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Correlations Between Inhibition and Memory Components of Executive Function and Measures of Autistic Traits in the General Population

Correlations Between Inhibition and Memory Components of Executive Function and Measures of Autistic Traits in the General Population

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Abstract

This thesis comprises two studies (with the second study building upon the first) to assess core components of executive function orthogonally. Executive function can be defined as the combination of goal representation in working memory and the inhibition of goal-irrelevant responses stimuli. Both studies employed a paradigm with two tasks assessing working memory and inhibitory control processes concurrently. The modified Flanker task measured working memory and interference control, while the modified Spatial Conflict task measured working memory and response inhibition. The thesis aimed to examine main effects of memory and inhibitory load in each task when assessed concurrently, explore potential over-additive interactions between these executive function components, and investigate correlations between autistic traits in the general population and task performance.

In each study with 100 participants aged 18-25, Study 1 found that in the Flanker task, how quickly people reacted was significantly affected by the demands on working memory and inhibitory control. In the Spatial Conflict task, the time it took to react was strongly influenced by whether the presented information matched or conflicted (congruency). There's some suggestion that memory played a role, especially in incongruent trials (when the information conflicted). When it came to accuracy, congruency had a strong impact, but memory didn't seem to affect it.

In Study 2, significant progress was achieved through the implemented modifications. In the Spatial Conflict task, effects on reaction time were observed due to both memory and congruency load, and accuracy showed meaningful influence from congruency. Moderate evidence supporting a memory effect, particularly in congruent trials, was noted in accuracy. The Flanker task revealed a memory effect in both reaction time and accuracy. However, there was no evidence of a congruency effect in accuracy, and the congruency effect in reaction time was only evident in the low memory condition. Interactions between executive function components were not observed, and over-additive interactions were not supported.

Furthermore, Bayesian linear regression and correlation analyses found no meaningful evidence of an increasing correlation between task performance and ASC traits with increasing memory and inhibitory load. These tasks hold potential for future research in concurrently measuring core executive function components.

Acknowledgment

I want to express my heartfelt thanks to my parents for their unwavering support and my supervisor, Prof. Chris. Jarrold, for their invaluable guidance. Their belief in me has been instrumental in completing this dissertation.

Author's declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: Yasamin Rahmati DATE: 13/09/2023

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List of Tables and Illustrations

I hereby confirm that I have obtained ethics approval for both of my research studies in this thesis. Study 1 received approval on February 8, 2023, with reference number 13573, and Study 2 was approved on August 3, 2023, with reference number 15328. This declaration confirms that my research in this dissertation has adhered to ethical standards, as required by the regulations.

1 Chapter One (Introduction)

1.1 Executive function definitions and components

Cognitive scientists have long been intrigued by the human capacity to think, act thoughtfully and flexibly, and align behavior with goals rather than being solely driven by environmental cues, habits, desires, or impulsive emotions (Doebel & Müller, 2023). This ability is commonly referred to as "executive function".

Executive functions (EFs; also called executive control or cognitive control) is an umbrella term that captures a set of cognitive processes that allow for monitoring and regulating goal-directed behavior to flexibly adapt behavior to environmental requirements (Botvinick et al., 2001). Executive functions come into play when situations require concentration and attention, and relying on automatic or instinctual responses would be ill-advised, insufficient, or impossible (Burgess et al., 2005; Espy, 2004; Miller & Cohen, 2001).

Norman and Shallice’s (1986) model made a significant contribution to our understanding of cognitive control and executive functioning, according to this model the programming, regulating, and verifying of human actions and thoughts involve two systems, namely, a supervisory attentional system and contention scheduling. The former system, closely related to executive function, is responsible for regulating non-routine and novel tasks. The latter system, on the other hand, is responsible for routine and overlearned behaviors or tasks and allows us to prioritize the order of these behaviors and tasks (e.g., making a coffee while talking on the phone).

In this theoretical context, executive control primarily involves the capacity to keep task objectives in mind, thereby preventing unsuitable reactions to external stimuli. This statement establishes a clear *a priori* model illustrating the interaction between working memory and inhibition. Therefore, working memory (WM) and inhibitory control (IC) can be regarded as two fundamental components of executive function (Diamond, 2013), although some may also consider shifting, which refers to the ability to switch between tasks, operations, or mental sets in response to changing priorities, as another core component of EF (e.g., Lehto et al. 2003, Miyake et al. 2000). From these, higher-order EFs are built such as reasoning, problem solving, and planning (Collins & Koechlin 2012, Lunt et al. 2012).

Working memory, as defined by Baddeley (1992), involves the ability to maintain and manipulate online information. Inhibitory control (IC), in a broader sense, is the ability to cancel or suppress an action that is irrelevant, no longer needed, and/or inappropriate.

Inhibition, which is traditionally considered as a unitary construct, is now understood as multifaceted from a behavioral and cognitive neuroscience perspective (Aron, 2011; Friedman & Miyake, 2004; Nigg, 2000). Although various classifications have been proposed to categorize IC (Friedman & Miyake, 2004; Nigg, 2000; Stahl et al., 2014), there is substantial evidence supporting the idea that IC can be conceptualized as a multidimensional construct including response inhibition, which involves the ability to suppress automatic but inappropriate responses, and interference control, which pertains to the ability to filter out irrelevant but conflicting information (e.g., Friedman & Miyake, 2004; Gandolf et al., 2014; Howard et al., 2014; Rey-Mermet et al., 2018). However, some add a third component of inhibition called resistance to proactive interference which refers to processes where previously learned information becomes irrelevant and interferes with new information (Friedman & Miyake, 2004; Miyake & Friedman, 2012).

A wide range of measures have been employed to assess these three inhibitory control constructs. However, for the purposes of this thesis, the primary focus will be on prepotent response inhibition and interference control, as these facets of inhibition have been the most extensively studied within the context of neurodevelopmental disorders.

Therefore, this thesis examines working memory and inhibitory control (covering two distinct types of response inhibition and interference control). These are considered the core components of executive function.

1.2 Executive Function and Neurodevelopmental Conditions

Neurodevelopmental conditions encompass a diverse range of conditions that impact brain development and functioning, exhibiting significant genetic and clinical variability. These conditions tend to be characterized by developmental delays in cognitive, emotional, and motor milestones (Parenti et al., 2020). Extensive research has demonstrated that individuals with various neurodevelopmental conditions exhibit distinct performance differences compared to typically developing individuals on tasks involving executive functions (Diamond et al., 1997; Otterman et al., 2019; Pennington & Ozonoff, 1996; Sun & Buys, 2012). For instance, individuals with Attention Deficit and Hyperactivity Disorder (ADHD), Autism Spectrum Condition (ASC), and Tourette's Syndrome have all demonstrated deficits in executive functions (Diamond et al., 1997; Pennington & Ozonoff, 1996).

This thesis concentrates on executive function difficulties in individuals with traits of ASC and ADHD within the general population. Further details regarding executive function difficulties in these groups will be discussed below.

1.2.1 Executive Function and Autism Spectrum Conditions (ASC)

Autism spectrum condition is a heterogeneous, neurodevelopmental condition that is thought to last a lifetime (American Psychiatric Association, 2013). Core symptoms of ASC include qualitative difficulties in social communication and social interaction, and restricted, repetitive patterns of behavior, interests, or activities. ASC is also associated with difficulties in cognitive control (Solomon et al., 2008).

Extensive research has focused on investigating the core components of executive function, including inhibitory control and working memory, in individuals across different age groups diagnosed with ASC. Moreover, recent studies have challenged earlier findings that suggested spared executive function in these individuals (Ozonoff & Strayer, 1997, 2001) and revealed difficulties in inhibitory control and working memory among high-functioning children and adults with ASC (Christ et al., 2007; Geurts et al., 2004; Joseph et al., 2005; Luna et al., 2007; Steele et al., 2007; Tonizzi et al., 2022; Williams et al., 2005).

More specifically, in terms of inhibitory control, difficulties have been observed in each of prepotent response inhibition and interference control in some studies (e.g., Adams & Jarrold, 2011; Christ et al., 2011; Mosconi et al., 2009; Sinzig et al., 2008; Verte´ et al., 2005), but not all studies (e.g., Christ et al., 2007; 2011; Geurts et al., 2009). According to the meta-analysis of Guerts et al (2014), in contrast to the general belief at that time, difficulties in both prepotent response inhibition and interference control were observed in individuals with ASC. However, according to this meta-analysis, large variation between studies was also found, suggesting that factors beyond inhibition type, age, or IQ significantly influence inhibitory control performance among individuals with ASC.

Moreover, a recent meta-analysis by Tonizzi et al. (2022) supported the notion that both prepotent response inhibition and interference control are impaired in ASC. However, they found that intellectual functioning and age were relevant moderators. More specifically, age was a relevant moderator for prepotent response inhibition but not for interference control, and further, IQ was found to have a significant moderating effect on prepotent response inhibition tasks, but not on interference control tasks.

Furthermore, working memory processes encompass both visual working memory, responsible for temporarily storing and processing visual information like images, shapes, colors and spatial relationships, and verbal working memory components, which briefly hold and manipulate spoken or verbal information, such as words, numbers, or instructions (Smith et al., 1996). Both of these working memory components have been widely investigated in individuals with ASC. Contrary to initial reports of intact working memory in individuals with ASC (Ozonoff & Strayer, 2001), recent studies have revealed difficulties, particularly in spatial working memory (Christ et al., 2007; Geurts et al., 2004; Joseph et al., 2005; Luna et al., 2007; Steele et al., 2007; Williams et al., 2005).

Additionally, another study exploring working memory in autistic individuals, a meta-analysis by Habib et al. (2019), confirmed significant impairments in working memory, encompassing both phonological and visuospatial domains, in individuals with ASC when compared to typical individuals.

In summary, the current body of literature suggests the existence of executive function difficulties in individuals with Autism Spectrum Condition (ASC). However, it's crucial to highlight the significant heterogeneity observed across studies. These discrepancies emphasize the need for further research to advance our understanding of executive functioning in individuals with ASC.

1.2.2 Executive Function and Individuals with Subthreshold Autism Traits in the General Population

Autism is best understood as a spectrum condition, and recent findings indicating that it manifests to some degree not only in individuals diagnosed with autism, but also in those who exhibit a significant degree of autistic symptoms without meeting formal diagnostic criteria (Christ et al., 2010; Constantino & Todd, 2003; Constantino et al., 2004). Although the main body of studies on subthreshold autistic traits has focused on relatives of individuals with ASC, additional research suggests that the expression of subthreshold autism traits may extend beyond those with a family history of ASC and include the general population (Christ et al., 2010). For instance, in a study of university students, Baron-Cohen et al. (2001) found that a subsample of students (i.e., mathematicians) scored significantly higher on the AQ (autism quotient questionnaire) compared to other students (i.e., those studying the humanities and social sciences).

Recent research has investigated executive function in individuals with a broader autism phenotype and autistic traits. However, the findings from these studies have revealed inconsistencies. For example, Wong et al. (2006) reported that ASC parents and siblings performed comparably to their control counterparts on the Tower of London test (which assesses planning and sequencing abilities.). However, other studies using similar tasks have reported impaired performance for parents and siblings (Parents: Hughes et al., 1997; Piven & Palmer, 1997; Siblings: Delorme et al., 2007; Hughes et al., 1999; Ozonoff et al., 1993). The findings for other aspects of executive control are also mixed, with some studies reporting intact performance in first-degree relatives (e.g., Bölte & Poustka., 2006; Losh et al., 2009; Ozonoff et al., 1993; Szatmari et al., 1993) and others reporting impaired performance (e.g., Gokcen et al., 2009; Hughes et al., 1997; Hughes et al., 1999).

In a study by Christ et al. (2010), autism traits were found to significantly influence participants' overall executive function and specific executive domains even after controlling for ADHD symptomatology. According to the result of this study, although autism traits was a significant predictor of participants' function in most specific executive domains, there were no significant differences in inhibitory control and organization of materials scores between groups with high and low trait levels. Other studies, such as Ferraro et al. (2016) and Gokcen et al. (2009), have also reported executive function deficits in individuals in the general population with high autistic traits.

Despite the growing body of research, the impact of subthreshold autism traits on executive control remains uncertain which highlights the need for further research on executive function in individuals with ASC traits in the general population.

1.2.3 Executive Function and Attention-deficit/hyperactivity disorder (ADHD)

Attention-deficit/hyperactivity disorder (ADHD) is defined as a consistent pattern of inattention, impulsivity and/or hyperactivity (American Psychiatric Association, 2013). Although the neuropsychological profile of ADHD is heterogeneous, numerous studies indicate that it involves difficulties in various executive function domains (Barkley et al., 1992; Pennington & Ozonoff, 1996; Sergeant et al., 2002).

In a meta-analysis involving 83 studies, Willcutt et al. (2005) reported that ADHD children/adolescents exhibited significant difficulties compared to those without ADHD in neuropsychological measures of EF, such as planning, spatial and verbal WM, response inhibition, and vigilance.

In summary, when examining executive function components in individuals with ADHD, a substantial body of research has consistently demonstrated the presence of inhibitory processes difficulties in individuals with ADHD (Crosbie et al., 2013; Rajendran et al., 2013; Schreiber et al., 2014; Shimoni et al., 2012; Sonuga-Barke et al., 2002; Toll et al., 2011; Willcutt et al., 2005) as well as poorer working memory function in both children and adults with ADHD (e.g., Martinussen & Tannock, 2006, Rapport et al., 2008). Moreover, a few studies have focused on shifting abilities in children with ADHD, with mixed results. While some studies found no evidence of shifting difficulties (Biederman et al., 2007), others reported impaired shifting functions (O'Brien et al., 2010).

Therefore, ADHD is characterized by difficulties in executive functions, including inhibitory control, working memory deficits, and potential difficulties in shifting abilities.

1.2.4 Executive Function and Individuals with ADHD Traits

It has been argued that ADHD psychopathology can be viewed dimensionally with its traits, including inattention and hyperactivity-impulsivity, seen as existing on a continuum in the general population (Hudziak et al., 2007). This dimensional view of ADHD is supported by evidence from molecular genetics, suggesting that ADHD represents the extreme end of traits found in the general population (Martin et al., 2014). Moreover, even in general population samples, individuals with more pronounced ADHD traits tend to experience more difficulties with executive functions

(Otterman et al., 2019). For instance, Moses et al. (2022) conducted a study of a large general population sample investigating three potential endophenotypes for ADHD: working memory function, prepotent response inhibition, and reaction time variability. Their findings indicated that individuals with more ADHD traits showed lower working memory performance, poorer prepotent response inhibition, and increased reaction time variability.

Crosbie et al. (2013) delved into prepotent response inhibition, reaction time latency, and variability using the stop-signal task (Lappin & Eriksen, 1966, an adaptation of the go/no-go paradigm that measures an individual's ability to withhold responses to specific stimuli. This task involves stimuli that require a response and stimuli that should not elicit a response). The study was conducted in the general population, aiming to understand the connection between these cognitive factors and traits associated with ADHD. Notably, their findings emphasized a significant connection between higher scores on ADHD traits and difficulties in prepotent response inhibition, slower response times, and notably increased variability in reaction times. Response speed and variability reflect consistency of attention and effort. Meta-analysis shows a small-to-medium effect size for response latency and a medium effect size for variability (0.71) (Lipszyc & Schachar, 2010; Sergeant, 2000) in distinguishing individuals with and without an ADHD diagnosis.

These results highlight the relationship between ADHD traits in the general population and difficulties in cognitive control components.

1.2.5 Executive Function and Comorbidity of ASC and ADHD

Numerous studies suggest that ASC and ADHD may share a common genetic basis. Both family (Holtmann et al., 2007) and twin studies (Ronald et al., 2010) provide support for the hypothesis that ADHD and ASC originate from partly similar familial/genetic factors. Approximately 50 to 72% of the contributing genetic factors in both disorders show overlap (Leitner, 2014). These shared genetic and neurobiological underpinnings provide an explanation for why both disorders occur so frequently within the same patient and family. In fact, between 28 to 44% of children with ASC also present with a diagnosis of ADHD in comorbidity (Failla et al., 2021).

Given that ADHD is characterized by difficulties in executive functions, particularly inhibitory control, it is possible that some studies reporting differences in executive control among individuals with ASC may be influenced by the presence of co-occurring ADHD symptoms (Wallace et al., 2016). Therefore, when studying executive functions in ASC, it is valuable to recognize the potential insights that can emerge from considering the comorbidity with ADHD (Corbett & Constantine, 2006; Yerys et al., 2009).

Although previous research has separately investigated executive function difficulties in ADHD and ASC, recent literature has focused on directly comparing EF difficulties in ASC and ADHD. Some of these comparative studies have revealed that both ASC and ADHD traits contribute uniquely to the executive control abilities of individuals showing subthreshold autism symptoms. This emphasizes the significance of considering ADHD symptoms when studying ASC (Christ et al., 2010). A meta-analysis conducted by Tonizzi et al. (2022) concluded that the presence of comorbid ADHD did not yield statistically significant effects on executive function in individuals with ASC (Tonizzi et al., 2022).

Furthermore, in line with the emerging transdiagnostic framework, it is crucial to study the complex and interconnected relationship between ASC and ADHD, particularly concerning their effects on executive functions is important. A transdiagnostic approach involves going beyond traditional diagnostic categories to improve our understanding of psychological and neurological conditions. Rather than solely depending on fixed diagnostic labels, it focuses on dimensions and shared characteristics that may apply to various disorders. This approach recognizes that many individual challenges do not neatly fit within specific diagnostic categories, aiming to align research more closely with the real-life experiences and underlying mechanisms of these conditions. It also recognizes that factors like genetics often play a role in various neurodevelopmental difficulties, making it more sensible to study them from a transdiagnostic perspective (Astle et al, 2022). Hence, transdiagnostic studies focus on characteristics and mechanisms that may not align with any conventional diagnostic category (Astle et al, 2022).

In this thesis, one of the key objectives was to investigate the relationships between the inhibition and memory components of executive function and a measure of autistic traits in the general population. However, in line with the transdiagnostic approach and recognizing the importance of considering ADHD traits when studying executive function in ASC, this thesis examines both (ASC and ADHD) traits to gain a better understanding of executive function in ASC. Specifically, the investigation consists of two studies. In Study 1, the correlations between the inhibition and memory components of executive function and a measure of autistic traits were examined. In Study 2, further correlations between the inhibition and memory components of executive function and measures of both autistic traits and ADHD traits were explored.

1.3 The Role and Importance of Executive Function

Studying and measuring executive function is of great importance due to its significant impact on various aspects of human cognition and real-word outcomes. Executive functions constitute essential skills for both mental and physical well-being, achievement in education and life and cognitive, social, and psychological development (Diamond, 2013; Spiegel et al., 2021). furthermore, executive functions play a crucial role in developing and executing plans, forming analogies, adhering to social rules, problem-solving, adapting to unexpected situations, multitasking, and retrieving memories effectively (Grafman & Litvan, 1999). Therefore, studying executive function is crucial to support individuals who have conditions associated with EF difficulties such as ASC and ADHD.

1.4 Difficulties in Studying Executive Function

Despite its importance and the presence of extensive previous research, concerns persist regarding the conceptualization and measurement of EF (Doebel & Müller, 2023). There has been much disagreement regarding the characterization of the EF construct. More specifically, in adult models (Duncan & Owen, 2000; Shallice & Burgess, 1991), competing developmental accounts differ with respect to which they emphasize the unitary (Munakata, 2001; Zelazo et al., 2003) or fractionated (Diamond, 2006; Garon et al., 2008) nature of EF. Empirical work with adults, using sophisticated statistical techniques like confirmatory factor analysis (CFA), has reported evidence of three latent EF variables or component processes—set-shifting, updating (working memory), and inhibitory control—which are partially independent but still intercorrelated (Miyake et al., 2000).

Moreover, studies using similar methods with school-age children in part support this integrated framework (Huizinga et al., 2006; Lehto et al., 2003) however, some studies with 2- to 6-year-old children have instead reported evidence in line with a unitary model of EF (Wiebe et al., 2008; Wiebe et al., 2011).

A recent systematic review by Karr et al. (2018), which examined CFA studies on performance-based executive function tests across 46 samples and 9,756 participants, revealed that executive function appears to be more unidimensional in child and adolescent samples but shows both unity and diversity among adults.

The challenges in conceptualizing executive function also extend to its measurement. For various reasons traditional measures struggle to fully capture executive control. These reasons include the lack of consensus on the construct itself, its definition, and whether it is a unitary or fractionated construct (Kenworthy et al., 2010). Furthermore, existing research on executive function often utilizes separate tasks to measure core components of executive function independently. This approach involves employing multiple tasks to tap into various functions, such as working memory (e.g., backward digit span, Kirchner, 1958) and inhibition (e.g., Stroop-type tasks, Stroop, 1935; and go/no-go tasks). However, measuring separate core functions with separate tasks can be very time-consuming (Smith et al., 2019) and introduce confounding effects due to task-specific variances. This is because each task may have unique characteristics or demands that could influence the results, making it challenging to isolate the specific contributions of each core function. Additionally, these tasks may not be process-pure meaning that memory-based tasks can involve inhibitory aspects, and inhibitory tasks may require memory for rules (Simpson & Carroll, 2018). For instance, the backward digit span (Kirchner, 1958) requires participants to monitor a sequence of stimuli and indicate when the current stimulus matches the one presented “n” steps earlier. While primarily assessing working memory, this task also involves inhibitory control as participants need to inhibit responding when there is no match. Similarly, the Simon task (Simon, 1969) involves participants responding based on a specific rule, such as pressing a left or right button, while stimuli on the screen may be incongruent with the required response, creating interference. This task requires inhibitory control to suppress automatic responses based on stimulus location but also memory for rules to guide the response.

1.5 Investigating Executive Function in the Current Study

To address the limitations in the measurement and conceptualization of executive function, the present study utilized a novel measurement method for measuring core components of executive function, which not only offers an improved approach to assessing executive function but also contributes to a deeper understanding of this construct.

As mentioned before, the model of executive control, developed by Norman and Shallice in 1986, has been adopted by this study. The importance of WM and IC is highlighted by this model.

In general, inhibitory control, a fundamental aspect of executive functions, encompasses the capacity to manage one's attention, actions, thoughts, and emotions, overriding strong internal predispositions or external temptations in favor of more suitable or necessary responses. In this thesis, the focus has been placed on prepotent response inhibition and interference control, as these types of inhibition are the most frequently studied in the neurodevelopmental conditions' literature. Additionally, Tonizzi et al. (2022) revealed that autism affects both response inhibition and interference control similarly. However, these inhibitory control components are differentially influenced by factors like intellectual functioning and age. This underscores the significance of considering both types of inhibitory control in the context of autism.

The study utilized a battery of two tasks, each of which orthogonally manipulated working memory and one type of inhibitory control (see Jarrold et al., 2023). Specifically, a modified Spatial Conflict task was developed to investigate the interaction between working memory and prepotent response inhibition while, a modified Flanker task was used to examine the interaction between working memory and interference control. These modified tasks are respectively based on the widely used congruency tasks in cognitive control, named Simon task (Simon, 1969) and the Eriksen Flanker task (Eriksen & Eriksen, 1974). Details related to these conventional tasks are provided below.

The Simon task, or spatial conflict task, is consistently classified as a measure of prepotent response inhibition (Lu & Proctor, 1995). This refers to the ability to suppress a dominant motor response (Casey et al., 2001; Nigg, 2000), which requires completely cancelling the initiated response (Aron, 2011). Prepotent response inhibition is typically measured with tasks that require participants to respond as fast as possible to a majority of stimuli, while withholding (inhibiting) a response to a minority of stimuli, which are signaled by the presence of a specific feature (e.g., a specific characteristic or location). Hence, participants must completely countermand an initiated response to perform well. The Simon task rests on the assumption that the spatial location of the stimulus automatically activates the corresponding response option. For example, a stimulus presented on the left side of the screen automatically activates the left-hand response option. Participants are typically slower and less accurate on trials where the stimulus is presented on the opposite side to the correct response option (incongruent trials) compared to when the stimulus is presented on the same side as the correct response option (congruent trials) (see Simon, 1969). In this task, the primary measure of interest is the difference in accuracy and/or speed (reaction time) between these experimental conditions (Geurts et al., 2014).

The Erikson Flanker test is one of the most commonly used measures to assess interference control which refers to the efficiency with which one is able to ignore irrelevant information while processing target stimuli (Geurts et al., 2014). Typically, in this task, participants must respond to a target stimulus as quickly as possible. Simultaneously, information is presented that evokes either the same response as that associated with the target (congruent information) or an opposite response (incongruent information). Hence, interference control differs from response inhibition in that it involves conflicting information separate from the stimulus, whereas response inhibition deals with conflicting information as part of the stimulus itself. The main dependent measure is the difference in accuracy and/or speed between these conditions (Geurts et al., 2014).

However, as mentioned before, in the current study, an additional working memory load component was incorporated into the current versions of the Flanker test and Spatial Conflict task. Moreover, it is important to highlight that both tasks within the battery exhibit a similar structure, including the inclusion of two similar memory load conditions in both tasks, as well as the introduction of distractors in the Spatial Conflict task. This shared similarity allows for direct comparisons between the tasks and potentially offers the possibility of integrating them into a unified task in future research.

This framework offers several benefits. Firstly, it allows for controlled comparisons across different key functions e.g., ensuring consistency in participants' attention and motivation levels. Additionally, the task format and demands are controlled across the various executive function measures. Moreover, using this framework, which involves using a single task to extract multiple components simultaneously, is a highly efficient approach (Smith et al., 2019).

This framework allows for the investigation of interactions between different executive function components. The nature of executive function has been a subject of theoretical disagreement, with debates on whether it is a unitary construct with interactive components or a fractionated construct with additive components (Kenworthy et al., 2008). According to Roberts and Pennington's (1996) account, potentially distinguishable components of executive functions (working memory and inhibition) compete for a shared, limited-capacity pool of attentional resources. This predicts over-additive interactions between them, with their effects becoming more pronounced as their demands increase and deplete shared resources (Jarrold et al., 2023). By integrating multiple EF aspects in one task, researchers can explore these interactions and address the challenges in conceptualizing EF, determining whether its components interact in an over-additive/under-additive manner or remain independent.

In conclusion, executive function plays a critical role in human cognition, however, the conceptualization and measurement of executive function have posed challenges in research. To address these limitations, the current studies employed a novel approach using a battery of tasks that integrated working memory and inhibitory control components. This framework allows for controlled comparisons, consistency in participants' engagement, and efficient measurement of multiple executive function components. Additionally, the study sought to explore the potential interactions between these components and investigate their associations with autistic traits and ADHD-related traits. By examining these relationships, this work aimed to contribute to a deeper understanding of executive function and its implications for cognitive abilities and neurodevelopmental conditions.

2 Chapter Two (Study 1)

2.1 Introduction

This chapter centers on the methodology of the first study, aiming to introduce an innovative framework for concurrently measuring working memory and inhibitory control. Traditionally, research on executive function tends to assess working memory and inhibitory control separately, in contrast, the current study focuses on examining them simultaneously and investigating the potential interplay between them. As will be elaborated further in the subsequent sections, this study employs two distinct tasks. One task is designed to examine working memory and inhibitory control simultaneously, while the other task investigates the interplay between working memory and interference control. Furthermore, an additional goal of this study was to investigate the potential correlation between different aspects of task performance and the measurement of autistic traits using the AQ questionnaire, all within the general population.

This study has been preregistered on the Open Science Framework (OSF), emphasizing the commitment to predetermined research methods and hypotheses. Access to the preregistered study is available through the following link:

https://osf.io/2eh7m/?view_only=668514fe5778486497f30cf210182739

2.2 Tasks and Conditions (as preregistered on the OSF)

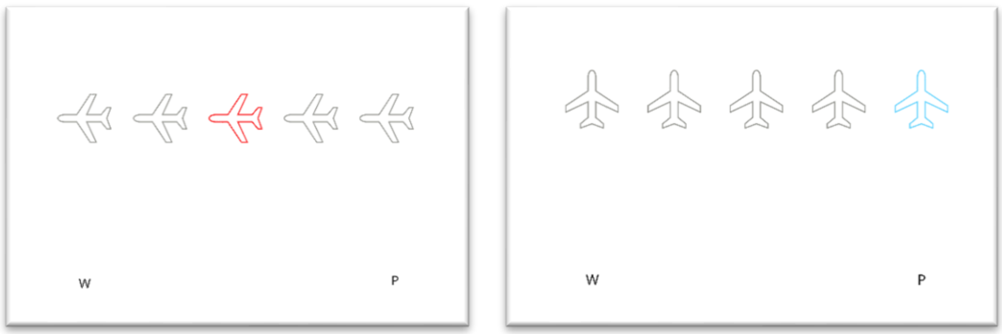
The executive function battery was a novel assessment that was presented online through the Gorilla Program. This battery consisted of two tasks each of which orthogonally manipulated working memory and one type of inhibitory control. More specifically, the Flanker task manipulated working memory load and interference control load and the Spatial Conflict task manipulated working memory load and response inhibition load. However, one of the novel aspects of the battery was that both tasks shared a very similar structure (see below), making them directly comparable.

The working memory load manipulation employed in both tasks varied the complexity of the response rules that had to be maintained. Both memory conditions of each task required participants to remember, and effect, the response associated with one of four different stimuli that could appear in that condition; in each case two stimuli were associated with one key press and the other two stimuli were associated with a different key press. In the low memory conditions of each task, these four stimulus-response mappings could readily be grouped into two rules (e.g., press W on the keyboard when you see a light or dark blue airplane and press P on the keyboard when you see a light or dark red airplane). In the high memory load conditions, participants were required to remember four different rules that could not be grouped together, (e.g., press W if you see a purple airplane and press W if you see a yellow airplane, press P if you see a brown airplane and press P If you see a green airplane). Within each memory condition of each task there were two trial types – congruent and incongruent trials – that reflected the inhibitory load manipulation (whether of interference control in the Flanker task or response inhibition in the Spatial Conflict task).

All of the participants started the experiment with the Flanker task (as the two tasks were quite similar in their structure but the organisation of the Spatial Conflict task was more complicated). However, the order of presentation of memory load conditions was counterbalanced within a task (leading to four orders of presentation of the battery). The Flanker task contained 212 trials consisting of 20 practice trials and 96 trials in each of the low and high memory load conditions. The Spatial Conflict task contained 200 trials including 24 practice trials and 88 trials in each of the low memory and high memory load conditions. There were an equal number of congruent and incongruent trials in each memory load condition of each task.

The general structure of the study was as follows. In each trial of each task participants first saw two letters (W and P) at the right (P) and left (W) bottom edges of a white blank page for 500 ms, and after that stimuli were presented. These stimuli consisted of 5 airplanes (four grey and one coloured) presented in a horizontal line at just above the midline of the page, in such a way that the W was located under the left-most airplane and the P was located under the right-most airplane (see Figure 2.1). In the Flanker task the airplanes were either all pointed to the right or all pointed to the left with the coloured target stimulus in the central position. On congruent trials all the stimuli pointed in the direction associated with the correct response prompted by the central target stimulus (e.g., left for a W key press); on incongruent trials all the stimuli pointed in the opposite direction to that associated with the central target stimulus. (e.g., right for a W key press). In the Spatial Conflict task all the airplanes were in an upright position with the coloured target stimulus being presented at either the extreme left or the extreme right of the row. On congruent trials the target stimulus appeared directly above the letter and response key associated with it (i.e., on the extreme left for a W key press); on incongruent trials the target stimulus appeared on the opposite side to its associated response (i.e., on the extreme right for a W key press).

Figure 2-1. Sample trials in cognitive tasks: Screenshots from the Gorilla program



A sample trial in the Flanker task A sample trial in the Spatial Conflict task

Participants started each task with the aforementioned number of practice trials and then they proceeded to the either low or high memory load condition of that task. Participants were instructed to make their responses according to the coloured airplane (the target stimulus) and to ignore the grey airplanes, and to make their responses as quickly and accurately as possible by touching one of two response buttons (W or P). During the practice trials of both tasks, participants received accuracy feedback for both their correct and incorrect responses, and if they made a mistake, the trial was repeated. However, in the experimental trials, they only received feedback following incorrect responses (without repeating the trial).

The target airplanes' colours, which participants needed to remember during practice trials for both the Flanker and Spatial Conflict tasks, remained consistent. Specifically, pink corresponded to P and orange to W, with the direction being upright for the Spatial Conflict task and directed to the left or right for the Flanker task. However, the target stimuli colours employed in the practice trials were different to the colours used for target stimuli in the experimental trials.

In the Flanker task's low memory trials, the designated colours were light and dark blue for W (pointing either to the right or left) and light and dark red for P (also pointing either to the right or left). Similarly, during the low memory trials of the Spatial Conflict task, the chosen colours were light and dark brown for W and light and dark green for P.

Given the limitation of available distinguishable colours for the high memory conditions, some colours from the low memory conditions were reused. However, great care was taken to maintain the same spatial position as in the low memory conditions. As a result, the high memory Flanker task employed brown and purple (pointing either to the right or left) for W, while yellow and green (pointing either to the right or left) were assigned to P. Likewise, in the high memory Spatial Conflict task, blue and purple were designated for W, and red and yellow were allocated to P.

Completing the battery took approximately 20-25 minutes.

2.3 Autism traits measure (AQ-S)

In line with preregistration methodology, autistic traits were measured using the Short Autism-Spectrum Quotient AQ (AQ-S; Hoekstra et al. 2011). The AQ-S is a shortened version of the full AQ (Baron-Cohen et al., 2001), designed for convenient use in large-scale studies where the full AQ's length may be impractical. Hoekstra et al. (2011) established the AQ-S structure and content through item selection and validation analyses involving individuals with ASC and control groups. The AQ was designed to capture the core dimensions of autistic traits in adults with normal intelligence. The AQ-S includes 28 of the 50 original AQ items and retains its broad dimensionality. Thus, the items measure the domains of social skills, routine, switching, imagination, and numbers/patterns and a higher-order social behaviour factor defined by the first four of these five factors. In ASC and control samples, CFA analyses have generally found reasonable fit of this structure for the AQ-S (Hoekstra et al. 2011; Kuenssberg et al. 2012).

2.4 Dependent Variables

As it was preregistered, the dependent variables of interest include reaction times (limited to correct responses) and accuracy in each trial, recorded for all keypress responses. Additionally, the study aims to measure ASC traits in the general population using AQ-S.

2.5 Aims and Hypothesis

In accordance to pre-registered plan for this study on OSF, the aims of this study were firstly to extract measures of working memory and response inhibition (from the Spatial Conflict task) and working memory and interference control (from the Flanker task) and assess whether the expected effects of the previously outlined measures of executive function were found when assessed simultaneously using a single task with a subsidiary objective of assessing whether these effects were independent of one another. Furthermore, the aim was to investigate the correlation between different measures of tasks performance with a measure of ASC traits in the general population.

Predictions[1]

A. It was hypothesized that significant main effects for working memory and response inhibition could be observed in the Spatial Conflict task.
B. It was hypothesized that significant main effects for working memory and interference could be observed in the Flanker task.
C. In the Spatial Conflict task, and in accordance with the results of Jarrold et al.'s (2023) research, it was predicted that working memory and response inhibition would act

[1] These predictions were not included in the preregistration.

independently, without enhancing each other's impact as their demands shifted, and without depleting their shared resource.

D. Applying the same reasoning to the Flanker task, it was expected that working memory and interference control would operate independently from each other.

E. It was predicted that these measures would be independent of each other.

F. It is hypothesized that there would be meaningful correlations between different task performance measures (reaction time and accuracy) across various conditions, including congruent and incongruent trials within both low and high memory loads, and the ASC traits in the general population. Specifically, it was expected that higher ASC traits would be associated with poorer task performance as memory and inhibitory load increased. This implies that as ASC traits increase alongside heightened working memory and inhibitory demands, the relationship between these factors becomes stronger.

2.6 Analyses

In accordance with the analysis plans outlined in the preregistered plan for this study, Bayesian ANOVAs were employed to assess the main effects of memory load and response inhibition load in the spatial conflict task, as well as the main effect of working memory and interference control in the Flanker task. Furthermore, the same analysis was conducted to investigate potential interactions between these factors. It is important to note that, as of now, the data related to these analyses are not available on OSF.

Additionally, Bayesian correlation was utilized to examine the zero-order correlations between measures derived from cognitive tasks and ASC traits (measured by AQ).

Following that, a subsequent analysis involved conducting a series of partial correlations to isolate memory load and inhibition load effects, with the aim of examining their relationship to ASC.

2.7 Sample Size

As it was pre-registered, a total of 100 participants (aged between 18-25) were included to ensure the ability to detect correlations of .32 or higher. The recruitment process involved the utilization of the host institution's course credit scheme (Experimental Hours Scheme of the University of Bristol).

2.8 Outliers and Exclusions

Reaction time outliers were trimmed utilizing the Median Absolute Deviation (MAD) method, as outlined by Leys et al. (2013), employing a +/-3 MAD criterion. Trimming was independently carried out for each participant and for trial types (congruent/incongruent) within each condition (resulting in eight MAD trims for each participant).

Furthermore, other exclusion criteria involved the removal of individuals who exhibited less than 60% accuracy in the congruent trials of the low working memory load condition from data analysis for that specific task. However, it is crucial to emphasize that no individuals were excluded based on this criterion, as everyone met this requirement.

Additionally, immediate repetitions of a stimulus across consecutive trials were not intentionally avoided. However, data from such trials were omitted and were not analyzed, in accordance with Bertelson (1965).

These trimming and exclusion plans were consistent with the pre-registered plan for this study.

2.9 Results

Bayesian Repeated Measures ANOVAs were carried out with two factors including memory and congruency and two levels in each (low and high levels in memory and congruent and incongruent levels in congruency) for each task. Analyses are presented for both reaction time and accuracy and first for the Flanker and second for the Spatial Conflict task.

In line with Jeffreys (1961), a Bayes factor between 1 and 3 is considered weak evidence, a Bayes factor between 3 and 10 is considered moderate evidence, and a Bayes factor greater than 10 is considered strong evidence (Jeffreys, 1961).

Data analysis was performed in JASP 0.17.3 (JASP Team, 2023). Bayes Factors for the inclusion or exclusion of effects and interactions were computed using the "across matched models" option in JASP, following the methodology of Keysers et al. (2020).

2.9.1 Reaction time in the Flanker task

Descriptive statistics for participants' reaction time in the Flanker task are shown in Table 2.1.

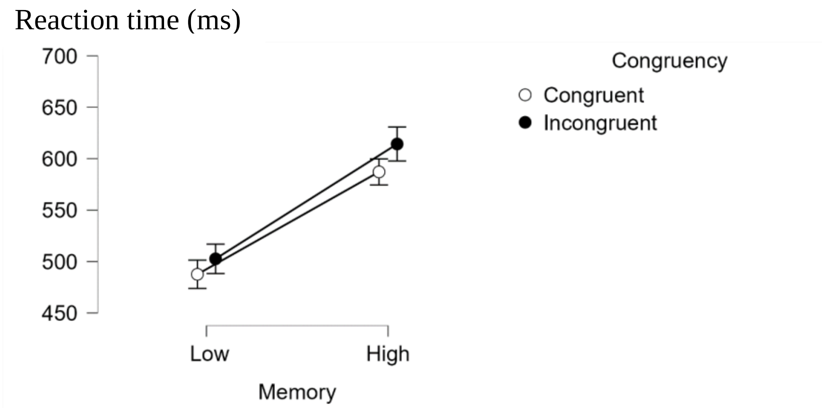
Table 2-1. Descriptive Statistics of reaction time (RT) in the Flanker task

	Flanker Low Congruent RT	Flanker Low Incongruent RT	Flanker High Congruent RT	Flanker High Incongruent RT
Valid	100	100	100	100
Missing	100	100	100	100
Mean	487.620	502.656	587.177	614.294
Std. Deviation	83.316	78.709	126.242	140.046
Minimum	345.321	352.974	369.846	399.656
Maximum	896.781	887.333	1426.918	1493.938

Bayesian Repeated Measures ANOVA revealed that the memory and congruency model provided the best fit for the reaction time in the Flanker task ($BF_{10}=6.083\times10^{+16}$). Moreover, as it is shown in Figure 2-2, there was strong evidence for the memory effect ($BF_{10}=3.968\times10^{+11}$). This reflected the fact that participants exhibited faster reaction times in low memory condition trials (including both congruent and incongruent trials, M=495, SD=78) compared to high memory condition trials (both congruent and incongruent trials, M=600ms, SD=130ms). Additionally, strong evidence was found for the congruency effect (BF_{10}=147931.027). This reflected thlat participants demonstrating faster reaction times on congruent trials (within both low and high memory conditions, M=537ms, SD=91ms) relative to incongruent trials (within both low/high memory loads, M=558ms, SD=92ms). Finally, the analysis provided weak evidence for the *absence* of an interaction between memory load and congruency load (BF01=1.196).

Moreover, a classical repeated measures ANOVA for reaction time (RT) in the Flanker task was also conducted, and the results are available in the appendix 6, Table A.

Figure 2-2. Reaction time (ms) in the Flanker task



2.9.2 Accuracy in the Flanker task

Descriptive statistics for participants' accuracy in the Flanker task are shown in Table 2.2.

Table 2-2. Descriptive Statistics of accuracy in the Flanker task

	Flanker Low and Congruent	Flanker Low and Incongruent	Flanker High and Congruent	Flanker High and Incongruent
Valid	100	100	100	100
Missing	100	100	100	100

	Flanker Low and Congruent	Flanker Low and Incongruent	Flanker High and Congruent	Flanker High and Incongruent
Mean	0.958	0.930	0.940	0.935
Std. Deviation	0.051	0.065	0.077	0.080
Minimum	0.625	0.644	0.333	0.362
Maximum	1.000	1.000	1.000	1.000

As it has shown in Figure 2-3, the Bayesian Repeated Measures ANOVA for accuracy in the Flanker task provided evidence *against* there being a meaningful memory effect (BF_{01}=3.001), however, there was strong evidence for a congruency effect (BF_{10}=144.621), reflecting a higher average accuracy on congruent trials (within both low and high memory conditions, M=0.949, SD =0.054) relative to incongruent trials (in both low/high memory conditions, M=0.932, SD=0.060).

Finally, there was strong evidence for the interaction of memory load x congruency load (BF_{10}=24.669) and according to the analysis, the best model of accuracy in the Flanker task was the model that included both main effects of memory and congruency and their interaction (BF_{10}=1197.197), however, since there was no evidence for the memory effect, a subsequent model comparison was conducted which included the main effect of memory in a revised null model. According to that analysis the best model of accuracy in the Flanker task was the model including the main effect of congruency and the interaction of memory load x congruency load (BF_{10}=3492.216).

Moreover, a classical repeated measures ANOVA for accuracy in the Flanker task was also conducted, and the results are available in the Table B, appendix 6.

Figure 2-3. Average of accuracy in the Flanker task

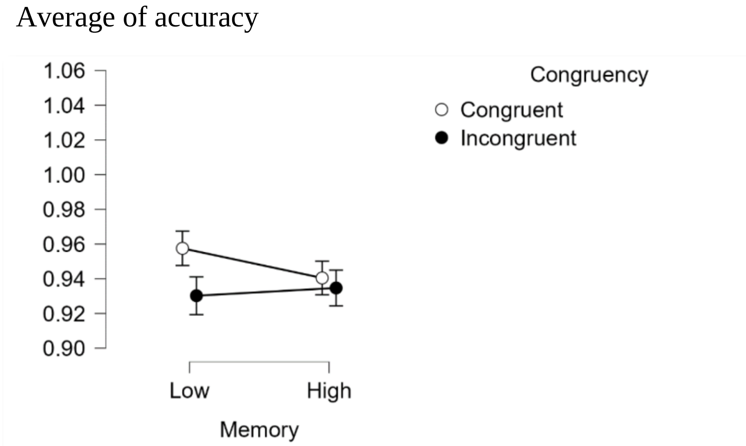


Figure 2.3 illustrates variations in the congruency effect across different memory loads, or conversely, differences in the memory effect between congruent and incongruent trials. To decompose this interaction, four Bayesian ANOVA were conducted:

1) Congruent trials: A Bayesian repeated measures ANOVA conducted only on the congruent trials (congruent in low memory load vs. congruent in high memory load) provided weak evidence for the memory effect (BF_{10}=1.613). As Figure 2.3 illustrates, accuracy was somewhat higher on congruent trials in the low memory condition.
2) Incongruent trials: A Bayesian repeated measures ANOVA performed only on the incongruent trials (incongruent within low memory vs. incongruent within high memory load) produced evidence for the *absence* of a memory effect within incongruent trials (BF_{01}=5.730).
3) Low Memory: A Bayesian repeated measures ANOVA was performed exclusively on the low memory condition (low memory congruent vs. low memory incongruent). The result of this analysis indicated strong evidence for the congruency effect within the low memory

condition (BF_{10}=5814.027); as Figure 2.3 indicates, incongruent trials were associated with slower responses than congruent trials, as would be expected.

4) High Memory: Similarly, a Bayesian repeated measures ANOVA was conducted focusing only on the high memory condition (high memory congruent vs. high memory incongruent). The analysis results provided moderate evidence for the *absence* of congruency effect within high memory condition (BF_{01} = 3.469).

To summarize, the results of these analysis provide limited evidence supporting the memory effect in congruent trials and evidence against the memory effects within the incongruent trials. Furthermore, strong evidence supporting a congruency effect within the low memory condition and no such congruency effect within high memory condition.

2.9.3 Reaction time in the Spatial Conflict Task

Table 2.3 displays descriptive statistics for participants' reaction time in the Spatial Conflict task.

Table 2-3. Descriptive Statistics of reaction time (RT) in the Spatial Conflict task

	Spatial Low and Congruent	**Spatial Low and Incongruent**	**Spatial High and Congruent**	**Spatial High and Incongruent**
Valid	100	100	100	100
Missing	100	100	100	100
Mean	650.583	695.224	631.310	653.505
Std. Deviation	153.778	151.248	104.974	100.686
Minimum	417.150	462.587	440.887	479.084
Maximum	1831.434	1846.338	1014.778	1058.058

The Bayesian Repeated Measures ANOVA of the reaction time in the Spatial Conflict task provided weak evidence for the memory effect, as indicated by a Bayes Factor (BF_{10}) of 1.512. However, there was strong evidence for a congruency effect ($BF_{10}=1.351\times10^{+10}$). This effect resulted from participants exhibiting faster reaction times on congruent trials within both low and memory conditions (M=640ms, SD=105ms) compared to incongruent trials within those conditions (M=674ms, SD=104ms).

Finally, the analysis provided strong evidence for the interaction between memory load and congruency load (BF10=17.274). Moreover, the best model for reaction time in this task included the main effects of memory and congruency, as well as their interaction ($BF_{10}= 4.498\times10^{+11}$).

Moreover, a classical repeated measures ANOVA for reaction time in the Spatial Conflict task was also conducted, and the results are available in the Table A, appendix 7.

Figure 2-4. Reaction time (ms) in the Spatial Conflict task

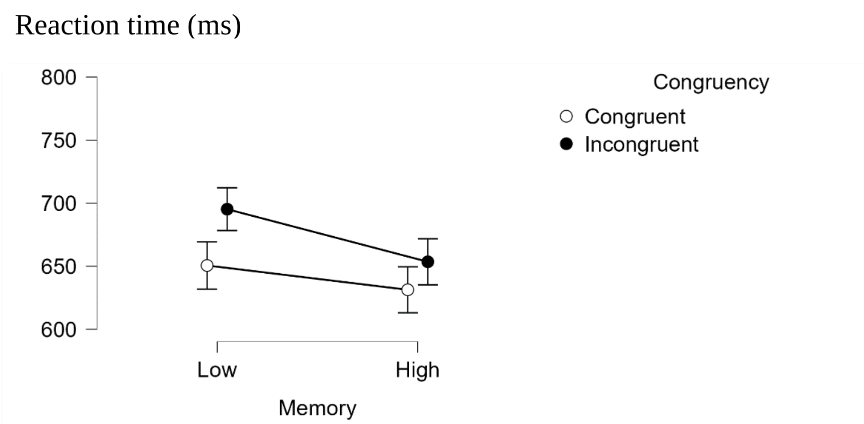


Figure 2.4 depicts changes in the congruency effect with varying memory loads or differences in the memory effect between congruent and incongruent trials. To analyze this interaction, four Bayesian ANOVA were performed.

1) Congruent trials: Bayesian repeated measures ANOVA performed exclusively on congruent trials (congruent under low memory load vs. congruent under high memory load) yielded moderate evidence suggesting the lack of a memory effect (BF_{01}=2.173).
2) Incongruent trials: A Bayesian repeated measures ANOVA conducted only on the incongruent trials (incongruent within low memory vs. incongruent within high memory load) showed moderate evidence for memory effect within incongruent trials (BF_{10}=5.812). As depicted in Figure 2.4, in line with expectations, reaction times were relatively slower under high memory load compared to low memory load.
3) Low Memory: A Bayesian repeated measures ANOVA was performed exclusively on the low memory condition (low memory congruent vs. low memory incongruent). The result indicated strong evidence for the congruency effect in low memory condition (BF_{10}=1.594×10^{+12}); as shown in Figure 2.3, in line with expectations, incongruent trials resulted in slower responses compared to congruent trials.
4) High Memory: Similarly, a Bayesian repeated measures ANOVA focusing only on the high memory condition (high memory congruent vs. high memory incongruent) provided strong evidence for congruency effect within high memory condition (BF_{10} = 109.824).

In summary, the analyses yield moderate evidence supporting the memory effect in incongruent trials, while indicating a lack of memory effects within congruent trials. Moreover, there is strong evidence supporting a congruency effect in both low and high memory conditions. However, the analysis highlights a "meaningfully stronger" congruency effect in low memory load compared to high memory load.

2.9.4 Accuracy in the Spatial Conflict condition

Table 2.4 presents descriptive statistics for participants' accuracy in the Spatial Conflict task.

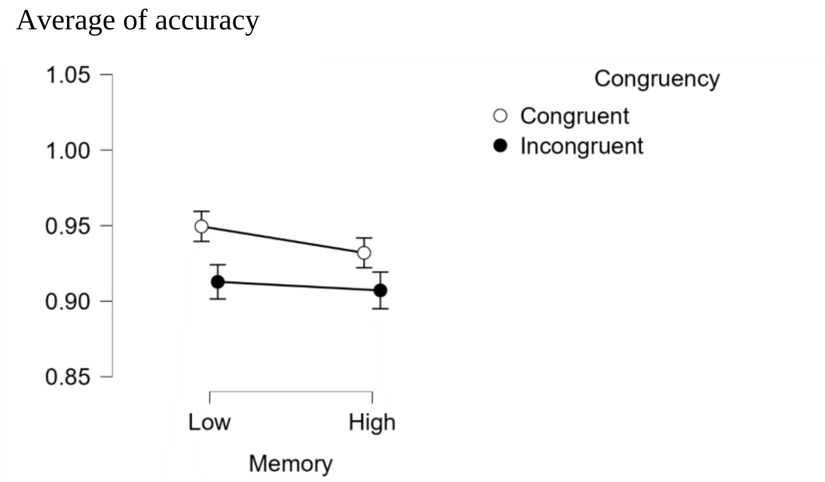
Table 2-4. Descriptive Statistics of accuracy in the Spatial Conflict task

	Spatial Low and Congruent	**Spatial Low and Incongruent**	**Spatial High and Congruent**	**Spatial High and Incongruent**
Valid	100	100	100	100
Missing	100	100	100	100
Mean	0.949	0.913	0.932	0.907
Std. Deviation	0.052	0.073	0.068	0.080
Minimum	0.763	0.667	0.575	0.548
Maximum	1.000	1.000	1.000	1.000

The Bayesian Repeated Measures ANOVA, of accuracy in the Spatial Conflict task produced a best model that consisted of just the main effect of congruency (BF_{10}=22358.449). Further, as it has shown in Figure 2-5, analysis of the accuracy effect revealed weak evidence for the absence of a memory effect (BF_{01}=1.208). However, there was strong evidence for the main effect of congruency (BF_{10}=22316.867). This effect reflected higher average accuracy for congruent trials within both low memory and high memory conditions (M=0.941, SD=0.051) compared to incongruent trials in the same conditions (M=0.910, SD=0.063). Lastly, there was evidence against the interaction of memory load and congruency load (BF_{01}=3.113).

Furthermore, a classical repeated measures ANOVA for reaction time in the Spatial Conflict task was also conducted, and the results are available in the Table B, appendix 7.

Figure 2-5. Average of accuracy in the Spatial Conflict task



2.10 Correlation between the measures from the cognitive tasks and ASC traits

1. Bayesian correlation was used to test the zero-order correlation between:
    a) Reaction times for congruent/incongruent trials within each low/high memory condition of each task (eight measures) and the measure of ASC traits to investigate whether there was a pattern of increasing correlations with an increase in inhibitory load and memory load.
    b) Accuracy of each trial type within each condition of each task and the measure of ASC traits to investigate any patterns of increasing correlations with increasing inhibitory load and memory load.

Table 2.5 presents descriptive statistics for ASC traits (measured by AQ-S) in the Study 1.

Table 2-5. Descriptive Statistics of ASC traits in the Study 1.

	AQ
Valid	100
Missing	100
Mean	62.190
Std. Deviation	11.231
Minimum	42.000
Maximum	98.000

Table 2.6. contains the details of these Bayesian correlation analyses.

Table 2-6. Bayesian Pearson Correlations of the task's measures and AQ-S

Evidence for the absence of meaningful correlation

Flanker task	Low		High	
	Congruent	Incongruent	Congruent	Incongruent
RT	BF_{01}=3.761	BF_{01}=3.713	BF_{01}=7.650	BF_{01}=7.215
Accuracy	BF_{01}=6.369	BF_{01}=7.889	BF_{01}=7.720	BF_{01}=7.316
Spatial Conflict task	Low		High	
	Congruent	Incongruent	Congruent	Incongruent
RT	BF_{01}=6.150	BF_{01}=7.487	BF_{01}=6.537	BF_{01}=2.749
Accuracy	BF_{01}=3.525	BF_{01}=6.760	BF_{01}=5.032	BF_{01}=4.887

The Bayesian correlation analysis provided evidence indicating a lack of meaningful correlation between various measures of the Flanker task, encompassing congruent and incongruent trials across both low and high memory load conditions, and AQ-S in terms of both reaction time and accuracy. These findings suggest the absence of a substantial correlation between the measures of the Flanker task and ASC traits across different levels of inhibitory load and memory load.

Similarly, in the Spatial Conflict task, the Bayesian correlation analysis showed evidence for the *absence* of meaningful correlation between various measures of the Spatial conflict task, (including congruent and incongruent trials within both low/high memory conditions) and AQ-S in terms of both reaction time and accuracy. This suggests a lack of consistent correlation between different measures of the Spatial conflict task and ASC traits across various loads of inhibitory and memory. The Bayesian correlation matrix plots for Accuracy/Reaction time in the Flanker and Spatial Conflict tasks, along with AQ, are showcased in Figures 2-6, 2-7, 2-8, and 2-9.

Figure 2-6. Bayesian correlation matrix plot of Accuracy in Flanker task and AQ

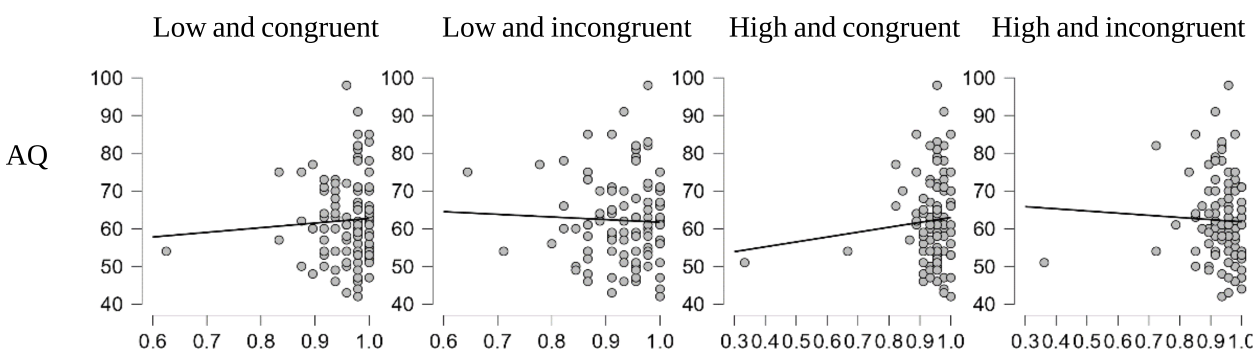


Figure 2-7 Bayesian correlation matrix plot of Reaction time in Flanker task and AQ

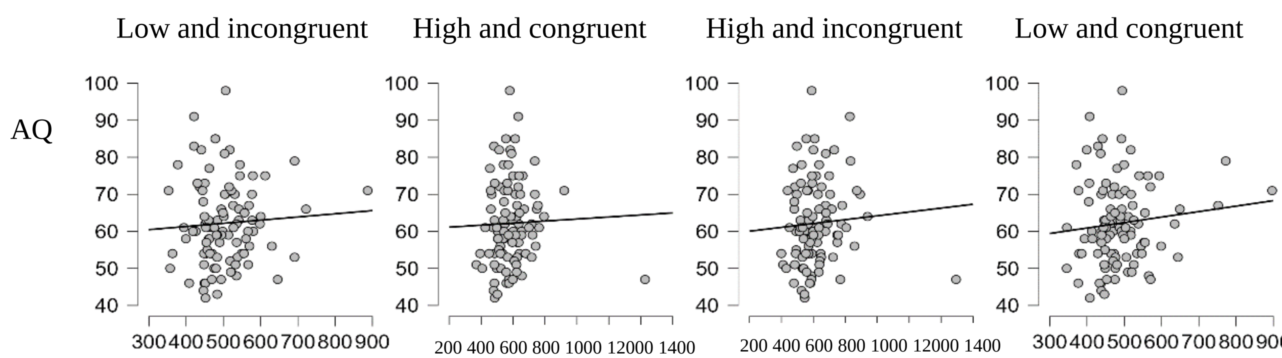


Figure 2-8. Bayesian correlation matrix plot of Reaction time in Spatial Conflict task and AQ

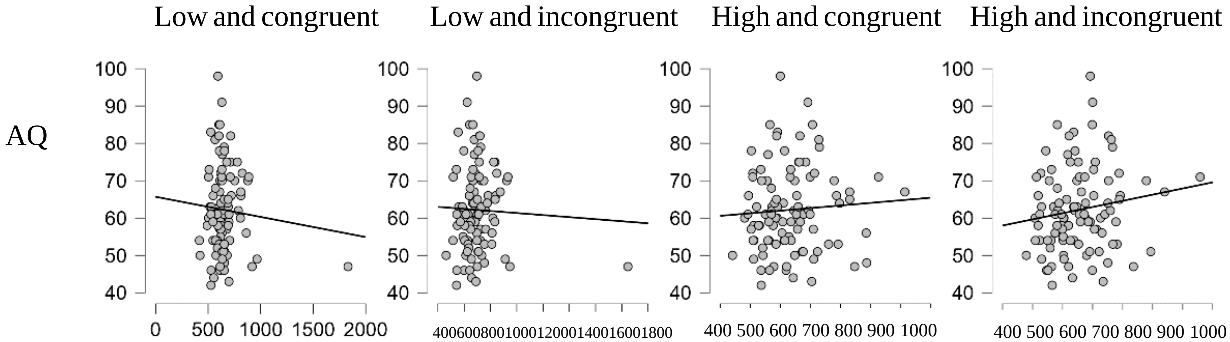
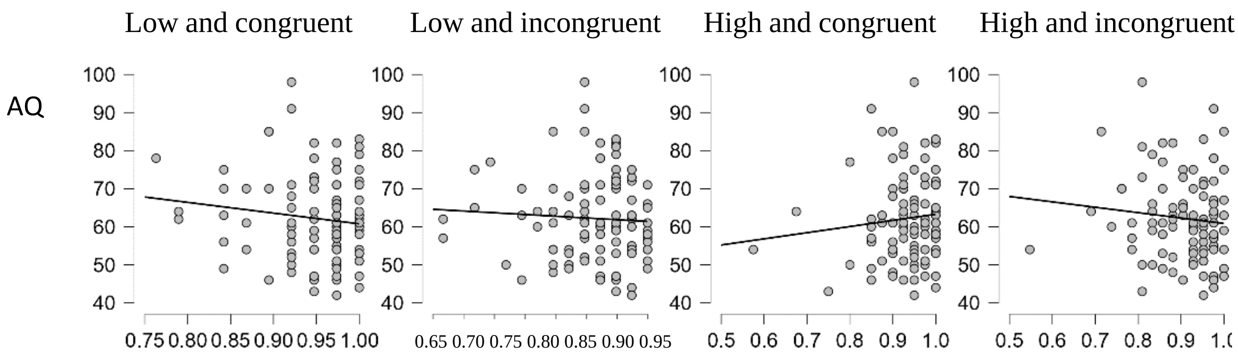


Figure 2-9. Bayesian correlation matrix plot of Accuracy in Spatial Conflict task and AQ



Moreover, the Pearson's correlations between accuracy/reaction time in the Flanker task/Spatial Conflict task and ASC traits were also conducted, and the results are available in the appendix 10.

2. Partial correlations (Bayesian Linear regression)

A series of partial correlations were conducted to examine the effects of memory load and inhibition load and their association with ASC traits. Bayesian regression ANOVA analyses were carried out using JASP for both reaction time (RT) and accuracy in each task. Correlations were explored between Incongruent trial performance across both low and high memory conditions, while controlling for congruent trial performance (serving as an index of the congruency effect) and ASC traits. Similarly, correlations were evaluated between high memory condition performance across both congruent and incongruent trials, while controlling for low memory condition performance, representing the memory effect, and AQ-S scores.

The decision on whether to aggregate high/low memory trial scores across congruent and incongruent trials or to aggregate congruent/incongruent trials across low and high memory trials was guided by the results of the Bayesian ANOVA. The results are outlined in the Table 2-7 for both RT and accuracy.

Table 2-7. The partial correlation between the measures from the Flanker/Special Conflict task and AQ-S

Evidence for the absence of meaningful correlation

Task	Partial correlation design	RT	Accuracy
Flanker task	Incongruent trial performance (across both low and high memory conditions) and AQ-S (controlling for congruent trial performance)	BF_{01}=20.488	BF_{01}=2.022
	High memory condition performance (including both congruent and incongruent trials) and AQ-S (controlling for low memory condition performance)	BF_{01}=5.022	BF_{01}=4.263
Spatial Conflict task	Incongruent trial performance (across both low and high memory conditions) and AQ-S (controlling for congruent trial performance)	BF_{01}=3.972	BF_{01}=3.052
	High memory condition performance (including both congruent and incongruent trials) and AQ-S (controlling for low condition performance)	BF_{01}=1.767	BF_{01}=4.696

Bayesian linear regression, examining the correlation between the size of congruency effect and ASC traits, provided evidence against any meaningful correlation in terms of accuracy or reaction time in both tasks. Additionally, the results showed evidence for the *absence* of a meaningful correlation between the size of memory effect and ASC traits in relation to both reaction time and accuracy in both tasks.

2.11 Conclusion

In conclusion, the primary objective of this study was to develop a novel framework for concurrently measuring the fundamental components of executive function, specifically, working memory and inhibitory control. This framework also has the potential to investigate interactions between these components. To achieve this objective, a single general paradigm comprising two tasks with a very similar structure was developed. One task aimed to explore the potential effects of working memory and response inhibition within a single task, while also investigating interactions between these components (the Spatial Conflict task). The other task aimed to simultaneously measure the effects of working memory and interference control, as well as investigate the potential interaction between them (the Flanker task).

Integrating core executive function components into a single task yielded valuable insights. Concerning the main effects observed in this study, the Bayesian ANOVAs conducted on the Flanker task demonstrated strong evidence supporting both memory and congruency effects in reaction time, aligning with expectations and hypotheses.

Additionally, in the Flanker task, when examining accuracy, the results of these analyses provided limited evidence supporting the memory effect, but only in congruent trials. Furthermore, there was strong evidence supporting a congruency effect, but only in the low-memory condition.

In the Spatial Conflict task, there was moderate evidence for a memory effect, but specifically in incongruent trials. Furthermore, there was strong evidence for a congruency effect in both low and high memory conditions. In terms of accuracy in the Spatial Conflict task, the analysis showed weak evidence for the absence of a memory effect. However, there was strong evidence for the main effect of congruency.

In summary, as expected, the main effects of working memory and inhibitory control were present in the Flanker task, particularly in reaction time (which is a more suitable dependent variable for this task, as it will be discussed in greater detail later). However, further investigation is required to confirm the genuineness of the Flanker effect, as in the current study, the direction of the central stimuli was aligned with the flankers to enhance the likelihood of obtaining a congruency effect, necessitating a shift to an upright position for verification in next study. Moreover, in the Spatial Conflict task in reaction time, the expected main effect of congruency was observed. However, there was only moderate evidence for the main effect of memory, and this effect was evident only in incongruent trials. Therefore, in the following study, an attempt was made to enhance the likelihood of obtaining memory effects in both tasks by increasing the number of items requiring memorization from 4 to 6. Moreover, in contrast to this experiment where all participants began the executive function battery with the Flanker task, the subsequent study divided participants into two groups. One group began with the Flanker task, while the other commenced with the Spatial Conflict task. This division aimed to explore any potential variation in the size of the memory effect in the Spatial Conflict task that results from experiencing the Flanker task first. More specifically, due to the limited distinguishable colours, some of the colours used in the Flanker task (which was the first task participants experienced) were repeated in the Spatial Conflict task. It was hypothesized that the absence of a memory effect in the second task (Spatial Conflict task) might be attributed to participants carrying over memory rules from the first task to the second task.

Furthermore, valuable insights were yielded by the integration of core executive function components within a single task into how these components interact. Regarding interaction effects, they were only observed in two instances. Firstly, in the Flanker task, an interaction between working memory and interference control, specifically in terms of accuracy, was detected.

Secondly, interaction in reaction time within the Spatial Conflict condition between working memory and response inhibition was observed. However, this finding is influenced by the fact that the evidence for the memory effect was moderate and limited to incongruent trials.

Hence, interaction between core components of executive function was not observed consistently, and even in the two cases where it did appear, it was under-additive rather than the over-additive pattern predicted by Roberts and Pennington's (1996) model. The absence of consistent interactions in both tasks even complicates the conclusion that they measure different constructs and emphasizing the intricate nature of executive function. Further discussion of this will be provided in more detail in the final chapter.

Additionally, Bayesian correlation and linear regression analyses indicated no evidence of a correlation between the task measures and autistic traits measured by the AQ questionnaire. It could be argued that this lack of correlation might arise from various potential factors, first, there might not actually be a genuine relationship between the task measures and the autistic traits being measured. Secondly, another possibility is the sensitivity of the AQ questionnaire itself. Specifically, it is possible that the questionnaire may not possess the precision required to capture subtle variations in autistic traits, potentially impacting its ability to accurately detect correlations. However, it's important to note that the reliability of this questionnaire has been demonstrated in various studies, and it exhibited good reliability in the current study. A more detailed discussion of these findings will be provided in the final chapter.

Lastly, it is possible that prior research (reporting difficulties in executive function in ASC) has inadvertently placed more emphasis on traits associated with ADHD rather than pure autistic traits. Given the well-documented high comorbidity between ASC and ADHD (e.g., Failla et al., 2021; Leitner, 2014) coupled with the established link between ADHD and challenges in executive functions (e.g., Crosbie et al., 2013; Rajendran et al., 2013; Schreiber et al., 2014; Shimoni et al., 2012; Sonuga-Barke et al., 2002; Toll et al., 2011; Willcutt et al., 2005; Martinussen & Tannock, 2006) differences in executive function findings within ASC individuals might potentially be related to their concurrent ADHD symptoms. As a result, these concerns were actively addressed in the subsequent second study. Therefore, the follow-up study utilized a different questionnaire to measure ASC and also included measurements of ADHD traits. The aim was to explore the potential correlation between these two sets of traits and better understand the relationship between executive function findings and the presence of both ASC and ADHD traits.

3 Chapter Three (Study 2)

3.1 Introduction

This chapter will focus on the second, follow-up study aimed at addressing specific aspects of the previous study (presented in Chapter 2). In this second investigation, focus was directed towards altering the direction of the central stimuli in the Flanker task, specifically shifting them to the upright position. This was because, despite observing an effect of distractor congruency in the earlier study, the alignment of the central stimulus direction with the distractors required further exploration to determine the observed effect was indeed a genuine flanker effect. Additionally, in contrast to the first study where the Flanker task was the initial task for all participants, the second study involved the division of participants into two groups: one in which the Flanker task was the first task experienced and another in which the Spatial Conflict was the first task that participants received. Furthermore, to enhance the likelihood of observing a memory effect in both tasks, the quantity of stimuli requiring memorization in each condition was increased from four to six.

Moreover, the initial findings from the first study revealed no evidence of a meaningful correlation between the measure of autistic traits (AQ-S) and performance on the executive function tasks. Considering this, potential factors were hypothesized, including the following:

i) the absence of a meaningfully underlying correlation, ii) limitations in questionnaire sensitivity and iii) the influence of unmeasured ADHD traits in prior research. This latter factor suggests that the documented high comorbidity between ASC and ADHD (e.g., Failla et al., 2021), alongside the established association of ADHD with executive function difficulties, could lead to variations in executive function findings among ASC individuals potentially arising from co-existing ADHD symptoms (Wallace et al., 2016).

Consequently, in the second study, both ADHD and autistic traits were assessed, and the assessment of autistic traits was expanded using the Comprehensive Autistic Trait Inventory (CATI, English, 2021). The CATI is a new test that measures a broad range of autistic traits, and it aims to correct some ‘blind spots’ that other common tests (e.g., AQ, Baron-Cohen et al., 2001; BAPQ, Hurley et al., 2007) have in the various autistic trait dimensions. The 42-item CATI comprises six subscales: Social Interactions, Communication, Social Camouflage, Repetitive Behaviours, Cognitive Rigidity, and Sensory Sensitivity. The CATI showed convergent validity at both the total-scale (r≥.79) and subscale level (r≥.68). The CATI also showed superior internal reliability for total-scale scores (α=.95) relative to the AQ (α=.90) and BAPQ (α=.94), consistently high reliability for subscales (α>.81), greater predictive ability for classifying autism (Youden's Index=.62 vs .56 -.59), and demonstrated measurement invariance for sex (English et al.,2021, see Appendix 2).

Additionally, for the purpose of validating the CATI as a measure of autistic traits, a central coherence measure was employed. Central coherence, as described by Frith (1989), refers to the ability of our cognitive system to effectively integrate various sources of information to establish coherent and meaningful interpretations. Weak Central Coherence (WCC) is characterized by a tendency for local rather than global processing and a preference for details when recognizing stimuli, which makes it challenging to grasp the overall form and any meaning that requires global processing (Frith & Happé, 1994; Happé & Frith; 2006). WCC has been defined as a perceptual-cognitive style associated with the behavioural phenotype in ASC (Happé et al., 2001). For example, Happé et al (2001) studied 43 parents of individuals with autism, 30 parents of individuals with dyslexia, and 20 parents of typically developing children. Results showed that parents of children with autism, especially fathers, demonstrated weak central coherence in tasks involving semantics, perceptual judgment, and visuospatial abilities. Moreover, in another study, Best et al. (2007) investigated Weak Central Coherence and executive dysfunction in relation to behavioural markers of autism, regardless of whether individuals had a formal autistic spectrum disorder diagnosis. The study involved sixty young participants who completed assessments, including the Social Communication Questionnaire (SCQ), a block design test, viewing visual illusions, and an ambiguous figure task. Utilizing logistic regression, the study revealed that central coherence and ambiguous figure variables significantly contributed to predicting autism-related behavioural markers. Therefore, given the association of weak central coherence to ASC, employing a central coherence measure can serve as a potential way of confirming the validity of the utilized measure of autistic traits.

This study has been preregistered on the Open Science Framework (OSF), demonstrating a commitment to transparency and the establishment of research methods and hypotheses in advance of data collection. The preregistered study can be accessed via the following link: https://osf.io/5cqha/?view_only=4361a58bdfea4d7597c00ab4fe13ae39

3.2 Executive function task and conditions (as preregistered on the OSF)

The executive function battery remained the same as used in Study 1, except for the previously mentioned changes, and was administered online using the Gorilla Program. This battery included two tasks, each orthogonally manipulating working memory and a specific inhibitory control aspect. Specifically, the Flanker task continued to manipulate working memory load and interference control load, while the Spatial Conflict task continued to manipulate working memory load and response inhibition load. Importantly, one of the key features of the battery that persisted was the closely shared structure between both tasks (as described below), facilitating their direct comparison.

The study's overall framework followed this structure: Half of the participants began with the Flanker task, and the remaining half started with the Spatial Conflict task. Participants commenced each task with practice trials before proceeding to experimental trials. Both tasks included conditions of low memory and high memory load, encompassing two trial types (congruent and incongruent trials) for each condition. The presentation order of these conditions was counterbalanced within each task and the number of congruent and incongruent trials was equal within each condition.

In each trial of each task, participants were initially presented with two letters (W and P) at the lower edges of a white blank page for a duration of 500 ms. Subsequently, stimuli were introduced, consisting of 5 airplanes (four grey, one coloured) arranged horizontally slightly above the midline of the page. Notably, the W aligned with the left-most airplane, and the P aligned with the right-most airplane (see Figure 3.1).

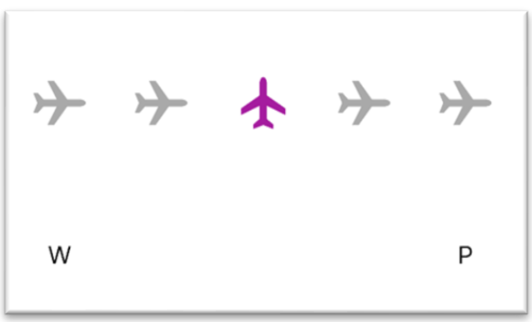
In the Flanker task, participants were required to select the W or P key on the keyboard in accordance with the response associated with the central stimulus. Each trial featured a centered upright target airplane of a specific colour, flanked by four light grey airplanes (distractors) – two on each side. Participant responses were expected to align with the instructions related to the target airplane, while disregarding the distractors. This task comprised a total of 308 trials, including 20 practice trials and 144 trials in each of low memory and high memory conditions.

The Spatial Conflict task involved determining the spatial response location associated with each stimulus. In each trial, a target coloured airplane appeared with 4 light grey airplanes (distractors) either on the left or right side of it (all to the left, or all to the right, so that the target appears on the right or the left of the display respectively). Participants were instructed to press either W or P and respond based on the instruction associated with the target airplane and ignore the distractors. This task encompassed a total of 288 trials, including 24 practice trials and 132 trials in each of low memory and high memory conditions.

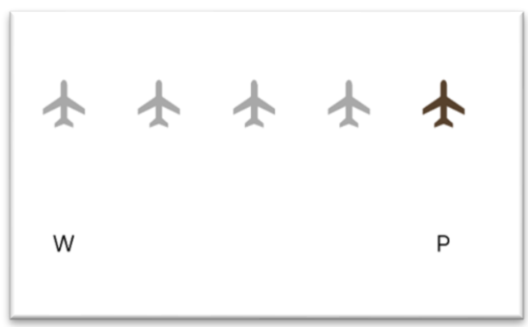
In both tasks, participants were instructed to swiftly and accurately respond by pressing one of two designated buttons (W or P). Additionally, during the practice trials for both tasks, participants received feedback on the accuracy of both their correct and incorrect responses. If an error was made, the trial was repeated. However, during the experimental trials, feedback was only provided after incorrect responses (without repeating the trial).

The completion of the battery took approximately 30 minutes.

Figure 3-1. Sample trials in cognitive tasks: Screenshots from the Gorilla program



A sample trial in the Flanker task



A sample trial in the Spatial Conflict task

The manipulation of the EF's components is described in detail below:

Memory

To manipulate the memory load, the complexity of the response rule that had to be maintained was varied in each condition. In the low memory conditions, participants were required to learn six rules, which had the potential to be grouped into three categories (e.g., W for light, mid, or dark blue airplanes; P for light, mid, or dark red airplanes). In the high memory load conditions, participants were instructed to remember six distinct rules. (e.g., W for brown, purple, or orange airplanes; P for yellow, green, or dark grey airplanes).

The target airplane colours for practice trials in both Flanker and Spatial Conflict tasks stayed the same (pink for W and gold for P). In the low memory trials of the Flanker task, the chosen colours were light/mid/dark blue for W and light/mid/dark red for P and for the low memory trials of the Spatial Conflict task, the selected colours were light/mid/dark brown for W and light/mid/dark green for P.

As in the previous study, colours were reused in high memory conditions due to limitations in the availability of distinct colours, maintaining their positions from low memory conditions. Consequently, for the high memory Flanker task, brown, purple, and orange were assigned to W, while yellow, green, and dark grey were allocated to P. Similarly, within the high memory Spatial Conflict task, blue, purple, and orange were designated for W, while red, yellow, and dark grey were assigned to P.

Inhibition

a) In the Spatial Conflict task, inhibition was manipulated by varying the presentation location of the target stimulus in congruent or incongruent positions with the response key. This manipulation involved presenting the target stimuli either on the left or right side of the screen for each trial in a pseudo-random order. In congruent trials, the target's position aligned with the response key (e.g., presenting the target on the left side when the response key was W). In incongruent trials, the target's position conflicted with the response key (e.g., presenting the target on the right side when the response key was W).
b) In the Flanker condition, the direction of the distractors around the upright central stimulus was manipulated to be either incongruent or congruent with the correct response key. In congruent trials, the direction of the distractors matched the correct response key (e.g., distractors pointing left when the correct response was W). In incongruent trials, the distractors' direction conflicted with the correct response key (e.g., distractors pointing right when the correct response was W).

3.3 Autistic traits measure

Common traits seen in autism can also appear to varying degrees in the broader population (English et al., 2021). To assess these traits in the second study, in accordance with the preregistered methodology, the Comprehensive Autistic Trait Inventory (CATI, English, 2021) was employed.

3.4 ADHD traits measure

As it was preregistered, the Adult ADHD Self-Report Scale (ASRS, Kessler et al., 2005) was utilized to measure ADHD traits in the general population for this study. The ASRS is an 18-item self-report questionnaire designed to assess symptoms of attention deficit hyperactivity disorder (ADHD) in individuals aged 18 and above. This scale is based on the World Health Organization Composite International Diagnostic Interview (2001), and the questions are consistent with DSM-IV (American Psychiatric Association, 2000) criteria, but reworded to better reflect symptom manifestation in adults. This questionnaire is divided into two parts. Part A consists of 6 items, which have been identified as the most predictive of ADHD and are suitable for screening purposes. Part B includes an additional 12 questions aligned with DSM criteria. These questions provide additional cues and serve as deeper inquiries into the patient's symptoms. For an individual's symptoms to be considered consistent with an ADHD diagnosis, they must meet specific severity level criteria, requiring 4 or more responses in Part A of the ASRS. The ASRS has high internal consistency (Cronbach's alpha = 0.88) and concurrent validity (r = 0.84) (Adler et al., 2006). See Appendix 3 for additional details regarding the questions in this questionnaire.

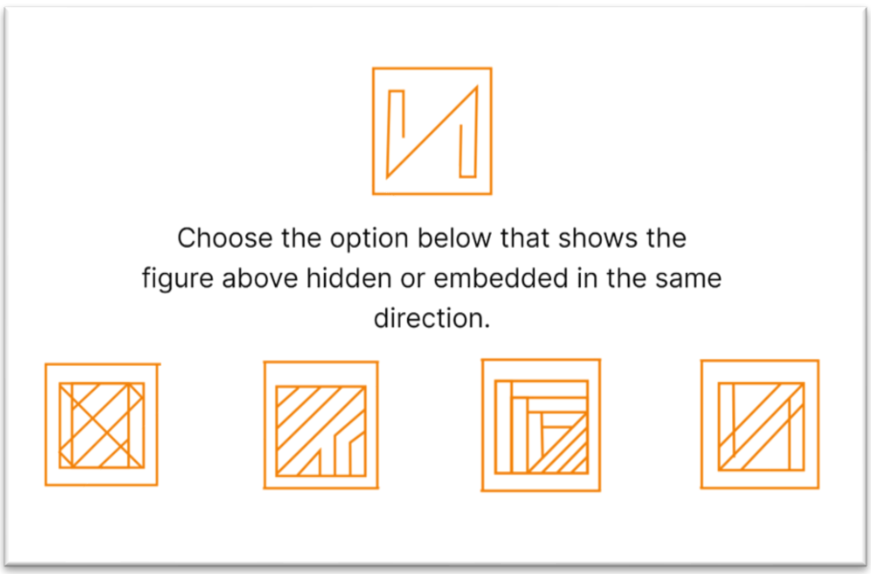
3.5 Embedded figures test

In light of the well-established connection between weak central coherence and autism spectrum condition in the broader literature, a central coherence task was employed to validate the use of the autistic traits measure (CATI). To assess central coherence abilities, an online free embedded figures test was employed (Singh, 2021), consistent with the preregistered methodology. The initial version consisted of 15 questions. However, some questions had errors in the suggested correct answers, and irregularities were observed in the shapes of some others. Consequently, these problematic questions were excluded, and the best 11 questions were selected from the original set, one of which served as a practice trial.

In this assessment, participants are presented with an image along with four alternative response option images to choose from (see Figure 3-2). The aim is to correctly select the option that includes the question picture as a component. This test evaluates an individual's ability to concentrate on and extract relevant details from complex visual stimuli, involving the cognitive process of identifying smaller patterns within larger, complex images. The comprehensive version of the task is available in Appendix 1.

It is worth noting that the assessment of performance in this test was based on accuracy, referring to the proportion of correct answers.

Figure 3-2. Sample trials in Embedded figures test



3.6 Dependent Variables

As outlined in the preregistered research plan, the study focused on several dependent variables, including reaction times (restricted to correct responses) and accuracy recorded for all keypress responses in each trial of the two experimental tasks, ASC traits (measured by the CATI), ADHD traits (measured by the ASRS), and central coherence (measured by the online embedded figures test).

3.7 Aims and Hypothesis

In line with preregistered research plan, the study aimed to extract measures of working memory and response inhibition (from the Spatial Conflict task) and working memory and interference control (from the Flanker task). The first objective was to evaluate whether the anticipated effects of the previously defined measures of executive function could be observed when assessed simultaneously within a single general paradigm (this involved the evaluation of working memory and response inhibition from the Spatial Conflict task, along with working memory and interference control from the Flanker task).

Secondly, the correlation between different measures of tasks performance and a measure of ASC traits and ADHD traits was investigated.

Thirdly, the validity of the autistic traits measure (CATI) was assessed by examining its correlation with a measure of central coherence.

The predictions, as preregistered on OSF are as follows:

G. It was hypothesized that significant main effects for working memory and response inhibition could be observed in the Spatial Conflict task.
H. It was hypothesized that significant main effects for working memory and interference could be observed in the Flanker task.
I. In accordance with the results of Jarrold et al.'s (2023) research, in the Spatial Conflict task, it was predicted that working memory and response inhibition would act independently, without magnifying each other's effects as their demands changed and without depleting their shared resource.
J. Similarly, applying the same logic to the Flanker task, it was anticipated that working memory and interference control would operate independently of each other.
K. It was hypothesized that higher levels of ASC/ADHD traits would align with poorer task performance as the memory and inhibitory load increase, resulting in slower reactions and lower accuracy.
L. It was anticipated that there would be evidence for the correlation between a measure of autistic traits and performance on the central coherence test. Indicating that the CATI measure effectively captured the cognitive characteristic of weak central coherence, which is associated with autistic traits.

3.8 Analyses

Bayesian ANOVAs were employed to analyse the main effects of memory load and response inhibition load within the Spatial Conflict task, as well as the main effects of working memory and interference control within the Flanker task. Additionally, any potential interactions between these factors were examined using these Bayesian ANOVAs.

Furthermore, Bayesian correlation analyses were employed to investigate the zero-order correlation between the measures from cognitive tasks and both ASC traits and ADHD traits, and the correlation between measures of autistic traits and weak central coherence. In a subsequent correlational analysis, using partial correlations, memory load and inhibition load effects were extracted to examine whether these related to ASC and ADHD traits.

All of these analysis plans were in accordance with the preregistered plan of this study.

3.9 Sample Size

Participants in the study were 100 adults aged between 18 and 25, in accordance with the preregistered plan, securing a power of 94% for the detection of a correlation equal to or higher 0.32. The Prolific platform was employed for participant recruitment in this research, and in order to encourage participation, individuals were compensated for their involvement. The average reward offered per hour of participation was £13.19.

3.10 Outliers and Exclusions

As it was preregistered in OSF, reaction time outliers were trimmed using the Median Absolute Deviation (MAD) method, as described by Leys et al. (2013), with a criterion of +/-3 MAD. Trimming was carried out individually for each participant and at the trial type level (congruent/incongruent) within each condition, resulting in eight MAD trims for each participant.

Moreover, any participant who achieved an accuracy below 60% in the congruent trials of the low working memory load condition within a task was excluded from data analysis for that specific task. According to this criterion, data from one participant was omitted from the Flanker task dataset, and data from two participants were excluded from the Spatial Conflict task dataset.

Additionally, immediate stimulus repetitions across successive trials were not deliberately avoided; nonetheless, data from these trials were excluded and not analysed (see Bertelson, 1965).

3.11 Results

For each task two Bayesian Repeated Measures ANOVAs were performed, each involving two factors: memory (with low and high levels) and congruency (with congruent and incongruent levels). This analysis was performed separately for reaction time and accuracy measures.

The strength of evidence was assessed according to Jeffreys' classification: Bayes factors ranging from 1 to 3 were regarded as weak evidence, those ranging from 3 to 10 as moderate evidence, and a Bayes factor exceeding 10 was considered strong evidence (Jeffreys, 1961).

In this study, as in Study 1, Data analysis was performed in JASP 0.17.3 (JASP Team, 2023). Moreover, the "across matched models" option in JASP was used to compute Bayes Factors for the inclusion or exclusion of effects and interactions (Keysers et al., 2020). The results of these analyses will be presented below for the Flanker task and the Spatial Conflict task, respectively.

3.11.1 Reaction time in the Flanker task

Table 3.1 displays the descriptive statistics for participants' reaction time in the Flanker task.

Table 3-1. Descriptive Statistics of reaction time in the Flanker task

	Flanker Low and Congruent	**Flanker Low and Incongruent**	**Flanker High and Congruent**	**Flanker High and Incongruent**
Valid	99	99	99	99
Missing	0	0	0	0
Mean	549.152	559.451	729.859	723.469
Std. Deviation	125.821	135.302	206.714	212.517
Minimum	361.600	368.876	466.252	448.565
Maximum	974.660	1114.102	1697.362	1921.738

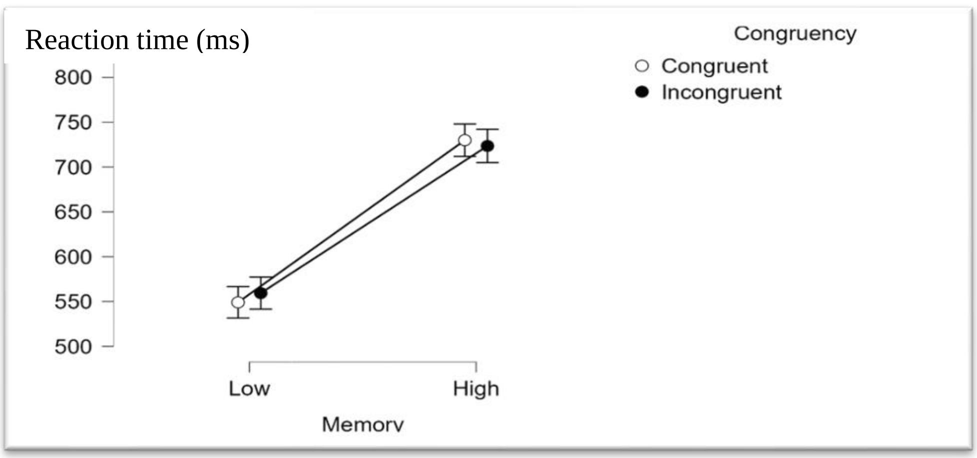
The Bayesian Repeated Measures ANOVA for reaction time in the Flanker task indicated that there was strong evidence for a memory effect ($BF_{10}=1.613\times10^{+16}$), reflecting the fact that participants exhibited quicker reaction times in low memory trials (including both congruent and incongruent trials, M=554, SD= 129), as compared to high memory trials (encompassing both congruent and incongruent trials, M=726, SD= 208).

There was evidence for the *absence* of a congruency effect ($BF_{01} = 6.683$), but strong evidence for an interaction between memory load and congruency ($BF_{10} = 10.892$) was observed.

Moreover, the Bayesian Repeated Measures ANOVA demonstrated that the best model for explaining reaction time in the Flanker task was the one involving memory, congruency, and their interaction (BF_{10}=2.726×10^{+16}). However, since there was evidence against a congruency effect a subsequent model comparison was carried out. This comparison encompassed the main effect of congruency within a revised null model. Based on this, the best model for explaining accuracy in the Flanker task consisted of the main effect of memory and the interaction between memory and congruency (BF10=1.710×10+17).

Moreover, a classical repeated measures ANOVA for reaction time in the Flanker task was also conducted, and the results are available in Table A, in the appendix 8.

Figure 3-3. Reaction time (ms) in the Flanker task



The data presented in Figure 3.3 indicates a variation in the congruency effect across the two levels of memory. Alternatively, this can be expressed as a dissimilarity in the memory effect at the two levels of congruency. To decompose the interaction reflected in this figure, four separate Bayesian repeated measures ANOVA were conducted:

1) Low Memory: To explore the interaction, a Bayesian repeated measures ANOVA was performed exclusively on the low memory condition (low memory congruent vs. low memory incongruent). The result of this analysis indicated strong evidence for the congruency effect within the low memory condition (BF10=22.123); However, as illustrated in Figure 3.3, congruent trials unexpectedly showed slower responses compared to incongruent trials, contrary to expectations.

2) High Memory: Similarly, a Bayesian repeated measures ANOVA was conducted focusing only on the high memory condition (high memory congruent vs. high memory incongruent). The analysis results provided evidence for the *absence* of congruency effect within high memory condition (BF_{01} = 3.171).
3) Congruent trials: A Bayesian repeated measures ANOVA focused solely on the congruent trials (congruent in low memory load vs. congruent in high memory load) yielded strong evidence for the memory effect ($BF_{10}=3.629\times10^{+17}$). As depicted in Figure 3.3, the reaction time was notably slower in trials with high memory load compared to those with low memory load.
4) Incongruent trials: A Bayesian repeated measures ANOVA performed only on the incongruent trials (incongruent within low memory vs. incongruent within high memory load) produced strong evidence for memory effect within incongruent trials ($BF_{10}=3.943\times10^{+14}$). Figure 3.3 shows slower reaction times in high memory load trials compared to low memory load trials.

In summary, these findings indicate a strong memory effect in both congruent and incongruent trials, alongside a clear congruency effect in low memory conditions. However, this effect was not observed in high memory conditions.

3.11.2 Accuracy in the Flanker task

Table 3.2 Displays the descriptive statistics for participants' accuracy in the Flanker task.

Table 3-2. Descriptive Statistics of accuracy in the Flanker task

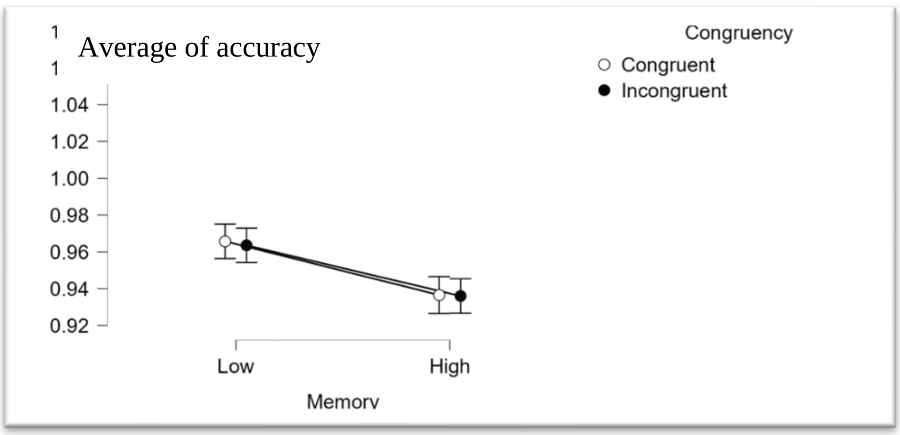
	Flanker Low and Congruent	**Flanker Low and Incongruent**	**Flanker High and Congruent**	**Flanker High and Incongruent**
Valid	99	99	99	99
Missing	0	0	0	0
Mean	0.966	0.964	0.937	0.936
Std. Deviation	0.043	0.042	0.085	0.085
Minimum	0.732	0.797	0.583	0.526
Maximum	1.000	1.016	1.000	1.000

The Bayesian Repeated Measures ANOVA demonstrated that the best model for explaining accuracy in the Flanker task was the one involving just the main effect of memory (BF_{10}=103.247).

Consistent with this best model, there was strong evidence for the memory effect (BF_{10}=103.984), reflecting the fact that participants were more accurate in trials with low memory demands (both congruent and incongruent, M=0.965, SD= 0.039), compared to trials with higher memory demands (both congruent and incongruent, M=0.936, SD=0.082). However, there was evidence for the *absence* of a congruency effect (BF_{01}=6.822) and, similarly, for the *absence* of the interaction of memory load x congruency load (BF_{01}=6.168).

Moreover, a classical repeated measures ANOVA for accuracy in the Flanker task was also conducted, and the results are available in Table B, in the appendix 8.

Figure 3-4. Average of accuracy in the Flanker task



3.11.3 Reaction time in the Spatial Conflict task

Table 3.3 displays the descriptive statistics for participants' reaction time in the Spatial Conflict task.

Table 3-3. Descriptive Statistics of reaction time in the Spatial Conflict task

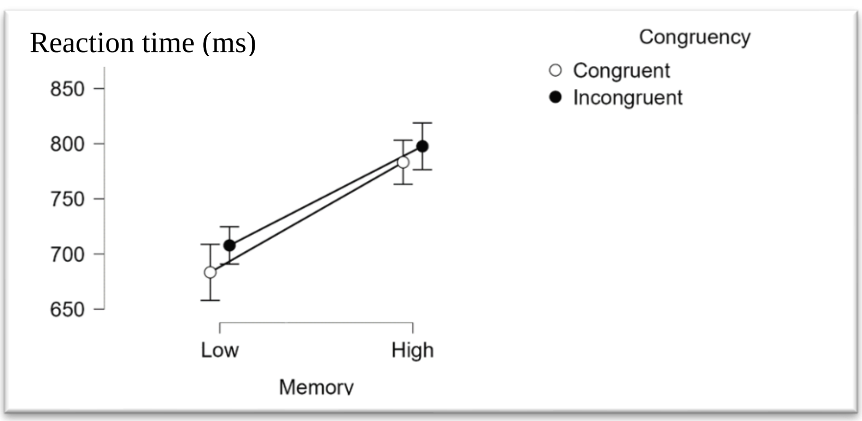
	Spatial Low and Congruent	**Spatial Low and Incongruent**	**Spatial High and Congruent**	**Spatial High and Incongruent**
Valid	98	98	98	98
Missing	0	0	0	0
Mean	683.312	707.769	783.156	797.702
Std. Deviation	204.939	160.142	185.586	197.968
Minimum	440.187	482.021	532.234	538.830
Maximum	1992.643	1423.214	1726.206	1714.786

As it has shown in figure 3-5, the Bayesian Repeated Measures ANOVA for reaction time in the Spatial Conflict task revealed strong evidence for the main effects of both memory and congruency, characterized by Bayes Factors of 31965.107 and 96.724 respectively. These effects reflected the fact that participants exhibited quicker reaction times on trials with low memory load (in both congruent and incongruent trials, M = 695ms, SD = 179ms) compared to high memory load (in both congruent and incongruent trials, M = 790ms, SD = 190ms). Furthermore, participants demonstrated faster reaction times in congruent trials (under both low and high memory loads, M = 733ms, SD = 170ms) in comparison to incongruent trials (within the low and high memory load, M = 752ms, SD = 161ms).

However, there was evidence for the *absence* of interaction of memory load x congruency load (BF_{01}=3.441) and the best model for reaction time in the Spatial Conflict task was the model including just the main effects of memory and congruency ($BF_{10}=3.177\times10^{+6}$).

Moreover, a classical repeated measures ANOVA for reaction time in the Spatial Conflict task was also conducted, and the results are available in Table A, in the appendix 9.

Figure 3-5. Reaction time (ms) in the Spatial Conflict task



3.11.4 Accuracy in the Spatial Conflict task

Table 3.4 Displays the descriptive statistics for participants' accuracy in the Spatial Conflict task.

Table 3-4. Descriptive Statistics of accuracy in the Spatial Conflict task

	Spatial Low and Congruent	**Spatial Low and Incongruent**	**Spatial High and Congruent**	**Spatial High and Incongruent**
Valid	98	98	98	98
Missing	0	0	0	0
Mean	0.963	0.920	0.943	0.930
Std. Deviation	0.047	0.069	0.073	0.078
Minimum	0.745	0.692	0.558	0.500
Maximum	1.000	1.000	1.000	1.000

The analysis of the accuracy data revealed evidence for the *absence* of memory effect (BF_{01}=3.789). Nevertheless, strong evidence emerged for the main effect of congruency (BF_{10}=2.157×10^7), reflecting higher average accuracy for congruent trials (under both low and high memory loads, M=0.953, SD=0.051) in comparison to incongruent trials within both low and high memory loads (M=0.925, SD=0.063).

Additionally, there was strong evidence for the interaction between memory load and congruency load (BF_{10}=2736.185). Furthermore, the best model for accuracy in the Spatial Conflict task included the main effects of memory and congruency, and their interaction (BF_{10}=1.617×10^{10}). However, since no evidence for a memory effect was found, a subsequent model comparison was conducted. This comparison included the main effect of memory within a revised null model. A model that included the main effect of congruency and the interaction between memory and congruency was preferred over this revised null model by a Bayes Factor of 6.219×10^{10}.

Moreover, a classical repeated measures ANOVA for accuracy in the Spatial Conflict task was also conducted, and the results are available in Table B, in the appendix 9.

Figure 3-6. Average of accuracy in the Spatial Conflict task

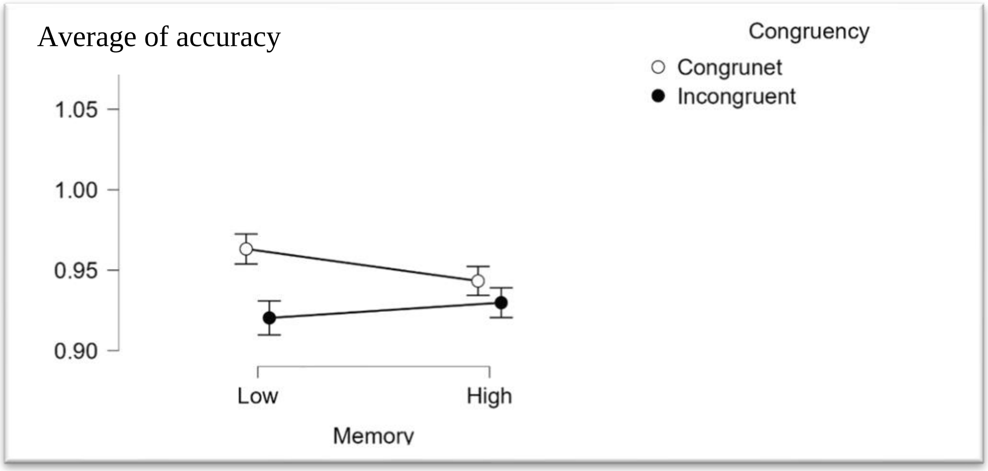


Figure 3.6 indicates variations in the congruency effect across memory levels, or alternatively, differences in the memory effect between two levels of congruency. Four post-hoc Bayesian ANOVA were performed to understand this interaction and to identify where the memory and congruency effects appear. These analyses focused on:

5) Congruent trials: To explore the interaction, a Bayesian repeated measures ANOVA was conducted solely on the congruent trials (congruent trials within the low memory condition vs. congruent trials within the high memory condition). The result of this analysis provided moderate evidence for the memory effect within congruent trials (BF_{10}=6.287)
6) Incongruent trials: a Bayesian repeated measures ANOVA was performed only on the incongruent trials (incongruent trials within the low memory condition vs. incongruent trials within the high memory condition). The result of this analysis provided evidence for the absence of a memory effect within incongruent trials (BF_{01}=3.293)
7) Low Memory: A Bayesian repeated measures ANOVA was performed exclusively on the low memory condition (low memory congruent vs. low memory incongruent). The result showed strong evidence for the congruency effect in low memory condition ($BF_{10}=3.508\times10^{+8}$); as shown in Figure 3.6, in line with expectations, incongruent trials resulted in slower responses compared to congruent trials.
8) High Memory: Similarly, a Bayesian repeated measures ANOVA focusing only on the high memory condition (high memory congruent vs. high memory incongruent) provided

strong evidence for congruency effect within high memory condition (BF10 =11.009); As depicted in Figure 3.6, consistent with predictions, incongruent trials led to slower response times when compared to congruent trials.

Therefore, these findings provide evidence supporting the memory effect on accuracy in congruent trials while showing no substantial memory effects in incongruent trials. Furthermore, strong evidence supporting the congruency effect was observed across both memory loads.

3.12 Investigating Memory and Congruency Effects Based on Task Order: Bayesian Repeated Measures ANOVA

A series of Bayesian repeated measures ANOVAs were conducted to explore variations in the memory and congruency effects based on the task order. These analyses were carried out separately for reaction time and accuracy. In contrast to the previous study (presented in Chapter 2) where all participants started the battery with the Flanker task, in this study, 50 participants initiated the task with the Flanker task, while the other 50 began with the Spatial Conflict task. This arrangement was intended to deepen our comprehension of how components of executive functions are influenced by task order. The results of these analyses are detailed in Appendix 4 and 5. Notably, there was no meaningful order effect observed.

3.13 Correlation between the measures from the cognitive tasks and ASC traits (measured by CATI) and ADHD traits (measured by ASRS)

1) Bayesian correlation analysis was employed to examine the zero-order correlation between the following variables:

a) Reaction times for congruent and incongruent trials within both low and high memory conditions for each task (eight measures), and the measures of ASC and ADHD traits. These analyses investigate whether there is a pattern of increasing correlations with an increase in inhibitory load and memory load.

b) Accuracy of each trial type within each condition of each task and the measure of ASC and ADHD traits to again investigate whether correlations will be increased with higher inhibitory and memory loads.

Table 3.5 displays the descriptive statistics for ASC traits (measured by CATI) and ADHD traits (measured by ASRS)

Table 3-5. Descriptive Statistics for ASC and ADHD traits

	ASRS	**CATI**
Valid	97	99
Missing	2	0
Mean	36.660	121.949
Std. Deviation	14.118	26.187
Minimum	2.000	57.000
Maximum	63.000	175.000

Details regarding Bayesian correlation analysis can be found in Table 3.6 and 3.7.

Table 3-6. Bayesian Pearson Correlations of the task's measures and CATI

Evidence for the absence of meaningful correlation

Flanker task	Low		High	
	Congruent	Incongruent	Congruent	Incongruent
RT	BF_{01}=3.761	BF_{01}=3.713	BF_{01}=7.650	BF_{01}=7.215
Accuracy	BF_{01}=6.369	BF_{01}=7.889	BF_{01}=7.720	BF_{01}=7.316
Spatial Conflict task	Low		High	
	Congruent	Incongruent	Congruent	Incongruent
RT	BF_{01}=6.470	BF_{01}=4.727	BF_{01}=7.020	BF_{01}=6.086
Accuracy	BF_{01}=2.350	BF_{01}=7.797	BF_{01}=5.596	BF_{01}=6.613

The Bayesian correlation analysis revealed evidence for the absence of a meaningful correlation between accuracy/reaction times of both congruent and incongruent trial types within both low and high memory load conditions in the Flanker task /Spatial Conflict task and the autism measure (CATI). These findings suggest that there is no consistent relationship between accuracy/reaction time in the Flanker task/Spatial Conflict task and autistic traits across different levels of inhibitory load and memory load. The Bayesian correlation matrix plots for Accuracy/Reaction time in the Flanker and Spatial Conflict tasks, along with CATI, are presented in Figures 3-7, 3-8, 3-9, and 3-10.

Figure 3-7. Bayesian correlation matrix plot of accuracy in Flanker task and CATI

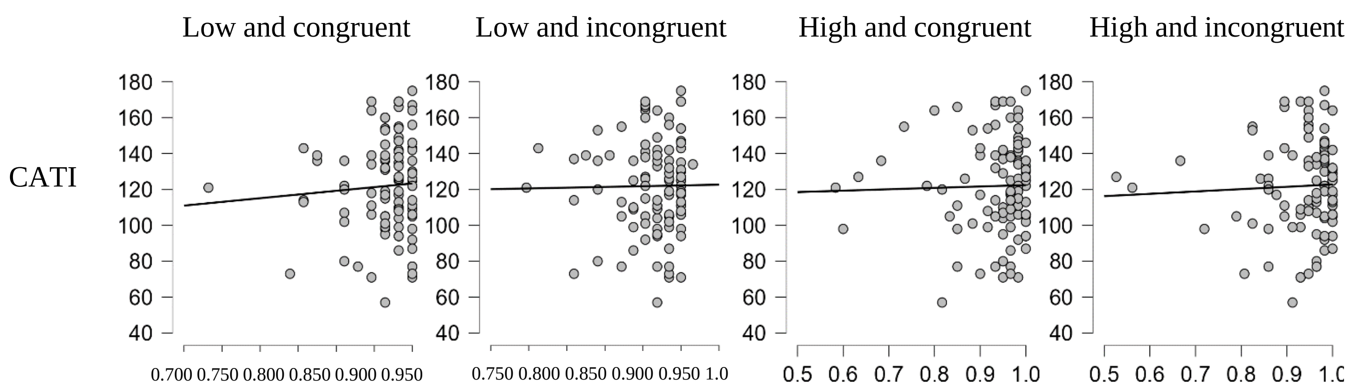


Figure 3-8. Bayesian correlation matrix plot of reaction time in Flanker task and CATI

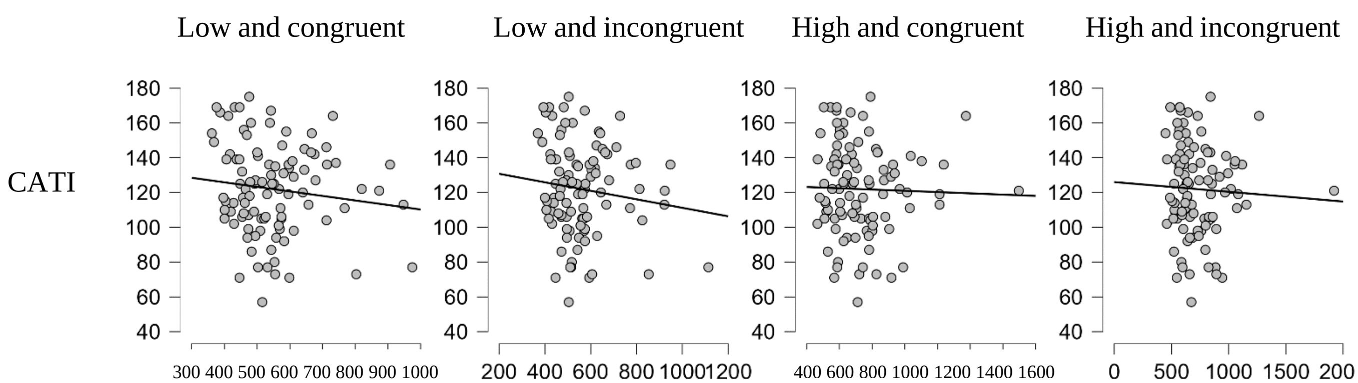


Figure 3-9. Bayesian correlation matrix plot of accuracy in Spatial Conflict task and CATI

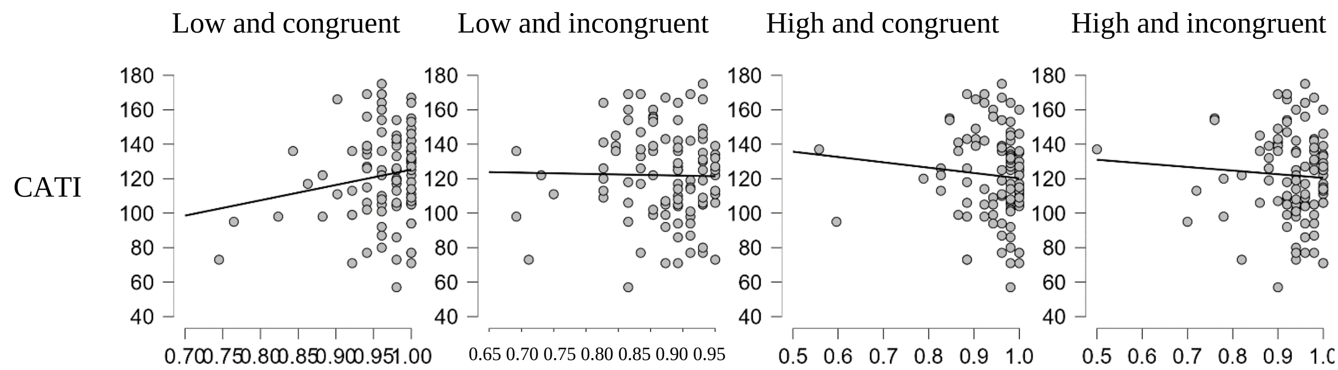


Figure 3-10. Bayesian correlation matrix plot of reaction time in Spatial Conflict task and CATI

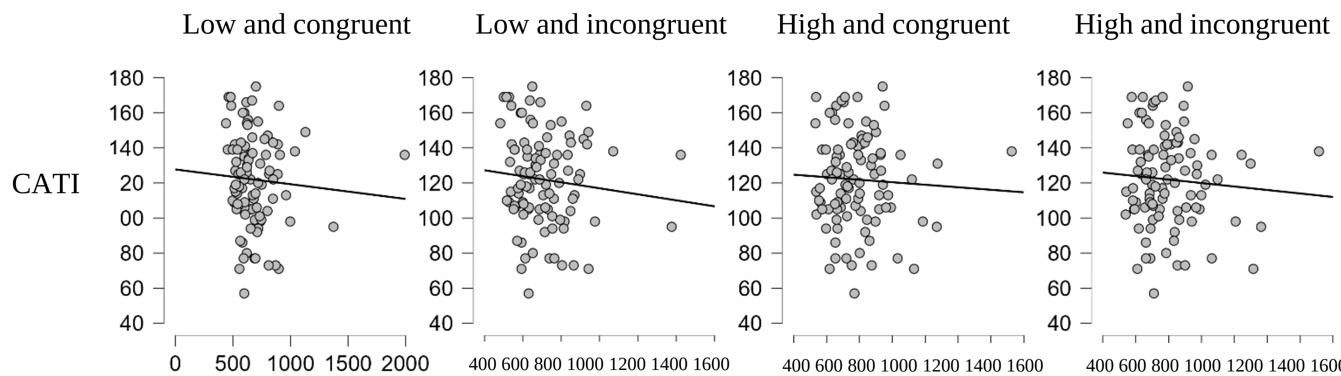


Table 3-7. Bayesian Pearson Correlations of the task's measures and ASRS
Evidence for the absence of meaningful correlation

Flanker task	Low		High	
	Congruent	Incongruent	Congruent	Incongruent
RT	BF_{01}=7.275	BF_{01}=7.039	BF_{01}=5.814	BF_{01}=5.057
Accuracy	BF_{01}=5.127	BF_{01}=2.170	BF_{01}=6.626	BF_{01}=7.220
Spatial Conflict task	Low		High	
	Congruent	Incongruent	Congruent	Incongruent
RT	BF_{01}=6.332	BF_{01}=7.604	BF_{01}=7.589	BF_{01}=7.828

Accuracy	BF_{01}=4.989	BF_{01}=5.283	BF_{01}=7.622	BF_{01}=7.827

The outcomes of the Bayesian correlation analysis provided consistent evidence for the absence of meaningful correlations between accuracy/reaction times of both congruent and incongruent trial types within both low and high memory load conditions in the Flanker task/Spatial Conflict task and the ASRS. These findings imply an absence of a meaningful correlation between accuracy/reaction time in the Flanker task/ Spatial Conflict task and ADHD traits across varying degrees of inhibitory load and memory load. The Bayesian correlation matrix plots for Accuracy/Reaction time in the Flanker and Spatial Conflict tasks, along with ASRS, are presented in Figures 3-11, 3-12, 3-13, and 3-14.

Figure 3-11. Bayesian correlation matrix plot of accuracy in Flanker task and ASRS

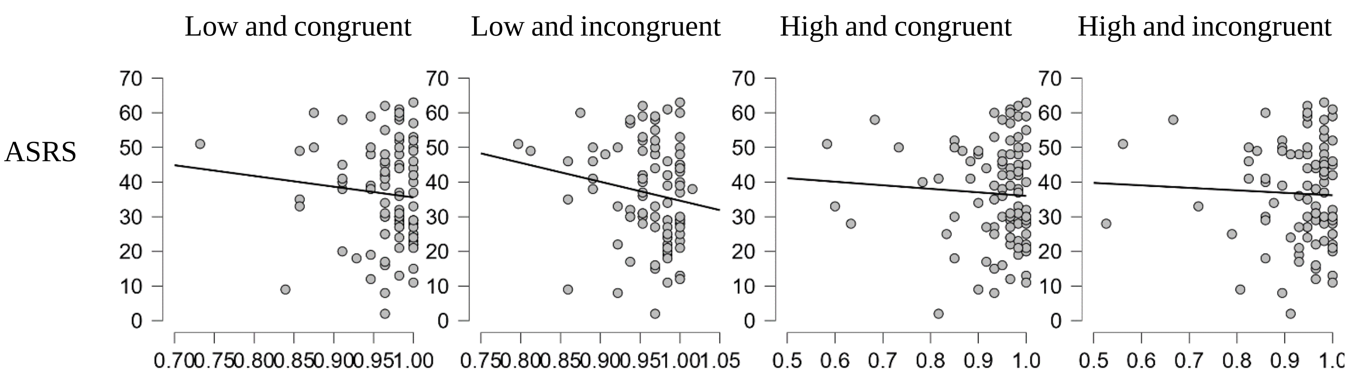


Figure 3-12. Bayesian correlation matrix plot of reaction time in Flanker task and ASRS

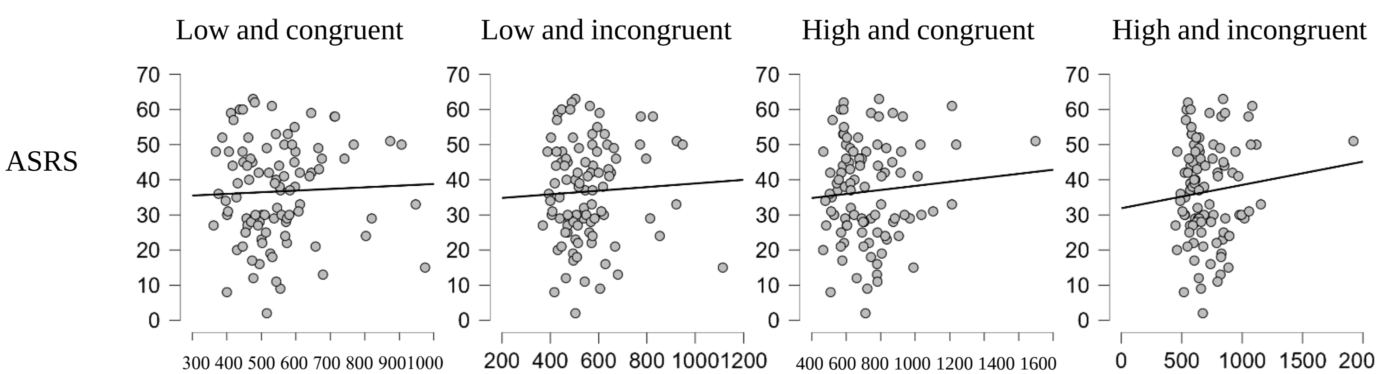


Figure 3-13. Bayesian correlation matrix plot of accuracy in Spatial Conflict task and ASRS

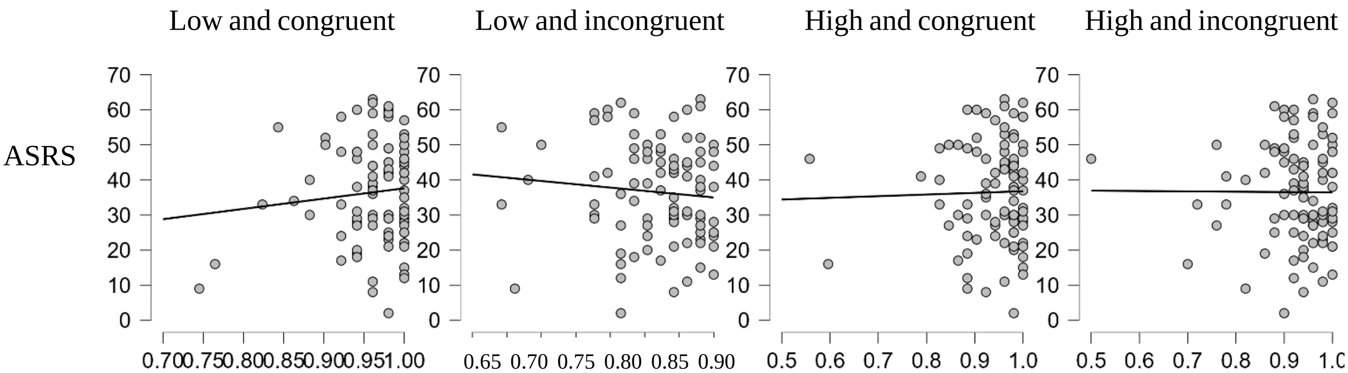
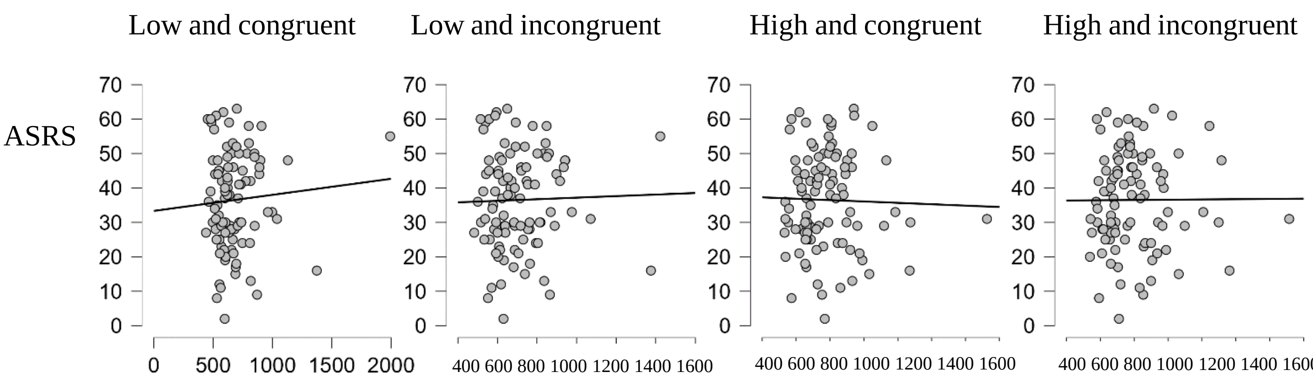


Figure 3-14. Bayesian correlation matrix plot of reaction time in Spatial Conflict task and ASRS



Moreover, the Pearson's correlations between accuracy/reaction time in the Flanker task/Spatial Conflict task and ASC/ADHD traits were also conducted, and the results are available in the appendix 11.

2) Partial correlations (Bayesian Linear regression)

A series of partial correlations was conducted to extract the effects of memory load and inhibition load and their association with ASC/ADHD traits. Bayesian regression ANOVA analyses were carried out using JASP for both reaction time (RT) and accuracy in each task. Correlations were explored between Incongruent trial performance across both low and high memory conditions, while being controlled for by congruent trial performance (serving as an index of the congruency effect) and ASC/ ADHD traits. Furthermore, correlations were assessed between high memory condition performance across both congruent and incongruent trials, controlling for low memory condition performance, serving as an index of memory effect, and their association with ASC and ADHD traits.

The outcomes of the Bayesian ANOVA determined whether it was appropriate to combine high/low memory trial scores across congruent and incongruent trials, or to combine congruent/incongruent trials across low and high memory trials. The resultant analyses are summarised below in Table 3-7.

Table 3-6. The correlation between the measures from the Flanker/Spatial Conflict task and CATI Evidence for the absence of meaningful correlation

Task name	Trial Types	RT	Accuracy
The Flanker task	Incongruent trial performance (within both low and high memory conditions) and CATI (controlling for congruent trial performance)	BF_{01}=31.093	BF_{01}=15.545
	High memory condition performance (including both congruent and incongruent trials) and CATI (controlling for low memory condition performance)	BF_{01}=6.295	BF_{01}=4.706
Spatial Conflict task	Incongruent trial performance (within both low and high memory conditions) and CATI (controlling for congruent trial performance)	BF_{01}=13.617	BF_{01}=6.679
	High memory condition performance (including both congruent and incongruent trials) and CATI (controlling for low memory condition performance)	BF_{01}=5.983	BF_{01}=2.641

Based on the results of the Bayesian linear regression, evidence against any meaningful correlation in terms of accuracy or reaction time was found in both tasks regarding the correlation between the size of the congruency effect and ASC traits. Furthermore, meaningful correlations between the size of the memory effect and ASC traits in relation to both reaction time and accuracy were absent in both tasks.

Table 3-7. The correlation between the measures from the Flanker/Spatial Conflict task and ASRS Evidence for the absence of meaningful correlation

Task name	Trial Types	RT	Accuracy

The Flanker task	Incongruent trial performance (within both low and high memory conditions) and ASRS (controlling for congruent trial performance)	BF_{01}=29.202	BF_{01}=14.348
	High memory condition performance (including both congruent and incongruent trials) and ASRS (controlling for low memory condition performance)	BF_{01}=5.876	BF_{01}=4.708
Spatial Conflict task	Incongruent trial performance (within both low and high memory conditions) and ASRS (controlling for congruent trial performance)	BF_{01}=25.102	BF_{01}=2.766
	High memory condition performance (including both congruent and incongruent trials) and ASRS (controlling for low memory condition performance)	BF_{01}=5.410	BF_{01}=4.848

Bayesian linear regression, examining the correlation between the size of congruency effect and ADHD traits, provided evidence against any meaningful correlation in terms of accuracy or reaction time in both tasks. Additionally, the results showed evidence for the absence of a meaningful correlation between the size of memory effect and ADHD traits in relation to both reaction time and accuracy in both tasks.

3.14 Correlation between a measure of autistic traits (CATI) and a measure of central coherence (embedded figures test)

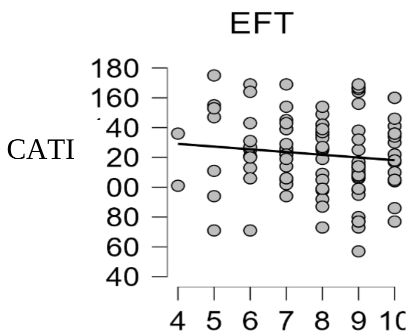
Given the previously established association between weak central coherence and ASC in the broader literature, and in order to validate the measure of autistic traits which was used (CATI), a central coherence task was utilized. However, the results of the Bayesian correlation provide evidence for the absence of a meaningful correlation between CATI scores and performance on the embedded figures test measured in term of accuracy (BF01=4.401). The Bayesian correlation matrix plot for CATI and EFT is presented in Figure 3-15. Table 3.8 displays the descriptive statistics for a measure of central coherence (embedded figures test).

Table 3-8. Descriptive Statistics for embedded figures test

Valid	99
Missing	0
Mean	7.909
Std. Deviation	1.591
Minimum	4.000

Maximum	10.000

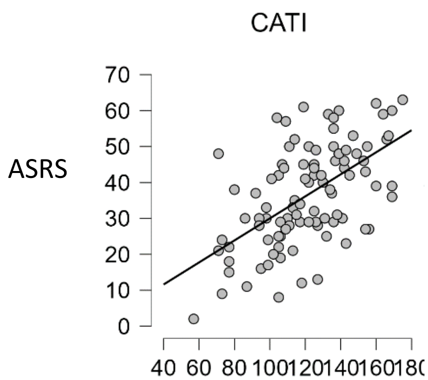
Figure 3-15. Bayesian correlation matrix plot of CATI and EFT



3.15 Correlation between a measure of autistic traits (CATI) and a measure of ADHD Traits (ASRS)

A Bayesian correlation between the two measures provided strong evidence for a meaningful relationship between CATI and ASRS scores (BF_{10}=7.521×10^{+6}), highlighting the relationship between traits related to autism and ADHD. The Bayesian correlation matrix plot for CATI and ASRS is presented in Figure 3-16.

Figure 3-16. Bayesian correlation matrix plot of CATI and ASRS



It worths to note that, the Pearson's correlations between the measure of ASC traits, the measure of ADHD traits and embedded figure test were also conducted, and the results are available in the appendix 12.

3.16 Conclusion

The second study was conducted to address specific issues identified in the first study, with the aim of increasing the likelihood of obtaining strong main effects of the core components of executive function within a single general paradigm. This, in turn, would facilitate a more comprehensive investigation of potential correlations between these components. The changes implemented included:

First, to enhance the chances of observing a memory effect in both tasks, two adjustments were implemented. These changes included increasing the number of items participants had to memorize from four to six. Additionally, in this second study, half of the participants commenced the battery with the Flanker task, while the other half initiated with the Spatial Conflict task. This contrasted with the first study, where all participants started with the Flanker task. The modification in the task sequence aimed to address a specific concern regarding the repetition of colours of target stimuli between the Flanker task and the second task, Spatial Conflict. The issue arose due to limitations in the availability of distinguishable colours, leading to the repetition of some colours in both tasks. The adjustment in the task sequence was designed to investigate whether these changes would impact the likelihood of observing a memory effect in the Spatial Conflict task. Notably, in the first study, a memory effect was only observed in the Flanker task and not in the Spatial Conflict task. This alteration was motivated by the hypothesis that participants might carry over memory rules from the first task, potentially influencing their performance in the second task. [However, concerning task orders, it should be noted that no valuable insights into significant changes in the size of memory or inhibitory effects were obtained through the analysis (see Appendices 4 and 5 for more details)].

Second, in the Flanker task, the position of the central stimuli was changed to an upright position. This adjustment was made to verify the authenticity of the congruency effect observed in the previous study. In the first study, all stimuli, including the central target, pointed either to the right or left. The second study introduced upright central stimuli to ensure that the observed Flanker congruency effect was genuine.

Regarding the main effects, the results of this second study demonstrated significant progress relative to Study 1, as both memory and congruency effects on reaction time within the Spatial Conflict task were successfully obtained. The analysis of accuracy in the Spatial Conflict task revealed a meaningful congruency effect, though there was just moderate evidence supporting the presence of a memory effect and only in congruent trials.

A meaningful memory effect was observed in both reaction time and accuracy during the analysis of the Flanker task. Observing this effect on reaction time in the second study, indicating that changes in task order did not impact its occurrence. Furthermore, concerning the observation of this effect in terms of accuracy, it can be noted that increasing the memory load from 4 items in Study 1 to 6 items in Study 2 appeared to make the former "easy" Flanker task challenging enough to more effectively capture the memory effect in terms of accuracy. As previously discussed, and as will be explored in greater depth later, it appears that accuracy may not be the most suitable dependent variable in relatively straightforward tasks such as the Flanker task when compared to reaction time. Even the addition of a memory load of 4 items in Study 1 did not seem to make it sensitive enough with respect to accuracy. However, increasing the memory load from 4 in Study 1 to 6 in Study 2 appeared to introduce sufficient complexity to capture the memory effect in terms of accuracy.

However, in the Flanker task in this second study, after changing the direction of the central stimuli to the upright position, the Bayesian ANOVA did not provide strong evidence for a congruency effect in terms of accuracy. However, in reaction time, there was strong evidence supporting the consistency of the congruency effect in the low memory condition in Study 2. Conversely, there was no evidence supporting this effect in the high memory load condition. One potential explanation, which will be further discussed in Chapter 4, could be that in the high memory load condition, the increase in cognitive load related to memory rules (6 items) may have caused participants to narrow their attention primarily to remembering the rules associated with the colour of the central target stimuli. This narrowing of focus might have led them to disregard the flankers around it, potentially resulting in the absence of a congruency effect in high memory load condition.

Concerning interaction effects, they were only evident in two specific cases. Firstly, in the Flanker task, an interaction was observed between working memory and interference control, specifically in relation to reaction time. Secondly, interaction within the Spatial Conflict condition between working memory and response inhibition was observed in accuracy. Hence, once again, similar to Study 1, a consistent interaction between core components of executive function was not observed. In the two cases where it did appear, it was over-additive in the first case and under-additive in the second case.

In summary, in Study 2, where the main effects were stronger following modifications, a meaningful interaction between core components of EF was once again absent. This finding aligns with the study by Jarrold et al. (2023), which suggests a lack of interaction between these components, contrary to the notion of competition for shared limited cognitive capacity in an over-additive manner as predicted by Roberts and Pennington's (1996) account. These findings support the idea that these components operate independently of each other. A more detailed discussion on this topic will be presented in the final chapter.

Moreover, similar to Study 1, Bayesian correlation and Bayesian linear regression analyses in Study 2 also revealed an absence of a meaningful correlation between task performance and traits associated with ASC (and ADHD), as assessed by the CATI and ASRS, respectively. However, it is crucial to note that there was strong evidence supporting a meaningful correlation between ASC and ADHD traits, affirming the validity of these measures (further discussed in Chapter four).

Nevertheless, it is important to mention that no meaningful correlation was found between CATI scores and the measure of weak central coherence, which was intended to validate the CATI. This lack of correlation may be attributed to potential validity issues with the central coherence task itself.

Potential hypotheses for further exploration encompass the possibility of a genuine absence of correlation between ASC/ADHD traits and executive functioning, potential sensitivity limitations in the novel tasks used, and the sensitivity of ASC and ADHD trait measures. These hypotheses will be discussed in greater detail in Chapter 4.

4 Chapter Four (Conclusion)

4.1 Introduction

This thesis aimed to concurrently measure the core components of executive function, encompassing both working memory and inhibitory control. In earlier research, the assessment of these core components of executive function often entailed distinct tasks, each targeting either working memory or inhibitory control individually. However, that approach carries certain limitations, including being time-consuming, vulnerable to task-related variations, and more importantly, lacking process purity. Specifically, the working memory tasks employed usually tend to encompass elements of inhibitory control and similarly, inhibitory control tasks often contain embedded working memory aspects.

Additionally, a secondary aim was to investigate potential interactions between these core executive function components. This exploration was prompted by the varying perspectives within current theories of executive function, which differ on whether executive function is a unitary construct with interactive components (e.g., Zelazo et al., 2003) or a fractionated construct with additive components (e.g., Diamond, 2006).

Consequently, the key purpose of this study was to measure these core components systematically and concurrently within a unified framework. This approach aimed to overcome the limitations associated with separate task utilization, enabling a more systematic evaluation of working memory and inhibitory control without the complications of task related variance. This design also improves efficiency and provides the chance to explore potential interactions between executive function components within a single comprehensive paradigm.

Another key goal of this thesis was to investigate the correlation between executive function (evaluated using this single paradigm) and autistic traits in the general population. This research extends beyond the well-established executive function difficulties commonly found in individuals diagnosed with autism (e.g., Christ et al., 2007; Geurts et al., 2004; Joseph et al., 2005; Luna et al., 2007; Steele et al., 2007; Tonizzi et al., 2022; Williams et al., 2005) to explore executive function in individuals with varying degrees of autistic traits. Despite a growing body of research, the impact of subthreshold autism traits on executive control remains uncertain. This goal has the potential to enhance our understanding of neurodiversity.

Considering these goals, the primary research questions were as follows:

1. Can the main effects of the core components of executive function (working memory and inhibitory control) be extracted when assessing them simultaneously?
2. Are these core components dependent on or independent of each other?
3. Is there any meaningful correlation between task performance and ASC traits in the general population?

The results addressing these questions will be presented in three separate sections, corresponding to each question.

4.2 Section One: Main Effects of Core Executive Function Components

This thesis consisted of two studies. The second study was a follow up and improved version of the first study, aiming at addressing issues identified in the initial research. Each of these two studies employed a novel single paradigm (a battery) that incorporated two distinct tasks to simultaneously measure core components of executive function. Specifically, in both studies, a modified version of the Flanker task was used to evaluate working memory and interference control simultaneously. Additionally, a modified iteration of the Spatial Conflict task was employed to assess working memory and response inhibition concurrently. Importantly, in both studies, these two tasks shared a highly similar structure enabling a direct and meaningful comparison between them.

The term "modified" was applied to both the Flanker task and the Spatial Conflict task due to the introduction of memory load. Additionally, to align the structure of the Spatial Conflict task with the Flanker task, distractors were added to the former. Specifically, in the Spatial Conflict task, the central-coloured stimuli were presented at either the right edge or left edge of the row, accompanied by a sequence of four grey distractor airplanes. One of the main differences between the two studies' task structures was related to the orientation of the central stimuli in the flanker task. In Study 1, the central stimulus was oriented to the right or left, aligned with the flankers around it. Conversely, in Study 2, the central stimuli were in an upright position (the reason for this change in the central stimuli's orientation within the flanker task will be explained later).

Both the modified Flanker task and the modified Spatial Conflict task encompassed two memory load conditions: low memory and high memory and within each condition, there were two trial types including congruent and incongruent trials. The memory load manipulation involved changing the complexity of response rules in each condition. More specifically, in Study 1, during low memory condition, participants were tasked with learning four rules that could be grouped into pairs and in high memory load condition, participants were required to remember four distinct and non-groupable rules. Furthermore, in Study 2, participants in the low memory condition were required to learn six rules that could be grouped into three pairs and in the high memory load condition, participants needed to remember six different and non-groupable rules. The rationale for the increase in the number of memorized items from four in Study 1 to six in Study 2 will be explained later in this chapter.

Additionally, interference control in the Flanker task was manipulated by changing the direction of the flankers/ all stimuli to be either incongruent or congruent with the correct response key. In Study 1, all stimuli, including the central one, were oriented either congruently or incongruently with the correct response key's direction and in Study 2, the flankers surrounding the central upright stimulus were aligned either congruently or incongruently with the correct response key's direction.

Furthermore, response inhibition in the Spatial Conflict task was manipulated by altering the presentation location of the target stimulus, which was either congruent or incongruent with the response key in both studies.

By using these innovative tasks, this project aimed to explore the potential for obtaining working memory effect and interference control effects by concurrently assessing them through the modified version of the Flanker task. Furthermore, it sought to investigate the possibility of observing main effects of working memory and response inhibition by simultaneously measuring them using the modified Spatial Conflict task. To do that a series of Bayesian ANOVAs were conducted, and a summarized overview of their outcomes is available in Table 4.1 and Table 4.2.

According to the pre-registered hypotheses for both studies, the thesis expected to find main effects of working memory and interference control using the modified Flanker task. Additionally, it was hypothesized that main effects of working memory and response inhibition would be observed by simultaneously assessing them through a modified Spatial Conflict task.

Table 4-1. A summary of Bayesian ANOVA outcomes evaluating main effects and interactions of core executive function components across both studies in the Flanker task

Flanker task	Study 1			Study 2		
	Memory Effect	Congruency Effect	Memory × Inhibition	Memory Effect	Congruency Effect	Memory × Inhibition
Reaction time	✓	✓	✕	✓	Only in low memory condition	✓
Accuracy	Limited evidence only in congruent trials	Only in low memory condition	✓	✓	✕	✕

In relation to the main effects and according to the findings presented in Table 4.1, there was strong evidence supporting both memory and congruency effects in terms of reaction time in the Flanker task in Study 1. In Study 2, two modifications were introduced to the Flanker task. Firstly, the number of items participants needed to memorize was increased (related to memory load). Secondly, and as already noted, the direction of the central stimulus was altered. Although a meaningful congruency effect was detected in Study 1, further investigation was necessary to confirm whether the effect was a genuine Flanker effect or influenced by the central stimuli's direction. As a result, in Study 2, the orientation of the central stimuli was changed to an upright position. Following this change (and as shown in Table 4.1), although strong evidence for the memory effect persisted, the congruency effect was exclusively observed in the low memory condition. Indeed, in the low memory condition, changing the position of the central stimuli did not lead to a noticeable difference in the size of the congruency effect. More specifically, in Study 1, for low memory congruent trials, the mean reaction time (RT) was 487 ms, while for low memory incongruent trials, it was 502 ms. This resulted in a congruency effect of 15 ms in Study 1 (incongruent RT minus congruent RT). In study 2, slight variations were observed. The mean RT for low memory congruent trials in Study 2 was 549 ms and for low memory incongruent trials, it was 559 ms. Thus, in Study 2, the congruency effect was 10 ms. Therefore, this congruency effect remained notably small in both studies.

However, these modifications to Study 2 resulted in the absence of evidence for the congruency effect in high memory load conditions. One possible explanation for this outcome could be the increase in the number of items that needed to be memorized, from 4 in Study 1 to 6 in Study 2. This increase in memory load might have caused participants to prioritize memorizing the rules associated with the central stimuli, possibly leading to less attention being allocated to the direction of the flankers surrounding them. This potentially clarifies why the congruency effect was observed in task one where the memory rules were easier, and also in low memory condition of task two, where the rules could be grouped in 3 pairs, but not in the high memory condition of task two, meaning that attention tends to narrow or become more focused when cognitive load increases. This is in line with Lavie's load theory of attention (Lavie, 1995; 2005) which suggests that awareness will be restricted to the content of focused attention when the attended information involves high perceptual load, however, distractors will intrude upon awareness in conditions of low load. According to load theory, perceptual processing has limited capacity but proceeds automatically in an involuntary, mandatory manner on all information within its capacity. It follows, therefore, in tasks requiring substantial information processing, like those with high perceptual load, that attention's capacity is completely utilized by the task at hand, leaving no room for the perception of unattended information. Conversely, in low perceptual load tasks, since perception cannot be voluntarily stopped, spare processing capacity spills over, causing the unintended perception of irrelevant information that individuals had intended to ignore (Lavie et al., 2014). Hence, a high cognitive load in task two (particularly in the high memory load condition) might have made participants focus on remembering memory rules related to the central stimuli resulting in them ignoring distractions around it (reducing the congruency effect). However, there may be limitations to this explanation. As discussed later in this chapter, we observed main effects of both memory and congruency in the reaction time data of the Spatial Conflict task. This raises questions about why these main effects were observed in the Spatial Conflict task reaction time but not in the Flanker task reaction time. Potential explanations for this inconsistency will be addressed in later discussions related to the results of the Spatial Conflict task.

Considering the findings for accuracy on the Flanker task, as summarised by Table 4.1, Study 1 displayed strong evidence supporting the congruency effect, but exclusively in the low memory condition. However, only slight evidence was observed for the memory effect and only in congruent trials. Furthermore, Study 2 showed a strong memory effect but no meaningful evidence for the congruency effect.

One possible reason for the failure to observe meaningful main effects of core executive function components on Flanker task accuracy could be that accuracy might not be the most suitable measure for this task compared to reaction time. Indeed, in relatively simple tasks such as the Flanker task, where the cognitive demands are not very high, accuracy may not be as informative as reaction time in some contexts. This task is mainly concerned with speed of response, as a result, there are often very few errors in performance, although accuracy is often measured as a dependent variable (McMorris, 2016). Furthermore, in the novel and modified versions of the Flanker task used in both studies of this thesis, despite the addition of memory load that increased task difficulty, participants achieved a remarkably high average accuracy. Specifically, in Study 1, it was around 90% (90.61%) and in Study 2, the accuracy was almost 80% (78.25%).

Table 4.2 presents the results of both studies for the Spatial Conflict task, summarising the main effects and interactions of core executive function components (interactions will be discussed in the second section).

Table 4-2. A summary of Bayesian ANOVA outcomes evaluating main effects and interactions of core executive function components across both studies in the Spatial Conflict task

Spatial Conflict task	Study 1			Study 2		
	Memory Effect	Congruency Effect	Memory × Inhibition	Memory Effect	Congruency Effect	Memory × Inhibition
Reaction time	Moderate evidence only in incongruent trials	✓	✓	✓	✓	✗
Accuracy	✗	✓	✗	Only in congruent trials	✓	✓

Regarding the main effects in the Spatial Conflict task in Study one, summarised in Table 4.2, strong evidence for the congruency effect was observed in the reaction time data. However, for the memory effect, moderate evidence was only present on incongruent trials. To enhance the likelihood of obtaining a memory effect in the Spatial Conflict task in the second study, two strategies were implemented. Firstly, similar to the approach in the Flanker task, the Spatial

Conflict task in Study 2 required participants to memorize an increased number of rules (increasing from four rules in task one to six rules in task two). Secondly, in Study 2, the participants were divided into two groups: half started the battery with the Flanker task, while the other half commenced with the Spatial Conflict task. This differed from Study 1, where all participants began with the Flanker task. This modification stemmed from the observation that memory load effects were present in the reaction time data of the Flanker task in Study 1 but were not evident in the Spatial Conflict task of that study. Hence, it was hypothesized that this inconsistency might be connected to the tasks' order. More specifically, due to the limitation in number of obvious available colours, certain colours used in the Flanker task were reused in the Spatial Conflict task (with their positions unchanged). This situation, in Study 1, might have led participants to carry over memorization from the first task (the Flanker task) to the second task (the Spatial Conflict task): a form of learning. Consequently, the absence of a memory effect in the Spatial Conflict task could be due to this carryover effect.

Taking these two modifications into account, the main effect of memory load in the Spatial Conflict task was effectively captured in the second study (in reaction time data). Additionally, the strong evidence for the congruency effect remained consistently evident.

It is important to note that in discussing the results from the second study's Flanker task (see earlier in the chapter), a hypothesis was provided to explain the absence of evidence for the congruency effect (in reaction times) during high memory conditions relating to Lavie's load theory. According to this theory, as memory load increases, participants narrow their attention to focus on memorizing rules tied to the central stimuli, ignoring surrounding distractors due to high cognitive load. The potential question that then arises is: why were both memory and congruency effects successfully detected in the Spatial Conflict task? A possible explanation for this can be found in the design of the tasks. In the Flanker task, the target-coloured airplane that participants had to base their responses on, was consistently placed in the central position. This arrangement makes focusing on the central target and ignoring the surrounding distractors possible. However, in the Spatial Conflict task, the target-coloured stimuli appeared randomly on either the right or left of the screen. Participants therefore had to focus not only on the memory rules but also on the target's position (congruent or incongruent with the response key) to respond correctly. This requirement makes it difficult (or impossible) to narrow attention solely to memory rules. Instead, participants had to distribute their attention between rules related to the target and its location (the congruency effect). This dual attention demand likely explains the successful observation of both memory and congruency effects in the Spatial Conflict task in Study 2.

As shown in Table 4.2, in Study 1, accuracy data showed a clear congruency effect in the Spatial Conflict task, without their being evidence for a memory effect. In Study 2, implementing the aforementioned changes led to the persistence of the congruency effect. However, evidence for the memory effect was only observed on congruent trials. This could be due to participants' attentional focus, specifically, in congruent trials, where the target stimuli’s location was aligned with the response key; participants could have directed their attention to the memory rules linked with the stimuli, possibly enhancing the memory effect. In incongruent trials, where the target stimuli’s location was positioned opposite to the response key, attention might have been split between memory rules and the task's demand to respond to incongruent stimuli. This division could have weakened the memory effect's strength in incongruent trials.

However, a question arises: why did this occur exclusively in accuracy and not in reaction time, where both memory and congruency effects were obtained? The difference might be related to the distinct cognitive demands of each measure, specifically, accuracy emphasizes decision-making, while reaction time involves cognitive processing and decision speed, facilitating simultaneous effects.

In terms of practical considerations of these novel tasks, it can be noted that, particularly in Study 2, that modifications to the tasks enabled the successful extraction of key executive function effects in reaction time data. Specifically, working memory and response inhibition effects were successfully extracted in the Spatial Conflict task, while the Flanker task successfully captured working memory and congruency effects (though limited to the low memory condition). These outcomes demonstrate the novel tasks' sensitivity in capturing core aspects of executive function demands. Furthermore, due to its unique design that manipulates memory load and inhibition systematically, this approach has the potential to purely measure working memory and two distinct types of inhibition. Moreover, this design creates opportunities to investigate how these components interact and influence each other. However, there remains potential for enhancing the task design, particularly regarding the Flanker task, to increase the chance of observing congruency effect within high memory load trials as well. Possible strategies to achieve this will be discussed later in the section on future directions.

4.3 Section Two: Interplay between Core Components of Executive Function

Consistent with the results of Jarrold et al.'s (2023) research and aligned with the hypotheses preregistered for both studies, it was hypothesized that working memory and inhibitory control are independent components and do not exhibit any meaningful over-additive interactions. As discussed earlier in the introduction chapter of this thesis, according to Roberts and Pennington's (1996) account, potentially distinguishable executive functions of working memory and inhibition compete for a shared, limited-capacity pool of attentional resources. This predicts an over-additive interaction between working memory and inhibitory loads, with the effects of each factor becoming more pronounced as the demands of each increase and deplete this shared resource (Jarrold et al., 2023)

In this study, the novel task design facilitated an exploration into whether the demands of the mentioned components of tasks (across varying loads of working memory and inhibitory control) display an independent and additive character, or if they instead interact over-additively with each other.

In this thesis, concerning the Flanker task, as shown in Table 4.1, no meaningful interactions were found for reaction time in Study 1 or for accuracy in Study 2. However, meaningful interactions were observed in the accuracy data for Study 1 and in the reaction time data for Study 2. Regarding the interaction in the Spatial Conflict task (as summarized in Table 4.2), no meaningful interactions were observed between the core components of executive function in terms of accuracy in Study 1 or reaction time in Study 2. However, meaningful interactions were evident in the reaction time data for Study 1 and in the accuracy data for Study 2.

Therefore, interaction was not consistently observed. Moreover, out of the four instances where the interaction was observed, it was under-additive in three cases (Flanker task accuracy in Study 1, Spatial Conflict task accuracy in Study 1, and Spatial Conflict task reaction time in Study 2), with an over-additive interaction observed only in the Flanker task reaction time in Study 2.

In conclusion, as hypothesized in this thesis, the data presented here do not support any meaningful interactions or interplay among the core components of executive function in an over-additive manner, as predicted by Roberts and Pennington's 1996 account. Based on the thesis data, it can be concluded that two core components of executive function, namely working memory and the two types of inhibitory control, function independently. There appears to be no evidence of interaction or competition for limited executive function capacity.

4.4 Section Three: Correlation between Task Performance and ASC Traits

The thesis also aimed to explore potential correlations between task performance (measured by accuracy and reaction time) and autistic traits within the general population. It delves into the cognitive profiles of individuals with varying degrees of autistic traits, examining how subthreshold autism traits impact executive control. This extends beyond studying executive function in individuals diagnosed with ASC.

To assess autistic traits in the general population, in Study 1, the short form of the Autism Quotient (AQ-S) was employed. A series of Bayesian correlation analysis was conducted to examine the zero-order correlation between the following: a) Reaction times for congruent/incongruent trials in low/high memory conditions of each task and ASC traits, and b) Trial accuracy within each task's condition and ASC traits. This analysis aimed to uncover any correlations in relation to increasing inhibitory and memory load. In this thesis it was hypothesized that higher levels of ASC traits would align with poorer task performance as the memory and inhibitory load increase, resulting in slower reactions and lower accuracy. This means that as the levels of ASC traits increase, and as the demands on working memory and congruency also increase, the correlation between these factors becomes stronger. In other words, there should be a more noticeable link between ASC traits and task performance under higher working memory and inhibitory demands. However, according to the data from the first study, there was no evidence indicating an increase in meaningful correlation between ASC traits in the general population and task performance (slower reaction time and lower accuracy) as memory and inhibitory load increased.

Following that, a secondary analysis employed a series of partial correlations to extract memory load and inhibition load effects, aiming to investigate their connections with ASC traits more directly. Bayesian linear regression (partial correlation) examined the correlation between performance on incongruent trials and ASC traits controlling for performance on congruent trials (index of the congruency effect), revealing no meaningful correlation between the size of congruency effect and ASC trait in none of accuracy or reaction time. Additionally, high memory trial performance showed no meaningful correlation with ASC traits when controlling for low memory trials (index of memory effect) for both reaction time and accuracy.

Therefore, potential explanations were offered. Firstly, the actual existence of the relationship could be in question. Secondly, the AQ questionnaire's limited sensitivity might hinder observing accurate correlations. However, other studies that have examined the psychometric properties of AQ-S have supported its good validity and reliability (Hurst et al., 2007; Kurita et al., 2005; Lau et al., 2013), and reported its relative success in capturing some core dimensions of individual differences in traits associated with ASC. Furthermore, the reliability of the AQ-S questionnaire was assessed in our current study and found to be satisfactory, with a total McDonald's ω coefficient of 0.855. Lastly, prior research on executive function difficulties in ASC may have unintentionally focused more on ADHD-related traits than pure autistic traits. Considering ASC and ADHD comorbidity, coupled with the known executive difficulties in ADHD, observed differences in executive function findings among ASC individuals (in previous research) could stem from concurrent ADHD symptoms.

To address these potential issues, in the second study, both ADHD and autistic traits were examined. Autistic traits were comprehensively evaluated using the Comprehensive Autistic Trait Inventory (CATI, English, 2021), which covers a broad spectrum of traits across various dimensions. ADHD traits were measured using the Adult ADHD Self-Report Scale (ASRS, Kessler et al., 2005). Furthermore, given the established connection between weak central coherence and ASC in prior research (e.g., Happé et al., 2001), a central coherence task was utilized to validate the CATI measure of autistic traits.

Continuing in line with Study 1’s methodology, in Study 2, a series of Bayesian correlation analyses were employed to investigate zero-order correlations: a) between reaction times for congruent/incongruent trials in low/high memory conditions for each task and ASC/ADHD traits, and b) trial accuracy within each task's condition and ASC/ADHD traits. However, in the second study, there was also no significant evidence of an increasing correlation between task performance (higher reaction times and lower accuracy) and ASC/ADHD traits in the general population as memory and inhibitory load increased. Consequently, as in Study 1, a subsequent step involved a secondary analysis utilizing partial correlations to extract memory load and inhibition load effects, aiming to explore their associations with ASC and ADHD traits. Employing Bayesian linear regression (partial correlation), the analysis investigated the link between incongruent trial performance and ASC/ADHD traits, controlling for performance on congruent trials (index of congruency effect), but no meaningful correlation emerged between the size of congruency effect and ASC/ADHD traits for either accuracy or reaction time. Similarly, high memory trial performance exhibited no meaningful correlation with ASC/ADHD traits when controlling for performance on low memory trials (index of memory effect), in terms of both reaction time and accuracy.

These findings could be influenced by various factors, and one possible explanation for this lack of correlation could be related to how sensitive the CATI (Comprehensive Autism Trait Inventory) and ASRS (Adult ADHD Self-Report Scale) questionnaires are in identifying traits associated with autism and ADHD within the general population. As previously mentioned, a central coherence task (an online embedded figures test) was used to validate the CATI. However, Bayesian correlation results indicated no significant correlation between CATI scores and performance on this task, increasing the concerns about the CATI's validity further. Nevertheless, it is crucial to highlight that despite sensitivity concerns, prior research has established the reliability of both measures (CATI and ASRS). Moreover, in this study, a Bayesian correlation analysis was applied to the scores derived from the CATI and ASRS questionnaires. This analysis yielded strong evidence of a meaningful correlation between these two measures. This finding not only emphasizes the strength of the relationship between these questionnaires but also highlights the sensitivity of these measures when it comes to evaluating traits linked to autism and ADHD. This correlation indicates that these two questionnaires reliably capture shared traits and exhibit consistent patterns of measurement. Thus, the absence of correlation between the CATI and the online embedded figures test could potentially be related to the validity of the online embedded figures test rather than the CATI.

Another potential explanation could be the sensitivity of the novel tasks used in this thesis in measuring core executive function components (working memory and inhibitory control). However, in Study 2, task modifications allowed for the successfully extraction of these effects in the reaction time data. More specifically, working memory and response inhibition effects were successfully extracted in the Spatial Conflict task, and in the Flanker task working memory and congruency effects (although only for low memory trials) were also obtained. These findings illustrate that the novel tasks are indeed sensitive to capturing core components of executive function demands. However, other possible explanation for this lack of correlation with trait questionnaire measures could be that the tasks used in this thesis tap into specific aspects of executive function that are distinct from the traits assessed by the CATI and ASRS questionnaires. More specifically, while these questionnaires focus on broader traits related to autism and ADHD, the tasks could demand narrower and more specialized executive function skills. This might explain why there is no connection between task performance and traits of ASC and ADHD.

One other possible explanation might be that, according to Hedge et al. (2018), individual differences in cognitive tasks, even well-established ones, might not be reliable for studying correlations between cognitive performance and other factors. This is because these tasks are designed to produce consistent results across people, but this resulting low variation among individuals makes it difficult to find meaningful correlations. More specifically, when everyone performs similarly on a task, it becomes hard to measure how it relates to other factors. Therefore, the tasks utilized in this thesis may not necessarily reflect correlations with ASC and ADHD traits as the original flanker tasks and the specialized conflict tasks are primarily designed to yield consistent experimental outcomes rather than capture individual differences.

4.5 Future directions

To address potential methodological limitations, several strategic approaches can be considered for future research. Firstly, focusing on improving task design, particularly in the case of the Flanker task, could be beneficial. An effective approach could involve adjusting the colour contrast between the central airplane and the surrounding flankers. In the present design, where the central airplane is coloured and the flankers are grey, participants may primarily focus on the memory rules associated with the coloured central airplane, potentially overlooking the grey flankers. This tendency might be even higher under the high memory load condition, where the participant's limited cognitive capacity is directed towards recalling complicated memory rules. However, by reducing the contrast and introducing colour variation to both the central airplane and the flankers (using distinct tones of the same colour, such as employing a lighter or darker blue for flankers when the central airplane is blue) participants might be prompted to divide their attention across both memory and congruency aspects concurrently. This adjustment has the potential to increase the task's sensitivity. Moreover, through refining task design and enhancing the chances of obtaining stronger main effects, future research can delve into potential interactions between the core components of executive function to confirm and validate the absence of interaction between core components of executive function.

Secondly, the inclusion of individuals formally diagnosed with ASC (or ADHD), beyond considering ASC (or ADHD) traits in the general population alone, could increase the chances of observing a correlation between ASC traits and task performance. To enhance the likelihood of detecting differences in task performance related to ASC traits, one possibility is to increase the spread of autism traits by considering employing an extreme group design. This approach involves studying individuals who are formally diagnosed with ASC and comparing their task performance to those without the diagnosis. This approach can increase our understanding of how the correlation between ASC traits and task performance can be heightened when memory and inhibitory load is increased.

4.6 Conclusion

In summary, this thesis consisted of two studies, each involving 100 participants aged between 18-25, with the second study building upon the first. Both studies employed a single paradigm featuring two tasks designed to simultaneously assess working memory and specific inhibitory control processes. The modified Flanker task measured working memory and interference control, while the modified Spatial Conflict task measured working memory and response inhibition. The thesis aimed to examine the main effects of memory load and inhibitory load in each task when assessed concurrently, investigate potential over-additive interactions between these EF's components, and explore the correlation between ASC traits and task performance. According to the results from Bayesian ANOVAs, in Study 1, meaningful main effects of working memory and inhibitory control were observed in the Flanker task, primarily in reaction time. In the Spatial Conflict task, the main effect of congruency was exhibited in reaction time, while there was only moderate evidence for the memory effect, primarily in incongruent trials. Accuracy showed no memory effect but a strong congruency effect. In Study 2, introduced modifications revealed significant progress. In the Spatial Conflict task, memory and congruency effects on reaction time were observed, with a meaningful congruency effect in accuracy. However, only moderate evidence for a memory effect, particularly in congruent trials, was observed in accuracy. In the Flanker task, a memory effect was observed in both reaction time and accuracy. However, there was no evidence of a congruency effect in accuracy, and the congruency effect in reaction time was only evident in the low memory condition. Furthermore, as hypothesized, interactions between executive function components were not observed, and the data did not support over-additive interactions. Additionally, in both studies, Bayesian linear regression and Bayesian correlation analyses found no meaningful evidence of an increasing correlation between task performance and ASC traits with increasing memory and inhibitory load. These tasks hold potential for future research in concurrently measuring core executive function components.

5 References

Adams, N. C., & Jarrold, C. (2012). Inhibition in autism: Children with autism have difficulty inhibiting irrelevant distractors but not prepotent responses. *Journal of autism and developmental disorders*, *42*, 1052-1063.

Adler, L. A., Spencer, T., Faraone, S. V., Kessler, R. C., Howes, M. J., Biederman, J., & Secnik, K. (2006). Validity of pilot Adult ADHD Self- Report Scale (ASRS) to Rate Adult ADHD symptoms. Annals of Clinical Psychiatry: Official Journal of the American Academy of Clinical Psychiatrists, 18(3), 145–148. https://doi.org/10.1080/10401230600801077

Alderson, R. M., Rapport, M. D., Hudec, K. L., Sarver, D. E., & Kofler, M. J. (2010). Competing core processes in attention-deficit/hyperactivity disorder (ADHD): do working memory deficiencies underlie behavioral inhibition deficits?. *Journal of abnormal child psychology*, *38*, 497-507.

American Psychiatric Association (2000). Diagnostic and Statistical Manual of Mental Disorders, 4th ed., Text Revision. Washington, DC: American Psychiatric Association. Pp. 85–93. OCLC 43483668.

Aron, A. R. (2011). From reactive to proactive and selective control: developing a richer model for stopping inappropriate responses. *Biological psychiatry*, *69*(12), e55-e68.

Astle, D. E., Holmes, J., Kievit, R., & Gathercole, S. E. (2022). Annual Research Review: The transdiagnostic revolution in neurodevelopmental disorders. *Journal of Child Psychology and Psychiatry*, *63*(4), 397-417.

Baddeley, A. (1992). Working memory. *Science*, *255*(5044), 556-559.

Barkley, R. A., Grodzinsky, G., & DuPaul, G. J. (1992). Frontal lobe functions in attention deficit disorder with and without hyperactivity: A review and research report. *Journal of abnormal child psychology*, *20*, 163-188.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high-functioning autism, malesand females, scientists and mathematicians. *Journal of autism and developmental disorders*, *31*, 5-17.

Bertelson, P. (1965). Serial choice reaction-time as a function of response versus signal-and-response repetition. *Nature*, *206*(4980), 217-218.

Bertelson, P. (1965). Serial choice reaction-time as a function of response versus signal-and-response repetition. Nature, 206(4980), 217-218.

Best, C. S., Moffat, V. J., Power, M. J., Owens, D. G., & Johnstone, E. C. (2008). The boundaries of the cognitive phenotype of autism: Theory of mind, central coherence and ambiguous figure perception in young people with autistic traits. *Journal of autism and developmental disorders*, *38*, 840-847.

Biederman, J., Petty, C. R., Fried, R., Doyle, A. E., Spencer, T., Seidman, L. J., ... & Faraone, S. V. (2007). Stability of executive function deficits into young adult years: a prospective longitudinal follow-up study of grown up males with ADHD. *Acta Psychiatrica Scandinavica*, *116*(2), 129-136.

Bölte, S., & Poustka, F. (2006). The broader cognitive phenotype of autism in parents: how specific is the tendency for local processing and executive dysfunction?. *Journal of Child Psychology and Psychiatry*, *47*(6), 639-645.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological review*, *108*(3), 624.

Burgess, P. W., Simons, J. S., Halligan, P. W., & Wade, D. T. (2005). 18 Theories of frontal lobe executive function: clinical applications. *The effectiveness of rehabilitation for cognitive deficits*, *211*.

Casey, B. J., Durston, S., & Fossella, J. A. (2001). Evidence for a mechanistic model of cognitive control. *Clinical Neuroscience Research*, *1*(4), 267-282.

Christ, S. E., Holt, D. D., White, D. A., & Green, L. (2007). Inhibitory control in children with autism spectrum disorder. *Journal of autism and developmental disorders*, *37*, 1155-1165.

Christ, S. E., Kanne, S. M., & Reiersen, A. M. (2010). Executive function in individuals with subthreshold autism traits. *Neuropsychology*, *24*(5), 590.

Christ, S. E., Kester, L. E., Bodner, K. E., & Miles, J. H. (2011). Evidence for selective inhibitory impairment in individuals with autism spectrum disorder. *Neuropsychology*, *25*(6), 690.

Collins, A., & Koechlin, E. (2012). Reasoning, learning, and creativity: frontal lobe function and human decision-making. *PLoS biology*, *10*(3), e1001293.

Constantino, J. N., & Todd, R. D. (2003). Autistic traits in the general population: a twin study. *Archives of general psychiatry*, *60*(5), 524-530.

Constantino, J. N., Gruber, C. P., Davis, S., Hayes, S., Passanante, N., & Przybeck, T. (2004). The factor structure of autistic traits. *Journal of Child Psychology and Psychiatry*, *45*(4), 719-726.

Corbett, B. A., & Constantine, L. J. (2006). Autism and attention deficit hyperactivity disorder: Assessing attention and response control with the integrated visual and auditory continuous performance test. *Child Neuropsychology*, *12*(4-5), 335-348.

Crosbie, J., Arnold, P., Paterson, A., Swanson, J., Dupuis, A., Li, X., ... & Schachar, R. J. (2013). Response inhibition and ADHD traits: correlates and heritability in a community sample. *Journal of abnormal child psychology*, *41*, 497-507.

Delorme, R., Goussé, V., Roy, I., Trandafir, A., Mathieu, F., Mouren-Siméoni, M. C., ... & Leboyer, M. (2007). Shared executive dysfunctions in unaffected relatives of patients with autism and obsessive-compulsive disorder. *European Psychiatry*, *22*(1), 32-38.

Diamond, A. (2006). The early development of executive functions. *Lifespan cognition: Mechanisms of change*, *210*, 70-95.

Diamond, A. (2013). Executive functions. *Annual review of psychology*, *64*, 135-168.

Diamond, A., Prevor, M. B., Callender, G., & Druin, D. P. (1997). Prefrontal cortex cognitive deficits in children treated early and continuously for PKU. *Monographs of the society for research in child development*, i-206.

Doebel, S., & Müller, U. (2023). The Future of Research on Executive Function and Its Development: An Introduction to the Special Issue. *Journal of Cognition and Development*, *24*(2), 161-171.

Duncan, J., & Owen, A. M. (2000). Common regions of the human frontal lobe recruited by diverse cognitive demands. *Trends in neurosciences*, *23*(10), 475-483.

English, M. C., Gignac, G. E., Visser, T. A., Whitehouse, A. J., Enns, J. T., & Maybery, M. T. (2021). The Comprehensive Autistic Trait Inventory (CATI): development and validation of a new measure of autistic traits in the general population. *Molecular Autism*, *12*(1), 1-23.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & psychophysics*, *16*(1), 143-149.

Espy, K. A. (2004). Using developmental, cognitive, and neuroscience approaches to understand executive control in young children. *Developmental neuropsychology*, *26*(1), 379-384.

Failla, M. D., Schwartz, K. L., Chaganti, S., Cutting, L. E., Landman, B. A., & Cascio, C. J. (2021). Using phecode analysis to characterize co-occurring medical conditions in autism spectrum disorder. *Autism*, *25*(3), 800-811.

Ferraro, F. R., Hansen, R., & Deling, L. (2018). Executive Function Index (EFI) performance in nonclinical individuals with high levels of autistic traits. *Applied Neuropsychology: Adult*, *25*(2), 149-154.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variable analysis. *Journal of experimental psychology: General*, *133*(1), 101.

Frith, U. (2003). *Autism: Explaining the enigma*. Blackwell publishing.

Frith, U., & Happé, F. (1994). Autism: Beyond “theory of mind”. *Cognition*, *50*(1-3), 115-132.

Gandolfi, E., Viterbori, P., Traverso, L., & Usai, M. C. (2014). Inhibitory processes in toddlers: a latent-variable approach. *Frontiers in psychology*, *5*, 381.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: a review using an integrative framework. *Psychological bulletin*, *134*(1), 31.

Geurts, H. M., Corbett, B., & Solomon, M. (2009). The paradox of cognitive flexibility in autism. *Trends in cognitive sciences*, *13*(2), 74-82.

Geurts, H. M., van den Bergh, S. F., & Ruzzano, L. (2014). Prepotent response inhibition and interference control in autism spectrum disorders: Two meta-analyses. Autism Research, 7(4), 407-420.

Gokcen, S., Bora, E., Erermis, S., Kesikci, H., & Aydin, C. (2009). Theory of mind and verbal working memory deficits in parents of autistic children. *Psychiatry Research*, *166*(1), 46-53.

Grafman, J., & Litvan, I. (1999). Importance of deficits in executive functions. *The Lancet*, *354*(9194), 1921-1923.

Habib, A., Harris, L., Pollick, F., & Melville, C. (2019). A meta-analysis of working memory in individuals with autism spectrum disorders. *PloS one*, *14*(4), e0216198.

Happé, F., & Frith, U. (2006). The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *Journal of autism and developmental disorders*, *36*(1), 5-25.

Happé, F., Frith, U., & Briskman, J. (2001). Exploring the cognitive phenotype of autism: weak "central coherence" in parents and siblings of children with autism: I. Experimental tests. *The Journal of Child Psychology and Psychiatry and Allied Disciplines*, *42*(3), 299-307.

Hedge, C., Powell, G., & Sumner, P. (2018). The reliability paradox: Why robust cognitive tasks do not produce reliable individual differences. *Behavior research methods, 50*, 1166-1186.

Hoekstra, R. A., Vinkhuyzen, A. A., Wheelwright, S., Bartels, M., Boomsma, D. I., Baron-Cohen, S., ... & Van Der Sluis, S. (2011). The construction and validation of an abridged version of the autism-spectrum quotient (AQ-Short). *Journal of autism and developmental disorders*, *41*, 589-596.

Holtmann, M., Bölte, S., & Poustka, F. (2007). Attention deficit hyperactivity disorder symptoms in pervasive developmental disorders: association with autistic behavior domains and coexisting psychopathology. *Psychopathology*, *40*(3), 172-177.

Howard, S. J., Johnson, J., & Pascual-Leone, J. (2014). Clarifying inhibitory control: Diversity and development of attentional inhibition. *Cognitive Development*, *31*, 1-21.

Hudziak, J. J., Achenbach, T. M., Althoff, R. R., & Pine, D. S. (2007). A dimensional approach to developmental psychopathology. *International journal of methods in psychiatric research*, *16*(S1), S16-S23.

Hughes, C., Leboyer, M., & Bouvard, M. (1997). Executive function in parents of children with autism. *Psychological medicine*, *27*(1), 209-220.

Hughes, C., Plumet, M. H., & Leboyer, M. (1999). Towards a cognitive phenotype for autism: increased prevalence of executive dysfunction and superior spatial span amongst siblings of children with autism. *Journal of Child Psychology and Psychiatry*, *40*(5), 705-718.

Huizinga, M., Dolan, C. V., & Van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia*, *44*(11), 2017-2036.

Hurley, R. S., Losh, M., Parlier, M., Reznick, J. S., & Piven, J. (2007). The broad autism phenotype questionnaire. *Journal of autism and developmental disorders*, *37*, 1679-1690.

Hurst, R. M., Mitchell, J. T., Kimbrel, N. A., Kwapil, T. K., & Nelson-Gray, R. O. (2007). Examination of the reliability and factor structure of the Autism Spectrum Quotient (AQ) in a non-clinical sample. *Personality and Individual Differences*, *43*(7), 1938-1949.

Jarrold, C., Li, K., & Wang, T. (2023). A novel approach to measuring the developmental interactions between working memory and inhibitory control in young children. *Cognitive Development*, *67*, 101362.

JASP Team. (2023). *Advancements in Statistical Software*. [FAQ - JASP - Free and User-Friendly Statistical Software (jasp-stats.org)]

Jeffreys, H. (1961). Theory of probability (3rd edt.) oxford university press. *MR0187257*, *432*.

Joseph, R. M., McGrath, L. M., & Tager-Flusberg, H. (2005). Executive dysfunction and its relation to language ability in verbal school-age children with autism. *Developmental neuropsychology*, *27*(3), 361-378.

Karr, J. E., Areshenkoff, C. N., Rast, P., Hofer, S. M., Iverson, G. L., & Garcia-Barrera, M. A. (2018). The unity and diversity of executive functions: A systematic review and re-analysis of latent variable studies. *Psychological bulletin*, *144*(11), 1147.

Kenworthy, L., Case, L., Harms, M. B., Martin, A., & Wallace, G. L. (2010). Adaptive behavior ratings correlate with symptomatology and IQ among individuals with high-functioning autism spectrum disorders. *Journal of autism and developmental disorders*, *40*, 416-423.

Kenworthy, L., Yerys, B. E., Anthony, L. G., & Wallace, G. L. (2008). Understanding executive control in autism spectrum disorders in the lab and in the real world. *Neuropsychology review*, *18*, 320-338.

Kessler, R. C., Adler, L., Ames, M., Demler, O., Faraone, S., Hiripi, E. V. A., … & Walters, E. E. (2005). The World Health Organization Adult ADHD Self-Report Scale (ASRS): a short screening scale for use in the general population. *Psychological medicine*, *35*(2), 245-256.

Kessler, R. C., Andrews, G., Mroczek, D., Ustun, B., & Wittchen, H. U. (1998). The World Health Organization composite international diagnostic interview short-form (CIDI-SF). *International journal of methods in psychiatric research*, *7*(4), 171-185.

Keysers, C., Gazzola, V., & Wagenmakers, E. J. (2020). Using Bayes factor hypothesis testing in neuroscience to establish evidence of absence. *Nature neuroscience*, *23*(7), 788-799.

Kirchner, W. K. (1958). Age differences in short-term retention of rapidly changing information. *Journal of experimental psychology*, *55*(4), 352.

Kuenssberg, R., Murray, A. L., Booth, T., & McKenzie, K. (2014). Structural validation of the abridged Autism Spectrum Quotient–Short Form in a clinical sample of people with autism spectrum disorders. *Autism*, *18*(2), 69-75.

Kurita, H., Koyama, T., & Osada, H. (2005). Autism-Spectrum Quotient–Japanese version and its short forms for screening normally intelligent persons with pervasive developmental disorders. *Psychiatry and clinical neurosciences*, *59*(4), 490-496.

Lau, W. Y. P., Gau, S. S. F., Chiu, Y. N., Wu, Y. Y., Chou, W. J., Liu, S. K., & Chou, M. C. (2013). Psychometric properties of the Chinese version of the Autism Spectrum Quotient (AQ). *Research in developmental disabilities*, *34*(1), 294-305.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human perception and performance*, *21*(3), 451.

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in cognitive sciences*, *9*(2), 75-82.

Lavie, N., Beck, D. M., & Konstantinou, N. (2014). Blinded by the load: attention, awareness and the role of perceptual load. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1641), 20130205.

Lehto, J. E., Juujärvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British journal of developmental psychology*, *21*(1), 59-80.

Leitner, Y. (2014). The co-occurrence of autism and attention deficit hyperactivity disorder in children–what do we know?. *Frontiers in human neuroscience*, *8*, 268.

Leys, C., Ley, C., Klein, O., Bernard, P., & Licata, L. (2013). Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *Journal of experimental social psychology*, *49*(4), 764-766.

Lipszyc, J., & Schachar, R. (2010). Inhibitory control and psychopathology: a meta-analysis of studies using the stop signal task. *Journal of the International Neuropsychological Society*, *16*(6), 1064-1076.

Losh, M., Adolphs, R., Poe, M. D., Couture, S., Penn, D., Baranek, G. T., & Piven, J. (2009). Neuropsychological profile of autism and the broad autism phenotype. *Archives of general psychiatry*, *66*(5), 518-526.

Lu, C. H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic bulletin & review*, *2*, 174-207.

Luna, B., Doll, S. K., Hegedus, S. J., Minshew, N. J., & Sweeney, J. A. (2007). Maturation of executive function in autism. *Biological psychiatry*, *61*(4), 474-481.

Lunt, L., Bramham, J., Morris, R. G., Bullock, P. R., Selway, R. P., Xenitidis, K., & David, A. S. (2012). Prefrontal cortex dysfunction and 'Jumping to Conclusions': Bias or deficit?. *Journal of neuropsychology*, *6*(1), 65-78.

Martin, J., Hamshere, M. L., Stergiakouli, E., O'Donovan, M. C., & Thapar, A. (2014). Genetic risk for attention-deficit/hyperactivity disorder contributes to neurodevelopmental traits in the general population. *Biological psychiatry*, *76*(8), 664-671.

Martinussen, R., & Tannock, R. (2006). Working memory impairments in children with attention-deficit hyperactivity disorder with and without comorbid language learning disorders. *Journal of clinical and experimental neuropsychology*, *28*(7), 1073-1094.

McMorris, T. (2016). History of research into the acute exercise–cognition interaction: A cognitive psychology approach.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual review of neuroscience*, *24*(1), 167-202.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current directions in psychological science*, *21*(1), 8-14.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive psychology*, *41*(1), 49-100.

Mosconi, M. W., Kay, M., D'cruz, A. M., Seidenfeld, A., Guter, S., Stanford, L. D., & Sweeney, J. (2009). Impaired inhibitory control is associated with higher-order repetitive behaviors in autism spectrum disorders. *Psychological medicine*, *39*(9), 1559-1566.

Moses, M., Tiego, J., Demontis, D., Bragi Walters, G., Stefansson, H., Stefansson, K., ... & Bellgrove, M. A. (2022). Working memory and reaction time variability mediate the relationship between polygenic risk and ADHD traits in a general population sample. *Molecular Psychiatry*, *27*(12), 5028-5037.

Munakata, Y. (2001). Graded representations in behavioral dissociations. *Trends in cognitive sciences*, *5*(7), 309-315.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological bulletin*, *126*(2), 220.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In *Consciousness and self-regulation: Advances in research and theory volume 4* (pp. 1-18). Boston, MA: Springer US.

O'Brien, J. W., Dowell, L. R., Mostofsky, S. H., Denckla, M. B., & Mahone, E. M. (2010). Neuropsychological profile of executive function in girls with attention-deficit/hyperactivity disorder. *Archives of Clinical Neuropsychology*, *25*(7), 656-670.

Otterman, D. L., Koopman-Verhoeff, M. E., White, T. J., Tiemeier, H., Bolhuis, K., & Jansen, P. W. (2019). Executive functioning and neurodevelopmental disorders in early childhood: A prospective population-based study. *Child and adolescent psychiatry and mental health*, *13*, 1-12.

Ozonoff, S., & Strayer, D. L. (1997). Inhibitory function in nonretarded children with autism. *Journal of autism and developmental disorders*, *27*, 59-77.

Ozonoff, S., & Strayer, D. L. (2001). Further evidence of intact working memory in autism. *Journal of autism and developmental disorders*, *31*, 257-263.

Ozonoff, S., Rogers, S. J., Farnham, J. M., & Pennington, B. F. (1993). Can standard measures identify subclinical markers of autism?. *Journal of autism and developmental disorders*, *23*(3), 429-441.

Parenti, I., Rabaneda, L. G., Schoen, H., & Novarino, G. (2020). Neurodevelopmental disorders: from genetics to functional pathways. *Trends in Neurosciences*, *43*(8), 608-621.

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of child psychology and psychiatry*, *37*(1), 51-87.

Piven, J., Palmer, P., Jacobi, D., Childress, D., & Arndt, S. (1997). Broader autism phenotype: evidence from a family history study of multiple-incidence autism families. *American Journal of Psychiatry*, *154*(2), 185-190.

Rajendran, K., Rindskopf, D., O'Neill, S., Marks, D. J., Nomura, Y., & Halperin, J. M. (2013). Neuropsychological functioning and severity of ADHD in early childhood: a four-year cross-lagged study. *Journal of abnormal psychology*, *122*(4), 1179.

Rey-Mermet, A., Gade, M., & Oberauer, K. (2018). Should we stop thinking about inhibition? Searching for individual and age differences in inhibition ability. *Journal of Experimental Psychology:* Learning, Memory, and Cognition, 44(4), 501.

Roberts Jr, R. J., & Pennington, B. F. (1996). An interactive framework for examining prefrontal cognitive processes. *Developmental neuropsychology*, *12*(1), 105-126.

Ronald, A., Edelson, L. R., Asherson, P., & Saudino, K. J. (2010). Exploring the relationship between autistic-like traits and ADHD behaviors in early childhood: findings from a community twin study of 2-year-olds. *Journal of abnormal child psychology*, *38*, 185-196.

Schreiber, J. E., Possin, K. L., Girard, J. M., & Rey-Casserly, C. (2014). Executive function in children with attention deficit/hyperactivity disorder: The NIH EXAMINER battery. *Journal of the International Neuropsychological Society*, *20*(1), 41-51.

Sergeant, J. (2000). The cognitive-energetic model: an empirical approach to attention-deficit hyperactivity disorder. *Neuroscience & Biobehavioral Reviews*, *24*(1), 7-12.

Sergeant, J. A., Geurts, H., & Oosterlaan, J. (2002). How specific is a deficit of executive functioning for attention-deficit/hyperactivity disorder?. *Behavioural brain research*, *130*(1-2), 3-28.

Shallice, T., & Burgess, P. (1991). Higher-order cognitive impairments and frontal lobe lesions in man.

Shimoni, M. A., Engel-Yeger, B., & Tirosh, E. (2012). Executive dysfunctions among boys with Attention Deficit Hyperactivity Disorder (ADHD): Performance-based test and parents report. *Research in developmental disabilities*, *33*(3), 858-865.

Simon, J. R. (1969). Reactions toward the source of stimulation. *Journal of experimental psychology*, *81*(1), 174.

Simpson, A., & Carroll, D. J. (2018). Young children can overcome their weak inhibitory control, if they conceptualize a task in the right way. *Cognition*, *170*, 270-279.

Singh, V. (2021). *Embedded Figures Test Online Free Questions for Competitive Exams*. Exams book. https://www.examsbook.com/embedded-figures-test-online-free

Sinzig, J., Morsch, D., Bruning, N., Schmidt, M. H., & Lehmkuhl, G. (2008). Inhibition, flexibility, working memory and planning in autism spectrum disorders with and without comorbid ADHD-symptoms. *Child and adolescent psychiatry and mental health*, *2*(1), 1-12.

Smith, E. E., Jonides, J., & Koeppe, R. A. (1996). Dissociating verbal and spatial working memory using PET. *Cerebral cortex*, *6*(1), 11-20.

Smith, L., Hedge, C., & Jarrold, C. measure executive function in Down syndrome, with applications for early clinical diagnosis of dementia. American Journal on Intellectual and Developmental Disabilities, 124 (4), 354-373.

Solomon, M., Ozonoff, S. J., Cummings, N., & Carter, C. S. (2008). Cognitive control in autism spectrum disorders. *International Journal of Developmental Neuroscience*, *26*(2), 239-247.

Sonuga-Barke, E. J., Dalen, L., Daley, D., & Remington, B. (2002). Are planning, working memory, and inhibition associated with individual differences in preschool ADHD symptoms?. *Developmental neuropsychology*, *21*(3), 255-272.

Spiegel, J. A., Goodrich, J. M., Morris, B. M., Osborne, C. M., & Lonigan, C. J. (2021). Relations between executive functions and academic outcomes in elementary school children: A meta-analysis. *Psychological bulletin*, *147*(4), 329.

Stahl, C., Voss, A., Schmitz, F., Nuszbaum, M., Tüscher, O., Lieb, K., & Klauer, K. C. (2014). Behavioral components of impulsivity. *Journal of Experimental Psychology: General*, *143*(2), 850.

Steele, S. D., Minshew, N. J., Luna, B., & Sweeney, J. A. (2007). Spatial working memory deficits in autism. *Journal of autism and developmental disorders*, *37*, 605-612.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental psychology*, *18*(6), 643.

Sun, J., & Buys, N. (2012). Early executive function deficit in preterm children and its association with neurodevelopmental disorders in childhood: a literature review. *International journal of adolescent medicine and health*, *24*(4), 291-299.

Szatmari, P., Jones, M. B., Zwaigenbaum, L., & MacLean, J. E. (1998). Genetics of autism: overview and new directions. *Journal of autism and developmental disorders*, *28*, 351-368.

Toll, S. W., Van der Ven, S. H., Kroesbergen, E. H., & Van Luit, J. E. (2011). Executive functions as predictors of math learning disabilities. *Journal of learning disabilities*, *44*(6), 521-532.

Tonizzi, I., Giofre, D., & Usai, M. C. (2022). Inhibitory control in autism spectrum disorders: meta-analyses on indirect and direct measures. *Journal of Autism and Developmental Disorders*, *52*(11), 4949-4965.

Vahia, V. N. (2013). Diagnostic and statistical manual of mental disorders 5: A quick glance. *Indian journal of psychiatry*, *55*(3), 220.

Verté, S., Geurts, H. M., Roeyers, H., Oosterlaan, J., & Sergeant, J. A. (2005). Executive functioning in children with autism and Tourette syndrome. *Development and psychopathology*, *17*(2), 415-445.

Wallace, G. L., Kenworthy, L., Pugliese, C. E., Popal, H. S., White, E. I., Brodsky, E., & Martin, A. (2016). Real-world executive functions in adults with autism spectrum disorder: Profiles of impairment and associations with adaptive functioning and co-morbid anxiety and depression. *Journal of autism and developmental disorders*, *46*, 1071-1083.

Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental psychology*, *44*(2), 575.

Wiebe, S. A., Sheffield, T., Nelson, J. M., Clark, C. A., Chevalier, N., & Espy, K. A. (2011). The structure of executive function in 3-year-olds. *Journal of experimental child psychology*, *108*(3), 436-452.

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: a meta-analytic review. *Biological psychiatry*, *57*(11), 1336-1346.

Williams, D. L., Goldstein, G., Carpenter, P. A., & Minshew, N. J. (2005). Verbal and spatial working memory in autism. *Journal of autism and developmental disorders*, *35*, 747-756.

Wong, D., Maybery, M., Bishop, D. V., Maley, A., & Hallmayer, J. (2006). Profiles of executive function in parents and siblings of individuals with autism spectrum disorders. *Genes, Brain and Behavior*, *5*(8), 561-576.

Yerys, B. E., Wallace, G. L., Sokoloff, J. L., Shook, D. A., James, J. D., & Kenworthy, L. (2009). Attention deficit/hyperactivity disorder symptoms moderate cognition and behavior in children with autism spectrum disorders. *Autism Research*, *2*(6), 322-333.

Zelazo, P. D., Müller, U., Frye, D., Marcovitch, S., Argitis, G., Boseovski, J., ... & Carlson, S. M. (2003). The development of executive function in early childhood. *Monographs of the society for research in child development*, i-151.

6 Appendix

Appendix 1

Embedded Figures test questions

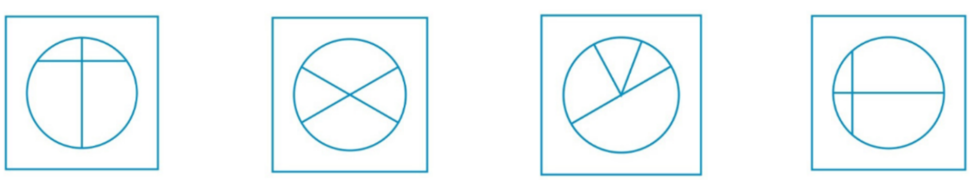
Task Instructions

From the given answer figure select the one in which the question figure is hidden/embedded in the same direction.

Next

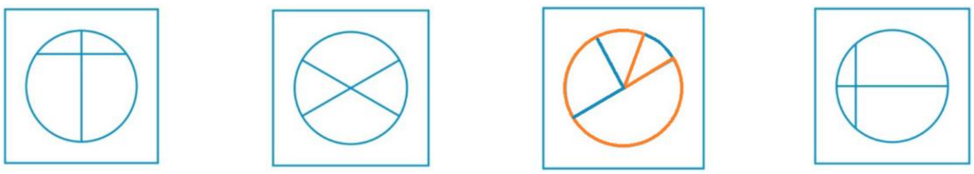
Let's Practice!

Choose the option below that shows the figure above hidden or embedded in the same direction.



Choose This 👆
To observe the embedding of the figure above within the current figure

Choose the option below that shows the figure above hidden or embedded in the same direction.



Proceed to the experiment

We will now begin the experimental trials. Please note that no feedback will be provided during this part. Your task is to select the correct response as promptly as possible.

Proceed to the expreminet

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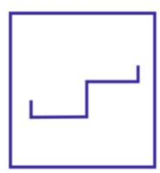

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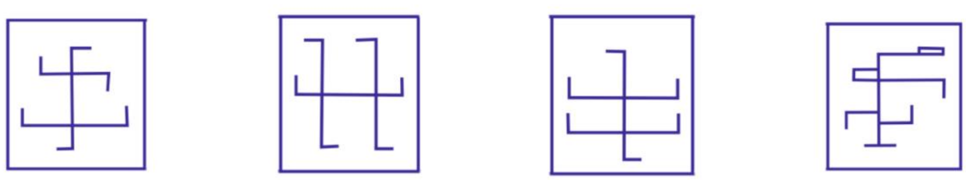

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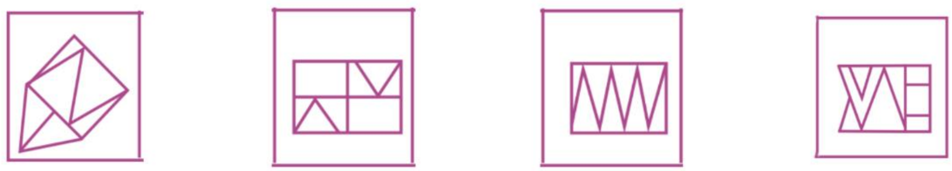

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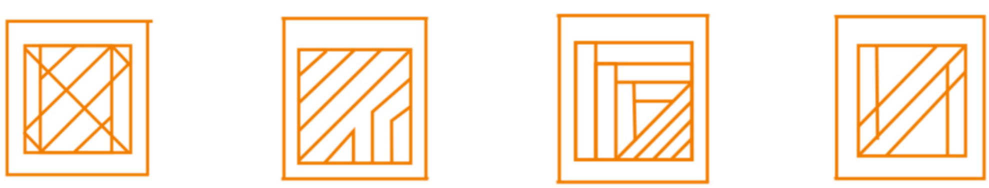

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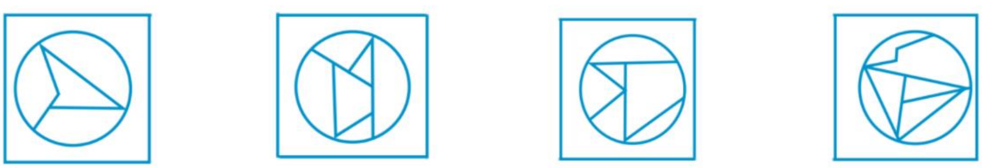

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Appendix 2.

Comprehensive Autistic Trait Inventory (CATI)

CATI

Date: Name/ID:

INSTRUCTIONS

Below is a list of statements relating to various personality traits, behaviours, and characteristics. Using the five response options select the option that best describes you. For items of a social nature, think about situations that do not involve very close friends or family members. Try not to spend too much time thinking about each choice.

		Definitely Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Definitely Agree
1	I often find myself fiddling or playing repetitively with objects (e.g. clicking pens)					
2	I like to stick to certain routines for every-day tasks					
3	I expend a lot of mental energy trying to fit in with others					
4	I am over-sensitive to bright lighting					
5	There are certain activities that I always choose to do the same way, every time					
6	Sometimes I watch people interacting and try to copy them when I need to socialise					
7	I often rock when sitting in a chair					
8	I generally enjoy social events					
9	I look for strategies and ways to appear more sociable					
10	In social situations, I try to avoid interactions with other people					
11	There are times when I feel that my senses are overloaded					
12	There are certain objects that I fiddle or play with that can help me calm down or collect my thoughts					
13	Reading non-verbal cues (e.g. facial expressions, body language) is difficult for me					
14	I like my belongings to be sorted in certain ways and will spend time making sure they are that way					
15	Social interaction is easy for me					
16	When interacting with other people, I spend a lot of effort monitoring how I am coming across					
17	I find social interactions stressful					
18	I am over-sensitive to touch					
19	I can tell how people feel from their facial expressions					
		Definitely Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Definitely Agree

		Definitely Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Definitely Agree
20	I have a tendency to pace or move around in a repetitive path					
21	I feel discomfort when prevented from completing a particular routine					
22	I rely on a set of scripts when I talk with people					
23	I find it easy to sense what someone else is feeling					
24	I am over-sensitive to particular tastes (e.g. salty, sour, spicy, or sweet)					
25	I engage in certain repetitive actions when I feel stressed					
26	I rarely use non-verbal cues in my interactions with others					
27	I often insist on doing things in a certain way, or re-doing things until they are 'just right'					
28	I feel confident or capable when meeting new people					
29	Before engaging in a social situation, I will create a script to follow where possible					
30	Social occasions are often challenging for me					
31	Sometimes the presence of a smell makes it hard for me to focus on anything else					
32	There are certain repetitive actions that others consider to be 'characteristic' of me (e.g. stroking my hair)					
33	Metaphors or 'figures of speech' often confuse me					
34	It annoys me when plans I have made are changed					
35	I find it difficult to make new friends					
36	I react poorly to unexpected loud noises					
37	I have difficulty understanding someone else's point-of-view					
38	I like to arrange items in rows or patterns					
39	I try to follow certain 'rules' in order to get by in social situations					
40	I am sensitive to flickering lights					
41	I have certain habits that I find difficult to stop (e.g. biting/tearing nails, pulling strands of hair)					
42	I have difficulty understanding the 'unspoken rules' of social situations					
		Definitely Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Definitely Agree

ADMIN ONLY						
TOTAL	SOC	COM	CAM	RIG	REP	SEN

Appendix 3.

Adult ADHD Self-Report Scale (ASRS-v1.1)

Adult ADHD Self-Report Scale (ASRS-v1.1) Symptom Checklist

Patient Name		Today's Date	

Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, place an X in the box that best describes how you have felt and conducted yourself over the past 6 months. Please give this completed checklist to your healthcare professional to discuss during today's appointment.	Never	Rarely	Sometimes	Often	Very Often
1. How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?					
2. How often do you have difficulty getting things in order when you have to do a task that requires organization?					
3. How often do you have problems remembering appointments or obligations?					
4. When you have a task that requires a lot of thought, how often do you avoid or delay getting started?					
5. How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?					
6. How often do you feel overly active and compelled to do things, like you were driven by a motor?					
					Part A
7. How often do you make careless mistakes when you have to work on a boring or difficult project?					
8. How often do you have difficulty keeping your attention when you are doing boring or repetitive work?					
9. How often do you have difficulty concentrating on what people say to you, even when they are speaking to you directly?					
10. How often do you misplace or have difficulty finding things at home or at work?					
11. How often are you distracted by activity or noise around you?					
12. How often do you leave your seat in meetings or other situations in which you are expected to remain seated?					
13. How often do you feel restless or fidgety?					
14. How often do you have difficulty unwinding and relaxing when you have time to yourself?					
15. How often do you find yourself talking too much when you are in social situations?					
16. When you're in a conversation, how often do you find yourself finishing the sentences of the people you are talking to, before they can finish them themselves?					
17. How often do you have difficulty waiting your turn in situations when turn taking is required?					
18. How often do you interrupt others when they are busy?					
					Part B

Appendix 4.

Bayesian repeated measures ANOVA results for the flanker task (both reaction time and accuracy) based on task order.

RT

Flanker First

Bayesian Repeated Measures ANOVA RT ▼

Model Comparison ▼

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. subject and random slopes)	0.200	9.219×10^{-10}	3.688×10^{-9}	1.000	
memory	0.200	0.753	12.223	$8.173 \times 10^{+8}$	1.890
memory + congruency	0.200	0.201	1.008	$2.184 \times 10^{+8}$	5.442
memory + congruency + memory ✻ congruency	0.200	0.045	0.189	$4.904 \times 10^{+7}$	5.039
congruency	0.200	2.298×10^{-10}	9.192×10^{-10}	0.249	1.675

Note. All models include subject, and random slopes for all repeated measures factors.

Analysis of Effects

Effects	P(incl)	P(excl)	P(incl|data)	P(excl|data)	BF_{incl}
memory	0.400	0.400	0.955	1.152×10^{-9}	$8.290 \times 10^{+8}$
congruency	0.400	0.400	0.201	0.753	0.267
memory ✻ congruency	0.200	0.200	0.045	0.201	0.225

Note. Compares models that contain the effect to equivalent models stripped of the effect. Higher-order interactions are excluded. Analysis suggested by Sebastiaan Mathôt.

Spatial First

Bayesian Repeated Measures ANOVA RT

Model Comparison

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. subject and random slopes)	0.200	4.879×10^{-9}	1.952×10^{-8}	1.000	
memory + congruency + memory ✻ congruency	0.200	0.994	708.891	$2.038 \times 10^{+8}$	2.928
memory	0.200	0.005	0.019	978043.122	1.730
memory + congruency	0.200	8.392×10^{-4}	0.003	172014.030	2.215
congruency	0.200	8.536×10^{-10}	3.414×10^{-9}	0.175	1.139

Note. All models include subject, and random slopes for all repeated measures factors.

Analysis of Effects

Effects	P(incl)	P(excl)	P(incl|data)	P(excl|data)	BF_{incl}
memory	0.400	0.400	0.006	5.732×10^{-9}	978803.079
congruency	0.400	0.400	8.392×10^{-4}	0.005	0.176
memory ✻ congruency	0.200	0.200	0.994	8.392×10^{-4}	1184.883

Note. Compares models that contain the effect to equivalent models stripped of the effect. Higher-order interactions are excluded. Analysis suggested by Sebastiaan Mathôt.

	Accuracy

Flanker First

Bayesian Repeated Measures ANOVA accuracy ▼

Model Comparison ▼

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. subject and random slopes)	0.200	0.016	0.067	1.000	
memory	0.200	0.746	11.760	45.602	1.682
memory + congruency	0.200	0.176	0.857	10.778	3.009
memory + congruency + memory ✻ congruency	0.200	0.057	0.244	3.507	7.375
congruency	0.200	0.004	0.015	0.226	1.487

Note. All models include subject, and random slopes for all repeated measures factors.

Analysis of Effects

Effects	P(incl)	P(excl)	P(incl|data)	P(excl|data)	BF_{incl}
memory	0.400	0.400	0.923	0.020	45.984
congruency	0.400	0.400	0.180	0.763	0.236
memory ✻ congruency	0.200	0.200	0.057	0.176	0.325

Note. Compares models that contain the effect to equivalent models stripped of the effect. Higher-order interactions are excluded. Analysis suggested by Sebastiaan Mathôt.

Spatial First

Bayesian Repeated Measures ANOVA accuracy

Model Comparison

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. subject and random slopes)	0.200	0.494	3.903	1.000	
memory	0.200	0.331	1.979	0.670	1.287
congruency	0.200	0.088	0.385	0.178	1.483
memory + congruency	0.200	0.059	0.252	0.120	1.734
memory + congruency + memory ✻ congruency	0.200	0.028	0.116	0.057	3.221

Note. All models include subject, and random slopes for all repeated measures factors.

Analysis of Effects

Effects	P(incl)	P(excl)	P(incl|data)	P(excl|data)	BF_{incl}
memory	0.400	0.400	0.390	0.582	0.671
congruency	0.400	0.400	0.147	0.825	0.178
memory ✻ congruency	0.200	0.200	0.028	0.059	0.474

Note. Compares models that contain the effect to equivalent models stripped of the effect. Higher-order interactions are excluded. Analysis suggested by Sebastiaan Mathôt.

Appendix 5.

Bayesian repeated measures ANOVA results for the Spatial Conflict task (both reaction time and accuracy) based on task order.

	RT

Spatial First

Bayesian Repeated Measures ANOVA RT

Model Comparison

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. subject and random slopes)	0.200	0.139	0.643	1.000	
memory	0.200	0.485	3.772	3.503	5.268
memory + congruency	0.200	0.236	1.236	1.704	6.532
memory + congruency + memory ✻ congruency	0.200	0.074	0.319	0.533	7.891
congruency	0.200	0.066	0.284	0.478	1.927

Note. All models include subject, and random slopes for all repeated measures factors.

Analysis of Effects

Effects	P(incl)	P(excl)	P(incl|data)	P(excl|data)	BF_{incl}
memory	0.400	0.400	0.721	0.205	3.521
congruency	0.400	0.400	0.302	0.624	0.485
memory ✻ congruency	0.200	0.200	0.074	0.236	0.313

Note. Compares models that contain the effect to equivalent models stripped of the effect. Higher-order interactions are excluded. Analysis suggested by Sebastiaan Mathôt.

Flanker First

Bayesian Repeated Measures ANOVA RT

Model Comparison

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. subject and random slopes)	0.200	1.094×10^{-9}	4.375×10^{-9}	1.000	
memory + congruency	0.200	0.784	14.536	$7.170\times10^{+8}$	3.081
memory + congruency + memory ✻ congruency	0.200	0.214	1.092	$1.960\times10^{+8}$	3.531
memory	0.200	0.001	0.006	$1.272\times10^{+6}$	1.821
congruency	0.200	6.622×10^{-7}	2.649×10^{-6}	605.371	1.783

Note. All models include subject, and random slopes for all repeated measures factors.

Analysis of Effects

Effects	P(incl)	P(excl)	P(incl|data)	P(excl|data)	BF_{incl}
memory	0.400	0.400	0.786	6.632×10^{-7}	$1.184\times10^{+6}$
congruency	0.400	0.400	0.784	0.001	563.721
memory ✻ congruency	0.200	0.200	0.214	0.784	0.273

Note. Compares models that contain the effect to equivalent models stripped of the effect. Higher-order interactions are excluded. Analysis suggested by Sebastiaan Mathôt.

Accuracy

Spatial First

Bayesian Repeated Measures ANOVA accuracy

Model Comparison

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. subject and random slopes)	0.200	1.112×10^{-4}	4.448×10^{-4}	1.000	
memory + congruency + memory ✻ congruency	0.200	0.963	103.770	8659.688	3.401
congruency	0.200	0.021	0.086	188.741	2.197
memory + congruency	0.200	0.016	0.065	143.316	3.025
memory	0.200	8.307×10^{-5}	3.323×10^{-4}	0.747	2.318

Note. All models include subject, and random slopes for all repeated measures factors.

Analysis of Effects

Effects	P(incl)	P(excl)	P(incl|data)	P(excl|data)	BF_{incl}
memory	0.400	0.400	0.016	0.021	0.759
congruency	0.400	0.400	0.037	1.943×10^{-4}	190.063
memory ✻ congruency	0.200	0.200	0.963	0.016	60.424

Note. Compares models that contain the effect to equivalent models stripped of the effect. Higher-order interactions are excluded. Analysis suggested by Sebastiaan Mathôt.

Flanker First

Bayesian Repeated Measures ANOVA accuracy

Model Comparison

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. subject and random slopes)	0.200	1.854×10^{-5}	7.417×10^{-5}	1.000	
memory + congruency + memory ✻ congruency	0.200	0.711	9.863	38370.293	3.900
congruency	0.200	0.217	1.110	11718.295	2.568
memory + congruency	0.200	0.071	0.307	3840.982	3.252
memory	0.200	6.650×10^{-6}	2.660×10^{-5}	0.359	6.912

Note. All models include subject, and random slopes for all repeated measures factors.

Analysis of Effects

Effects	P(incl)	P(excl)	P(incl|data)	P(excl|data)	BF_{incl}
memory	0.400	0.400	0.071	0.217	0.328
congruency	0.400	0.400	0.289	2.519×10^{-5}	11452.076
memory ✻ congruency	0.200	0.200	0.711	0.071	9.990

Note. Compares models that contain the effect to equivalent models stripped of the effect. Higher-order interactions are excluded. Analysis suggested by Sebastiaan Mathôt.

Appendix 6.

Classical repeated measures ANOVAs results for the Flanker task (both reaction time and accuracy) in the Study 1.

Table A. Classical repeated measure ANOVA for the reaction time in the Flanker task in study 1.

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
memory	$1.115\times10^{+6}$	1	$1.115\times10^{+6}$	82.780	< .001
Residuals	$1.334\times10^{+6}$	99	13470.528		
congruency	44421.070	1	44421.070	40.973	< .001
Residuals	107331.484	99	1084.156		
memory ✻ congruency	3648.838	1	3648.838	3.021	0.085
Residuals	119562.692	99	1207.704		

Note. Type III Sum of Squares

Table B. Classical repeated measure ANOVA for the accuracy in the Flanker task in study 1.

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
memory	0.004	1	0.004	0.760	0.386
Residuals	0.517	99	0.005		
congruency	0.027	1	0.027	16.555	< .001
Residuals	0.163	99	0.002		
memory ✻ congruency	0.012	1	0.012	10.978	0.001
Residuals	0.104	99	0.001		

Note. Type III Sum of Squares

Appendix 7.

Classical repeated measures ANOVAs results for the Spatial Conflict task (both reaction time and accuracy) in the Study 1.

Table A. Classical repeated measure ANOVA for the reaction time in the Spatial Conflict task in study 1.

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Memory	93000.211	1	93000.211	4.210	0.043
Residuals	$2.187\times10^{+6}$	99	22088.662		
Congruency	111676.005	1	111676.005	79.695	< .001
Residuals	138727.837	99	1401.291		
Memory ✻ Congruency	12594.936	1	12594.936	9.207	0.003
Residuals	135429.104	99	1367.971		

Note. Type III Sum of Squares

Table B. Classical repeated measure ANOVA for the accuracy in the Spatial Conflict task in study 1.

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Memory	0.013	1	0.013	3.806	0.054
Residuals	0.349	99	0.004		
Congruency	0.095	1	0.095	29.498	< .001
Residuals	0.317	99	0.003		
Memory ✻ Congruency	0.003	1	0.003	1.538	0.218
Residuals	0.224	99	0.002		

Note. Type III Sum of Squares

Appendix 8.

Classical repeated measures ANOVAs results for the Flanker task (both reaction time and accuracy) in the Study 2.

Table A. Classical repeated measure ANOVA for the reaction time in the Flanker task in study 2.

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
memory	$2.941 \times 10^{+6}$	1	$2.941 \times 10^{+6}$	129.816	< .001
Residuals	$2.220 \times 10^{+6}$	98	22656.493		
Congruency	378.334	1	378.334	0.403	0.527
Residuals	92100.924	98	939.805		
memory ✻ Congruency	6893.880	1	6893.880	8.524	0.004
Residuals	79262.864	98	808.805		

Note. Type III Sum of Squares

Table B. Classical repeated measure ANOVA for the accuracy in the Flanker task in study 2.

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Memory	0.080	1	0.080	14.672	< .001
Residuals	0.532	98	0.005		
Congruency	1.794×10^{-4}	1	1.794×10^{-4}	0.284	0.595
Residuals	0.062	98	6.309×10^{-4}		
Memory ✻ Congruency	7.002×10^{-5}	1	7.002×10^{-5}	0.088	0.767
Residuals	0.078	98	7.963×10^{-4}		

Note. Type III Sum of Squares

Appendix 9.

Classical repeated measures ANOVAs results for the Spatial Conflict task (both reaction time and accuracy) in the Study 2.

Table A. Classical repeated measure ANOVA for the reaction time in the Spatial Conflict task in study 2.

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Memory	882367.132	1	882367.132	30.427	< .001
Residuals	$2.813 \times 10^{+6}$	97	28999.732		
Congruency	37269.063	1	37269.063	16.725	< .001
Residuals	216146.758	97	2228.317		
Memory ✻ Congruency	2406.904	1	2406.904	1.217	0.273
Residuals	191895.480	97	1978.304		

Note. Type III Sum of Squares

Table B. Classical repeated measure ANOVA for the accuracy in the Spatial Conflict task in study 2.

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
memory	0.003	1	0.003	0.618	0.434
Residuals	0.418	97	0.004		
congruency	0.078	1	0.078	50.921	< .001
Residuals	0.148	97	0.002		
memory ✻ congruency	0.021	1	0.021	21.542	< .001
Residuals	0.095	97	9.806×10^{-4}		

Note. Type III Sum of Squares

Appendix 10.

The results of Pearson’s Correlation between accuracy/reaction time in the Flanker/Spatial Conflict task and autistic traits (measured by AQ-S) in the Study 1.

Table A. Pearson's Correlations between accuracy in the Spatial Conflict task and AQ.

Variable		Spatial Low Congruent Accuracy	Spatial Low Incongruent Accuracy	Spatial High Congruent Accuracy	Spatial High Incongruent Accuracy	AQ
AQ	Pearson's r	-0.130	-0.059	0.098	-0.101	—
	p-value	0.197	0.559	0.332	0.317	—

Table B. Pearson's Correlations between reaction time in the Spatial Conflict task and AQ.

Variable		Spatial Low Congruent RT	Spatial Low Incongruent RT	Spatial High Congruent RT	Spatial High Incongruent RT	AQ
AQ	Pearson's r	-0.074	-0.037	0.065	0.148	—
	p-value	0.465	0.714	0.522	0.141	—

Table C. Pearson's Correlations between accuracy in the Flanker task and AQ.

Variable		Flanker Low Congruent Accuracy	Flanker Low Incongruent Accuracy	Flanker High Congruent Accuracy	Flanker High Incongruent Accuracy	AQ
AQ	Pearson's r	0.056	-0.041	0.089	-0.041	—
	p-value	0.582	0.687	0.378	0.687	—

Table D. Pearson's Correlations between reaction time in the Flanker task and AQ.

Variable		Flanker Low Congruent RT	Flanker Low Incongruent RT	Flanker High Congruent RT	Flanker High Incongruent RT	AQ
AQ	Pearson's r	0.110	0.060	0.031	0.065	—
	p-value	0.277	0.553	0.760	0.522	—

Appendix 11.

The results of Pearson's Correlation between accuracy/reaction time in the Flanker/Spatial Conflict task and autistic/ADHD traits in the Study 2.

Table A. Pearson's Correlations between accuracy in the Flanker task and CATI and ASRS.

Variable		Flanker Low Congruent Accuracy	Flanker Low Incongruent Accuracy	Flanker High Congruent Accuracy	Flanker High Incongruent Accuracy	CATI	ASRS
CATI	Pearson's r	0.068	0.014	0.025	0.042	—	
	p-value	0.501	0.893	0.804	0.679	—	
ASRS	Pearson's r	-0.096	-0.165	-0.061	-0.043	0.564	—
	p-value	0.350	0.106	0.553	0.674	< .001	—

Table B. Pearson's Correlations between reaction time in the Flanker task and CATI and ASRS.

Variable		Flanker Low Congruent RT	Flanker Low Incongruent RT	Flanker High Congruent RT	Flanker High Incongruent RT	ASRS	CATI
ASRS	Pearson's r	0.041	0.049	0.081	0.097	—	
	p-value	0.688	0.632	0.432	0.343	—	
CATI	Pearson's r	-0.125	-0.126	-0.029	-0.045	0.564	—
	p-value	0.217	0.213	0.777	0.655	< .001	—

Table C. Pearson's Correlations between accuracy in the Spatial Conflict task and CATI and ASRS.

Variable		Spatial Low Congruent Accuracy	Spatial Low Incongruent Accuracy	Spatial High Congruent Accuracy	Spatial High Incongruent Accuracy	ASRS	CATI
ASRS	Pearson's r	0.099	-0.092	0.025	-0.005	—	
	p-value	0.338	0.371	0.812	0.958	—	
CATI	Pearson's r	0.160	-0.018	-0.086	-0.062	0.567	—
	p-value	0.116	0.859	0.401	0.545	< .001	—

Table D. Pearson's Correlations between reaction time in the Spatial Conflict task and CATI and ASRS.

Pearson's Correlations

Variable		Spatial Low Congruent RT	Spatial Low Incongruent RT	Spatial High Congruent RT	Spatial High Incongruent RT	ASRS	CATI
	p-value	< .001	< .001	< .001	—		
5. ASRS	Pearson's r	0.068	0.026	-0.026	0.005	—	
	p-value	0.510	0.804	0.798	0.959	—	
6. CATI	Pearson's r	-0.065	-0.104	-0.051	-0.075	0.567	—
	p-value	0.522	0.306	0.621	0.465	< .001	—

Appendix 12.

The results of the Pearson's correlations between the measure of ASC traits, the measure of ADHD traits and embedded figure test.

Table A. Pearson's Correlations

Variable		CATI	ASRS	EFT
1. CATI	Pearson's r	—		
	p-value	—		
2. ASRS	Pearson's r	0.567	—	
	p-value	< .001	—	
3. EFT	Pearson's r	-0.113	-0.180	—
	p-value	0.270	0.080	—