2013). In line with this, it is expected that students who report worse symptoms of ADHD will have more executive function deficits, meaning that higher ADHD-Index scores will be associated with lower EFI Total scores. However, a sub-research question (1b) remains of whether specific executive functions assumed to be key deficits in ADHD such as inhibition, proposed by Barkley (1997), and motivation, introduced by Van der Meere (2005), are linked to ADHD symptomology. Thus, it is expected that lower scores on IC and MD subscales will be related to higher ADHD Index scores on CAARS.

The second question (2) is whether the ER manipulations in the Go-No/Go task are valid in inducing under-activation and over-activation states in all participants. The Go/No-Go task with ER manipulations has been used successfully to influence the psychophysiological states of test subjects by either enhancing or reducing the quality of their executive function, as seen in differences between the fast and slow conditions in reaction times (RTs), reaction time variability (SDMRT), and percentage of errors to no-go stimuli (i.e., EOC). (Kooistra et al., 2010; Metin et.al, 2012; Wiersema et al., 2006). It is expected that RTs, SDMRTs and EOC will differ significantly between the fast and slow conditions, regardless of ADHD Index scores on CAARS. Specifically, we expect longer RTs and more variation (SDMRT) in the slow compared to the fast, but more EOC in the fast compared to the slow (Sanders, 1983).

The third research question (3) is whether higher levels of ADHD symptoms measured by CAARS are associated with worse task performance on the Go/No Go task. This question is divided by two other sub-questions.

The first research sub-question (3a) is whether ADHD symptoms' manifestations are associated with ineffective allocation of effort, which would suggest deficits in motivation (Van der Meere et al., 2010). In line with state-regulation theory, studies show an interaction between ER conditions of Go/No Go tasks and ADHD levels, with slower and more variable response times in the slow condition, and worse accuracy in the fast condition for children with ADHD compared to their peers (Wiersema et al., 2006; Metin et al., 2012). This, it is expected that higher ADHD-index scores on CAARS to be associated with more impulsive errors (i.e., EOC) in the fast condition of the task compared to the slow, and an equal number of errors in the slow, but more inattentive responding seen in higher MRTs and higher SDMRTs compared to the fast.

The second research sub-question (3b) is whether ADHD symptomatology is linked to inhibition impairments which are not affected by environmental context. Non-optimal environmental contingencies (e.g., external, or internal stimulation, medication, stress, sleep) are known to play a role in motivation (Sanders, 1983). Based on the executive dysfunction theory (Barkley, 1997), inhibition deficits in children are apparent in the Go/No-Go task in more impulsive responses corresponding with more errors to no-go stimuli (Vaurio et al., 2009). It is expected that ADHD groups (i.e., high, and low levels) will differ significantly in their accuracy on the task. More specifically, it is expected that higher ADHD-Index scores on CAARS will be associated with more overall EOC (i.e., regardless of ER conditions).

The fourth (4) and last research question is whether more executive dysfunction such as poor impulse control and weak motivational drive are associated with worse task performance on the task. Weyandt et al., (2013) found inconsistent results between students' self-reported levels of executive functioning (i.e., "inhibit" scale of Behavior Rating Inventory of Executive Function- Adult Version [BRIEF-A]) and performance on a CPT used to measure behavioural inhibition and sustained attention. Moreover, since motivation is a complex cognitive process related to extra effort allocation to energetical pools for optimal sustained attention and performance (Van der Meere, 2005), it is possible that motivation deficits in ADHD sufferers are only visible in neurocognitive tasks and not in behavioural measures such as self-reported motivational drive. However, there is too little research done on the association of the Go/No-Go task (with fast and slow event rates) performance and the EFI subscales in students to make a hypothesis about this. This question will be explored for the purpose of adding more knowledge to the research questions of this study by examining the association between the EFI subscales, IC and MD, and speed, variability, and accuracy on the Go/No-Go task. This question will be split in two. Firstly (question 4a), we want to know whether the MD subscale will be associated with difference scores of RT, SDMRT and EOC between fast and slow ER conditions. Secondly (question 4b), we are interested in whether the IC subscale will be associated with RT, SDMRT and EOC, regardless of ER conditions.

Methods

Participants

The study consisted of a convenience sample recruited predominantly via a portal called SONA, where first-year psychology students collect credits to pass the course ‘A Practical Introduction to Research Methods’ (PSBE1-28.2022-2023.1). All subjects had to be university students between the ages of 17 to 31. The pool of participants consisted of 394 students with an average age of 20 (*M* = 20.14, *SD* = 2.12). In terms of sex, 75.1 % of participants were females (*n* = 296), while 24.9% were males (*n* = 98). Lastly, 5.6 % subjects (*n* = 22) have been clinically diagnosed with ADHD.

For the second part of the study, participants from the SONA portal who completed the questionnaires were invited to participate in a follow-up experimental study. Furthermore, acquaintances of the researchers who met the aforementioned criteria were invited to volunteer in the study. For the participants outside of the SONA System, doing the questionnaires prior to the task was not a requirement, as there was no reason to think that the questionnaires would influence the performance on the task. In total, 49 participants responded to our invitation, 32 from the SONA System and 17 volunteers. For the analysis, participants were split in two groups based on their T-score on CAARS. It was found that scoring higher than 60 in CAARS could require clinical attention (Vizgaitis et al., 2023).

Hance, an ADHD index score of 60 or higher was considered high and an ADHD index score lower than 60 was considered low.

Moreover, the data for our bachelor project underwent careful participant selection to exclude those who did not complete the Go/No-Go task or the CAARS and EFI questionnaires. Out of the initial 49 participants in the task, one participant from the high ADHD level group (*T* = 84.14) experienced technical issues in the middle of the task and had to re-do it, but was included in the analysis, as it was unlikely to affect their performance. Additionally, only 43 participants completed the CAARS, while two did not provide necessary identification information and were excluded. Similarly, 41 participants completed the EFI questionnaire, with three missing demographic details, which were deemed irrelevant for our project's focus and were not excluded. No participants were excluded based on outlier criteria due to the heterogeneity of ADHD symptoms and neurocognitive deficits (Kofler et al., 2016). The final sample size for analysis was 41 (Table 1).

Table 1.

Final Sample Size of ADHD groups

		N
ADHD_level	high	16
	low	25

Note: Table 1 gives the final sample size of each ADHD group (i.e., high and low) used for analysis of CAARS and task performance.

To sum up, from the final sample of 41 participants, with ages between 18 and 27 *(M* = 21.83, *SD* = 2.32), 51% of participants were females (*n* = 21), while 49% were males (*n* = 20). All participants had normal to corrected vision. Furthermore, five participants had a primary diagnosis of ADHD (12.19%), four participants had other psychological disorders (9.75%) and one had both ADHD and four comorbidities (2.43%). Written consent was provided by all participants. Lastly, the study has been approved by the Ethical Committee of Psychology at the University of Groningen.

Measures

Questionnaires

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

CAARS-S:L is composed of eight subscales. These subscales are Inattention/Memory Problems, Hyperactivity/Restlessness, Impulsivity/Emotional Lability, Problems with Self-Concept, DSM-5: Inattentive Symptoms, DSM-5: Hyperactive-Impulsive Symptoms, DSM-5: Symptoms Total, which together contain 66 questions. Part of the scale are also specific items, which are able to identify individuals who are at risk for having ADHD diagnosis. These specific items together create the ADHD Index subscale. All of the questions are organized on a Likert scale, ranging from option 0- '*Not at all, Never*' to 3-'*Very much, Very frequently*'. For this study, T-scores of each of all of the above mentioned subscales and T-score of the overall score have been calculated. Overall score indicates levels of ADHD symptoms. In this case, high score indicates higher levels of ADHD symptoms and low score indicates low levels of ADHD symptoms (Conners, 2002). The scale that was used for the analysis is the T-score of the ADHD Index scale.

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

The EFI is composed of five subscales which are Motivational Drive (MD) Impulse Control (IC), Empathy (EM), Organization (ORG) and Strategic planning (SP). The subscales add up to 27 items further divided into questions. Questions are organized on a Likert scale ranging from option 1-'*not at all*' to 5- '*very much'*. Some of the questions in the test are reversed based on the sentence structure. Therefore, some of the scores indicate lower instead of higher executive functioning. Reversed questions are Question 4 from MD Subscale, all questions from ORG and IC subscales and Question 12 from EM subscale. The sum of the scores in the test presents the general index of EF levels where higher scores represent better EF. The scales that are used for the analysis are EFI Total, IC and MD.

Go/No-Go Task

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

Task. For the purpose of this study, a simple Go/No-Go task with two event-rate manipulations was used (Borger & Van Der Meere, 2000) To give their responses, participants had to either press “B” at the Go trials or withhold their response to press “B” at the No-Go trials (Figure 2). In addition, our task consisted of two conditions (event rates; [ER]), as measured by the inter-stimulus-interval (ISI) duration of each trial (Metin, 2013). According to the meta-analysis of Metin et al. (2012), a fast condition with an ER of maximum 2 seconds (s) and a slow condition with an ER of at least 6 seconds (s) would alter the states of the individuals with ADHD and elicit worse task performance. Therefore, the fast condition had an ER of 1.2 s while the slow condition had an ER of 7.2 s. A 2-minute mandatory break was added between the two to counterbalance fatigue or primacy effects.

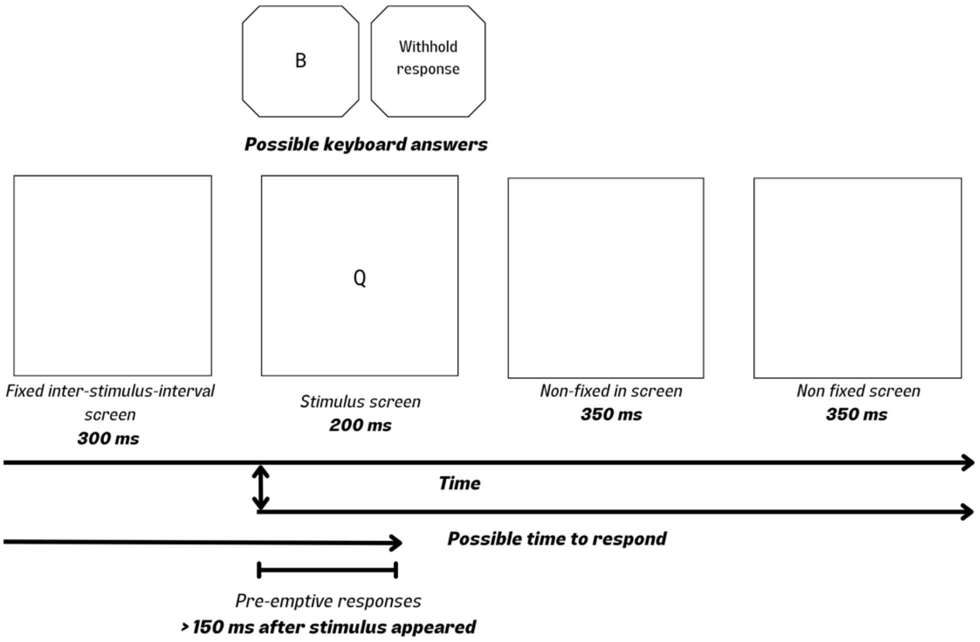
Trials. The trials in each condition were composed of a fixed ISI, the stimuli screen, and two identical screens in which participants' responses on each screen are recorded. The time between each trial depended on the response of the participant. If there was a keyboard response (keyboard press “B”) prior to the ending of the stimulus screen or the two empty screens, the stimulus screen would end with the press.

The fast condition started with one practice block consisting of six trials, five Go-trials and one No-Go trial. This was preceded by one experimental block consisting of four Go-trials and one No-Go trials that were repeated 20 times, resulting in a total of 100 trials. The trials in each block were presented in a randomized order to decrease order effects. The stimuli screen is always presented for 200 ms after a fixed ISI screen of 300 ms, and is followed by two identical screens of 700 ms (i.e., 350 ms each) (Figure 2a).

In the slow condition, there was one practice block and one experimental block. The practice block consisted of five trials, one Go trial and four No-Go trials. Proceeding this, there was one experimental block with four Go trials and one No Go trial that repeated 10 times and resulted in a total of 50 trials. Every trial starts with a fixed ISI of 5000 ms before the stimulus is presented. The stimuli is presented for 200 ms, followed by two identical screens of 2000 (i.e., 1000 ms each) (Figure 2b).

Figure 2a

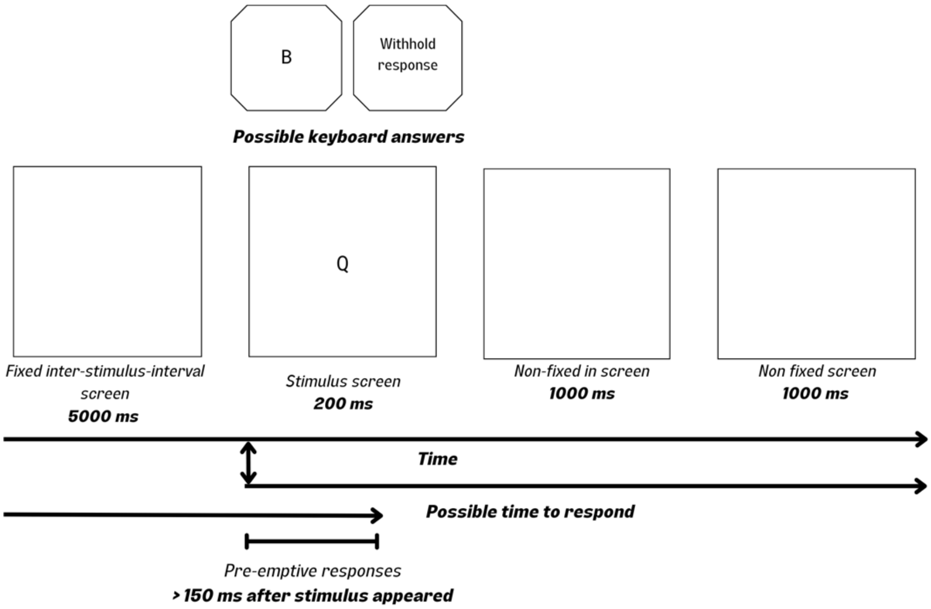
Example trial in fast condition



Note: Figure 2a. shows an example of a trial in the fast condition. First, a fixed ISI screen is presented for 300 ms, which is followed by the stimuli screen that remains visible for 200 ms. Participants' possible responses during the task are to either press "B" when the Go-stimuli ("O") is on the screen or withhold their responses to "B" when the No-Go stimuli ("Q") presented on the screen. The last two screens are identical screens of 350 ms each, where participants' responses are recorded. Preemptive responses are responses of test subjects recorded 150 ms after the stimuli screen is presented.

Figure 2b

Trial example of slow condition



Note: Figure 2b provides an example of the slow condition in the study. Initially, a screen with a fixed ISI is displayed for a duration of 5000 ms. This is followed by the presentation of the stimuli screen, which remains visible for 200 ms. During the task, participants are required to press the "B" key when the Go-stimuli ("O") appears on the screen. In contrast, they need to refrain from pressing the "B" key when the No-Go stimuli ("Q") is presented. The final two screens, each lasting 1000 ms, are identical and serve the purpose of recording participants' responses. Preemptive responses refer to the responses of the test subjects that are recorded 150 ms after the stimuli screen is presented.

Stimuli. The experiment had two types of stimuli, an O (the Go stimuli) and a Q (the No-Go stimuli), which were shown against a white screen. The letters were always presented in the middle of the screen ($x = 0$, $y = 0$) and had a black color, HTML format and mono font, to contrast the white screen. Due to the possibility that a fixation dot would interfere with our experimental manipulations and that the stimuli will always be presented in the middle of the screen, there is no fixation dot on the screen before the start of each trial. Thus, at the beginning of each trial, a white empty screen with 32 x 32 px grid is presented, followed by the stimuli screen. Lastly, in the practice block as well as the experimental block of both the slow and the fast conditions, there were always 20% No-Go stimuli and 80% Go stimuli (ratio was 1:4). It is known that ratio of Go to No-Go stimuli impacts impulsivity (i.e., difficulty in inhibiting responses)(Young et al., 2017).

Procedure

Participants completed the questionnaires online, starting with the CAARS-S:L and concluding with the EFI. The CAARS-S:L questionnaire began with an informative page, followed by a consent page for participation. They were asked for their SONA number, age, biological sex, job (if applicable), first language, diagnosis of physical, psychiatric, or neurological conditions, and any medication they were taking. The following pages consisted of the CAARS-S:L questionnaire, where participants rated their agreement to each item. Optional consent for processing student grades was requested on the subsequent page, followed by a page for participants to provide any additional comments or questions for the researchers.

For the EFI questionnaire, participants were asked for their consent on the first page. Further, they were asked to provide their SONA number. On the next page, participants completed the EFI questionnaire by rating their agreement to each item. A last opportunity to provide comments was provided in the subsequent page.

Next, the participants were invited to the lab to carry out the Impulsivity experiment and a second Inhibition experiment which was used by another thesis group. In total, both experiments took about 20 minutes per participant. Participants sat behind a computer in a room without any distractions, where the lighting and the sounds were controlled for. The computer had a 1920 x 1080 mm HP display. Before starting the experiment, the participants had to read the information sheet about our experiment and sign a consent form (Appendix A). Afterwards, they were instructed to fill in their personal number at the beginning of the experiment. Furthermore, in order to counterbalance fatigue or primacy effects, participants started with either the Inhibition task or the Impulsivity task, decided with a randomly generated number between one and two.

For the impulsivity task, the participants were first presented with a welcome screen (Figure C1, Appendix C), which is followed by a brief informed consent screen in which they have the possibility to opt not to participate (Figure C2, Appendix C). Next, an instruction screen appeared (Figure C3, Appendix C). The participants were informed that either an ‘O’ or a ‘Q’ would appear on screen. Whenever the participant saw an ‘O’, they had to press the ‘B’ key. When a ‘Q’ appeared, they had to withhold their response. The main goal of the task was to react as fast and as accurately as possible. Following that, the participants were directed to the practice block to become acquainted with the task. Afterwards, the participants were notified that the practice block ended and that the main experiment would begin, as well as reminded of the instructions. For the purposes of our experiment, the participants received no feedback once the practice and experimental blocks were completed. When the participant finished both experiments, they were asked about their experiences, and could leave. The experimenter would then send the questionnaires to the participant, depending on if the participant had already filled them out or not.

Design

The experiment used in this study had a 2 x 2 mixed-subjects factorial design with one between subject factor (i.e., ADHD level) and one within subject factor (i.e, ER) and each participant (i.e., who had either high, or low scores on CAARS) was exposed to all levels of the independent variable. The independent variable was ER (i.e., fast, and slow stimuli presentation rates), while the dependent variables were speed of responding on correct trials, variability in speed of responding and accuracy.

Data analysis

Data preparation for CAARS and EFI

Firstly, sum scores and T-scores were computed for CAARS. Similarly, sum scores and a total score were calculated for EFI. To analyze the questionnaires, the T-scores of the ADHD Index (ADHD symptoms) and the DSM Total (ADHD DSM symptoms) from the CAARS were calculated and added to a Google Sheet (2023) prior to the analysis. Next, the sum scores of the Impulse Control (IC) scale, the Motivational Drive (MD) scale, and the Total score from the EFI were also added. Lastly, the analysis was performed in IBM SPSS Statistics (version 28).

Hypothesis 1a, 1b association between ADHD and EFI Total Score, IC, MD subscales

Determining the distribution of the variables (T-scores of ADHD Index and DSM Total, IC, MD and EFI Total) was important for choosing the appropriate test. Therefore, the assumption of normality has been tested using the Shapiro-Wilk test. From the test, it was concluded that the distribution of all variables significantly deviated from a normal distribution (Table B1, Appendix B). To check for linearity, the Normal Q-Q plots of all variables were inspected and all variables were approximately linear.

Since the data is not normally distributed, we made use of non-parametric tests to examine the relationships under the first hypotheses. To test whether that there was a negative relationship between ADHD symptoms and executive functions (hypothesis 1a), Spearman correlations were used between ADHD Index scores and EFI Total scores. In addition, to test whether ADHD is negatively related to IC and MD subscales (i.e., hypothesis 1b), Spearman correlations were conducted.

Data preparation for Go/No-Go Task

Mean reaction times (MRT), standard deviation of mean reaction times (SDMRT) and errors of commissions (EOC) were measured per participant in each condition (i.e., fast, and slow). Reaction times (RTs) in milliseconds (ms) were measured after each screen excluding the fixed ISI prior to the beginning of each trial (e.g., Figure 2). MRTs were calculated by the average of individual RTs in screens in which no errors occurred ([mrt_fast_corr]; [mrt_slow_corr]). Accuracy for every participant was also computed for each screen by the percentage of correct answers (correct=1) to wrong answers (correct=0). Responses to the letter Q were considered EOC ([perc_errors_fast]; [perc_errors_slow]). In addition, the variability in RTs was measured by SDMRT on correct trials ([sd_rt_fast_corr]; [sd_rt_slow_corr]). Additionally, the difference scores between the fast and slow conditions were calculated for MRT, SDMRT and EOC ([diff_mrt_slow_fast]; [diff_sd_slow_fast]; [diff_perc_errors_fast_slow]). Overall, there were nine relevant variables used for analysis of task performance.

A data analysis template was developed in the latest version of google sheets (2023) to calculate the relevant measures. Afterwards, relevant T-scores and task performance measures were added together prior to importing data into SPSS (version 28).

Hypothesis 2 Task validation

To test the second hypothesis which was that ER manipulations in the Go/No-Go task were valid, we checked for the main effect of task (i.e., significant differences between the fast and slow conditions) on reaction times, variability of mean reaction times and percentage of errors to no-go stimuli using the Mixed ANOVA with repeated measures. Prior to conducting the ANOVA, we first needed to check for important assumptions. Shapiro-Wilk tests and Q-Q Plots were used for both ADHD groups to assess normality in task performance data separately by MRT, percentage of EOC, SDMRT (Appendix B, Table B2) The test of normality revealed no significant deviations for MRTs and SDMRTs of participants from each ADHD group on either condition. Moreover, the normality assumption was met for percentage of EOC in the high ADHD group. However, in the low ADHD group, the percentage of EOC deviated significantly from normality in the fast (W (25) = 0.900, p = .018) and the slow conditions (W (25) = 0.898, p = .016). Regardless, Q-Q plots for percentage of EOC of each ADHD group and each condition showed only slight deviations from normality (Figure C4, C5, C6, C7, Appendix C), which seemed to be due to the presence of an outlier. Further, the Central Limit Theorem states that when the sample size is larger than 30 (in this case, n =41), small deviations from normality do not alter the result of an Analysis of Variance (Kwak & Kim, 2017).

In addition, tests of homogeneity and sphericity were conducted. To check for homogeneity of variances, Lavene’s test was used. Results showed that this assumption was also met for MRT (Table B3) and percentage of EOC (Table B4, Appendix B). Conversely, this assumption was not met for SDMRT (Table B5, Appendix B). However, this was not needed because this score is the variance of MRT, for which the homogeneity assumption was already met. Further, based on prior research, we expected more variability in responses in the high ADHD group in the slow condition (Metin et al., 2012). Lastly, the assumption of sphericity was not necessary because we only use one within-subjects factor with two levels of the independent variable.

Hypothesis 3a, 3b worse task performance in ADHD group due to inhibition or motivation deficits

For the two sub-questions under the third hypothesis, a Mixed Analysis of Variance (ANOVA) with repeated measures was used in SPSS (version 28) to test whether participants showed primary deficits in inhibitory control (i.e., hypothesis 3a) or in motivation (i.e., hypothesis 3b) based on their levels of ADHD on CAARS. As mentioned above, assumption test (i.e., Shapiro-Wilk, Lavene's test) and plots were investigated, and it was concluded that no significant deviations would interfere with the results. Consequently, a Mixed ANOVA with repeated measures was used to assess whether there is a significant interaction between ER manipulations and ADHD group in task performance measured separately by MRT, SDMRT and percentage of EOC (hypothesis 3a) or whether there is a significant main effects of group for MRT, SDMRT and percentage of EOC, regardless of ER conditions (hypothesis 3b).

Moreover, Spearman correlations were used to investigate whether ADHD groups employed a different strategy on the task. For this, the data was split between low and high ADHD groups. The difference scores between conditions in MRT (diff_mrt_slow_fast) and EOC (diff_perc_errors_fast_slow) were correlated separately for each ADHD group.

Lastly, since Mixed ANOVA only analyses group variance differences, an additional bivariate correlation was used to assess the association between ADHD groups and task performance for each participant. Because the ADHD Index scores deviated from normality, non-parametric Spearman correlation were used between ADHD groups and difference scores between conditions (i.e., diff_mrt_slow_fast, diff_sd_slow_fast, diff_perc_errors_fast_slow).

Hypothesis 4a, 4b worse task performance is associated with lower self-reported impulse control and motivational drive

To investigate the fourth exploratory research questions, which were whether poorer task performance (i.e., in the Go/No-Go task) was associated with more self-reported motivational drive deficits (based on MD subscale scores) and impulse control problems (based on IC subscale scores), non-parametric Spearman correlations were computed. Because impulsivity is hypothesized to be observed regardless of ER manipulations (i.e., question 4a), the IC subscale was correlated with all dependent variables in the task (mrt_fast_corr, mrt_slow_corr, perc_errors_fast, perc_errors_slow, sd_rt_fast_corr, sd_rt_slow_corr). Moreover, because motivation difficulties are only apparent when individuals' performance differs between ER conditions (i.e., question 4b), the MD subscale was correlated with difference scores for task performance (diff_mrt_slow_fast, diff_sd_slow_fast, diff_perc_errors_fast_slow).

Results

Descriptive Statistics

CAARS and EFI sample

The descriptive statistics of scores on CAARS and EFI from the sample of 394 participants can be visualized in Table B6 (Appendix B).

CAARS and Go/No-Go task.

The descriptive statistics of the CAARS Index scores for the second part of this study can be found in Table B7 (Appendix B). Moreover, the descriptive statistics of participants' speed (measured by MRT), variability in responses (measured by SDMRT) and accuracy (measured by percentage of EOC) per ADHD group based on CAARS scores can be visualized in Tables 2, 3, 4.

Table 2

Descriptive Statistics for Mean Reaction Times on Event Rate Conditions for ADHD Groups

	ADHD_level	Mean	Std. Deviation	N
mrt_fast_corr	high	308.778488950	28.1297998509	16
	low	316.482101712	28.2629562754	25
	Total	313.475813805	28.1155380885	41
mrt_slow_corr	high	415.714216681	48.4182810038	16
	low	394.450140064	42.0530519862	25
	Total	402.748316305	45.2822525299	41

Note: Table 2 shows the mean and standard deviation of the mean reaction times (MRT) for the fast and slow condition for each ADHD group (i.e., high and low levels) including the sample size of these groups.

Table 3

Descriptive Statistics for Standard Deviations of the Mean Reaction Times on Event Rate Conditions for ADHD Groups

	ADHD_level	Mean	Std. Deviation	N
sd_rt_fast	high	67.0766339850	21.07236281477	16
	low	63.1091957928	19.25755097993	25
	Total	64.6574643556	19.82089307305	41
sd_rt_slow	high	97.3103991825	36.08111320352	16
	low	76.7472770296	18.78142803188	25
	Total	84.7719100649	28.33672423618	41

Note: Table 3 displays the mean and standard deviantion of variability in reaction times (SDMRT) for the slow and fast condition for each ADHD group (i.e., high levels and low levels) including the sample size of each group.

Table 4

Descriptive Statistics for percentage Errors of Commission on Event Rate conditions for ADHD Groups

	ADHD_level	Mean	Std. Deviation	N
perc_errors_slow	high	28.12	21.046	16
	low	21.60	18.184	25
	Total	24.15	19.362	41
perc_errors_fast	high	35.62	20.565	16
	low	28.20	18.193	25
	Total	31.10	19.252	41

Note: Table 4 portrays the mean and standard deviation of errors of commission (EOC) for the fast and slow condition for each ADHD group (i.e., high and low levels) including the sample size of these groups.

ADHD was associated with Executive Functions and Impulse Control, but not with Motivational Drive

For the first hypotheses, the strength and direction of the association between ADHD Index scores and EFI Total scores (1a) and between ADHD Index scores and IC and MD subscale scores (1b) was assessed with the non-parametric Spearman's correlation (Table 5). The Spearman's correlation coefficients between ADHD index and overall EFI score showed that there was a significant negative and moderate relationship between the two (r (392) = -.489, p < .01). This means that individuals who scored low on ADHD were more likely to score high on self-reported executive function. Moreover, we found a significant negative and moderate association between ADHD index and the scores on IC subscale (r (392) = -.353, p <.01) which is indicative of an association between impulse control and ADHD levels, with higher levels of ADHD being associated with lower impulse control. However, there was no significant association between ADHD index and scores on MD subscale, as their correlation was low and negative (r (392) = -.014, p = .782). This means that, as opposed to our expectations, lower self-reported motivational drive is not associated with higher ADHD levels in our sample.

Table 5

Correlations

			CAARS_TscoreADHDIndex	EFI_total[b]	IC[b]	MD[b]
Spearman's rho	CAARS_TscoreADHDIndex[b]	Correlation Coefficient	1,000	-,489**[a]	-,353**[a]	-,014
		Sig. (2-tailed)	.	<,001	<,001	,782
		N	394	394	394	394

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

b. CAARS_TscoreADHDIndex = Conner's Adult ADHD Rating Scale; EFI = Executive Function Index Scale; IC = Impulse Control Subscale from EFI; MD = Motivational Drive Subscale from EFI;

Note: Table 5. displays the Spearman's correlation coefficients for the associations between EFI total score, the subscales of EFI, MD score and IC score, and the CAARS T-score ADHD index. The two-sided significance level was calculated for each association.

The ER manipulations in the Go/No-Go task were valid

To check for the second hypothesis (2) regarding the validity of the task, the main effects of ER for MRT, SDMRT and percentage EOC were computed using Mixed ANOVA with repeated measures.

The main effect of ER significantly impacted speed of responding on task.

The Mixed ANOVA revealed a significant main effect of task on speed of responding measured in MRT (F (1, 39) = 243.527, p < .001, partial η2 = 0.862). This indicates that there were significant differences in MRT between the fast and slow conditions, with a large effect size. That is, the fast and slow ER manipulations in the task were valid in altering participants' states, which in turn impacted their speed of responding in the task.

The main effect of ER significantly impacted variability in speed of responding on task.

The Mixed ANOVA also indicated a significant main effect of task (F (1, 39) = 25.080, p < .001, partial η2 = 0.391) for SDMRT, which means that the differences in variability of responding as measured by SDMRT between fast and slow conditions were significant and had a medium effect size. This indicates that the task with fast and slow event rate manipulations was valid in producing expected changes in the psychophysiological states of participants, which affected variability in responding on the task.

The main effect of ER significantly impacted error of commission rates on task.

The Mixed ANOVA also demonstrated a statistically significant main effect of task (*F* (1, 39) = 6.949, p = .012, partial η2 = 0.151), which means that the differences in accuracy as measured by percentage of EOC between fast and slow conditions were significant and had a small effect size. This indicates that the task with fast and slow event rate manipulations was valid in producing expected changes in the psychophysiological states of participants, which affected participants' accuracy.

ER effects of Go/No-Go task on task performance of different ADHD groups

To test the third hypotheses that ADHD suffers have problems with motivation (3a) or with inhibition (3b), a Mixed ANOVA with repeated measures was used. For hypothesis 3a, the interaction effects between ER and ADHD groups for MRT, SDMRT and percentage EOC were relevant, while for hypothesis 3b, the main effect of ADHD groups in EOC (i.e., regardless of ER) was of interest.

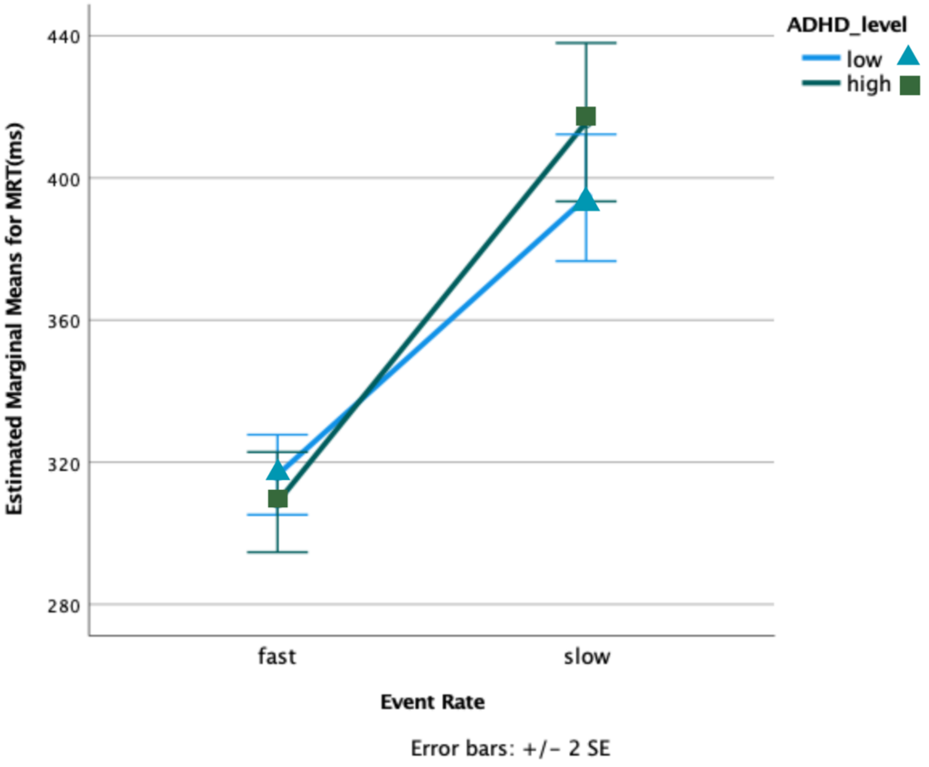
The ERs had different effects on speed of responding for the ADHD groups

For the third hypothesis (3a), we checked whether there was a significant interaction effect of ERs and ADHD in speed of responding measured by MRT. First, the main effect of group (i.e., of ADHD level) was not significant and had a small effect size (*F* (1, 39) = 0. 427, *p* = .517, partial η2 = 0.011), meaning that, without considering ER manipulations, ADHD groups did not differ in speed of responding on the task. However, according to the results of the mixed repeated-measures ANOVA, there was a significant interaction term between task effects (ERs) and ADHD levels in MRT with a small effect size (*F* (1, 39) =

5.977, *p* = .019, partial η2 = 0.133), which means that the event rates of task had a stronger effect on speed of responding in high ADHD group compared to low ADHD group, while the effect size was small. Figure 3 displays this interaction, where speed of responding given by MRT is slower in the ADHD group when the stimuli presentation rate (i.e., ER) is slow and is faster in the ADHD when ER is fast, which is in line with our expectations.

Figure 3.

Mean Reaction Times of ADHD groups on event rate conditions



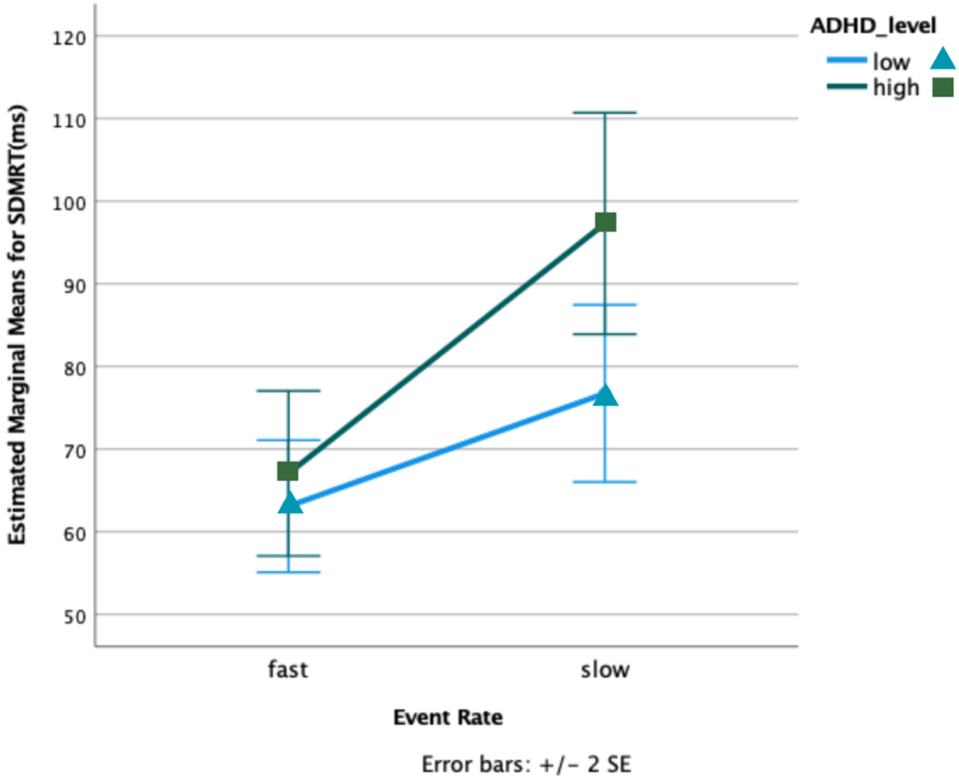
Note: This figure portrays the interaction between ADHD levels and mean RT in the fast and slow event rate manipulations. On the y-axis, the mean reaction times of participants are shown in milliseconds (ms). On the x-axis, the labels of event rate manipulations are given. There is a significant interaction effect between ADHD level and event rate. In the fast condition, individuals in the high ADHD group responded slightly faster than the low ADHD group, while in the slow condition, this difference is reversed.

Only the slow ER influenced variability of responding of the ADHD groups

A mixed ANOVA with repeated measures was performed to test the third hypothesis (3a) stating that variability measured by SDMRT is higher in the slow condition for the high ADHD group compared to the low ADHD group. The primary effect of group (i.e., high, vs low) was not significant (*F* (1, 39) = 3.954, *p* = .054, partial η2 = 0.092) and had a small effect size, indicating that ADHD groups did not differ in response speed variability, without considering ER manipulations. As seen in Figure 4, the variability of responding from the fast to the slow condition goes slightly upward for the high ADHD group, but almost stays the same in the low ADHD group. Regardless, the interaction effect between ER and ADHD level was not significant and had a small effect size (*F* (1, 39) = 3.589, *p* = .066, partial η2 = 084).

Figure 4.

Standard Deviations of Mean Reaction Times of ADHD Groups on Event Rate Conditions



Note: This figure shows the interaction between ADHD levels and standard deviation of the mean reaction time in the fast and slow event rate manipulations. On the y-axis, the mean reaction times of participants are shown in milliseconds (ms). On the x-axis, the labels of event rate manipulations are given. Although the interaction between ADHD level and event rate is not significant, there seems to be a trend in the data, in which variability of responding from the fast to the slow condition goes slightly upward for the high ADHD group, but almost stays the same in the low ADHD group, indicating the differences between groups were stronger in the slow condition.

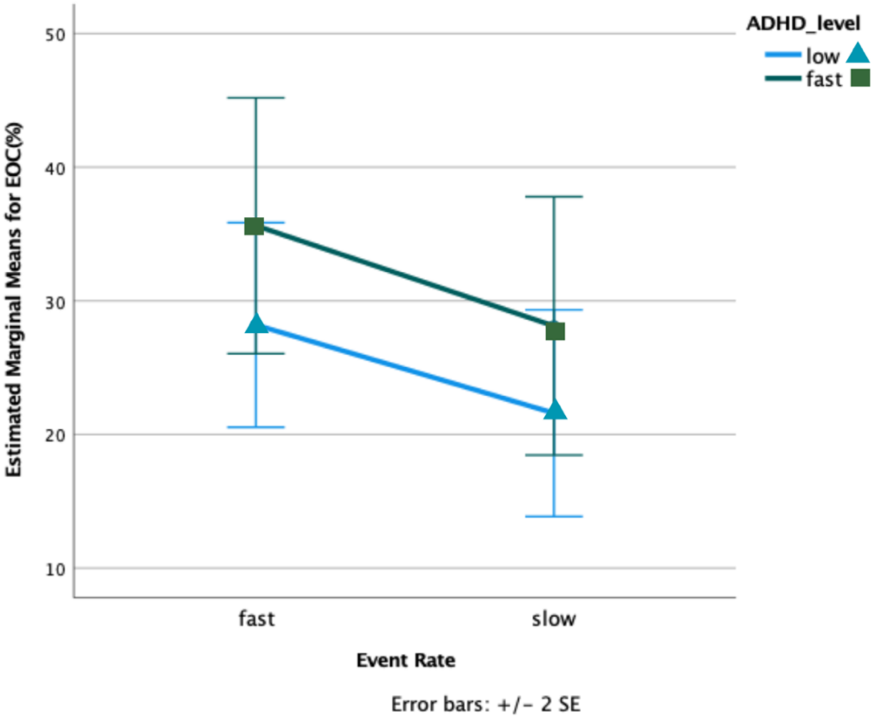
Consequently, a post hoc test was performed to verify whether this tendency is given by a significant difference between ADHD groups in the slow condition, but not in the fast. The t-test results showed a significance difference in the slow condition, between high ADHD group (*M* = 76.75, *SD* = 18.78) and low ADHD group (*M* = 97.32, *SD* = 36.08) with *t* (39) = -2.397, *p* = .021 (*Cohen's d* = 26.8). In contrast, the difference between high ADHD group (*M* = 63.11, *SD* = 19.26) and low ADHD group (*M* = 67.06, *SD* = 21.07) was not significant (*t* (39) = -0.620, p = .539, *Cohen's d* = 19.97). This indicates that, although variability in responding did not differ between groups in the fast condition, it differed significantly between groups in the slow, with high ADHD group showing higher SDMRTs than the low ADHD group (Figure 4).

The ERs did not differ in their effects on accuracy of the ADHD groups

Similarly, a mixed ANOVA with repeated measurements was used to test the third hypotheses. Hypothesis 3a stated that that the high ADHD group would make more errors in the fast condition than the low ADHD group and a similar number of errors in the slow condition. In contrast, hypothesis 3b stated that the ADHD group would make more overall EOC (i.e., regardless of ER conditions) than their counterparts. The main effect of the between subject factor (i.e., ADHD group) was not significant (*F* (1, 39) = 1.580, *p* = .216, partial η2 = 0.039) which indicates that overall, the ADHD groups did not differ significantly in their accuracy on task. Furthermore, the interaction effect of ER and ADHD was also not significant (*F* (1) = .028, *p* = .867, η2 = 0.001). Figure 5 shows that the separate lines for both groups are parallel, which indicates that there was no difference in the effect of ER conditions on ADHD groups in percentage of EOC.

Figure 5.

Percentage of EOC of ADHD Groups on Event Rate Conditions



Note: This figure shows the interaction between ADHD levels and percentages of EOC in the fast and slow conditions. On the y-axis, the mean of errors to letter "O" are shown in percentages (%). On the x-axis, the labels of event rate manipulations are given. The interaction effect of ER on ADHD groups was not significant. However, the main effect of event rate was significant. In the fast condition, individuals in both ADHD groups made more errors in the fast condition compared to the slow, but did not differ significantly in the errors they made overall. Moreover, the main effect of group was not significant, and groups did not differ in their accuracy on the task without considering ER conditions.

ADHD groups differed in strategies employed in the task from fast to slow ER.

The Spearmen correlation coefficients between MRT (diff_mrt_slow_fast) and EOC (diff_perc_errors_fast_slow) for the low ADHD group revealed a significant medium and positive association between speed of responding and errors between conditions (*r* (39) = .448, *p* = .025). This means that individuals low in ADHD used a consistent strategy throughout both conditions. Results could indicate that participants in the low ADHD group traded speed of responding (MRT) for accuracy (EOC).

In contrast the Spearmen correlation coefficients between MRT (diff_mrt_slow_fast) and EOC (diff_perc_errors_fast_slow) for the high ADHD group indicated that the relationship between reaction times and errors between conditions was non-significant (*r* (39) = .004, *p* = .987). This means that participants from the high ADHD group did not follow a consistent strategy throughout event rate condition possibly due to problems with state-regulation.

Correlations between ADHD groups and task performance measured by difference scores between ER conditions for MRT, SDMRT and EOC

Spearmen correlations between ADHD groups and difference scores of task performance measures were used to further inspect hypothesis 3b stating that motivation is a primary issue in ADHD.

The Spearmen correlation coefficient between ADHD groups and diff_mrt_slow_fast revealed a significant positive relationship between the two (*r* (39) = 0.359, *p* = .021). That means that the differences in speed of responding between event rate conditions (i.e., fast, and slow) were significantly different between individuals with higher levels of ADHD and individuals with lower levels of ADHD.

Subsequently, the Spearmen correlation coefficient between ADHD groups and diff_sd_slow_fast revealed a non-significant positive small relationship between the two (*r* (39) = 0.270, *p* = .087). That means that the differences in variability of responding between event rate conditions (i.e., fast, and slow) were similar between individuals with higher and lower levels of ADHD.

Lastly, the Spearmen correlation coefficient demonstrated a nonsignificant association between ADHD groups and diff_perc_errors_fast_slow (*r* (39) = 0.034, *p* =.087). That is, the error rates (% EOC) across event rate conditions (i.e., fast and slow) were similar between persons with greater and lower levels of ADHD.

General association between IC and task performance in the Go/No-Go

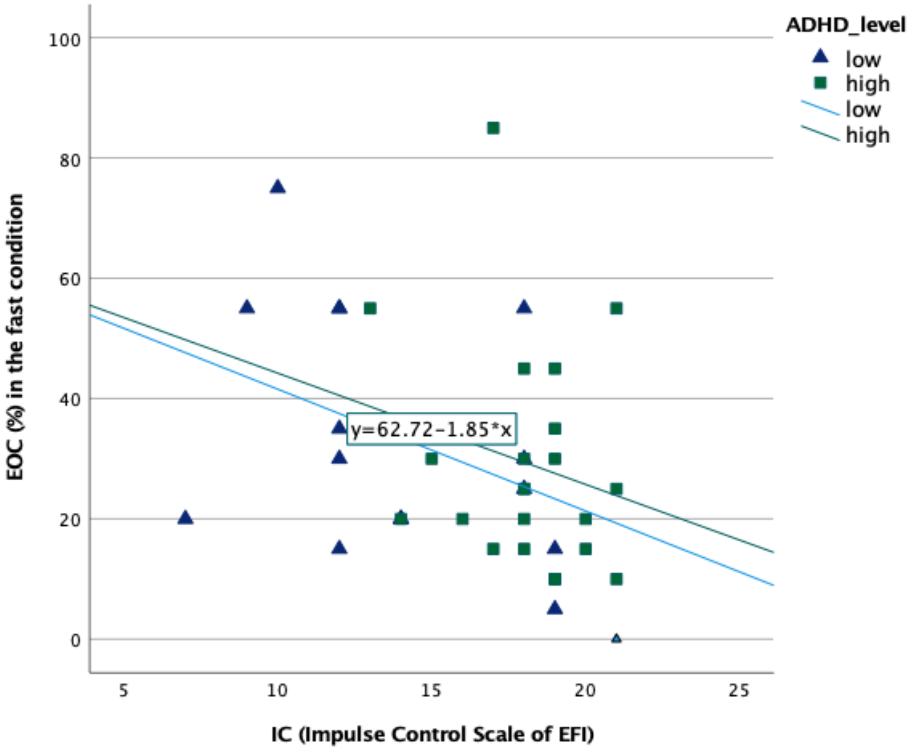
For the exploratory research question (4a) regarding whether IC subscale on the EFI is associated with task performance, non-parametric Spearmen correlations between IC score and all dependent variables were computed.

The Spearman's correlation coefficients between IC and mrt_fast_correct (*r* (39) = 0.232, *p* = .145) and IC and mrt_slow_corr (*r* (39) = 0.020, *p* = .901) revealed that these associations were not significant. Similarly, the Spearman's correlation coefficients between IC and sd_rt_fast_corr (*r* (39) = -0.195, *p* = .218) and IC and sd_rt_slow_corr (*r* (39) = -0.154, *p* = .335) demonstrated a non-significant association between the two. Results indicate that worse impulse control in EFI was not associated with slower speed and more variability of responding on the task.

Likewise, Spearman's correlations were used to assess the strength and direction of the link between IC and EOC in the fast (perc_errors_fast) and slow (perc_errors_slow). Surprisingly, Spearman correlation coefficients indicated that there was a significant medium and negative correlation between impulse control and accuracy on the fast condition (*r* (39) = -0.430, *p* = .005). However, the correlation between impulse control and EOC on the slow condition (*r* (39) = -0.191, *p* = .232) was not significant. That means that, although there was no association between self-reported impulse control in EFI and accuracy on slow condition of the task, there was an association in the fast condition. That is, the less impulse control one had, the more errors to no-go stimuli they would make on the fast condition, which is in line with what we expected. Figure 6 displays the scatterplot of this association split between ADHD groups, revealing that.

Figure 6

Scatterplot of association between IC and EOC (%) in fast condition



Note: This figure portrays the scatterplot of the association between the percentage of errors of commission (EOC) in the fast condition and the self-reported impulse control score labeled by ADHD groups (i.e., high, and low). There is a medium and negative association between the two, in which more self-reported impulse control is related to less errors on the task.

General association between MD and task performance in the Go/No-Go

To investigate the exploratory research question (4b) regarding whether MD subscale on the EFI is associated with task performance, the Spearmen correlations between MD subscale scores and difference scores between the fast and slow conditions of all dependent variables (diff_mrt_slow_fast, diff_sd_slow_fast, diff_perc_errors_fast_slow) were computed.

Non-significant Spearman's correlation coefficients were found between motivational drive reported on EFI and the difference scores of MRT (r (39) = -0.064, p = .691), SDMRT (r (39) = -0.004, p = .980) and EOC (r (39) = -0.051, p = .753). Results indicate that self-reported levels of motivational drive were not associated with task performance, seen in speed of responding, variability of responding and accuracy to no-go trials.

Discussion

The primary objective of this study was to examine the overall relationship between ADHD and executive functions among a group of students. Specifically, we aimed to investigate two executive functions that are believed to be core deficits responsible for the the disorder's symptoms: behavioral inhibition (often referred to as impulsivity) and motivation (namely, extra effort allocation). Highly relevant to this study were two well-established theories of ADHD, namely Barkley's executive dysfunction theory (Barkley, 1997) and Van der Meere's state-regulation deficit model (Van der Meere, 2005).

The significance of studying this topic stems not only from the fact that state-regulation was considered a confounding factor in the inhibition paradigm until the last two decades (Van der Meere, 2005), but also because the notion that ADHD affects adults differently than children is relatively recent (Davinson, 2007). Until now, the state-regulation deficit theory was mainly researched in children diagnosed with ADHD, by employing the Go/No-Go task with various event rates (e.g., low, medium, high), while the executive dysfunction theory was only studied in adults using self-reported measures of current basic executive functions. To answer our research questions, we utilized both a Go/No-Go task with fast (1.2s) and slow (7.2s) event rates, as well as two reliable questionnaires (CAARS and EFI). Crucially, we aimed to uncover whether adults with ADHD exhibit levels of behavioral or cognitive symptoms related to inhibition and motivation distinguishable from children.

In line with the literature of adult ADHD in relation to basic executive functions, we found that the more executive function problems students had in daily life, the more symptoms of ADHD they showed (Dvorsky & Langberg, 2019; Green & Rabiner, 2012; Weyandt et al., 2013). Consistent with Barkley's theory, the results also indicated that students with elevated levels of ADHD experienced more issues in day-to day life with controlling their impulses. However, contrary to expectations, these students did not report any issues related to motivational drive. Van der Meere (1999) suggested that the primary deficit in ADHD lies in cognitive motivation rather than behavioral inhibition. Therefore, it is plausible to consider that if impulsivity (which is an overt symptom of ADHD), arises as a result of motivational deficits, students may not perceive daily motivational drive as a prominent concern.

Particularly, the focus of our investigation was on behavioral inhibition and cognitive motivation as tested with a Go/No-Go task with two stimuli presentation rates. In this study, a simple Go/No-Go task was adapted based on research utilizing the task to identify deficient effort allocation in subjects with ADHD (Kooistra et al., 2010; Metin et al, 2016; Van der Meere, 2005). Significant differences were found in the response times (RT), variability of response times (SDMRT) and accuracy (EOC) of students between the trials with fast and slow event rates. These results highlight the robustness of our task's design in successfully altering students' psychophysiological states and impacting their performance outcomes as a result. It is consistently reported in the literature that manipulating the stimuli presentation rates in a Go/No-Go task can reliably induce changes in participants' states, which in turn affect their performance in a similar manner as the Cognitive Energetic Model of Sanders predicted (Sanders, 1983). Specifically, over-activation (seen in the fast condition) and under-activation (observed in the slow condition) occur when effort is not effectively allocated (Metin et al., 2012).

Regarding the specific executive function deficits investigated in this study, we found evidence that rather than a behavioral inhibition problem, students with ADHD primarily exhibited motivational deficits (Van der Meere, 2005). Consistent with the meta-analysis of Metin et. al (2012), students' performance on the go-no/go task with two conditions was reflected in their scores on CAARS. On one hand, if students had problems with applying extra effort to the activation pool (i.e., cognitive motivation) to perform optimally, test subjects with more self-reported symptoms of ADHD would perform more poorly (i.e., as seen in slower and more variable RTs, and more errors of comission) on the task than their counterparts, and this would be more obvious in the slow boring condition (due to under-activation) than in the fast exciting condition (due to over-activation). This hypothesis was supported by our results. Consistent with SRDM, students with more self-reported ADHD symptoms responded more slowly and more variably than their peers, particularly in the slow condition. Additionally, we found evidence that, while test subjects from the low ADHD group followed a strategy in the task which is an indication of successful regulation of states by effective allocation of effort, the ADHD group failed to employ a similar consistent strategy, indicative of a state-regulation problem (Van der Meere et al., 2010). However, these subjects did not make more errors of commission in the fast condition than those with lower symptoms of ADHD. These findings are consistent with performance measures found in studies with children (Borger & Van der Meere, 2000; Kooistra et al., 2010). It is possible that, as individuals' brains develop, state regulation deficits are only observed in reaction times, and not in accuracy due to the strategies adults employ to compensate for their shortcomings (Drake et al., 2019). In line with this, Van der Meere (1999) found that there is a developmental course in the state-regulation of children with ADHD, in which the number of errors of commission they made was negatively related to childrens' ages.

On the other hand, we expected that subjects with higher levels of ADHD would make more overall errors (i.e., responding to no-go stimuli), which would suggest primary impulse control deficits. Despite this, we did not find any differences in errors between the groups with high and low reported symptoms of ADHD, indicating that students with more symptoms of ADHD did not experience behavioral inhibition problems. These results challenge the theory of Barkley (1997). It is important to note, however, that inhibitory control is considered a complex entity encompassing various types of inhibitory processes and a wide range of tasks employed for its assessment (Littman & Takács, 2017). While our findings indicate that individuals with high levels of ADHD tend to report more difficulties with impulse control in daily life, this complexity poses challenges in determining the most suitable neurocognitive task for assessing behavioral inhibition in the adult population. An explanation in this case could be that students with ADHD are less confident in their ability to succeed academically and as a result, report higher EF in questionnaires (Green & Rabiner, 2012). Another possible explanation for the discrepancy in behavioral inhibition problems between children and adults in the Go/No-Go task is the developmental course of inhibitory control and different strategies employed in the task. Specifically, research has demonstrated that inhibitory control improves gradually from childhood, as evidenced by the maturation of different regions within the prefrontal cortex (Davis et al., 2003). Moreover, distinct activation patterns have been observed between adults and children in the prefrontal cortex during the Go/No-Go task (Rahman et al., 2017). These observed changes may help explain the absence of behavioral inhibition problems in adults compared to children.

Finally, since our study investigated executive functions both cognitively, and behaviourally, we were interested in whether behavioral inhibition and motivation measurements used in our sample were in agreement. Surprisingly, for inhibition, we only found congruence between the accuracy of subjects in the condition with a fast event rate and their self-reported impulse control problems, meaning that the more errors students in our sample made in the fast condition, the more problems they had with daily impulse control. However, reaction times, variability and errors in the slow condition were not associated with these deficits. Similarly, we found no association between motivation as measures by the difference in performance (reaction times, standard deviation of reaction times and accuracy) between event rate conditions (i.e., fast and slow) and students' reported issues with motivational drive. These results are in agreement with many studies (Bodenburg et al., 2022; Burgess et al., 2006; Leontyev et al., 2018). Although they are both designed to investigate the same notion, objective measures of executive functions (i.e., neurocognitive tasks) have little to no association with the subjective, self-reported measures. A reason for this could be that the design of lab-based neurocognitive tasks is not complex enough to resemble the day-to-day environment that ADHD sufferers are exposed to. Consistent with this idea, Burgess et al., 2006 suggested that performance-based executive function evaluations lack ecological validity. Leontyev et al. (2018) further proposed that in contrast to self-reported measures of executive function that capture typical human conduct, only optimal performance is visible in such a highly organized laboratory setting.

Strengths and Implications

As mentioned in the previous sections, there are many studies that found a general relationship between symptoms of ADHD and executive functions reported by adults.

However, the studies that examined behavioral inhibition or state-regulation by employing a cognitive task in ADHD mostly used children.

The main strength of this study lies in the exploration of an under-investigated area in the research of ADHD, the association between ADHD and specific executive dysfunctions in adults. This study examined motivation and inhibition deficits in adults using both a neuro-cognitive task and two questionnaires (CAARS and EFI) to parallel these results. Moreover, since ADHD is a highly heterogeneous disorder, we ensured for a better quantification of the disorders' symptoms by using a multi-dimensional measure of ADHD. Further, we used a simple Go/No-Go task with event rates that were modified based on extensive literature review of state regulation and motivation in children with ADHD. By doing this, we found evidence of key state-regulation problems in our sample of students. This is relevant due to possible replications of the task effects, which could contribute to new knowledge about the association between ADHD and executive functions in adults. Lastly, it was important that the Go/No-Go task was employed in the laboratory, where environment contingencies other than the pace of stimuli presentation (e.g., noise distractors, different lighting, and apparatus size) could not interfere with participants' performance.

Limitations and Directions for Future Research

Although our findings regarding specific deficits of ADHD in adults are intriguing, this study is not without limitations. A primary limitation lies in our sample. The sample size of our study was relatively small, which might have affected the statistical power to detect significant effects of the event rate manipulations in the Go/No-Go task. Furthermore, although volunteers were encouraged to participate in our study, our convenient sample consisted mainly of first year students of the University of Groningen, which directly relates to the external validity of our study and the generalizability of our results. To add to this, despite collecting data on diagnosis, comorbidities and medication used by the students, participants who reported having one or multiple diagnoses, or taking medication were not excluded from the study due to the sample size limitations. This could have affected the internal validity of this study as well as reliability of the task. Although some studies found that state-regulation deficits in children were resistant to certain medications such as methylphenidate and clonidine (Borger & Van der Meere, 2000), others found that methylphenidate does influence children's ability to regulate their impulses (Trommer et al., 1991). Careful consideration must be given to these sample characteristics for an accurate measurement of deficits in ADHD. Future research should aim for a higher sample size with more variability in the ages and educational setting of these students for more generalizable results. Moreover, to increase the validity of similar studies, a stricter exclusion criterion should be used (e.g., excluding participants with comorbid diagnoses and those taking medication).

A second limitation of this study is the use of a baseline level of 60 on CAARS when separating high and low ADHD groups prior to the analysis. Even though we used a multi-dimensional approach to ADHD due to the highly intricate nature of the disorder, separating the groups could have altered our findings. That is, choosing a threshold level implied that the mixed ANOVA used to assess the variance between groups compared individuals who scored too close below (e.g., 59) or above (e.g., 61) this threshold. Future studies could benefit from splitting the participants into groups that are for example in the highest and lowest 25% of scores based on the sample distribution of T-scores on CAARS, which would further impact the task effects between ADHDs groups.

Finally, the Go/No-Go task was solely used to evaluate response velocity and accuracy and was not complemented with additional measurements to examine more closely what happened to test subjects when they completed the task.

Along with the employment of this Go/No-Go task with similar even-rates, additional measures are proposed for future investigations. For instance, video recordings might be employed to closely monitor the behavior of participants during the competition of the task. Furthermore, an electroencephalogram (EEG) might be carried out on test subjects to determine what areas of their brains are active throughout the task similar to the study of Leontyev et al. (2018). Alternatively, an electrocardiogram machine (EKG) (which measures heart rate variability [HRV]) and respiration bands could be used to determine when individuals are regulating their psychophysiological processes (Pham et al., 2021) and exerting greater effort (e.g., anticipating a go-stimuli compared to no-go stimuli) (Borger & Van der Meere, 2000). Lastly, an eye tracking device could be utilized to identify instances of attentional loss (i.e., getting distracted) in participants with ADHD.

Too little studies have examined the specific ADHD deficits together (see e.g., Leotti & Wager, 2010; Kuntsi et al., 2009). However, researching motivation and executive functions simultaneously is crucial in understanding ADHD symptomatology, as these two aspects are interconnected. Although motivation is not considered a basic EF, Walker (2012) found that these two concepts are closely linked in self-regulated learning. Students may desire to excel academically, but without the necessary self-regulatory abilities, they struggle to complete tasks and maintain optimal levels of motivation. And this is even more pronounced in ADHD sufferers. Their weaknesses in executive functions, such as planning, organizing, decision-making, goal setting, and working memory, directly impact motivation. Furthermore, Van der Meere et al. (2010) emphasized that the basic cognitive processing stages of the state-regulation theory (SRT), which are associated with arousal and activation levels, are also involved in executive functioning. Thus, researchers who studied these topics independently might benefit from accounting for the possibility that both are involved in ADHD behavioral symptomatology. Examining motivation and executive functions by adding incentives to the traditional Go/No-Go task with different event rates (i.e., fast, medium, and slow) could offer valuable insights into various theories that attempted to explain ADHD symptomatology in the last decades.

Conclusion

This study aimed to investigate the relationship between ADHD and executive functions. The findings demonstrate that students with more symptoms of ADHD face daily problems with executive functions. Moreover, by utilizing a Go/No-Go task, the present study specifically focused on behavioral inhibition and motivation. The results support Van der Meere's state-regulation deficit model, suggesting that the primary deficit in ADHD lies in cognitive motivation. Students with higher self-reported symptoms of ADHD performed more poorly on the task (i.e., being slower and more variable), and could not regulate their activation states for an optimal performance (i.e., no consistent strategy). However, no differences were found in accuracy between groups, challenging Barkley's executive dysfunction theory. The complexity and developmental course of inhibitory control in adults compared to children may contribute to the absence of impulsivity problems in students with ADHD. Additionally, this study found limited agreement between the task measures and the questionnaire of executive functions, suggesting that lab-based tasks may fail to capture the real-world challenges faced by individuals with ADHD. These findings highlight the need for a comprehensive understanding of executive functions and the importance of considering motivational deficits in the assessment and treatment of ADHD in adults.

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Appendices

Appendix A

Information sheet

INFORMATION ABOUT THE RESEARCH

VERSION FOR PARTICIPANTS

"EXECUTIVE FUNCTIONS AND ADHD, AN EXPERIMENTAL STUDY"

PSY-2021-S0094

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

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

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

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

Therefore, please read this information carefully.

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

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

- **Why this research?**

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

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

  - Before starting the research, you as a participant will be provided with necessary information about the study. Next, you will be asked for your consent to participate, and will have the liberty to make an informed decision. Your answers will and shall remain anonymous.

- The research solely contains two cognitive tasks completed on a computer. You will first receive instructions on how to complete the first task and then be asked to complete the second task. After that, you will receive instructions for the second task and will then be asked to complete the second task. You will also be asked to fill in some general information, like age and gender.
- In total, the study will take approximately 30 minutes (each task will take approx. 15 minutes).
- Participants that are in the first-year students SONA-pool will receive 1.5 Credits when completing the study. The participants who volunteer will receive a coffee after completing the tasks.

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

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

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

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

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

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

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

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

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

Informed consent

INFORMED CONSENT

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

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

☐ YES ☐ NO

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

☐ YES ☐ NO

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

☐ YES ☐ NO

Below I indicate what I am consenting to.

Consent to participate in the research:
☐Yes,I consent to participate; this consent is valid until 01-08-2023
☐No, I do not consent to participate

Consent to processing my personal data:
☐Yes, I consent to the processing of my personal data as mentioned in the research information. I know that until 01-08-2023 I can ask to have my data withdrawn and erased. I can also ask for this if I decide to stop participating in the research.
☐No, I do not consent to the processing of my personal data.

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

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

Appendix B

Table B1.

Tests of Normality for each subscale of the EFI and CAARS

	Shapiro-Wilk		
	Statistic	df	Sig.
CAARS_TScoreInat	,975	394	<,001
CAARS_TScoreHyper	,973	394	<,001
CAARS_TscoreImpul	,961	394	<,001
CAARS_TscoreSelfconc	,973	394	<,001
CAARS_TscoreDSM_Inattention	,974	394	<,001
CAARS_TscoreDSM_HypImp	,948	394	<,001
CAARS_TscoreDSM_Total	,956	394	<,001
CAARS_TscoreADHDIndex	,978	394	<,001
EFI_total	,990	394	,010
SP	,990	394	,007
MD	,981	394	<,001
IC	,976	394	<,001
ORG	,987	394	,001
EM	,935	394	<,001

a. Lilliefors Significance Correction

Note: This table shows the results of the Shapiro-Wilk test. The p-values displayed on the last raw show significant deviation from normality for every scale and subscale used (EFI and CAARS).

Table B2.

Tests of Normality

		Shapiro-Wilk		
	ADHD_level	Statistic	df	Sig.
mrt_fast_corr	high	.940	16	.350
	low	.942	25	.168
mrt_slow_corr	high	.956	16	.582
	low	.948	25	.223
perc_errors_fast	high	.916	16	.148
	low	.900	25	.018
perc_errors_slow	high	.917	16	.150
	low	.898	25	.016
RT_SD_fast_corr	high	.920	16	.166
	low	.940	25	.151
RT_SD_slow_corr	high	.939	16	.337
	low	.981	25	.908

Note: This table displays the result of the Shapiro Wilk test for all task performance measures (MRT, percentage EOC, SDMRT) per ADHD group. There was no significant deviation from normality for MRT and SDMRT. In contrast, accuracy as measured in percentage EOC deviates significantly from normality in the low ADHD group.

Table B3.

Levene's Test of Equality of Error Variances MRT

		Levene Statistic	df1	df2	Sig.
mrt_fast_corr	Based on Mean	.017	1	39	.898
	Based on Median	.015	1	39	.902
	Based on Median and with adjusted df	.015	1	38.996	.902
	Based on trimmed mean	.017	1	39	.897
mrt_slow_corr	Based on Mean	.419	1	39	.521
	Based on Median	.254	1	39	.617
	Based on Median and with adjusted df	.254	1	37.577	.617
	Based on trimmed mean	.395	1	39	.533

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

Table B4.

Levene's Test of Equality of Error Variances percentage of EOC

		Levene Statistic	df1	df2	Sig.
perc_errors_slow	Based on Mean	.451	1	39	.506
	Based on Median	.218	1	39	.643
	Based on Median and with adjusted df	.218	1	35.838	.644
	Based on trimmed mean	.548	1	39	.464
perc_errors_fast	Based on Mean	1.536	1	39	.223
	Based on Median	.988	1	39	.326
	Based on Median and with adjusted df	.988	1	38.888	.326
	Based on trimmed mean	1.497	1	39	.228

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

Table B5.

Levene's Test of Equality of Error Variances SDMRT

		Levene Statistic	df1	df2	Sig.
rt_SD_fast_correct	Based on Mean	.003	1	39	.960
	Based on Median	.033	1	39	.856
	Based on Median and with adjusted df	.033	1	38.753	.856
	Based on trimmed mean	.004	1	39	.952
RT_SD_corr_slow	Based on Mean	5.868	1	39	.020
	Based on Median	5.811	1	39	.021
	Based on Median and with adjusted df	5.811	1	28.200	.023
	Based on trimmed mean	5.844	1	39	.020

Note: Tests the null hypothesis that the error variance of the dependent variable is equal across groups. [a]

Table B6

Descriptive Statistics of CAARS and EFI only

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

Note: This table gives the descriptive statistics for the CAARS Index scores of participants who completed only the CAARS and EFI.

Table B7

Descriptive Statistics of CAARS for participants who completed the task

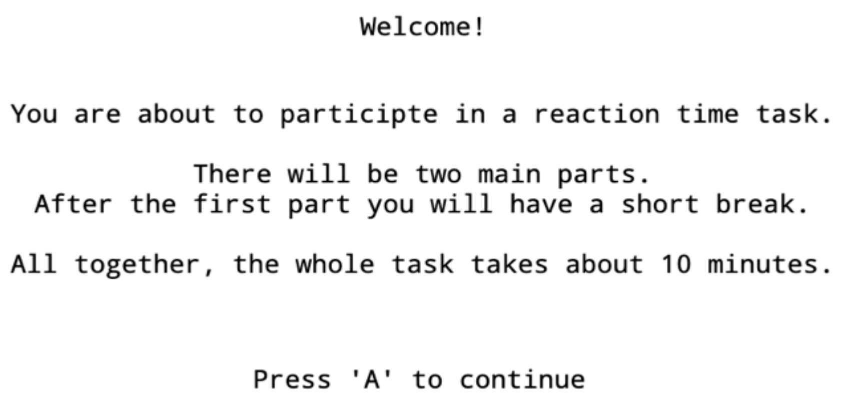
	N	Range	Minimum	Maximum	Mean	Std. Deviation
CAARS_TScoreADHDIndex	41	48.23	35.93	84.16	56.6149	12.25342
Valid N (listwise)	41					

Note: This table gives the descriptive statistics for the CAARS Index scores of participants who completed both the Go/No-Go task and the CAARS.

Appendix C

Figure C1

Welcome screen



Welcome!

You are about to participte in a reaction time task.

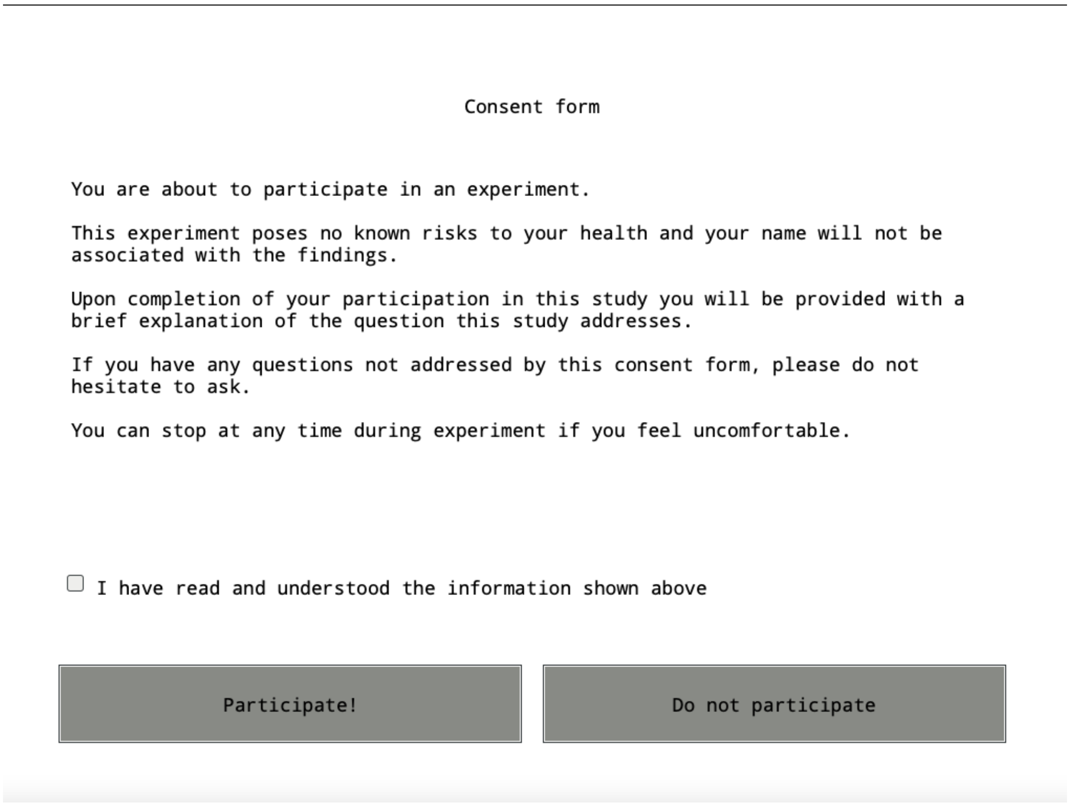
There will be two main parts.
After the first part you will have a short break.

All together, the whole task takes about 10 minutes.

Press 'A' to continue

Figure C2

Consent Form



Consent form

You are about to participate in an experiment.

This experiment poses no known risks to your health and your name will not be associated with the findings.

Upon completion of your participation in this study you will be provided with a brief explanation of the question this study addresses.

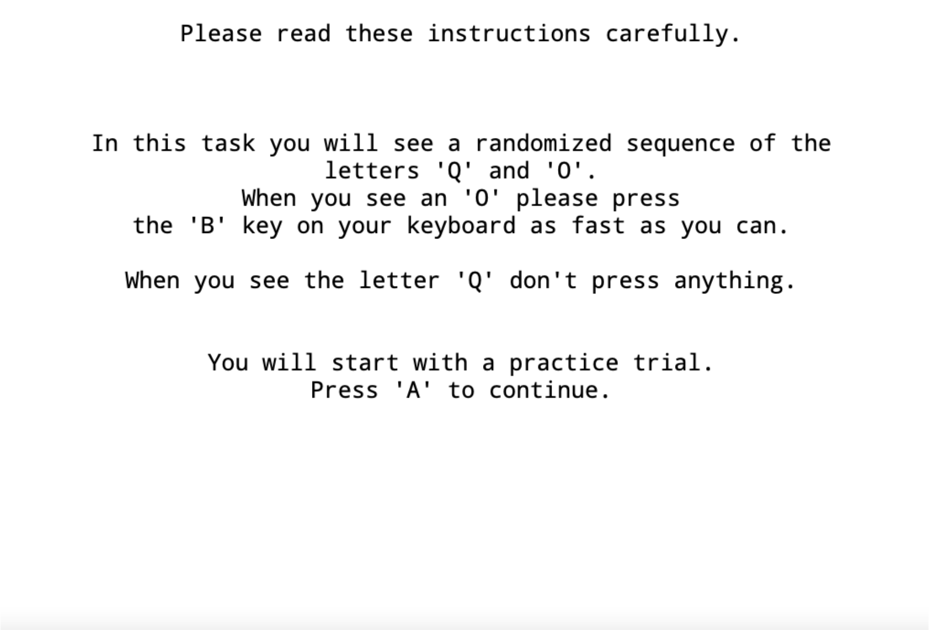
If you have any questions not addressed by this consent form, please do not hesitate to ask.

You can stop at any time during experiment if you feel uncomfortable.

☐ I have read and understood the information shown above

Figure C3

Instruction Screen



```
Please read these instructions carefully.


In this task you will see a randomized sequence of the
letters 'Q' and 'O'.
When you see an 'O' please press
the 'B' key on your keyboard as fast as you can.

When you see the letter 'Q' don't press anything.


You will start with a practice trial.
Press 'A' to continue.
```

Figure C4

Q-Q plots of low ADHD group scores on EOC in fast condition

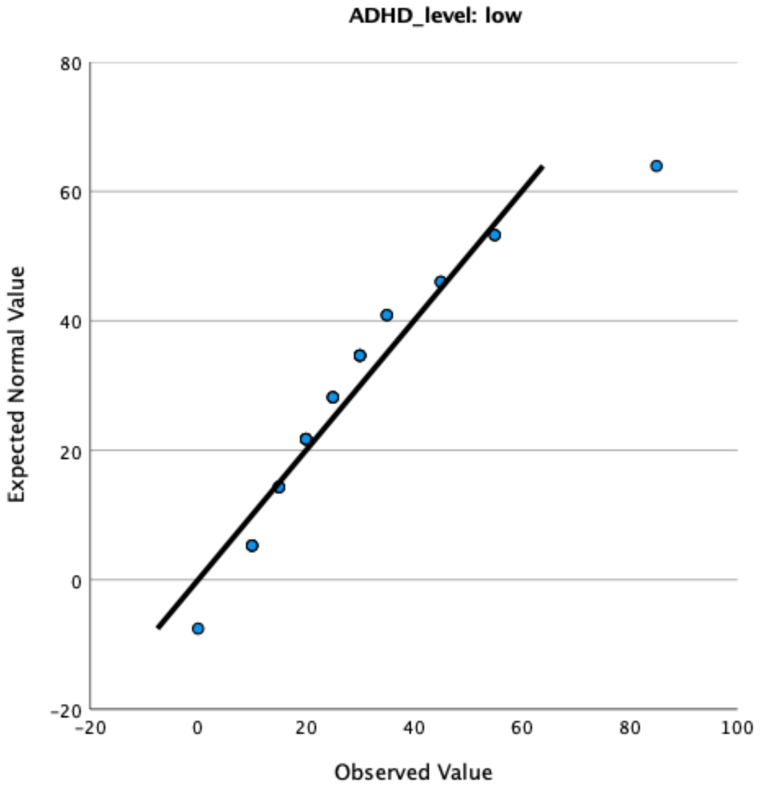


Figure C5

Q-Q plot of low ADHD group scores on EOC in slow condition

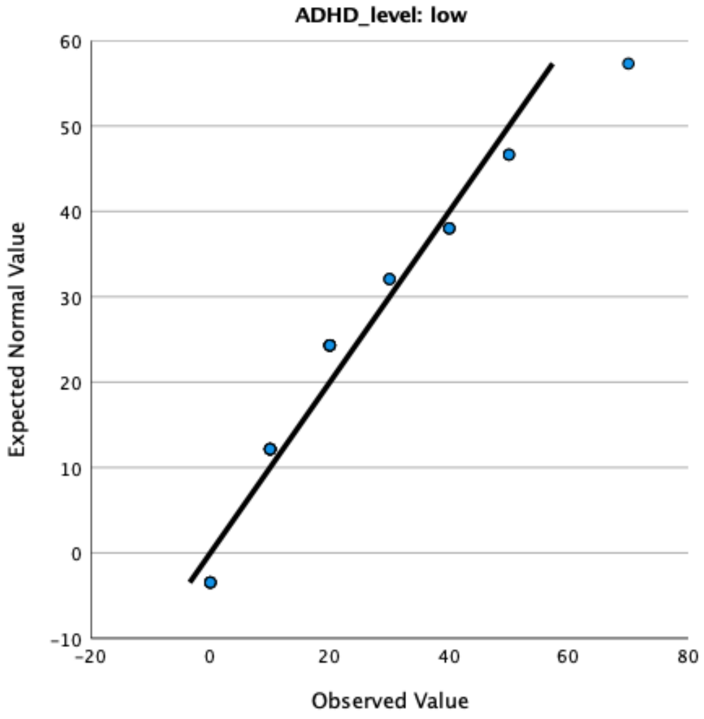


Figure C6

Q-Q plots of high ADHD group scores on EOC in the fast condition

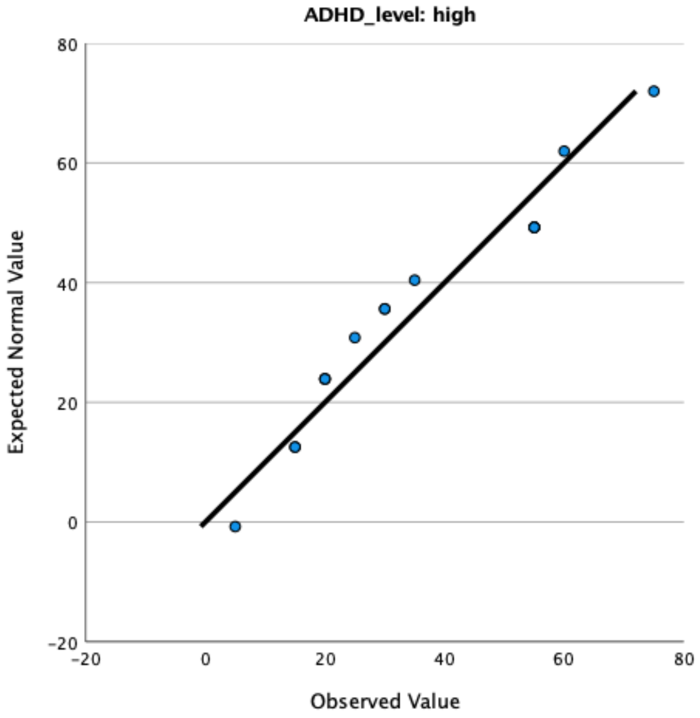


Figure C7

Q-Q plots of the high ADHD group scores on EOC in the slow condition