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Investigating the Role of the Anti-Saccade Task in the Evaluation of Executive Functions: Correlations with Traditional Neuropsychological Tests and Complex Cognitive Tasks

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To my beloved family and dearest friends, and to my supervisor, for your unwavering faith, boundless kindness, and radiant support that has lit my path, thank you.

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Abstract:

The capability to suppress reflexive responses on behalf of voluntary motor activity is fundamental for everyday living. Inhibitory control and task-switching abilities, as cognitive functions, can be effectively assessed by using the anti-saccade task and neuropsychological tests. Participants must perform a voluntary saccade to a symmetrical, stimulus-absent position in order to complete the anti-saccade task, which involves inhibition of automatic saccade toward a visual stimulus. Two conditions will be used for the task: prosaccade and anti-saccade. After receiving the stimulus indicating the necessary task, participants completed both tasks within the same experimental block. Additional cognitive tasks are included in the study to evaluate the Inhibitory control, task-switching abilities and cognitive flexibility. These tasks include the Stroop task, which measures inhibitory control and task-shifting ability by requiring participants to inhibit the automatic responses to word meaning and focus on the text color; The Stop Signal task which tests the inhibitory control by examine the capability of suppressing pre-planned motor responses when the stimulus presented; The Wisconsin Card Sorting Test measures more complex executive functions such as rule learning and cognitive flexibility, beside the inhibitory control and task switching; Go-No-Go task, which examines selective response, task requires, participants to inhibits the motor activity in “no-go” signal and perform the activity in “go” signal.

The purpose of this thesis is to examine the neural mechanisms and cognitive processes that support anti-saccade performance by correlating the outcomes of computerized cognitive tests, such as the Wisconsin Card Sorting Test, Stroop task, Stop Signal Task, and Go-No-Go task. Computerized tools were used to collect all the data. Through the anti-saccade task, Tobii eye-tracking used, which uses a non-invasive infrared camera, captured eye movements behalf of comprehending the temporal and spatial dynamics of saccadic reactions and accurate recording.

The research presents a comprehending approach to understanding the association between anti-saccade task performance and executive function abilities. By combining the behavioral and eye tracking data, the study aims to provide light on the neurological and cognitive underpinnings of inhibitory control and task-switching. The results could help to improve techniques for evaluating and diagnosing executive function impairments, which could have uses in both clinical and research settings.

CHAPTER 1: Introduction

1.1 Executive Functions: Definition, Scope, and Neural Basis

Cognitive domains, including sensation, perception, and various aspects of language and memory, are different from the domain of executive function. It partially overlaps with areas like problem-solving, reasoning, and attention. Set-shifting and set-maintenance, inhibition, interference control, integration across time and space, planning, and working memory are common lists of executive functions. Context-specific action selection is a key component of the executive function concept, particularly when confronted with highly competing but inappropriate responses. The integration of constraints from many other domains, including perception, memory, affect, and motivation, is necessary to achieve maximal constraint satisfaction in action selection, which is another key concept. Therefore, a lot of complex behavior, particularly social behavior in humans, requires executive function. (Pennington & Ozonoff, 1996).

Cicerone et al. (2000) suggested that executive functioning is the term used to describe the integrative cognitive processes that dominate the orderly performance of daily tasks and determine goal-directed and purposeful behavior. Although it is crucial that the term's anatomical and behavioral referents remain separate, this term includes a wide range of cognitive functions and dysfunctions and is frequently used to describe challenges caused by frontal lobe injury. These integrative functions include goal setting, initiating behavior, anticipating the effects of actions, planning and organizing behavior based on topical, temporal, spatial, or logical sequences, and monitoring and modifying behavior to suit a given task or situation. Impaired emotional and behavioral self-regulation, a diminished capacity for insight, and neurologically based disorders of awareness all seem to be associated with disturbances of these executive functions. These procedures are frequently conceived to mirror the related challenges of regular reasoning, problem-solving, and decision-making. Because problems in these domains affect not only specific skills but also the mental processes and structures that regulate how these skills are used, they are frequently challenging to implement. This is because they affect not only specific skills but also the cognitive processes and structures that regulate how these skills are used (Cristofori & Grafman, 2017). According to Stuss (1991), executive functions are located at the center of a hierarchical framework. The outcomes of these executive activities—such as reasoning, problem-solving, and planning—interact with lower-level systems such as memory and comprehension, where updating can take place, and with a higher level of "self," such as self-awareness. Furthermore, Butterfield and Belmont (1977) stated that self-regulation abilities are recognized as the foundation of executive functions in other domains, including educational, developmental, and cognitive psychology (Kennedy et al., 2008).

Conceptual frameworks of executive function (EF) and cognitive control (CC) are described in terms of how they relate to the functions of the prefrontal cortex (PFC) and associated areas and networks, as well as how they relate to goal-directed behavior versus habits and controlled versus automatic processing (Friedman & Robbins, 2021). Mischel et al. (2011) and Moffitt et al. (2011) suggested that the prefrontal cortex of the brain is frequently associated with executive functions, which are a set of general-purpose control mechanisms that control human cognition and behavior. Since executive functions are a fundamental part of self-control or self-regulation ability, which has been demonstrated to have wide-ranging and important implications for daily life, they are worth studying (Miyake & Friedman, 2012).

Kenedy and Coelho (2005) suggested that applying self-regulation to cognition is known as "metacognition," or “thinking about your thinking,” and it refers to "self-awareness or metacognitive beliefs, as well as self-monitoring and self-control of cognition while performing an activity." Each component of metacognition works in highly complex behavior and is structured around skill sets that include: (1) goal-setting; (2) self-monitoring, which involves comparing performance with goals or outcomes; (3) self-control, which involves deciding to alter one's behavior in order to achieve the desired outcome (e.g., choosing an alternative solution); and (4) execution of the behavioral change (e.g., implementing an alternative solution). Therefore, self-regulation or an executive function system that consists of a collection of skills rather than a single skill, is the source of highly complex behaviors (Kennedy et al., 2008).

A unique function for the frontal lobes in human cognition was once more suggested in the 20th century. Kurt Goldstein (1941) stated that "abstract attitude" was influenced by the frontal lobes. Furthermore, the frontal lobes are clearly linked to higher cognition; for example, Burdach (1819) referred to them as "the special workshop of the thinking process," and both Harlow (1868) and Bianchi (1922) highlighted the planning deficits that follow frontal injury. (Pennington & Ozonoff, 1996).

Crawford (2010) suggested that the concept of "executive functions" is a useful way to define a group of behavioral abilities that involve planning, sequencing, maintaining focus, resistance to interference, using feedback, coordinating multiple tasks at once, cognitive flexibility, and, more broadly, managing novelty. In contrast, Lezak (1982) provided a definition of the executive functions by the structure for conceptualizing the executive functions in terms of four main classes or functional categories of executive abilities. These classes are the skills required to set goals; the abilities involved in planning; the capabilities related to implementing plans to achieve the goals; and the competencies required to carry out these tasks successfully. Different sets of behavior are involved in these classes. All are required for proper, socially conscious, and successfully self-serving adult behavior.

Throughout the history of neuropsychology, there has been plenty of debate about the Prefrontal Corex's (PFC) function. Given their large relative size, special connectivity to the rest of the brain, and rapid expansion in primate brain evolution, early accounts did assign the PFC an important role in human cognition (Pennington & Ozonoff, 1996). The significance of brain regions such as the right hemisphere and subcortical and prefrontal contributions to executive functions are also examined by Lezak (1982).

The history of executive function research begins with neuropsychological examinations of individuals who have frontal lobe damage. It has long been recognized that people who have frontal lobe damage, such as the well-known patient Phineas Gage, have significant difficulties controlling and regulating their behavior and are unable to carry out daily tasks effectively. Domasio (1994) and Shallice & Burgess (1991) proposed that even though some of these patients perform exceptionally well on a variety of clearly defined cognitive tasks from IQ tests and neuropsychological test batteries, they frequently show some impairments on a variety of complex executive or frontal lobe tasks, such as the Tower of Hanoi task, the Tower of London task, as well as the Wisconsin Card Sorting Test (WCST). These frontal lobe tasks have served as the foundation for numerous hypotheses about the varieties of cognitive impairments that patients with frontal lobe disorders show and the types of control functions that healthy, normal frontal lobes appear to carry out (Miyake et al., 2000a).

All of the tasks and behaviors that are affected by frontal lesions require goal-directed behavior, typically in novel contexts with competing but incorrect response alternatives, despite the fact that their surface characteristics vary significantly. Despite being aware of the task's objective, patients with frontal lesions are unable to complete it due to a lack of initiative, perseverance, impersistence, or task-irrelevant behavior. This dysregulation of goal-directed behavior, which happens in tasks with different content and surface characteristics and cannot be linked to a more fundamental impairment in perception, memory, or language comprehension, has given rise to the current neuropsychological belief that the frontal lobes play a significant role in the "executive" or "supervisory" aspect of task performance. As a result, the long-standing debate about whether the frontal lobes are particularly important for higher cognition has been partially settled (Pennington & Ozonoff, 1996).

The term executive functions is frequently used to describe mental regulatory mechanisms. Even though it has long been known that executive functions are crucial for complex cognition, executive functions appear to be crucial for daily communication and may even be a significant factor in determining how well aphasic patients are able to interact with others and carry out independent daily tasks. Despite the difficulty of studying executive functions, there are several theoretical and clinical justifications for defining their nature, structure, and functions (Miyake, Emerson, & Friedman, 2000b).

Several models have been proposed to study executive function and its underlying processes. Across multiple works, Friedman and Miyake (2017), Miyake et al. (2000a), Miyake and Friedman (2012) introduced the Unity and Diversity Model, which distinguishes three core executive functions: updating (controlling working memory content), shifting (mentally switching between cognitive operations), and inhibition (suppressing undesirable actions) (Rodríguez-Nietoa et al., 2022). Similarly, Baddeley’s (1986) influential multicomponent model of working memory stresses the role of the central executive in regulating cognitive processes, closely associated with frontal lobe function. Monsell (1996) emphasized shifting as a critical executive function, involving the capability to transition between tasks or mental sets, while Norman and Shallice (1986) linked attentional control to task-switching as a core aspect of executive control (Miyake et al., 2000a).

The Dynamic Field Theory, on the other hand, was proposed by Buss and Spencer (2014) as a novel framework for the development of executive function through consistent patterns of neural activity that mirror decision-making processes in real time. Furthermore, Miyake et al. (2000a) offered a basic conceptual framework for task design that has impacted later studies in this area. This framework focused on pre-potent response inhibition, information updating and monitoring, and mental set shifting (Kramer et al., 2014).

Miyake, Emerson, and Friedman (2000b) centered on the three executive functions that are most frequently discussed in the literature on cognitive psychology. They include shifting, which is switching between several tasks or mental sets; updating, which is keeping an eye on incoming information to see if it is pertinent to the task at hand and then appropriately updating the informational content by substituting outdated, irrelevant information with more recent, pertinent information; and inhibition, which is purposefully suppressing dominant, automatic, or prepotent responses. The authors selected these functions because they are thought to be comparatively limited and basic in contrast to a more complex function like "planning" and help with the performance of complex "frontal" tasks, such as shifting for the Wisconsin Card Sorting Test.

Rodríguez-Nietoa et al. (2022) suggested that higher-order mental processes known as executive functions facilitate behavior that is goal-directed. Three of these functions as executive domains, which are inhibition, updating, and shifting. The method in the study demonstrated that the right and left hemispheres demonstrate strongly lateralized neural activation during inhibition and shifting, respectively. Furthermore, the two networks did not overlap with one another, but they did overlap with the updating network.

Diamond (2013), and Friedman and Miyake (2017) suggested that "higher-order" executive functions, like planning, are derived from the three "core" executive functions of inhibition, shifting, and updating. Higher-level mental processes are considered to regulate lower-level mental processes, which allows effective goal-directed behavior. The phrase "executive functions" refers to a broad range of related but distinct cognitive processes. To effectively simulate and assess a series of events before they are carried out, a person must apply a variety of executive skills (Rodríguez-Nietoa et al., 2022).

The shifting process is thought to entail the withdrawal of an irrelevant task set and the subsequent active participation of a relevant task set. This is arguably the most widely accepted explanation for this function. According to Jonides and Smith (1997), and Letho (1996), updating has been proposed as another possible executive function that is closely related to working memory. Goldman-Rakic (1996), and Smith and Jonides (1999) indicated that updating is frequently linked to the dorsolateral region of the prefrontal cortex. Inhibition involves the capacity to consciously suppress automatic, dominant, or prepotent reactions when called for (Miyake et al., 2000a).

Inhibition, a crucial function, underpins many successful behaviors. It empowers individuals to filter out distractions, concentrate on essential information, block irrelevant cues to recall specific memories, and inhibit automatic reactions to make new feasible choices (Dillon & Pizzagalli, 2007). Several tasks have been developed to assess inhibition ability: Stroop (1935) suggested the Stroop task, Hallet (1978) suggested the anti-saccade task, and Logan (1994) suggested the stop-signal task, which are utilized to activate the inhibition ability. All the tasks require purposefully inhibiting a largely automatic response. However, the precise response that must be suppressed varies depending on the task. Perret (1974), and Everling and Fischer (1998) suggested that both the Stroop task and the anti-saccade task show sensitivity to frontal lobe lesions and other forms of frontal lobe problems. While the stop-signal task has not been studied in a neuropsychological setting, Casey et al. (1997), and Kiefer (1998) demonstrated that both children's and adults' prefrontal cortex is strongly implicated in a simpler but similar "go–no-go" task (Miyake et al., 2000a).

On the one hand, the most widely used executive function test in neuropsychological populations, especially in patients with frontal lobe damage, is the Wisconsin Card Sorting Test (WCST). Berg (1948) suggested that the WCST is frequently thought of as a task that involves set-shifting because of its requirement to change the sorting categories following a specific number of successful trials. Set-shifting, often used as a measure of mental flexibility, refers to the ability to move forward and backward between different tasks or mental sets (Fuglset, 2019). On the other hand, Ozonoff and Strayer (1997) have given thought to the theory that, in order to suppress the current sorting category and switch to a new one, the task requires inhibitory control (Miyake et al., 2000a).

Cohen & Servan-Schreiber (1992) modeled by simulation the Wisconsin Card Sorting Task (WCST), the archetypal Executive Function task in neuropsychology. According to Heaton et al. (1993), the most popular highly sensitive variable generated by the WCST is a measure of perseverance, which is calculated by counting the times in which a subject sorts using a previously accurate principle in spite of negative feedback from the examiner (Pennington & Ozonoff, 1996). In addition, Milner (1963) suggested the WCST, which evaluates learning and shifting rules, while

Perret (1974) suggested the Stroop Color-Word Interference Test, which evaluates one's capacity to suppress irrelevant information (Cristofori & Grafman, 2017).

According to Luria (1973), complex higher cortical functions are the result of multiple brain regions cooperating, with certain brain regions specialized for particular functional activity aspects in regions of specificity. These areas are arranged hierarchically, and interactions with the environment have an impact on their development. In addition to providing flexibility during development, the complex nature of the interactions between regions may also allow for restructuring following injury (Christensen, 2010).

Luria (1960) suggested that voluntary action develops over a series of successive stages and emerges in the process of the child's relationships with the adult. It began as the child's ability to follow the adult's verbal instructions, but as the child's speech develops, it gradually changes into a system of self-regulating behaviors where external speech, followed by internal speech, the primary mechanism of voluntary action—plays a decisive role. As the executive function system continues to grow, children are able to control not only their physical behaviors but also their cognitive processes, giving them even more control over their actions (Bodrova, Leong & Akhutina, 2011).

1.2 Understanding the Anti-Saccade Task: Cognitive and Neurological Aspects

The anti-saccade task was proposed as a “novel task” by Peter Hallett. Hallet (1978) described that the reflexive prosaccade facing a stimulus must be inhibited in order to start anti-saccades, which are intentional eye movements directed away from the stimulus. The task became essential for examining prefrontal cortex function, inhibitory processes, and cognitive control (Hallett, 1978; Hallett & Adams, 1980). Additionally, it provides a unique instance of this type of spatiotemporal organization.The accurate representation of the anti-saccade task needs a minimum of two functional subprocesses: the capability to inhibit an automatic saccade towards the visual target and the capacity to execute a purposeful saccade in the mirror direction. The complete gaze network enables participants to inhibit an automatic prosaccade to the stimulus and provides them the necessary duration to execute a self-directed/intentional anti-saccade (Guitton et al., 1985).

One of the critical functions of the frontal lobes is inhibition, which allows individuals to suppress automatic impulses (Hellmuth et al., 2012). This function is essential for generating voluntary commands and making adaptive decisions (Everling & Fischer, 1998). The prefrontal cortex, a key region of the frontal lobes, plays a crucial role in inhibitory control, and impairments in this ability are commonly observed in a variety of brain disorders, particularly those involving damage or dysfunction of the frontal lobes (Mirsky et al., 2011).

A foundational study on the anti-saccade task indicates that impairment of automatic response inhibition can be identified with a large number of saccades toward the visual input; these movements are defined as prosaccades. On the other hand, impairment in executing purposeful movements will be recognized by a small number of saccades to the opposite side of the visual input, which are defined as anti-saccades (Everling & Fischer, 1998).

Anti-saccade and saccade tasks are widely recognized and commonly used measures of cognitive inhibition (Hellmuth et al., 2012). The task involves inhibiting an automatic eye movement toward a visual target and instead performing an eye movement in the opposite direction, while the pro-saccade task requires directing the gaze directly toward a visual target (Munoz & Everling, 2004). In the anti-saccade task, individuals must inhibit the automatic saccade to look at a target and instead direct their gaze to the opposite location, all while maintaining the task's context and requirements. Tasks emphasizing executive functions are correlated with anti-saccade errors, such as attentional set inhibition, planning, and set-shifting (Hutton et al., 2004) which are executive function domains (Rodríguez-Nietoa et al., 2022).

The capability to inhibit involuntary responses and execute voluntary motor commands releases people from stimulus-driven behavior to accomplish self-driven aims. The inhibition ability can be investigated in a single oculomotor task, which presents a visual stimulus on one side and requires participants to fix their gaze on the opposite side of the displayed visual cue (Everling & Fischer, 1998). Patients with frontal lobe lesions have been studied using this paradigm because, in some cases, they are unable to stop their eyes from moving to the stimulus (Guitton et al., 1985).

Recent studies on saccadic eye movement analysis show that many neurological and psychiatric conditions are linked with saccade inhibition impairment (Everling & Fischer, 1998). The natural oculomotor response in the anti-saccade task would be to focus on the location of the target's appearance. According to Guitton et al. (1985), patients with neurological problems who have lesions in the frontal eye fields are unable to manage this reaction and carry out anti-saccades. Rather, they unconsciously glance at the cue (Fischer & Weber, 1992). Everling and Fischer (1998) suggested that the fundamental metrics of anti-saccades are latency, duration, velocity, size, accuracy, and correction time, particularly in cases of saccades undershooting or overshooting the expected final location of the gaze. Participants are directed to fix their gaze on the central fixation point, after which a visual input is displayed in the periphery. According to the cue, participants should suppress the saccade (prosaccade) to the visual target and execute the saccade to the opposite position (anti-saccade). In the meantime, reaction time variables can be calculated from stimulus appearance, such as prosaccade reaction time, anti-saccade reaction time, and correction saccadic reaction time.

Hallet (1978) suggested some fundamental examinations on anti-saccade task performance: participants were capable of effectively fixing their gaze to the opposite side of the visual target. Everling and Fischer (1998) suggested that, in the beginning, subjects made a significant number of erratic saccades to the visual target before looking to the opposite side; however, over time, the error rate decreased. In contrast, later studies, such as Hallet and Adams (1980), showed that there was no significant reduction in error rate with practice, and the longer delay of anti-saccades compared to prosaccades was validated. Experiments show that anti-saccade task delay occurs because the saccade-producing system takes longer to program a saccade to a point where no visual stimulus appears, not because of the time required for an interhemispheric transfer. The presence of a reflex-like pathway linking the retina to the oculomotor nuclei mediating the express saccade is supported by observations (Fischer & Weber, 1992)

Human functional neuroimaging and lesion studies show that a number of frontal areas, especially those engaged in oculomotor control (e.g., frontal eye fields) and in cognitive function (e.g., dorsolateral prefrontal cortex), moderate performance in the anti-saccade task (Hutton et al., 2004). Mirsky et al. (2011) indicate that gray matter volume in the inhibitory control regions of the medial and lateral frontal lobes in cognitively normal older individuals is correlated with the percentage of correct anti-saccade (AS) reactions. In particular, the percentage of accurate AS responses was linked to gray matter volumes in the left inferior frontal junction (IFJ) and the right supplementary eye field (SEF). The study used regions of interest (ROIs) based on published functional MRI-derived coordinates and shows that, while anti-saccade (AS) performance was not directly associated with dorsolateral prefrontal cortex (DLPFC) gray matter volume, a significant correlation was found between gray matter volume in the inferior frontal junction (IFJ) region and the percentage of correct AS responses. The findings regarding the SEF and IFJ suggest that structural changes within the frontal lobe's inhibitory control network nodes are connected to a reduced percentage of correct AS responses. This association is observed in normal older adults, participants with cortical lesions, and individuals with dementia.

Deseilligny et al. (2003) support earlier findings in humans showing that reflexive saccade inhibition, the initial physiological process in the anti-saccade paradigm, is primarily regulated by the dorsolateral prefrontal cortex (DLPFC), with an associated bilateral increase in error rate. Another functional neuroimaging study shows that different brain regions contribute to the execution of saccadic eye movements in humans. The generation of voluntary saccades is associated with growing regional cerebral blood flow activity in the frontal eye field, supplementary motor area, and cerebellum (Fox et al., 1985). Other studies expanded the brain regions involved, identifying stimulation at the subcortical level in the globus pallidus, the striatum, and the thalamus, and at the cortical level in the cingulate gyrus and insula (Everling & Fischer, 1998). Sweeney et al. (1996) examined the relationship between regional cerebral blood flow and anti-saccade performance. The study reported that the ventromedial prefrontal cortex, left striatum, and bilateral medial-temporal cortex have lower regional cerebral blood flow, and these results express the inhibition of involuntary saccades. In addition, the study suggested that increased bilateral regional cerebral blood flow in the dorsolateral prefrontal cortex, posterior parietal cortex, and in the right frontal eye field and supplementary eye field indicates the execution of voluntary saccades.

Everling and Fischer (1998) suggested that cortical and subcortical structures involved in producing or executing anti-saccades include the anterior cingulate cortex, basal ganglia, frontal eye field, prefrontal cortex, posterior parietal cortex, superior colliculus, and supplementary eye field. Pierrot-Deseilligny et al. (2003) examined a participant with a lesion caused by a hematoma affecting the superior colliculus. In the first study, they found a large percentage of involuntary saccades toward the right side of the visual field. The results suggest that due to the lack of inhibitory input from the right side of the superior colliculus or damage to efferent fibers from the substantia nigra pars reticulata (SNpr), hyperactivation can occur in the superior colliculus. Surprisingly, the participant exhibited reflexive saccades in the anti-saccade task not only toward the right side but also toward the left side. These findings are puzzling and indicate that a higher error rate in the anti-saccade task cannot be solely explained by a failure in visual fixation. The research also demonstrated that the inhibition errors of involuntary saccades after superior colliculus lesions can be counterbalanced, as the error rates were reduced during the second examination. Guitton et al. (1985) suggested that advanced control of involuntary saccades is applied by the frontal cortex. In fact, the authors discovered that individuals with unilateral frontal lobe lesions either had trouble starting the anti-saccade or were rarely able to prevent an involuntary saccade toward the visual stimuli. Additionally, the frontal or supplementary eye fields were essential for performing the anti-saccade task correctly. However, further lesion research did not fully support these hypotheses.

To sum up, the brain structures involved in executing the anti-saccade task include the dorsolateral prefrontal cortex, frontal eye field, supplementary eye field, anterior cingulate, posterior parietal cortex, area 17, insula, thalamus, putamen, caudate, substantia nigra pars reticulata (SNPr), and superior colliculus (SC). Two functional subprocesses are crucial for the anti-saccade task to be performed correctly: the capability to execute a purposeful saccade to the opposite side and an intact fixation mechanism. The fixation mechanism includes omnipause neurons in the brain stem, fixation neurons in the rostral superior colliculus, parts of the caudate and substantia nigra pars reticulata (SNPr), and neurons in the supplementary eye field, frontal eye field, and area 46. In the anti-saccade task, any disruption in these areas can cause deficits in the inhibition of involuntary saccades (Everling & Fischer, 1998).

1.3 Bridging Executive Functions and Anti-Saccade Task

The prefrontal cortex is considered to be the neural basis of the executive functioning competencies. Crawford, Venneri, and O'Carroll (1998) suggested that, in contrast to the more localized deficits brought on by posterior lesions, executive deficits frequently have a bigger influence on the ability of a patient to effectively adapt. According to Reitan and Wolfson (1994), one of the most difficult areas in neuropsychological assessment is executive deficits because they are hard to measure (Crawford, 1998).

Lezak (1982) highlighted that patients who have experienced severe damage or conditions to the prefrontal area of the brain, especially if the orbital or medial regions have been affected, typically experience behavioral and personality abnormalities that make it impossible for them to lead normal, socially responsible lives. The ability to function fully and engage in social interactions as before may be reduced in people with mild injuries due to alterations in drive, the intensity, stability, or flexibility of response, or in social sensitivity. Frontal lobes have typically been attributed to executive activities since many of the most impairing alterations these individuals experience involve one or more of their executive capacities. Luria (1973) highlighted some crucial facts contribute to the limited scope of typical neurological symptoms: lesions of the highest (secondary or tertiary) zones of the cortex, which are thought to be uniquely human parts of the hemispheres, generally do not cause any basic sensory or motor defects and are inaccessible to traditional neurological examination. The development of complex behavioral programs, their control, and alterations in cognitive processes are all associated with functional disorders. For the local diagnosis of lesions in these intricate cortical zones, neuropsychological techniques must be used. Lesions in different parts of the brain cause very different types of deterioration within the same "functional system," rather than just affecting a specific complex of functions.

Mirsky et al. (2011) emphasize that, in a clearly defined cohort of older adults who are cognitively and functionally normal, the anti-saccade task is a sensitive indicator of executive dysfunction and frontal lobe structure. The percentage of correct anti-saccade responses was strongly correlated with executive functioning, specifically performance on the design fluency task, even after controlling demographic variables. According to research on people with neurological disorders, there is a strong correlation between accurate anti-saccade responses (including or excluding self-corrected errors) and various executive function measures in cognitively normal older adults. Research by Boxer et al. (2006) revealed that neuropsychological performance, especially on executive function measures, is significantly correlated with the percentage of correct anti-saccade (AS) responses (including or excluding self-corrected errors) in patients with neurodegenerative dementia. Similarly, Hutton et al. (1998) reported that schizophrenic patients have also shown these correlations.

Gray matter volume in the left inferior frontal junction (IFJ) and the right supplementary eye field (SEF), two important areas of the inhibitory control network, were correlated with the percentage of correct anti-saccade responses. The results show that, in cognitively normal older adults, the anti-saccade task is highly responsive to subtle frontal lobe dysfunction, which may indicate an increased risk of cognitive impairment in the future (Mirsky et al., 2011). According to the study by Chikazoe et al. (2007), the frontoparietal network involved in response inhibition in both manual and oculomotor tasks, especially when there is a strong prepotent response tendency, including the right inferior frontal gyrus (rIFG).

The area of the brain most closely linked to executive functioning is the prefrontal cortex. According to Baddeley and Wilson (1988), people who have lesions in various prefrontal cortex regions may exhibit symptoms of the so-called dysexecutive syndrome. Cicerone et al. (2000) suggest that this syndrome affects social behavior, emotion, goal-oriented behavior, and cognition. Al-Adawi, Powell and Greenwood (1998) suggest that deficits in motivational actions and social interactions result from damage to the orbitofrontal and anterior cingulate cortex. Higher-level cognitive issues involving goal-directed behaviors are present in people with dorsolateral prefrontal cortex lesions. (Cristofori et al., 2017). The large area anterior to the precentral sulcus, known as the lateral prefrontal cortex, may be the region of core executive functions. Dosenbach et al. (2007), Fair et al. (2007), and Morton (2010) suggested that executive function is not limited to the prefrontal cortex independently. Instead, an enormous system of areas within the frontal and posterior cortical regions is where cognitive flexibility and control originate (Buss & Spencer, 2014). Friedman and Robbins (2022) suggested that the prefrontal cortex is perfectly suited to take part in multiple neural networks and perform cognitive control operations in various functional domains due to its neuroanatomical connectivity to the majority of cortical and subcortical brain structures, including spatial, visual, and verbal domains.

According to Menon and D’Esposito (2022), and Haber et al. (2022), various networks involving the prefrontal cortex and other brain areas are highlighted by resting-state and functional connectivity data. These include the fronto-parietal network (FPN), which is based in the dorsolateral prefrontal cortex, dorsomedial prefrontal cortex, and posterior parietal cortex; the cingulo-opercular network (CON), which overlaps with the salience network and includes the anterior cingulate cortex, insula, and subcortical areas; the ventral attention network, which consists of the temporoparietal junction, areas of the insula, and the inferior frontal gyrus; the dorsal attention network, which involves the frontal eye fields and intraparietal sulcus; and the default mode network (DMN), which functions at rest and is linked to internal control processes, comprising posterior cortical areas and medial prefrontal cortex regions. Multiple Demand (MD) characteristics may be included in particular prefrontal cortex (PFC) areas in hybrid models of organization, while neural connectivity specificity enables control functions such as updating, response inhibition, cognitive flexibility, and other forms of cognitive control. According to neuroimaging research, Hampshire and Owen (2006) suggest that reversal learning stimulates the orbitofrontal cortex following negative feedback, whereas set shifting activates the lateral prefrontal cortex regions. Parietal stimulation occurs when stimulus-reward mapping is being overwritten, and the generation of new solutions is associated with dorsolateral prefrontal cortex activation (Friedman & Robbins, 2021).

According to the domain-specific analysis of Rodríguez-Nietoa (2022), for the inhibition paradigm, the findings show a slightly more right-lateralized fronto-parietal network that was comparable to the overall network observed in the global analysis. The thalamus, basal ganglia (caudate nucleus and putamen), and right fronto-insular network displayed significant activation. The left hemisphere showed similar clusters, with parietal, temporal, and occipital activations extending into the cerebellum, precuneus, and superior parietal lobule. While the anti-saccade task had less involvement, paradigm-specific analyses of tasks such as Flanker, Go/No-go, Stop Signal, Stroop, and anti-saccade revealed consistent activation in the middle frontal gyri and medial frontal regions. With the exception of the anti-saccade task, all tasks involved active inferior frontal gyri. Different precentral, parietal, and insular activations were observed; the Go/No-go and Stop Signal tasks recruited subcortical regions such as the striatum and thalamus, as well as fronto-insular-subcortical clusters. Conjunction analyses revealed that the insula, inferior frontal gyrus, and posterior-medial frontal cortex showed similar activation across inhibition paradigms. Additional activation was observed in occipital, temporal, and striatal regions during response inhibition tasks, such as the Go/No-go and Stop Signal tasks. However, more extensive inferior frontal activations were required for interference control tasks, such as Flanker and Stroop. According to contrast analyses, inhibition-specific activation was observed in the right striatal, right fronto-temporal, and bilateral parietal regions, particularly in the putamen and caudate nucleus.

For the Shifting paradigm, the findings revealed a fronto-parietal network that was somewhat more left-lateralized and had smaller clusters than the global analysis. The left insular lobe, precentral gyri, left middle and inferior frontal gyri, and subcortical areas like the thalamus, putamen, and caudate nucleus were all included in the largest activation cluster, which was located in the left frontal cortex. Although it was restricted to the right middle and inferior frontal and precentral gyri, a similar cluster was discovered in the right hemisphere. A left temporo-occipital cluster (left fusiform and inferior temporal gyri), a bilateral parietal cluster (peaking in inferior parietal areas, extending into the precuneus and superior parietal lobule), the precentral gyri, the posterior-medial frontal cortex, and a subcortical cluster in the right thalamus were also activated. Analyses of shifting paradigms independently revealed that the Dual Task paradigms only activated parts of the left hemisphere, specifically the left middle and inferior frontal gyri, the insular lobe, and the superior and inferior parietal regions. These parts were similar to those found in the Rule/Response Switching and Wisconsin Card Sorting Test. In the right insula, right infero-parietal cortex, and posterior-medial frontal cortex, Rule/Response Switching and Wisconsin Card Sorting overlapped. Additionally, Wisconsin Card Sorting stimulated bilateral thalamus, right middle frontal gyrus, and left hemisphere temporo-occipital regions. Intra-domain conjunction shows that general activations were observed in the left superior and inferior parietal lobules, left middle and inferior frontal gyri, and left insular lobe across Dual Task, Rule/Response Switching, and Wisconsin Card Sorting tasks. Contrast analyses revealed that shifting-specific activation was primarily left-lateralized and involved the precuneus, preSMA, precentral gyrus, superior and inferior parietal lobule, and left middle and inferior frontal gyri. The parietal lobe (precuneus, superior parietal lobe) and bilateral thalami exhibited the majority of shifting-specific activity in the right hemisphere.

To determine which brain regions were consistently active, conjunction analyses were performed for the executive functioning domains. In line with the global analysis, the results showed a significant fronto-parietal network that was portrayed as a "core" executive functioning network. The insular lobe, posterior-medial frontal cortex (preSMA), and bilateral frontal cortices (middle and inferior frontal gyri) all displayed overlapping activity in this network. The precunei and superior and inferior parietal lobules were covered by parietal activations. Furthermore, subcortical areas such as the bilateral thalami, left caudate nucleus, and pallidum, as well as a left-lateralized temporo-occipital cluster (fusiform and inferior temporal gyri), showed consistent activation.

Despite numerous research papers published in this area, the main purpose of this research is to determine whether the anti-saccade task effectively involves inhibition processes and task-switching by correlating the results obtained in this task with those computerized tests that evaluate inhibitory processes and task-switching, such as the Stop signal task, Go/no go Task, Wisconsin Cart Sorting task and the Stroop task. It is hypothesized that performance on the Anti-Saccade task which requires the inhibition of reflexive saccades will demonstrate significant correlations with tasks specifically designed to measure inhibition (e.g., the Stop Signal Task, the Go/No Go Task, and the Stroop Task), as well as task switching (e.g., the WCST). This study aims to clarify the cognitive mechanisms underlying Anti-saccade performance and its role as an indicator of executive function by examining these relationships.

CHAPTER 2: Material and methods

2.1 Subjects

For this study, 30 adult participants (25 females, 5 males; mean age mean age ± SD = 25.5± 3.17 years), "all of whom were University of Padova students pursuing either a bachelor's or master's degree," were recruited. All participants had normal or corrected-to-normal vision. The exclusion criteria were age under 18, having a serious head injury and brain damage, and not being fluent in English. Due to a technical problem, we could not have access to one of the participant's data. The final sample comprised a total of 29 participants (24 females, 5 males; mean age ± SD = 25.44 ± 3.15 years, 27 right-handed and 2 left-handed). Before taking part in the experiment, participants were given an informed consent form in compliance with EU regulations. The present study has been approved by the Ethics Committee of the Department of General Psychology of the University of Padua, Italy.

2.2 Procedure, Experimental Setup and Equipment

All participants underwent five different cognitive task sessions within a one-hour period, with data collected within a week. All participants performed the tasks in the following order: Saccade/Antisaccade Task, Go/No-Go Computerized Task, Stop Signal Computerized Task, Stroop Computerized Task, and Wisconsin Card Sorting Computerized Task. Data collection was performed by Python, PsychoPy, and Open-source software, and analysis of these tasks was conducted by Python, R, and R Studio software.

Eye movements during the Saccade/Antisaccade tasks were recorded using the Tobii Pro Spectrum eye-tracking system, which operates at a 600 Hz sampling rate with 0.03° RMS precision and 0.3° accuracy. The eye tracker was positioned at the bottom of the screen and recorded only the spatial coordinates of the eyes and pupil size, ensuring no personal visual information was captured. Infrared light was used to enhance data accuracy, and participants maintained a stable position to minimize head and body movement. Calibration and validation were conducted using a 9-point system prior to the experiment to ensure optimal tracking accuracy.

The computer configuration included an Intel Core i7-13700K processor, Asus ROG STRIX Z690-A GAMING WIFI D4 ATX LGA 1700 motherboard, 32 GB Corsair Vengeance LPX RAM (2x16, DDR4-3600 CL 18), an MSI GeForce RTX 3060 VENTUS 2x 12GB graphics card, and Windows 10 Pro (64-bit). The display used was a 23” EIZO FlexScan EV2451 IPS monitor with a 1920x1080 resolution, 60 Hz refresh rate, and 5 ms response time.

Data processing is conducted to ensure maximum security and confidentiality, using manual, IT, and telematic tools suitable for securely storing, managing, and transmitting data. The university does not employ automated decision-making processes, including profiling, that could impact on the rights of the data subject, in full compliance with the safeguards provided by Article 22 of the EU Regulation. The study was conducted in Laboratory C12, Department of General Psychology, Via Venezia, 8.

2.3. Materials

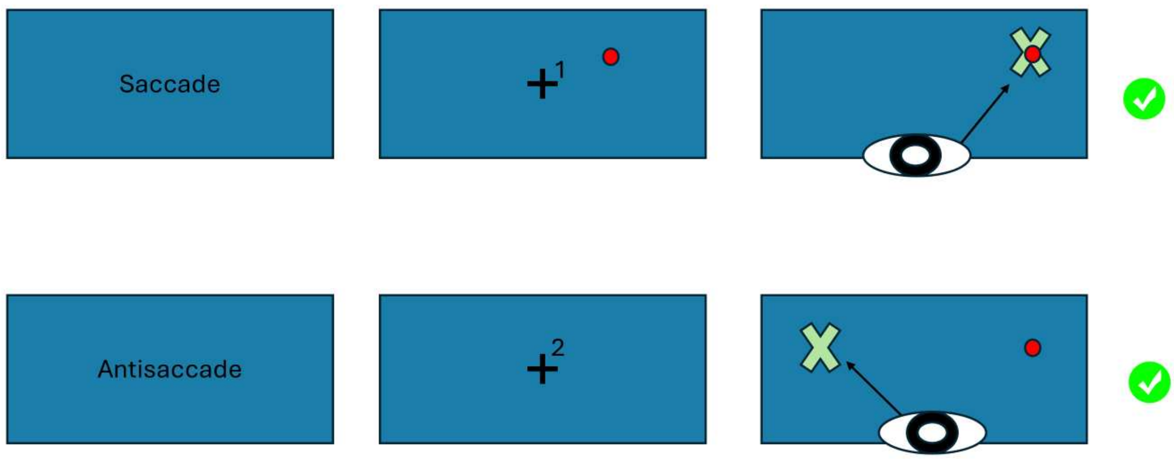
2.3.1. Saccade and Anti-Saccade Task: In this task, participants are required to fixate on the center of the screen. Peripheral light spots then appear, and participants must either make a saccade toward the light spot in Condition A or toward a symmetric position (where the light spot is absent) in Condition B, the anti-saccade task. Each trial within a block is preceded by a cue that indicates whether the upcoming task is a saccade (Task A) or an anti-saccade (Task B). Peter Hallett developed the anti-saccade task, which aims to search the mechanism underlying voluntary saccade control. Direction timing and frequency errors provide information to understand the process of saccade inhibition, which is required for suppression of automated signals (Coe & Munoz, 2017). The saccade task requires the effective functioning of systems supporting attention (Jazbec et al., 2006).

To initiate the experiment, a setup screen opens to allow the entry of various experimental parameters. These parameters include the date, which is automatically generated to reflect the current day, and language, where the user can choose between "ita" for Italian and "eng" for English instructions. Additionally, the parameter nTest specifies the number of tests conducted for each participant, while Participant is a unique progressive identifier assigned to each individual to ensure precise data tracking. The Side Stimuli parameter designates the side where the stimulus will appear, and Trials determine the total number of test trials included within each session.

At the start of each session, the participant is seated and positioned to ensure comfort, alignment with the eye tracker, and appropriate distance from the monitor. The initial calibration screen helps confirm that the participant is centered along the horizontal axis, critical for accurate eye tracking. Horizontal eye movements are recorded throughout the test, and eye position calibration is conducted at the beginning of each session, targeting an accuracy within 1.0 degree and data loss under 5%. The anti-saccade test for this study consists of 90 trials, which typically take 15 minutes to complete, with all data captured and analyzed using custom software.

The test begins with a fixation point (+) and a number displayed in the center of the screen, where the participant is instructed to fixate. After fixation, a target dot appears. If the displayed number is “1,” the participant should focus on the target dot. If the number is “2,” the participant should direct their gaze to a point equidistant from the target dot on the opposite horizontal side of the screen.

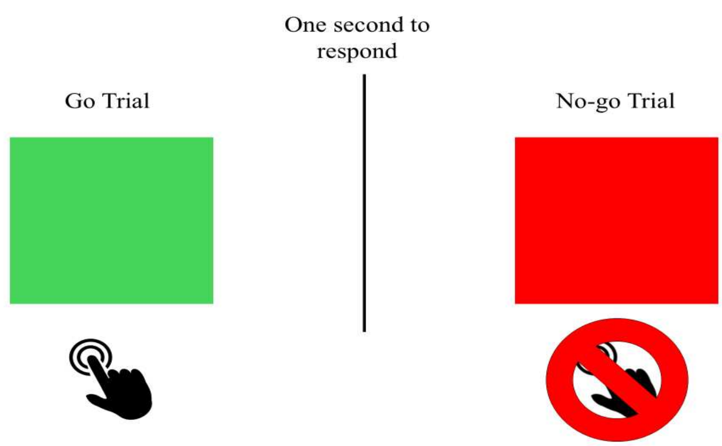
Figure 1: Description of The Saccade and Anti-Saccade Task



2.3.2. Cognitive Tasks: All participants performed the tasks in the following order: Go/No-Go Computerized Task, Stop Signal Computerized Task, Stroop Computerized Task, and Wisconsin Card Sorting Computerized Task.

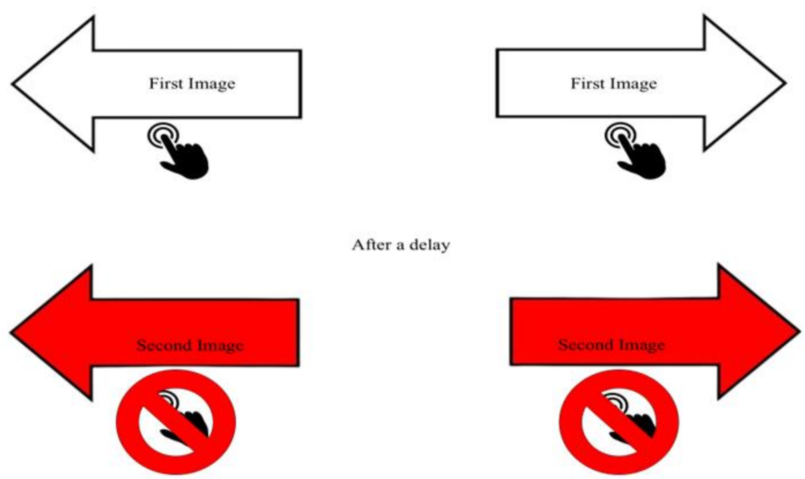
- *The Go/No-Go task* is developed to investigate cognitive processes such as attention, impulse control, and response inhibition. Participants are required to respond to certain stimuli; it investigates their capability to regulate automatic responses and sustain attention. The main variables measured in the Go/No-Go task include error rate, reaction time, and accuracy. The Go/No-Go task is a largely used and validated experimental paradigm, which generally applied in studies of response inhibition and cognitive control. The Go/No-Go task involves inhibition of automatic responses with little preparatory effort. It is generally carried out using a manual response modality, which indicates that, based on specific instructions, participants are required to act or refrain from acting. (Chikazoe et al., 2007), the Go/No-Go Computerized Task is an experimental paradigm that requires participants to respond by pressing a button when they see a “go” signal and not respond when they see the “no-go” signal. The “go” signal is described as a green square, and the “no-go” signal is described as a red square. All the participants administered 200 trials in this task, which typically takes about the estimated task duration, which is 5-10 minutes to complete. Data analysis mainly focused on calculating correctness and response times. Python software and R Studio software were used for programming the task, capturing data, and analyzing reaction time distributions, accuracy, and other relevant performance metrics.

Figure 2: Description of The Go/ No Go Task



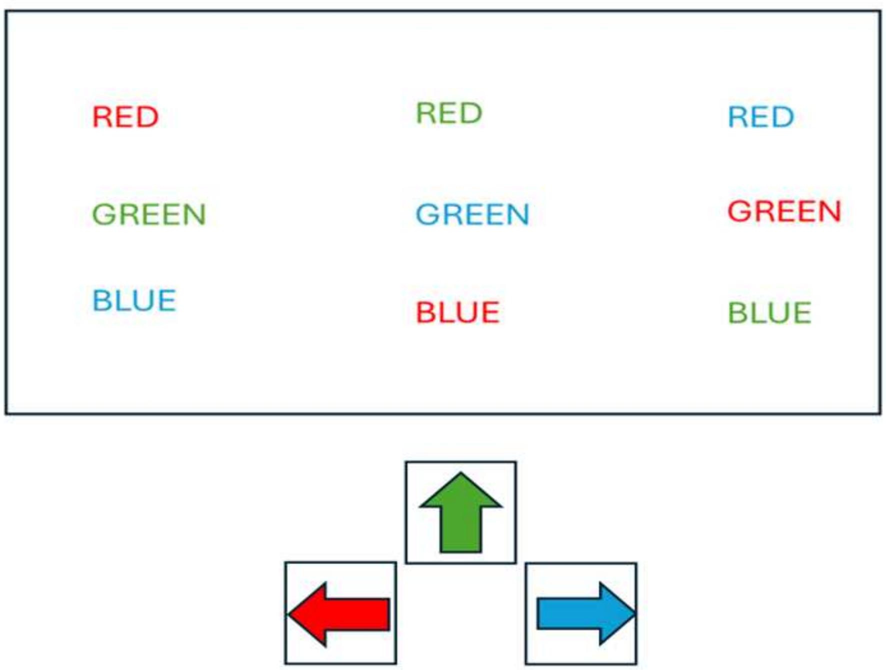
- *The Stop Signal Task* is a well-established experimental paradigm that developed to examine response inhibition, particularly the ability to stop executing the motor response that might already be underway. The task is used to study inhibitory control in both healthy and clinical populations across a variety of contexts (Dimitrov et al., 2003; Aron et al., 2003), and it has been validated in numerous studies (Congdon et al., 2012). The task measures cognitive controls and focuses on how efficient and quick participants can interrupt an automatic action. The Stop Signal Task is a paradigm that requires participants to respond quickly to a stimulus, except when a stop signal arrives. Data analysis generally focused on reaction time and correctness variables. Reaction time measures the time it takes for participants to stop an ongoing response after the stop signal is presented. Correctness measures the successful stops and failures to stop the action. All the participants administered 300 trials in this task, which typically takes about an estimated task duration, which is 10 minutes to complete. Python, open-source software, and R Studio software were used for programming the task, capturing data, and analyzing reaction time distributions, accuracy, and other relevant performance metrics.

Figure 3: Description of Stop Signal Task



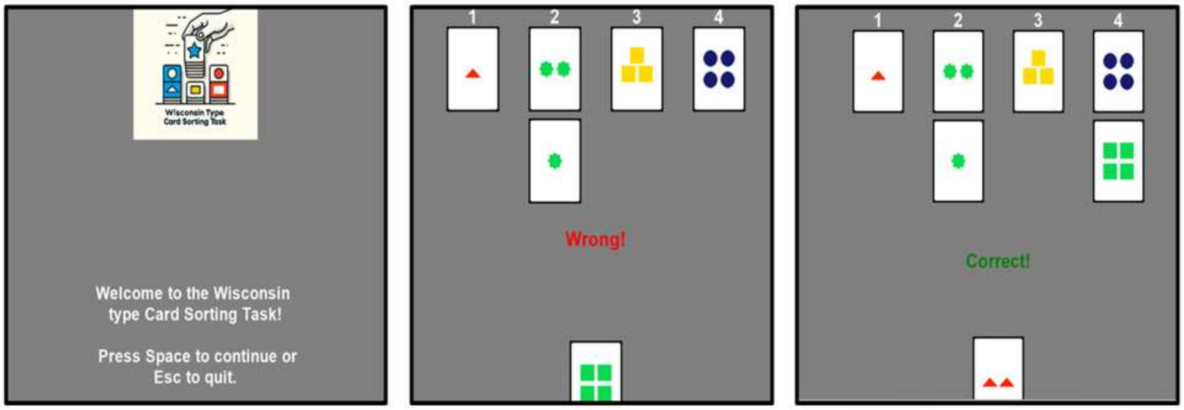
- *The Stroop Task* is a psychological assessment designed to evaluate an individual's capacity to control cognitive interference. It is one of the most used assessments of cognitive control and executive function, validated by numerous studies and considered a strong, reliable tool. It examines the capability of inhibiting the automatic response of reading a word, instead prioritizing the less automatic task of identifying the color of the ink. Data analysis generally focused on reaction time and correctness variables. The differences in reaction time are often referred to as the Stroop interference effect and are used to assess the level of cognitive interference. The Stroop effect represents the increase in reaction time when a participant inhibits the automatic response of reading and instead performs the task-relevant color-naming response (Erdoğan Bakar & Karakaş, 2020). All the participants administered 100 trials in this task, which typically takes about an estimated task duration, which is 10 minutes to complete, and a key was assigned for each color to record the responses: red, green, and blue, in that order from left to right. Python software and R studio software were used for programming the task, capturing data, and analyzing reaction time distributions, accuracy, and other relevant performance metrics.

Figure 4: Description of The Stroop Task



- *The Wisconsin Card Sorting Computerized Task* is a higher-level complex cognitive task that requires that each 'trial' participants 'match' the response card to one of the four stimulus cards without specific instruction by the administrator. The Wisconsin Card Sorting Test is a well-created neuropsychological test to measure cognitive flexibility, executive functioning, and problem-solving ability. It has been shown to be highly reliable and valid in measuring, particularly in studies of brain damage, aging, and neurodevelopmental disorders that have been demonstrated, such as the reliability and validity of the WCST in autism samples (Ozonoff, 1995). It challenges participants to adjust to changing rules and learn from feedback, making it a key measure of cognitive flexibility and the ability to adjust strategies in response to new information. The sorting rule is the dimension on which the card needs to be correctly matched, and the participant identifies the sorting rule through a process of trial and error. For example, a response card with two blue triangles can be matched according to color (blue), form (triangle), or number (two). After each response, the participant receives feedback (i.e., 'correct' or 'incorrect') that can be used to establish the correct sorting rule. Data analysis generally focuses on the number of correct matches, the number of perseverative errors, and the number of categories completed. We mainly focus on correctness variables according to other tasks. All the participants administered 65 trials in this task, which typically takes about an estimated task duration, which is 20 minutes to complete, and a key was assigned for each deck to record the responses: one, two, three, and four. Open-source software was used for the task and capturing the data, and R Studio software was used for analyzing correctness distributions, accuracy, and other relevant performance metrics. Performance scores of each participant were calculated by using the Heaton (1981) Wisconsin Card Sorting Manual.

Figure 5: Description of The Wisconsin Card Sorting Task



2.4 Analysis:

In the current data analysis, we examined the correlations using Pearson correlation between the Anti-saccade/saccade task and the computerized cognitive tasks: Stop Signal Task, Stroop Task, and Wisconsin Card Sorting Task. Unfortunately, because of a technical problem, we don't have access to Go/No Go Task data. A p-value threshold of 0.05 was utilized to evaluate the statistical significance of these correlations. Outliers that could potentially affect the correlation results were identified and eliminated using Grubbs' test to ensure the accuracy and reliability of the findings. After the removal of outliers, the correlation analysis was conducted again for consistency. Statistical analyses, including outlier detection and p-value calculations, were performed using R software version 3.5.2 and R Studio. The Grubbs test is essential for providing reliable statistical outcomes in small populations and improving the validity of research findings.

CHAPTER 3: Result

In the present study, we applied Pearson correlation analyses (r^2) to examine the correlations between saccade/anti-saccade task performance and cognitive task performance. The analysis centered on two main variables: correctness and reaction time. 29 participants were included in the study, and before correlation analysis, outliers were eliminated using the Grubbs test. A 0.05 α-level criterion was used to determine statistical significance.

3.1 Analysis of Correctness

The relationships between correctness variables across all tasks were investigated in the first section of the analysis. The pairwise comparisons listed below were examined: Correctness of stop signal and correctness of saccade; correctness of stop signal and correctness of anti-saccade; correctness of Wisconsin Card Sorting Task (WCST) and correctness of saccade; correctness of Wisconsin Card Sorting Task (WCST) and correctness of anti-saccade; correctness of saccade and correctness of Stroop test; correctness of anti-saccade and correctness of Stroop test.

3.2 Analysis of Reaction Time

The second part of the analysis concentrated on variables related to reaction time across tasks, excluding the WCST as it does not provide reaction time data. The pairwise comparisons listed below were carried out: In the tables, the analysis of the results is, respectively: reaction time of the saccade and the reaction time of the stop-signal task; the reaction time of the anti-saccade and the reaction time of the stop-signal task; the reaction time of the saccade and the reaction time of the Stroop task; and the reaction time of the anti-saccade and the reaction time of the Stroop task.

Detailed correlation coefficients (r^2) and p-values are presented in the accompanying tables.

3.1.1 Correlation Between Correctness of Saccade and Stop Signal Tasks

The first Pearson correlation analysis examined the relationship between saccade correctness and stop signal correctness before the Grubbs test for outlier exclusion was used. Table 1 provide a summary of the analysis's findings. The results of the analysis showed a weak positive correlation between saccade correctness and stop signal correctness, with a Pearson's product-moment correlation coefficient of $r=0.200$. But according to $t(27)=1.063$, $p>0.05$, this correlation was not statistically significant. To find any possible outliers in the data, the Grubbs test was then used. Both saccade correctness ($G=3.732$, $P<0.05$) and stop signal correctness ($G=3.606$, $P<0.05$) had significant outliers, according to the Grubbs test results. Following the removal of these outliers, a second Pearson correlation analysis showed that Saccade correctness and stop signal correctness showed a moderately positive correlation ($r=0.392$) in the updated analysis, which was statistically significant ($t(25)=2.129$, $P<0.05$). The removal of outliers, suggesting a statistically significant linear relationship between the two outcomes. These results imply that a significant correlation between saccade correctness and stop signal correctness was first masked by the existence of outliers.

Table 1

Pearson Correlation Analysis: Correctness of Saccade and Stop Signal (Before and After Outlier Removal)

Variable 1	**Variable 2**	**r**	**t**	**df**	**p-value**	**95% CI**
Saccade Correctness	Stop Signal Correctness	0.200	1.063	27	p>0.05	[-0.179, 0.528]
Saccade Correctness*	Stop Signal Correctness*	0.392	2.129	25	P<0.05	[0.014, 0.672]

Note. The second row represents the correlation analysis after outlier exclusion using the Grubbs test.

To more effectively determine the findings in Table 1 and visually inspect the characteristics of the variables' relationship, the relationship between saccade correctness and stop signal correctness represented using scatter plots. It is evident from these plots how outliers affect the analysis and how the relationship changes when they are eliminated. The change from a weak and non-significant relationship in the original analysis to a moderate and statistically significant relationship after removing outliers is visually supported by the scatter plot Figure 6A and 6B.

Figure 6A

Scatter Plot of Correctness of Saccade and Stop Signal (Before Outlier Removal)

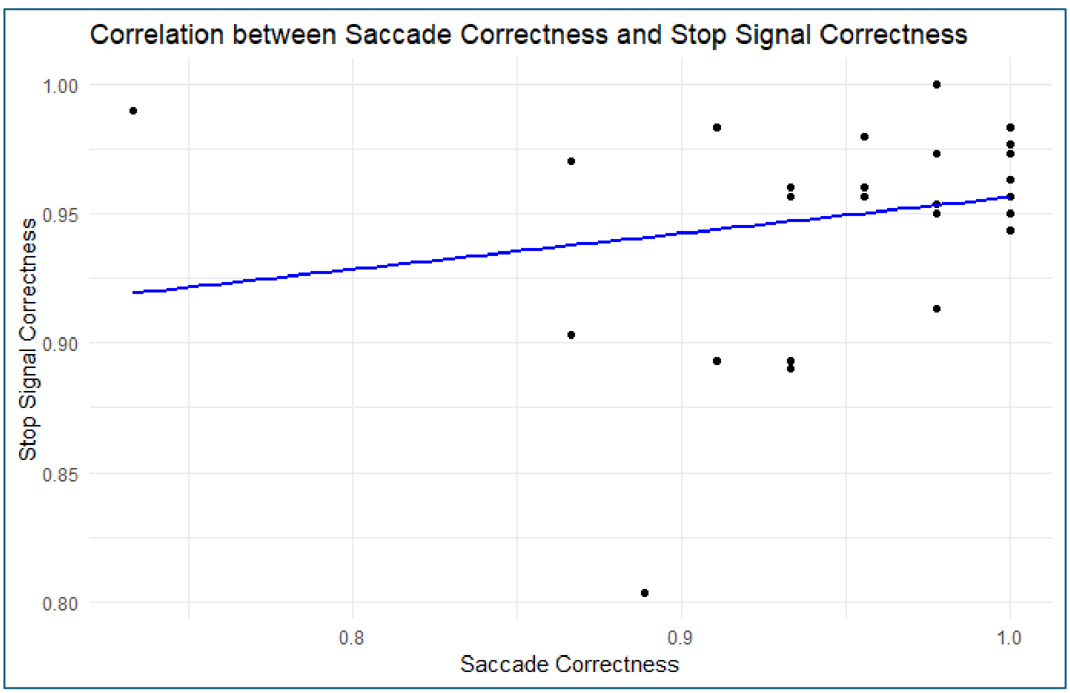
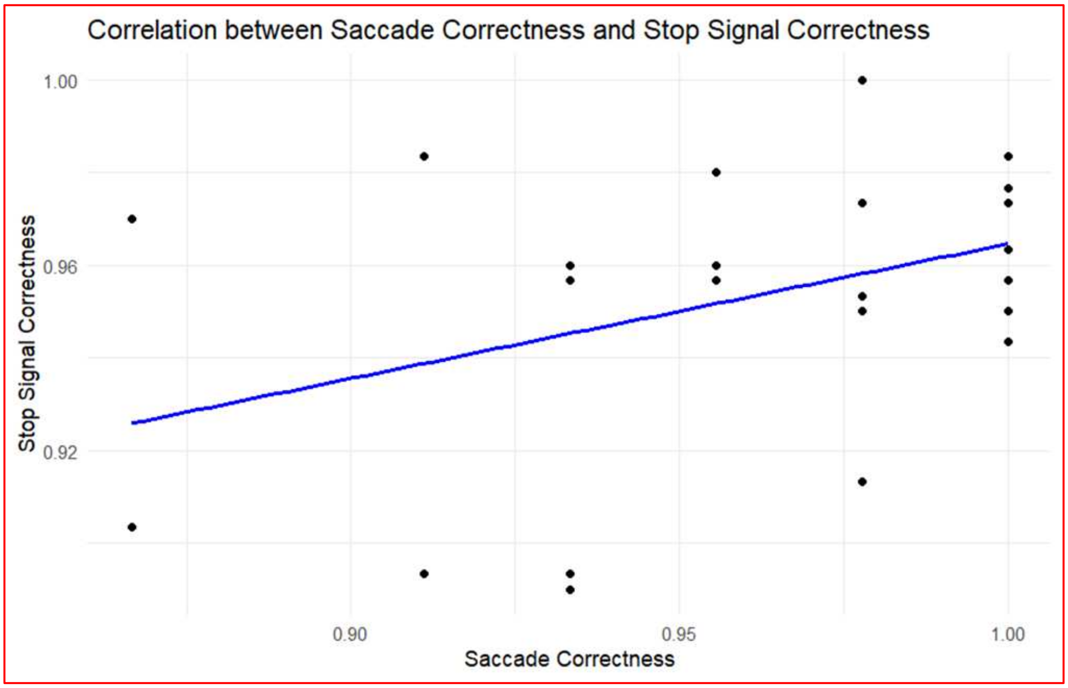


Figure 6B

Scatter Plot of Correctness of Saccade and Stop Signal (After Outlier Removal)



3.1.2 Correlation Between Correctness of Anti-Saccade and Stop Signal Tasks

Firstly, before applying the Grubbs test for outlier elimination, the correlation between Anti-saccade correctness and Stop Signal correctness was examined. The analysis's conclusions are summarized in Tables 1a and 1b. Although there was a weak positive correlation (r=0.162) in the results, it was not statistically significant (t (27) =0.856, p>0.05). In order to determine whether the data contained outliers, the Grubbs test was used. Results suggested significant outliers in anti-saccade accuracy (G=1.691, p<0.05) and stop signal accuracy (G=3.606, p<0.05). Following the elimination of these outliers, a second Pearson correlation study was conducted. A slightly stronger but still non-significant positive correlation between anti-saccade correctness and stop signal correctness was indicated by the updated analysis (r=0.242, t (25) =1.246, p>0.05). The results suggesting that the relationship was still not significant even after excluding outliers.

These findings reveal that there is no statistically significant linear correlation between anti-saccade correctness and stop signal correctness, regardless of whether outliers are included in the dataset. The presence of outliers did not mask the significant link because the correlation in both analyses remained weak and non-significant.

Table 2

Pearson Correlation Analysis: Anti-saccade Correctness and Stop Signal Correctness (Before and After Outlier Removal)

Variable 1	Variable 2	r	t	df	p-value	95% CI
Antisaccade Correctness	Stop Signal Correctness	0.162	0.856	27	p>0.05	[-0.217, 0.499]
Antisaccade Correctness*	Stop Signal Correctness*	0.242	1.246	25	p>0.05	[-0.152, 0.570]

Note. The second row represents the correlation analysis after outlier exclusion using the Grubbs test.

In order to illustrate the way outliers, affect the correlation analysis, two scatter plots were created. Without outlier removal, Figure 7A shows the relationship between anti-saccade correctness and stop signal correctness; following outlier removal, Figure 7B shows the relationship. The scatter plots provide a clear graphical representation of the effect of outlier removal which reflects on the variables' correlation. After outliers were eliminated, the correlation coefficient increased slightly, however the correlation was still not significant.

Figure 7A

Scatter Plot of Correctness of Anti-saccade and Stop Signal (Before Outlier Removal)

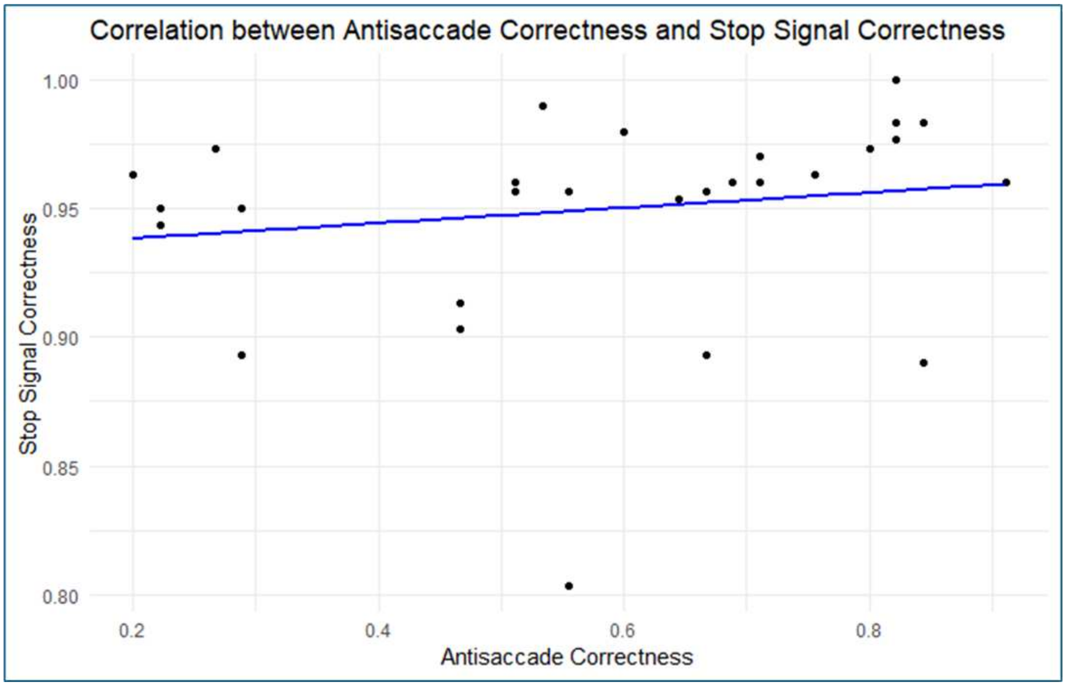
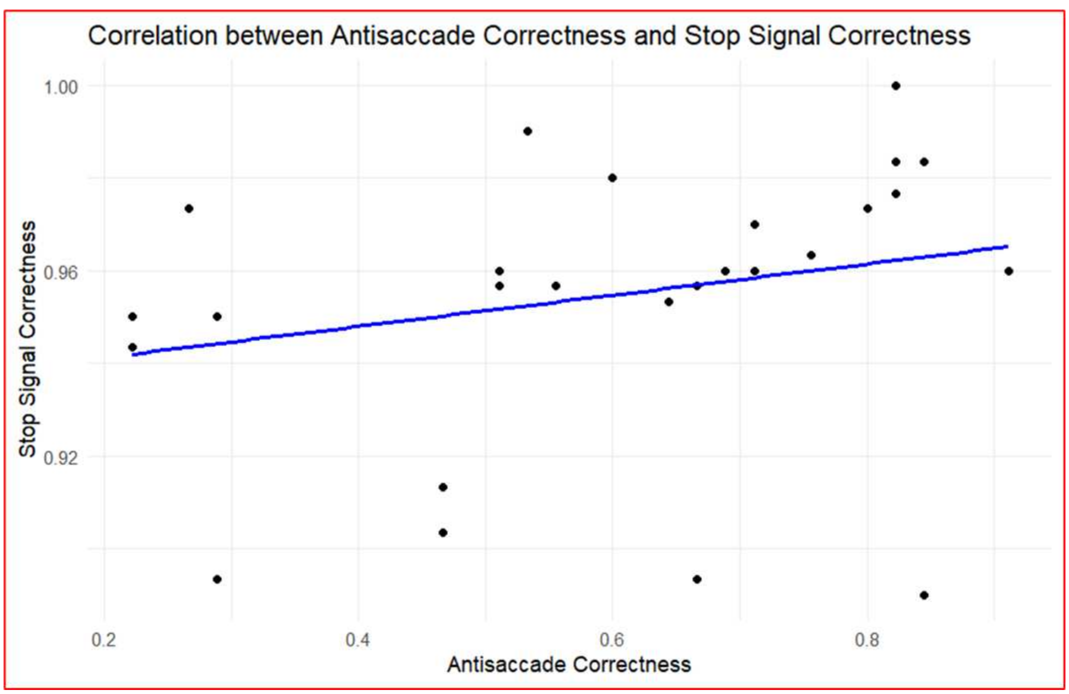


Figure 7B

Scatter Plot of Correctness of Anti-saccade and Stop Signal (After Outlier Removal)



3.1.3 Correlation Between Correctness of Saccade and Wisconsin Card Sorting Tasks

Both saccade and Wisconsin Card Sorting Task (WCST) correctness were evaluated by the first Pearson correlation analysis. The analyses demonstrate a minor positive correlation (r=0.155), however it did not appear to be of statistical significance (t (27) =0.814, p=0.423, p>0.05). It showed there was not a significant linear association between the two variables. The Grubbs test followed to identify the potential outliers in the data. The saccade correctness variable showed a significant outlier (G=3.732, p<0.05), but the WCST correctness outcomes indicated no significant outlier (G=2.606, p<0.05). The second Pearson correlation analysis was performed and revealed a stronger positive correlation (r=0.330), but didn't reach statistical significance (t (26) =1.782, p<0.05). After removal of the outlier, the results confirm that the relationship persisted as marginally non-significant. According to these results, the correlation between saccade correctness and WCST correctness improved once the outlier in saccade correctness was removed, however the association was still below the standard thresholds of statistical significance. Table 3 displays results of the correlation analysis.

Table 3

Pearson Correlation Analysis: Correctness of Saccade and Wisconsin Card Sorting Tasks (Before and After Outlier Removal)

Variable 1	Variable 2	r	t	df	p-value	95% CI
Saccade Correctness	WCST Correctness	0.155	0.814	27	p>0.05	[-0.224, 0.493]
Saccade Correctness*	WCST Correctness*	0.330	1.782	26	p>0.05	[-0.049, 0.626]

Note. The second row represents the correlation analysis after outlier exclusion using the Grubbs test

In order to show how the outlier influenced the correlation analysis, two scatter plots had been created. Saccade correctness and WCST correctness association before outlier elimination shown in Figure 3A, and after the outlier is removed, the association is displayed in Figure 3B. The scatter plots give an accurate visual representation of how the correlation of variables improved after the outlier had been removed. The correlation coefficient went from r=0.155 to r=0.330, but the relationship remained not statistically significant.

Figure 8A

Scatter Plot of Saccade Correctness and WCST Correctness (Before Outlier Removal)

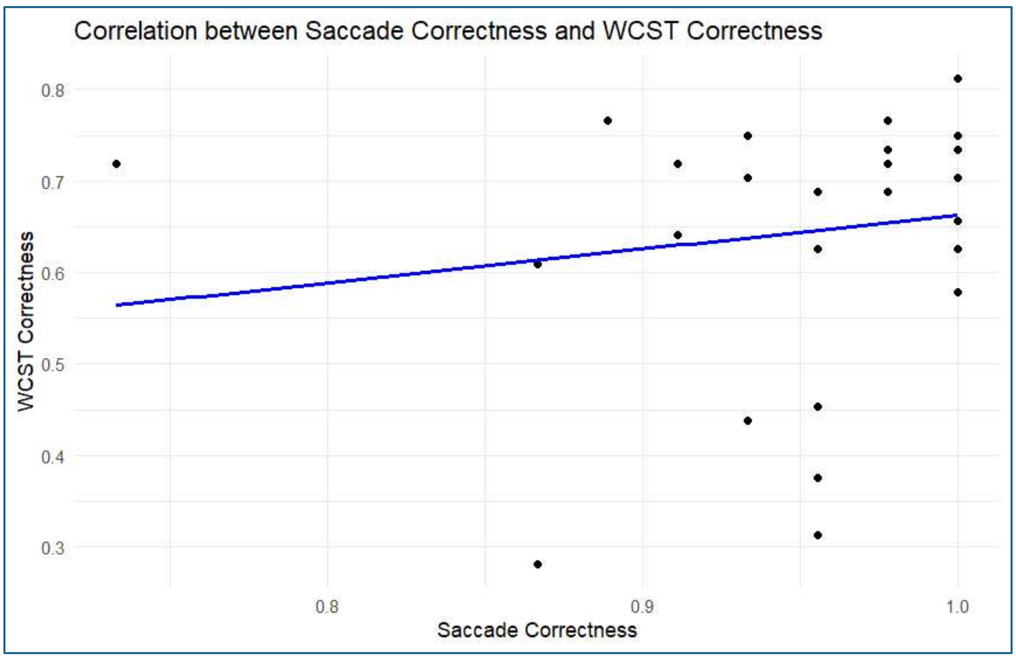
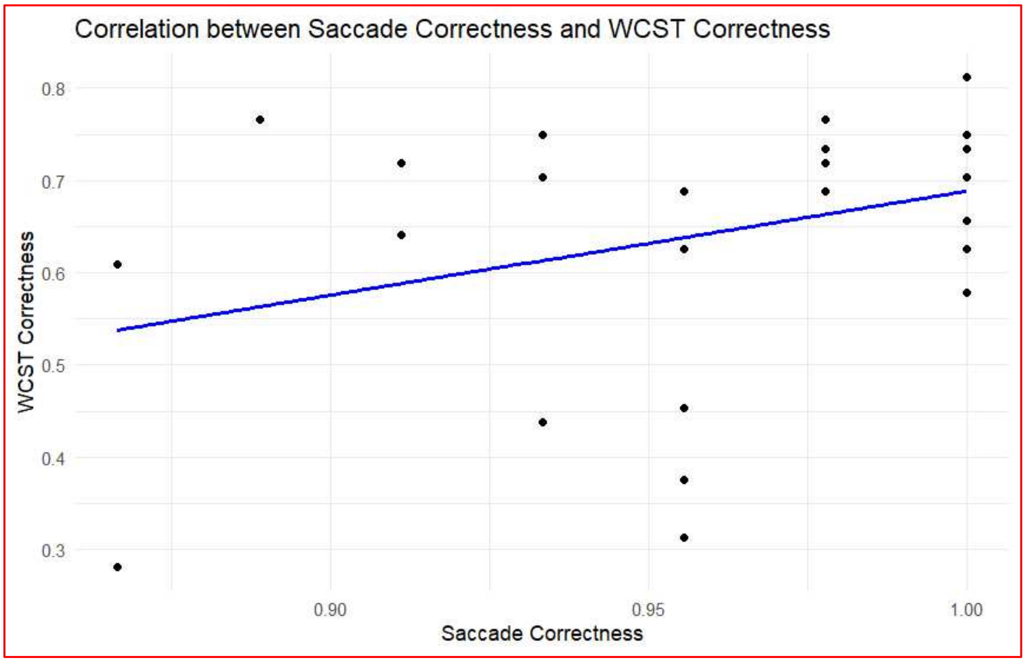


Figure 8B

Scatter Plot of Saccade Correctness and WCST Correctness (After Outlier Removal)



3.1.4 Correlation Between Correctness of Anti-Saccade and Wisconsin Car Sorting Tasks

Anti-saccade correctness and WCST correctness showed a very weak, non-significant negative correlation ($r=-0.023$, $t(27)=-0.117$, $p>0.05$) based on the first Pearson correlation analysis. The Grubbs test revealed that there was not an outlier in WCST correctness ($G=2.606$, $p>0.05$), but there was a significant outlier in anti-saccade correctness ($G=1.691$, $p<0.05$). Following the elimination of the outlier, the correlation ($r=-0.033$, $t(26)=-0.168$, $p>0.05$) was still weak and non-significant. Even after outliers are excluded, these findings indicate no visible linear relationship between the variables.

Table 4

Pearson Correlation Analysis: Antisaccade Correctness and WCST Correctness (Before and After Outlier Removal)

Variable 1	Variable 2	r	t	df	p-value	95% CI
Antisaccade Correctness	WCST Correctness	-0.023	-0.117	27	$p>0.05 p>0.05$	[-0.386, 0.347]
Antisaccade Correctness*	WCST Correctness*	-0.033	-0.168	26	$p>0.05 p>0.05$	[-0.401, 0.344]

Note. The second row represents the correlation analysis after outlier exclusion using the Grubbs test.

To illustrate the correlation between WCST correctness and Anti-saccade correctness, two scatter plots were made. The relationship is displayed in Figure 4A before the elimination of the outlier and in Figure 4B after the elimination of the outlier. The scatter plots suggest that the correlation remained weak and non-significant ($p>0.05$) with little effect from removing the outlier.

Figure 9A:

Scatter Plot of Anti-saccade Correctness and WCST Correctness (Before Outlier Removal)

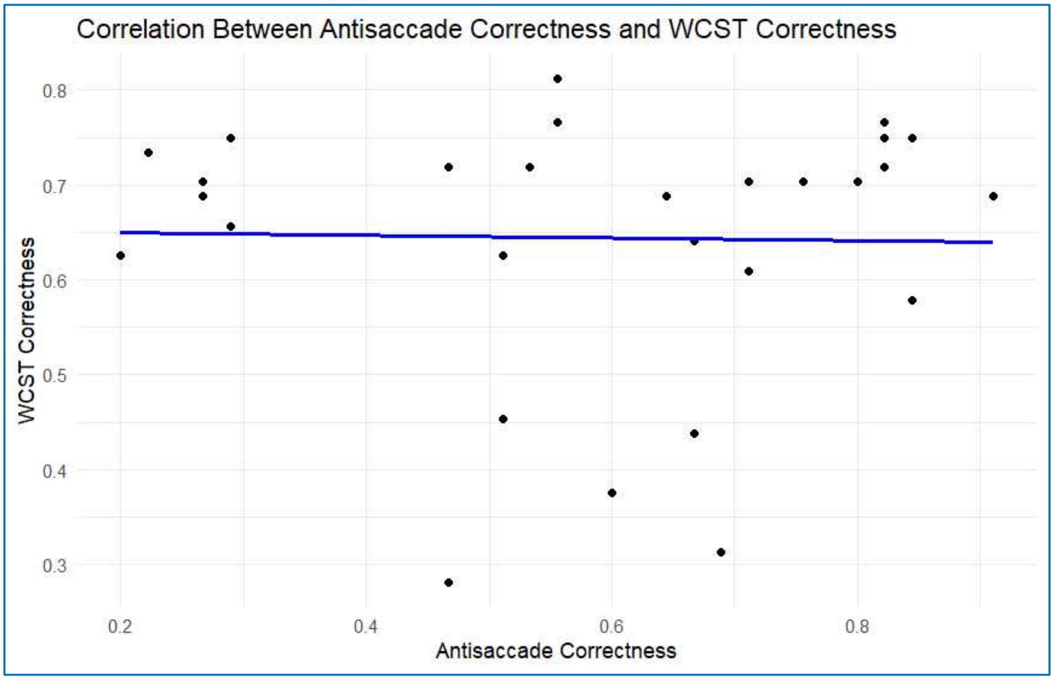
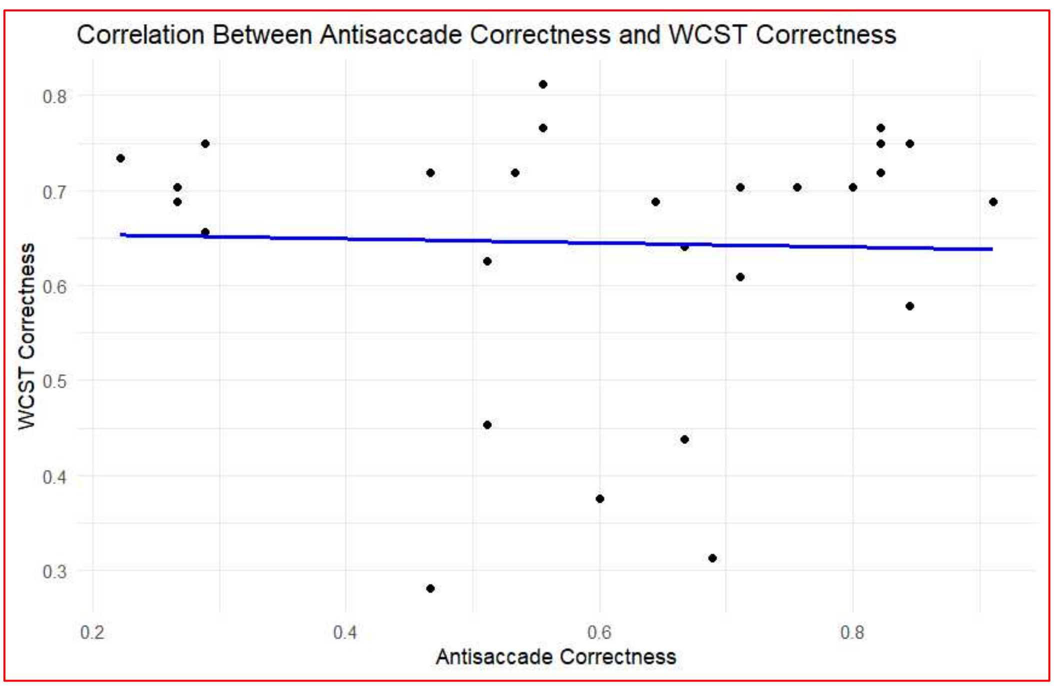


Figure 9B:

Scatter Plot of Anti-saccade Correctness and WCST Correctness (After Outlier Removal)



3.1.5 Correlation Between Correctness of Saccade and Stroop Tasks

Saccade correctness and Stroop correctness revealed a very weak, non-significant positive correlation ($r=0.079$, $t(27)=0.410$, $p>0.05$) with respect to the first Pearson correlation analysis. Significant outliers were detected by the Grubbs test in both saccade correctness ($G=3.732$, $p<0.05$) and Stroop correctness ($G=3.712$, $p<0.05$). Once the outliers were eliminated, the correlation ($r=0.153$, $t(25)=0.772$, $p>0.05$) continued to be weak and non-significant. Even when outliers are excluded, the results demonstrate no apparent linear relationship between the variables.

Table 5

Pearson Correlation Analysis: Saccade Correctness and Stroop Correctness (Before and After Outlier Removal)

Variable 1	Variable 2	r	t	df	p-value	95% CI
Saccade Correctness	Stroop Correctness	0.079	0.410	27	p>0.05	[-0.296, 0.433]
Saccade Correctness*	Stroop Correctness*	0.153	0.772	25	p>0.05	[-0.241, 0.503]

Note. The second row represents the correlation analysis after outlier exclusion using the Grubbs test.

To examine how saccade correctness and Stroop correctness correlate with one another, two scatter plots were developed. Before and after the outliers are eliminated, the relationship is displayed in Figure 5A and Figure 5B, respectively. Based on the scatter plots, the correlation remained weak and non-significant ($p>0.05$) following the outliers were eliminated.

Figure 10A

Scatter Plot of Saccade Correctness and Stroop Correctness (Before Outlier Removal)

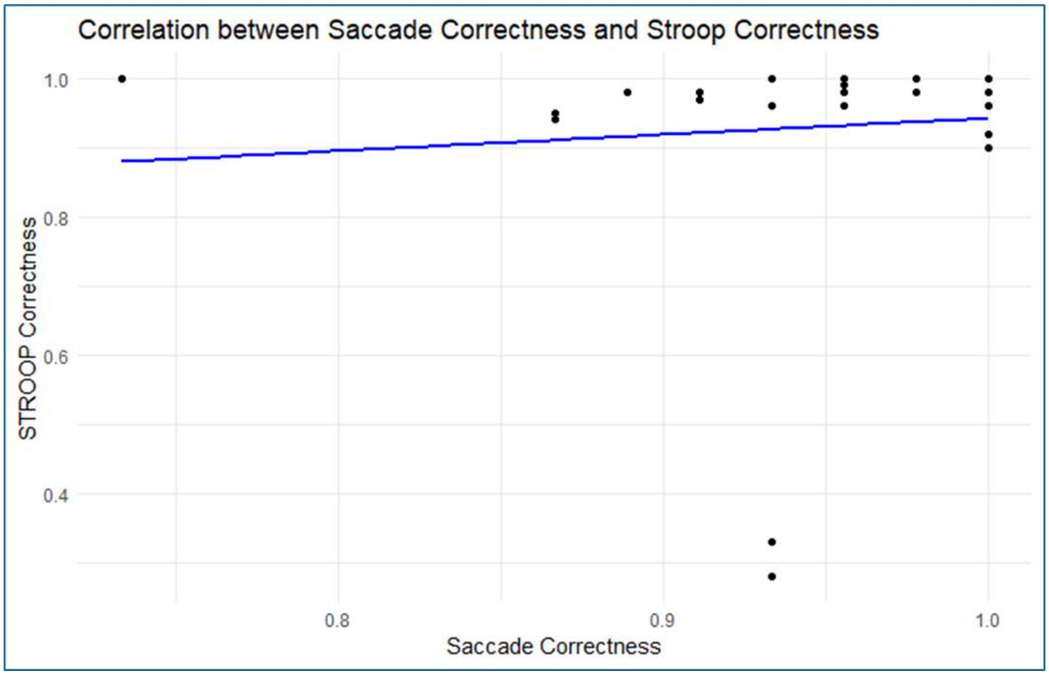
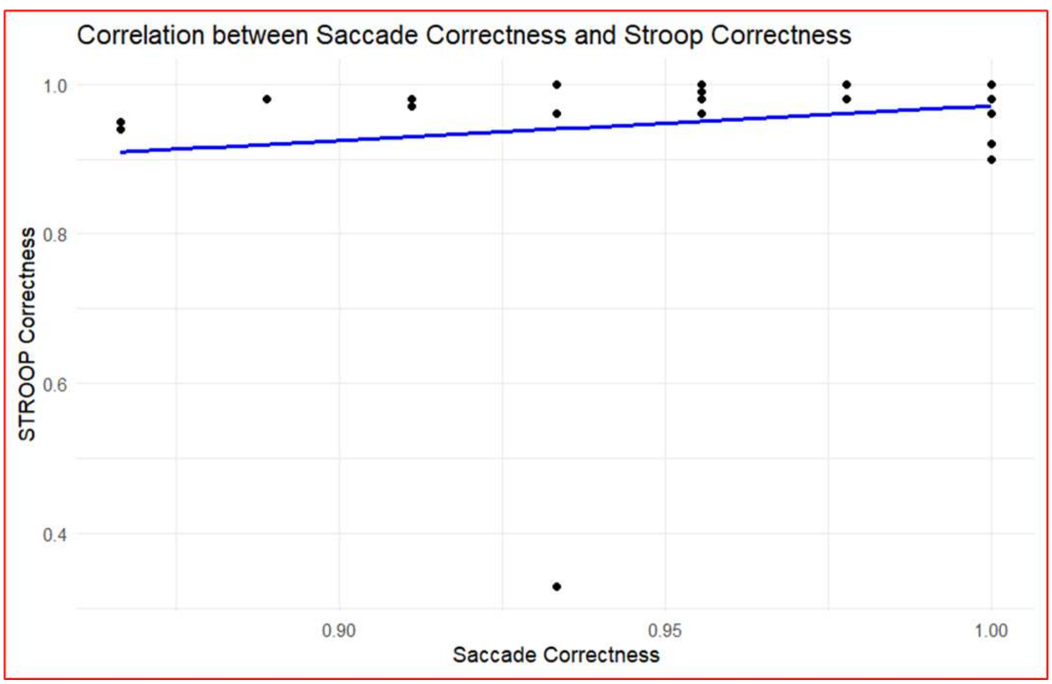


Figure 10B

Scatter Plot of Saccade Correctness and Stroop Correctness (After Outlier Removal)



3.1.6. Correlation Between Correctness of Anti-saccade and Stroop Tasks

A weak, non-significant negative correlation between Stroop correctness and antisaccade correctness was observed in the first Pearson correlation analysis ($r=-0.177$, $t(27)=-0.933$, $p>0.05$). Both Anti-saccade correctness ($G=1.691$, $p<0.05$) and Stroop correctness ($G=3.712$, $p<0.05$) had significant outliers found by the Grubbs test. After the outliers were removed, the correlation stayed weak and not significant ($r=-0.044$, $t(25)=-0.221$, $p>0.05$). Even if outliers are eliminated, these findings demonstrate no clear linear relationship between the variables.

Tablo 6

Pearson Correlation Analysis: Anti-saccade Correctness and Stroop Correctness (Before and After Outlier Removal)

Variable 1	Variable 2	r	t	df	p-value	95% CI
Antisaccade Correctness	Stroop Correctness	-0.177	-0.933	27	p>0.05*p*>0.05	[-0.510, 0.203]
Antisaccade Correctness*	Stroop Correctness*	-0.044	-0.221	25	p>0.05*p*>0.05	[-0.417, 0.342]

Note. The second row represents the correlation analysis after outlier exclusion using the Grubbs test.

The relationship between Stroop correctness and Anti-saccade correctness was visualized using two scatter plots. The relationship before and after the outliers are removed is depicted in Figure 6A and Figure 6B, respectively. The correlation remained weak and non-significant ($p>0.05$), as shown by the scatter plots, which show that eliminating the outliers had little effect. The Grubbs test results are shown in Table 2 and confirm that both variables have significant outliers ($p<0.05$).

Figure 11A:

Scatter Plot of Anti-saccade Correctness and Stroop Correctness (Before Outlier Removal)

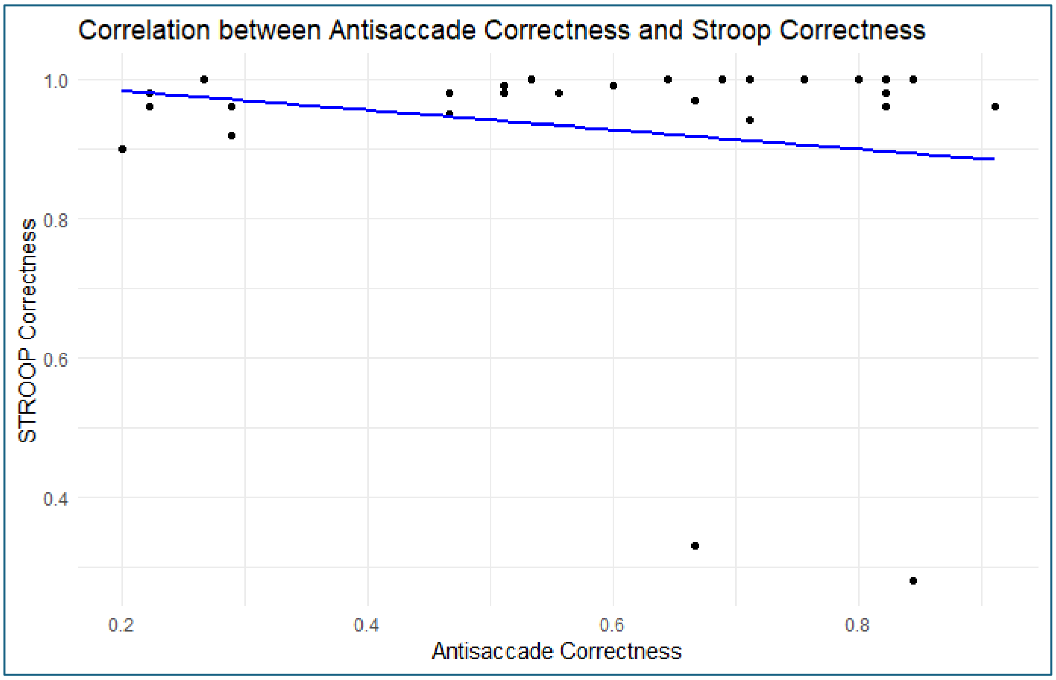
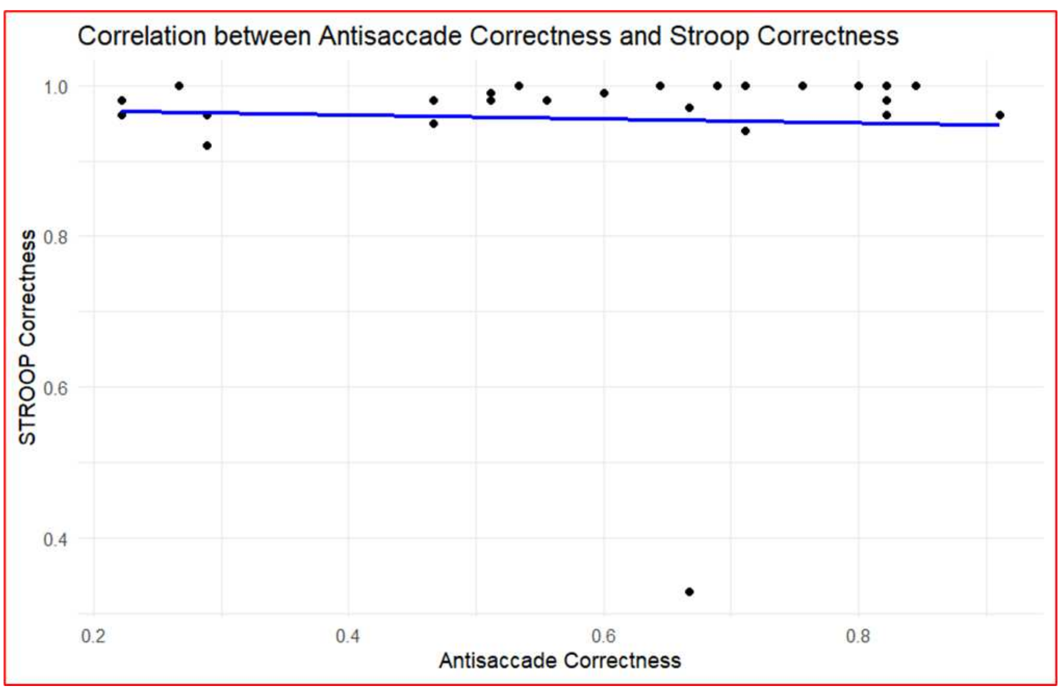


Figure 11B

Scatter Plot of Anti-saccade Correctness and Stroop Correctness (After Outlier Removal



3.2.1 Correlation Between Reaction Time of Saccade and Stop Signal Tasks

The correlation between Saccade RT and Stop-signal RT was examined. When outliers were included, the first Pearson correlation analysis showed a small, non-significant negative correlation ($r = -0.170$, $t(27) = -0.895$, $p > 0.05$). The Grubbs test results revealed that Saccade RT had no outlier ($G = 2.477$, $p > 0.05$) but Stop-signal RT had a significant outlier ($G = 3.026$, $p < 0.05$). The correlation remained small and non-significant ($r = -0.008$, $t(26) = -0.042$, $p > 0.05$) following the outliers were removed. These results indicate that Saccade RT and Stop-signal RT are not clearly have a linear correlation.

Table 7.

Pearson Correlation Analysis: Reaction Time of Saccade and Stop-Signal (Before and After Outlier Removal)

Variable 1	**Variable 2**	**r**	**t**	**df**	**p-value**	**95% CI**
Saccade RT	Stop-Signal RT	-0.170	-0.895	27	p>0.05	[-0.505, 0.210]
Saccade RT*	Stop-Signal RT*	-0.008	-0.042	26	p>0.05	[-0.380, 0.366]

Note. The second row represents the correlation analysis after outlier exclusion using the Grubbs test.

Scatter plots were created to display the correlation between Saccade RT and Stop-signal RT. Figure 7A displays the correlation before the removal of the outlier, while Figure 7B displays the relationship after the removal of the outlier. The low and non-significant correlation ($p > 0.05$) has been verified by both plots, suggesting that the results weren't significantly influenced by the outlier's removal.

Figure 12A.

Scatter Plot of Saccade Reaction Time and Stop Signal Reaction Time (Before Outlier Removal)

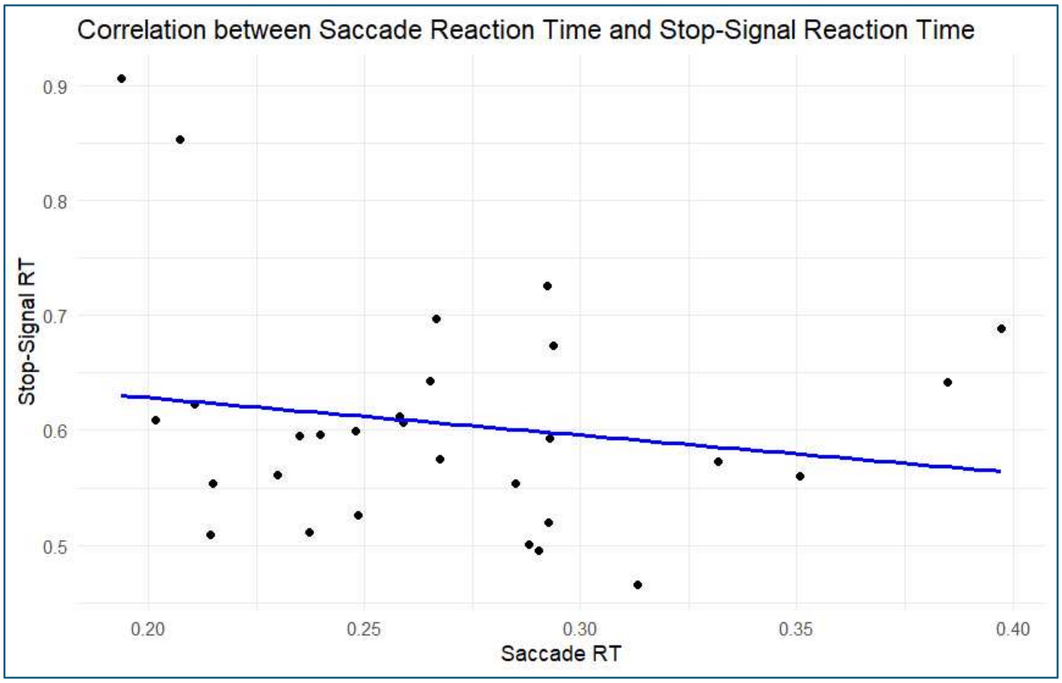
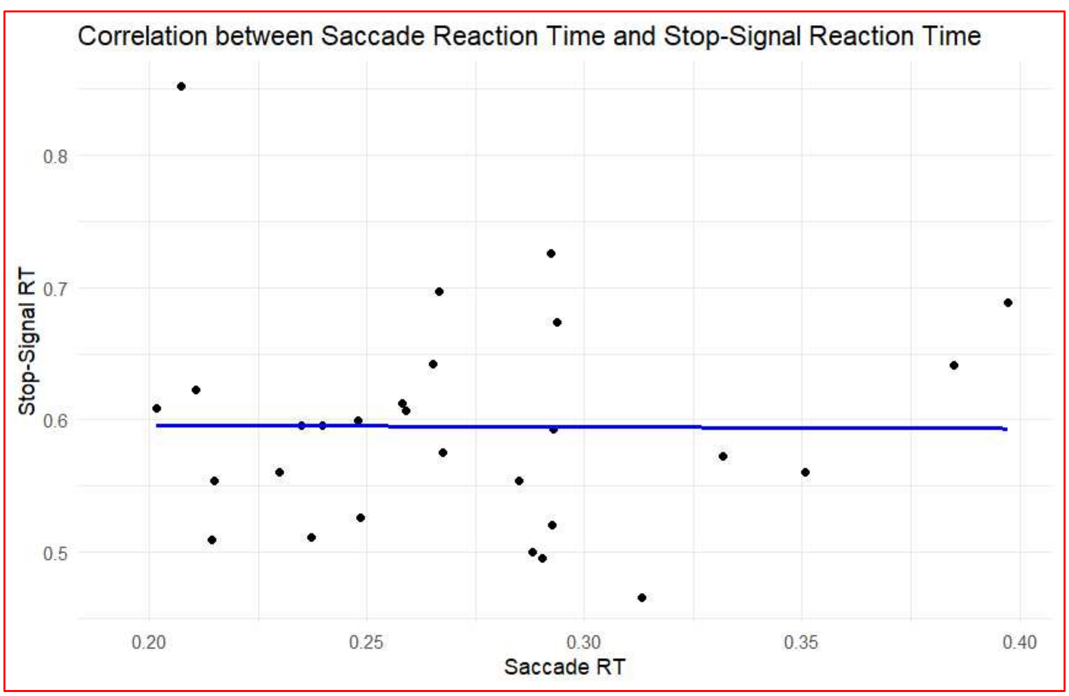


Figure 12B.

Scatter Plot of Saccade Reaction Time and Stop Signal Reaction Time (Before Outlier Removal)



3.2.2 Correlation Between Reaction Time of Anti-saccade and Stop Signal Tasks

Stop-signal RT and Anti-saccade RT's association was examined. There was a weak, non-significant negative correlation identified in the first Pearson correlation analysis, which included outliers ($r = -0.191$, $t(27) = -1.009$, $p > 0.05$). The Grubbs test determined that Stop-signal RT had an outlier that was significant ($G = 3.026$, $p < 0.05$), but Anti-saccade RT did not display a significant outlier ($G = 2.365$, $p > 0.05$). Even though the outlier had been removed, the correlation continued to be weak and not significant ($r = -0.091$, $t(26) = -0.466$, $p > 0.05$). The aforementioned results indicate that there is no significant linear correlation between stop-signal RT and anti-saccade RT.

Table 8.

Pearson Correlation Analysis: Reaction Time of Anti-saccade and Stop-Signal (With and Without Outliers)

Variable 1	Variable 2	r	t	df	p-value	95% CI
Antisaccade RT	Stop-signal RT	-0.191	-1.009	27	p > 0.05	[-0.521, 0.189]
Antisaccade RT*	Stop-signal RT*	-0.091	-0.466	26	p > 0.05	[-0.449, 0.292]

Note. The second row represents the correlation analysis after outlier exclusion using the Grubbs test.

Using scatter plots, the relationship between Anti-saccade RT and Stop-signal RT had been displayed. Before the outlier is eliminated, the correlation is illustrated in Figure 8A, and after the outlier is eliminated, the relationship is shown in Figure 8B. Both plots support the weak and non-significant correlation ($p > 0.05$), indicating that the findings weren't significantly impacted by the outlier's elimination.

Figure 13A

Scatter Plot of Anti-saccade Reaction Time and Stop Signal Reaction Time (Before Outlier Removal)

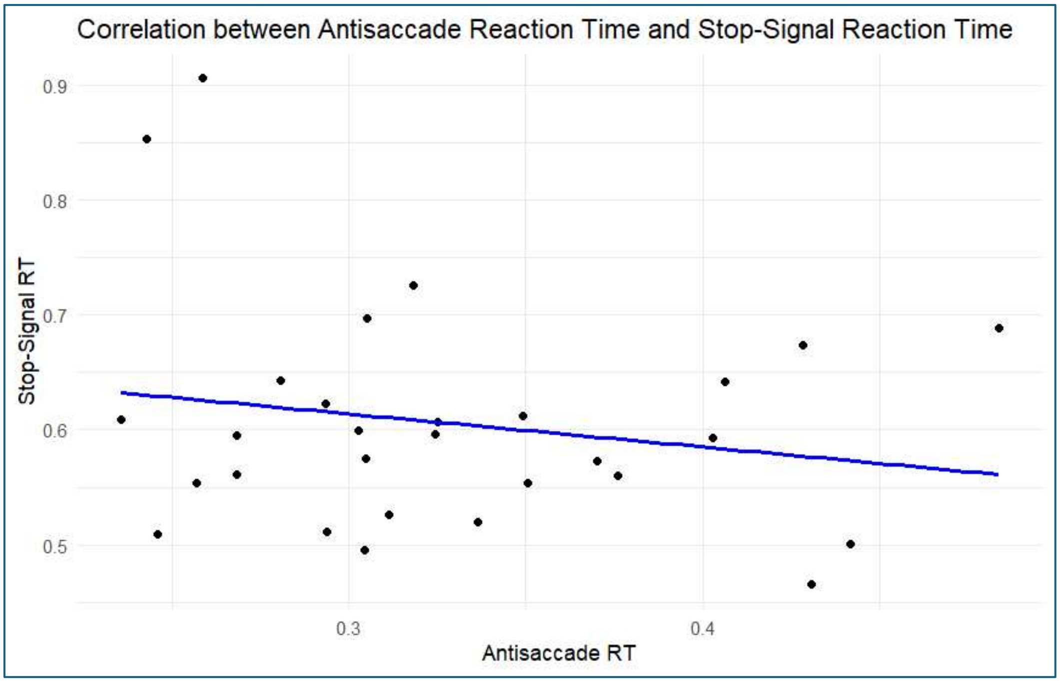
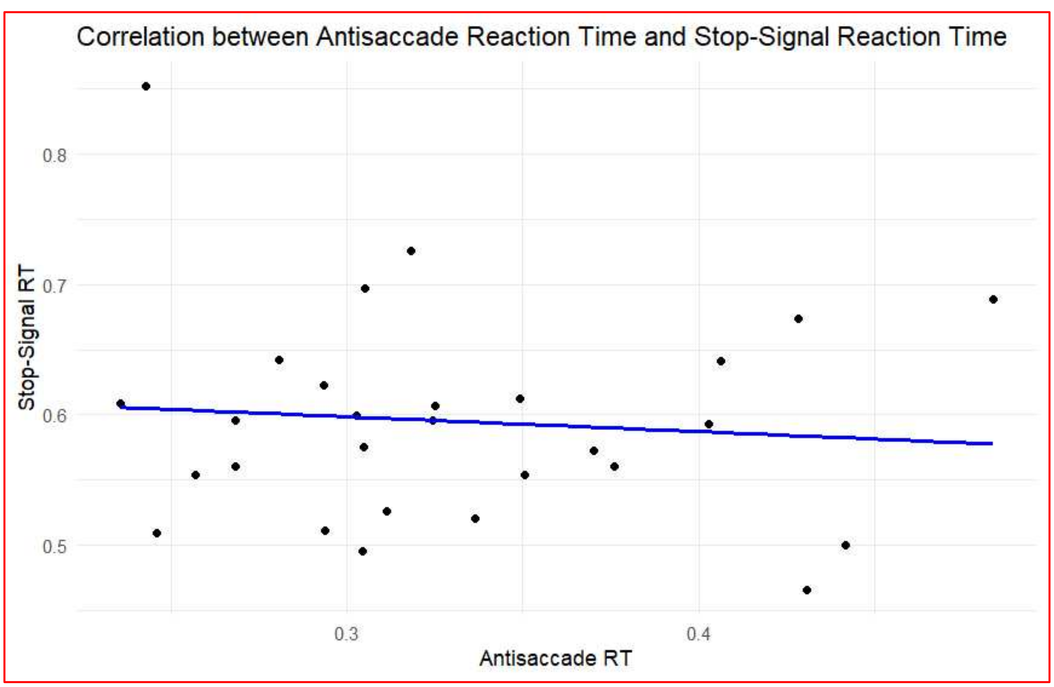


Figure 13B

Scatter Plot of Anti-saccade Reaction Time and Stop Signal Reaction Time (Before Outlier Removal)



3.2.3 Correlation Between Reaction Time of Saccade and Stroop Tasks

Saccade RT and Stroop RT's relationship was investigated. A very weak, non-significant positive correlation was found in the first Pearson correlation analysis, which included outliers ($r = 0.034$, $t(27) = 0.175$, $p > 0.05$). Stroop RT had a significant outlier ($G = 1.303$, $p < 0.001$) according to the Grubbs test, but Saccade RT had no significant outlier ($G = 2.477$, $p > 0.05$). Following the removal of the outlier, the correlation shifted to a negligible negative correlation ($r = -0.026$, $t(26) = -0.132$, $p > 0.05$), remaining extremely weak and non-significant. These results imply that Saccade RT and Stroop RT do not have a significant linear correlation.

Table 9

Pearson Correlation Analysis: Reaction Time of Saccade and Stoop (With and Without Outliers)

Variable 1	Variable 2	r	t	df	p-value	95% CI
Saccade RT	Stroop RT	0.034	0.175	27	p > 0.05	[-0.337, 0.395]
Saccade RT*	Stroop RT*	-0.026	-0.132	26	p > 0.05	[-0.395, 0.351]

Note. The second row represents the correlation analysis after outlier exclusion using the Grubbs test.

Using scatter plots, the correlation between Saccade RT and Stroop RT was presented. Figure 9B shows the correlation following the removal of the outlier, whereas Figure 9A represents the correlation previous to the removal of the outlier. The extremely weak and non-significant correlation ($p > 0.05$) is verified by both plots, implying that the results weren't significantly influenced by the outlier removal.

Figure 14A

Scatter Plot of Saccade Reaction Time and Stroop Reaction Time (Before Outlier Removal)

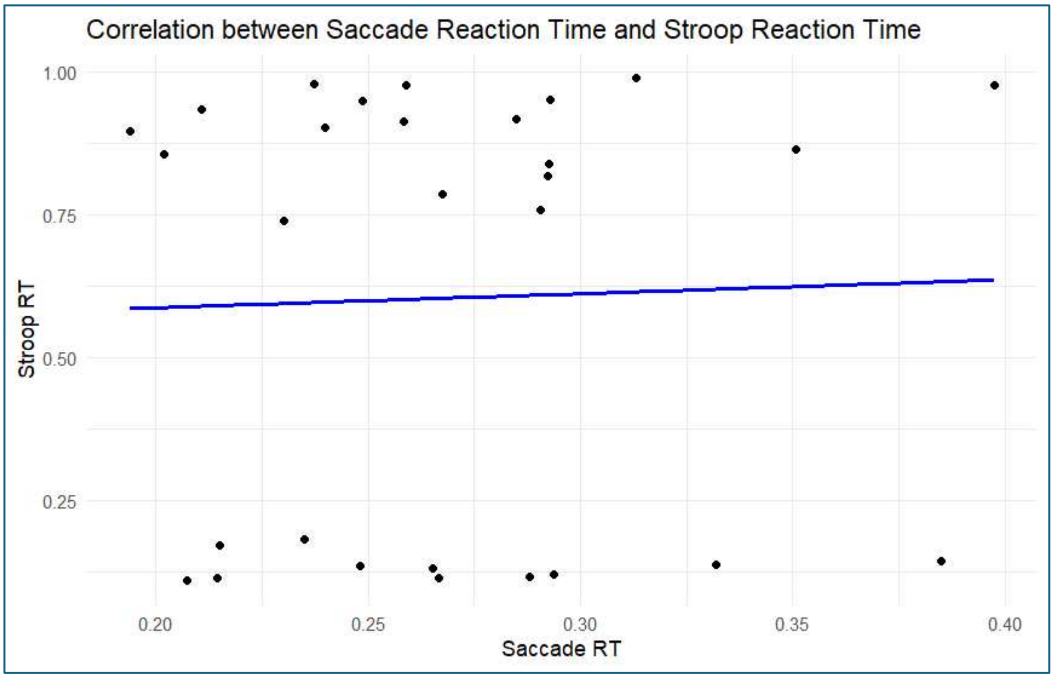
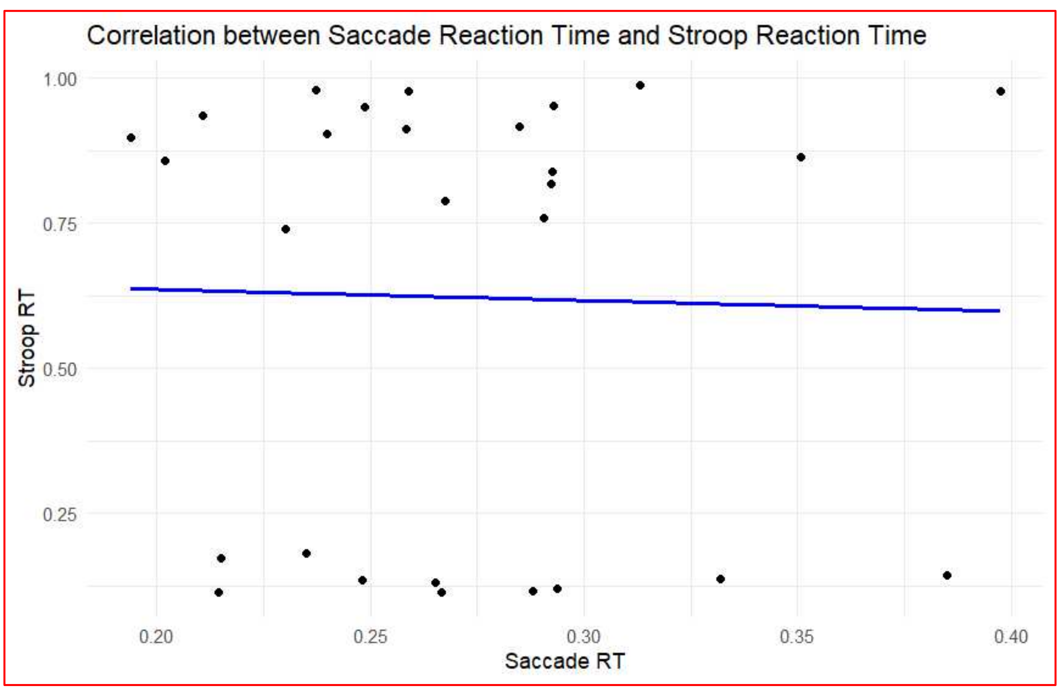


Figure 14B

Scatter Plot of Saccade Reaction Time and Stroop Reaction Time (Before Outlier Removal)



3.2.4 Correlation Between Reaction Time of Anti-saccade and Stroop Tasks

Stroop RT's and Anti-Saccade RT's association was investigated. When accounting for outliers, the first Pearson correlation analysis revealed a weak but non-significant positive correlation ($r = 0.117$, $t(27) = 0.610$, $p > 0.05$). The Grubbs test discovered that Stroop RT had a significant outlier ($G = 1.303$, $p < 0.001$), however Anti-saccade RT had no significant outlier ($G = 2.365$, $p > 0.05$). Even though the outlier was eliminated, the correlation continued to be weak and non-significant ($r = 0.058$, $t(26) = 0.295$, $p > 0.05$). The obtained results suggests that there is no significant linear association among Stroop RT and Anti-saccade RT.

Table 10

Pearson Correlation Analysis: Reaction Time of Anti-Saccade and Stoop (With and Without Outliers)

Variable 1	Variable 2	r	t	df	p-value	95% CI
Antisaccade RT	Stroop RT	0.117	0.610	27	p > 0.05	[-0.261, 0.463]
Antisaccade RT*	Stroop RT*	0.058	0.295	26	p > 0.05	[-0.322, 0.422]

Note. The second row represents the correlation analysis after outlier exclusion using the Grubbs test.

The correlation between Stroop RT and Anti-saccade RT is shown in scatter plots. Figure 10A displays the correlation before the outlier was eliminated, while Figure 10B shows the correlation after the outlier was eliminated. The small and insignificant correlation ($p > 0.05$) is confirmed by both plots, suggesting that the removal of the outlier had no noticeable effect on the results.

Figure 15A

Scatter Plot of Anti-saccade Reaction Time and Stroop Reaction Time (Before Outlier Removal)

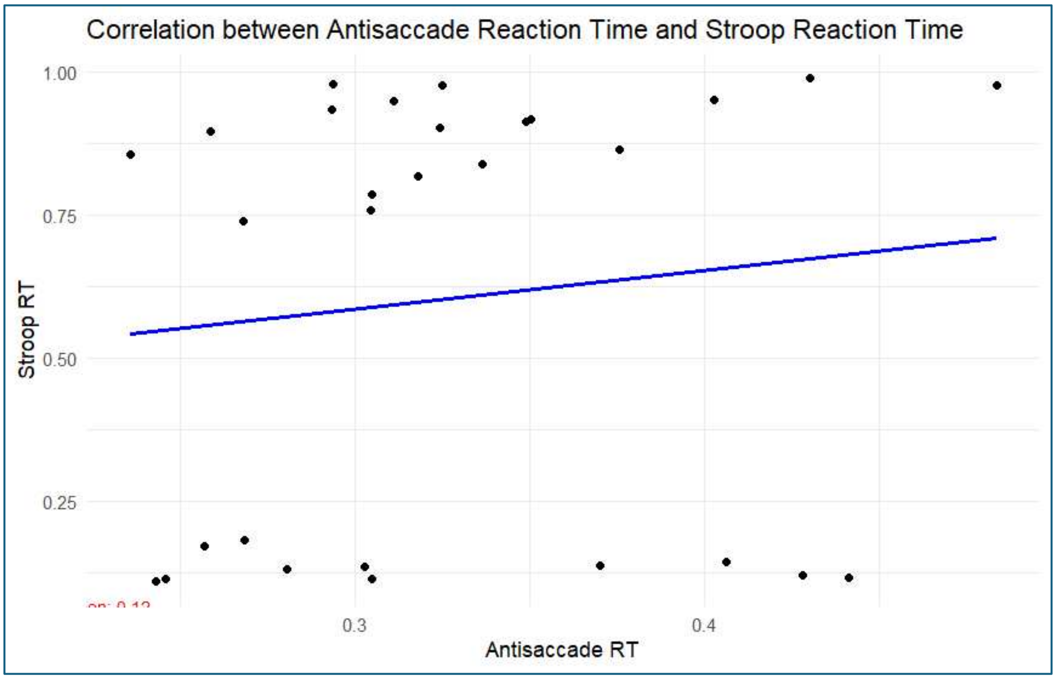
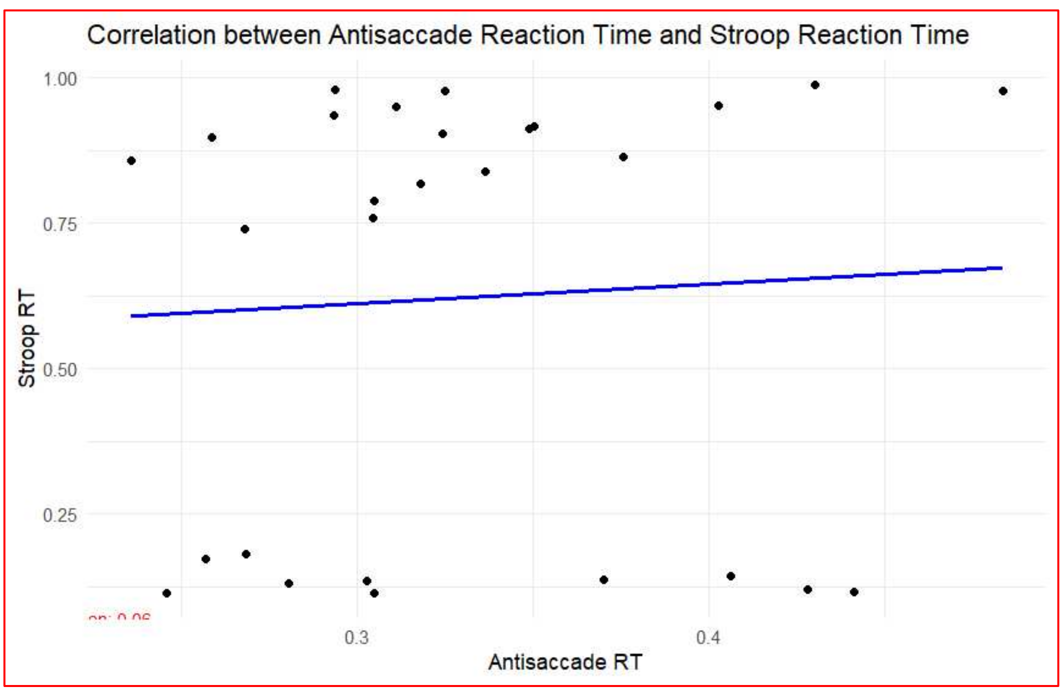


Figure 15B

Scatter Plot of Anti-saccade Reaction Time and Stroop Reaction Time (Before Outlier Removal)



CHAPTER 4. Discussion

The study focused on investigating the neural mechanisms and cognitive processes that facilitate anti-saccade performance through the correlation of the results of computerized cognitive tests, including the Go-No-Go task, Stroop task, Stop Signal task, and Wisconsin Card Sorting Test. Through the tasks, we mainly focused on inhibition, set shifting, and updating abilities to examine the correlation. To examine these abilities, we focused on correctness and reaction time variables. Our results showed a single positive statistically significant correlation after outlier elimination between the correctness of the saccade task and the stop signal task ($r=0.392$, $t(25)=2.129$, $P<0.05$).

On the other hand, the correlation between the correctness of Anti-saccade and Stop Signal Tasks ($r=0.242$, $t(25)=1.246$, $p>0.05$), the correctness of Saccade and Wisconsin Card Sorting Task ($r=0.330$, $t(26)=1.782$, $p<0.05$), the correctness of Anti-saccade and Wisconsin Card sorting task ($r=-0.033$, $t(26)=-0.168$, $p>0.05$), correctness of Saccade and Stroop task ($r=0.153$, $t(25)=0.772$, $p>0.05$), correctness of Anti-saccade and Stroop task ($r=-0.044$, $t(25)=-0.221$, $p>0.05$) remained non-significant after outlier removal.

In addition, analysis of the Reaction Time variables showed that the correlation between Saccade and Stop Signal Tasks ($r = -0.008$, $t(26) = -0.042$, $p>0.05$), the correlation between Anti-saccade and Stop Signal Tasks ($r = -0.091$, $t(26) = -0.466$, $p>0.05$), the correlation between Saccade and Stroop Tasks ($r = -0.026$, $t(26) = -0.132$, $p>0.05$) and the correlation between Anti-saccade and Stroop Tasks ($r = 0.058$, $t(26) = 0.295$, $p>0.05$) also showed non-significant correlation after outlier removal.

Chikazoe et al. (2017) demonstrated that variations in task structures require different cognitive processes. This also explains the various activation patterns reported in the right inferior frontal gyrus during anti-saccade and Go/No-Go tasks. Their meta-analyses indicated that activation in the right inferior frontal gyrus is responsive to changes in task structure. From this point, we can suggest that the cognitive demands of the anti-saccade task and other cognitive tasks, such as the Stroop Task, Stop Signal Task, and Wisconsin Card Sorting Task, are different, which can explain the lack of strong linear correlation between them. Furthermore, Miyake et al. (2000a) suggested that executive function skills, including inhibition, shifting, and updating, are slightly correlated but separable, which supports the claim that they represent distinct but related cognitive processes. Furthermore, the study conducted by Crawford et al. (2002) further emphasized the distinctions between the tasks. The researchers emphasized that saccadic eye movement paradigms enable experimental manipulations that can investigate behavior across various studies while utilizing a consistent behavioral response. Contrary to the majority of conventional neuropsychological evaluations, which depend on the acquisition of verbal and manual skills for efficient performance. The literature mentioned above makes clear that differentiation between task paradigms may also explain the non-significant correlations in our data.

Consistent with our research, a study conducted by Cappe et al. (2014) on a population of normally sighted people revealed a series of remarkably low correlations between performance levels in the different fundamental visual paradigms. Only four of the fifteen potential correlations were found to be significantly correlated. The correlation coefficients were extremely low (in the range 0.1 to 0.3), even for the four significant results. They suggested that the visual system is very modular, with minimal overlap between modules, and each module specializes in a different processing method. The results indicated that there is no clear general factor that underpins vision, as there are a limited number of statistically significant correlations among the fundamental visual tests. They propose that vision is significantly influenced by experience.

Another potential explanation for the non-significant findings is the absence of a single, comprehensive visual performance factor. Unlike Halpern et al. (1999), who employed a much smaller sample and different tests, Ward et al. (2017) employed seven visual psychophysical tests on a large sample of participants who were neurotypical. Factor analysis displayed no evidence of a single visual performance factor. Therefore, these findings suggest that visual skills are likely influenced by multiple mechanisms rather than a single factor. Additionally, Bosten et al. (2017) followed classical approach of Thurstone (1944) by using factor analysis to examine the factors influencing individual differences in visual abilities. Compared to earlier research, this study had a substantially larger sample size (n = 1060) and comprised 25 measures that covered the visual, oculomotor, and auditory domains, including an anti-saccade task. Exploratory factor analysis was used, and over half of the intercorrelations between their 25 performance tests were significant. However, the sizes of the correlations are usually modest. Evidence was found for both independent factors that explain performance on specific groups of measures and a general factor that underlies perceptual ability in their factor analysis of perceptual performance. Their findings support the idea that visual performance relies on a variety of different mechanisms and are very specific.

Additionally, the lack of significant correlations in our study may reflect the high specificity of visual processing. As proposed by Grzeczkowski et al. (2017), individual differences can be attributed to two factors: genetic diversity, since many genes may influence performance in a particular paradigm, and experience, since various experiences result in very particular perceptions. Since each paradigm depends on a variety of mechanisms, they claimed that vision is extremely specific, and there is no common factor. Certain perceptual learning, genetic variability, and other possible sources of variability can cause these mechanisms to differ among individuals. Similarly, according to Bosten and Mollon (2010), individual differences in contrast sensitivity can result from learned expectations about the visual world, which can evolve independently across individuals and stimulus dimensions, or from differences in neuronal features that are impacted by the environment or genetics. The low correlations found in our study are further explained by the fact that these factors contribute differently to each individual, resulting in a large combinatorial space where each observer represents a distinct point.

In line with the findings of Shakiri et al. (2019), who tested only healthy participants, they investigated biological motion perception with four conditions. Participants performed three cognitive tests (verbal fluency, digit span forward and backward, and the Wisconsin Card Sorting Test). Correlations between most tests are rather low, except for correlations between versions of one paradigm. They expected high correlations between perceptual and cognitive tests because differences in cognitive functions may strongly influence perception and vice versa. In the current research, we also observed no significant correlations between our measures except the single positive statistically significant correlation between the correctness of the saccade task and the stop signal task. Similar findings indicate that cognitive and perceptual abilities may operate through independent, task-specific mechanisms.

Contrary to our findings, Hellmuth et al. (2012) proposed that the Bedside Anti-saccade task is a reliable indicator of executive motor control in neurologic illness and aging, providing clinicians with a quick and easy clinical tool to assess the degree of dementia and executive functioning in their patients. Our findings are consistent with prior research, although individual differences and task paradigms may also be important factors. Mirsky et al. (2011) suggested that gray matter volume in frontal lobe regions such as the left inferior frontal junction and right supplementary eye field, as well as executive function measures such as Stroop inhibition and design fluency, are significantly correlated with the percentage of accurate anti-saccade responses. However, no associations between AS performance and assessments of language, memory, or visuospatial abilities were discovered. In addition, they observed that those with lower AS performance showed less Stroop inhibition than those with higher AS performance. Interestingly, in the lower education group (below the median of 18 years), Stroop inhibition errors were positively correlated with the percentage of correct AS responses; however, no such correlations were found in the higher education group. This suggests that education level may affect the association between executive function and AS performance, most likely because more educated people have mechanisms for cognitive reserve. The lack of significant associations between AS performance and executive function measures in our study may be explained by the fact that all participants had bachelor's or master's degrees, which may have led to ceiling effects or improved compensatory mechanisms in this group.

It is important to highlight that the existing data comes from a small group of university students who are young adults. The findings might not fully extend to groups with cognitive diversity, including individuals with neurological impairments, older adults, young children, or those who are not enrolled in college. Later studies may benefit from examining a more extensive sample. Legree, Pifer and Grafton (1996), proposed that the extent of separability among different executive functions may be diminished in less restricted samples (Miyake et al., 2000b). As we previously mentioned, the lack of significant correlations between specific measures in our highly educated sample may be influenced by ceiling effects or enhanced compensatory mechanisms, as previously mentioned. In order to overcome these constraints and provide more comprehensive insights, future research should strive to involve a more diverse group of participants.

In the present study, another potential limitation regarding the neuropsychological test use is the possibility of test interference. This refers to the scenario where the performance on one task might have been affected by the administration of other tasks. For instance, particularly cognitive tasks, the WCST, Stroop, Go/No-Go, and Stop-Signal tasks may have influenced one another, possibly impacting the outcomes. Following the guidance of Lezak et al. (2012), we organized the testing sequence to progress from simpler tasks to more complex ones, aiming to reduce fatigue and enhance the comfort of the participants. Nonetheless, it is important to acknowledge that the interplay between tasks, especially those that demand prolonged focus or higher-level cognitive control (such as the Wisconsin Card Sorting Test, Stroop Test, Go/No-Go, and Stop-Signal tasks), cannot be completely disregarded. Neuger et al. (1981) indicate that the sequence in which information is presented typically displays minimal impact on test results; however, it is possible that subtle interactions or fatigue effects may have influenced our findings. Future studies should take into account the role of counterbalancing the order in which tasks are administered or including rest periods to minimize possible interference effects (Lezak et al., 2012).

Last but not least, the Bayesian approach suggested by Gallistel (2009) presents a valuable opportunity for integration into future research activities. Cappe et al. (2014), and Grzeczkowski et al. (2017) utilized Bayesian methodology to analyze their findings, suggesting that the null hypothesis had a higher probability than the alternative hypothesis across all pairwise comparisons. Applying this methodology in future studies could lead to a deeper understanding of the data and improve the analysis of the results.

Conclusion

In conclusion, the present study primarily aimed to examine whether the anti-saccade task effectively engages inhibition and task-switching processes by correlating its results with computerized assessments such as Stop Signal, Go/No Go, Wisconsin Card Sorting, and Stroop tasks. The absence of significant correlations identified in this study may indicate modular properties of cognitive and visual processes, as noted in previous research. The findings of our study emphasize the importance of task-specific mechanisms and individual differences rather than a common underlying factor. To address limitations such as sample homogeneity and possible test interference, further investigations should include diverse populations, counterbalance task sequences, and use more advanced statistical techniques such as Bayesian analysis to improve understanding.

Attribution

This project includes the subsequent software and resources:

RStudio

RStudio Team. (2020). *RStudio: Integrated Development for R*. RStudio, PBC, Boston, MA. Retrieved from http://www.rstudio.com/

R (Version 4.3.1)

R Core Team. (2023). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from https://www.R-project.org

Python Language (Version 2.7)

Python Software Foundation. (n.d.). *Python Language Reference*, version 2.7. Retrieved from http://www.python.org

PsychoPy2

Peirce, J. W., Gray, J. R., Simpson, S., MacAskill, M. R., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*, *51*(1), 195-203. https://doi.org/10.3758/s13428-018-01193-y

Tobii Pro Lab

Tobii AB. (n.d.). *Tobii Pro Lab User Manual* (Version x.xxx). Tobii AB, Danderyd, Sweden.

WCST Open-Source Library

Ter Haar, W. (n.d.). *WCST*. GitHub. Retrieved March 7, 2025, from https://github.com/Wyko/WCST

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Bosten, J. M., & Mollon, J. D. (2010). Is there a general trait of susceptibility to simultaneous contrast? *Vision Research, 50*(17), 1656-1664. https://doi.org/10.1016/j.visres.2010.05.012

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Appendix: supplementary material

Grubbs Test results:

Table 1

Grubbs test results for outlier detection

Variable	G*G*	U*U*	p-value	Alternative Hypothesis
Saccade Correctness	3.732	0.485	P<0.05	Lowest value (0.733) is an outlier
Stop Signal Correctness	3.606	0.519	P<0.05	Lowest value (0.803) is an outlier

Table 2

Grubbs test results for outlier detection

Variable	G*G*	U*U*	p-value	Alternative Hypothesis
Antisaccade Correctness	1.691	0.894	p<0.05	Lowest value (0.200) is an outlier
Stop Signal Correctness	3.606	0.519	p<0.05	Lowest value (0.803) is an outlier

Table 3

Grubbs test results for outlier detection

Variable	G	U	p-value	Alternative Hypothesis
Saccade Correctness	3.732	0.485	p<0.05	Lowest value (0.733) is an outlier
WCST Correctness	2.606	0.749	p>0.05	Lowest value (0.281) is not an outlier

Table 4

Grubbs Test Results for Outlier Detection

Variable	G	U	p-value	Alternative Hypothesis
Antisaccade Correctness	1.691	0.894	p<0.05	Lowest value (0.200) is an outlier
WCST Correctness	2.606	0.749	p>0.05	Lowest value (0.281) is not an outlier

Table 5

Grubbs Test Results for Outlier Detection

Variable	G*G*	U*U*	p*p*-value	Alternative Hypothesis
Saccade Correctness	3.732	0.485	p<0.05*p*<0.05	Lowest value (0.733) is an outlier
Stroop Correctness	3.712	0.490	p<0.05*p*<0.05	Lowest value (0.280) is an outlier

Table 6

Grubbs Test Results for Outlier Detection

Variable	G	U	p-value	Alternative Hypothesis
Antisaccade Correctness	1.691	0.894	p<0.05	Lowest value (0.200) is an outlier
Stroop Correctness	3.712	0.490	p<0.05	Lowest value (0.280) is an outlier

Table 7

Grubbs Test Results for Outlier Detection

Variable	G	U	p-value	Alternative Hypothesis
Saccade RT	2.477	0.773	$p>0.05$	Highest value (0.397) is not an outlier
Stop-Signal RT	3.026	0.661	$p<0.05$	Highest value (0.905) is an outlier

Table 8

Grubbs Test Results for Outlier Detection

Variable	G	U	p-value	Alternative Hypothesis
Antisaccade RT	2.365	0.793	$p > 0.05$	Highest value (0.484) is not an outlier
Stop-signal RT	3.026	0.661	$p < 0.05$	Highest value (0.905) is an outlier

Table 9

Grubbs Test Results for Outlier Detection

Variable	G	U	p-value	Alternative Hypothesis
Saccade RT	2.477	0.773	$p > 0.05$	Highest value (0.397) is not an outlier
Stroop RT	1.303	0.937	$p < 0.001$	Lowest value (0.110) is an outlier

Table 10

Grubbs Test Results for Outlier Detection

Variable	G	U	p-value	Alternative Hypothesis
Antisaccade RT	2.365	0.793	$p > 0.05$	Highest value (0.484) is not an outlier
Stroop RT	1.303	0.937	$p < 0.001$	Lowest value (0.110) is an outlier