# INVESTIGATING THE INFLUENCE OF ATTENTIVENESS ON MOTOR IMAGERY PERFORMANCE

by

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Dalhousie University is located in Mi'kma'ki, the
ancestral and unceded territory of the Mi'kmaq.
We are all Treaty people.

**Table of Contents**

## List of Tables

## List of Figures

**Abstract**

Although much research has focused on motor imagery, the mental rehearsal of movement, little has examined the influence cognitive deficits have on its performance. Recent findings have shown that motor imagery is multidimensional, being comprised of three components: generation, maintenance, and manipulation. Given an apparent link between the cognitive functions of executive attention and working memory to the components, it stands that a deficit in these would impair motor imagery. This study investigates the influence of attention and working memory on motor imagery performance. Although it was hypothesized that lower attentiveness would lead to poorer motor imagery performance, the findings did not confirm this. The study did reveal that working memory capacity may have a significant impact on the manipulation component of motor imagery. The results suggest that the attentiveness scores within the study sample do not reach a severe enough level of inattentiveness to visibly impact motor imagery.

## List Of Abbreviations Used

**ADHD -** Attention Deficit Hyperactivity Disorder

**ASRS -** Adult ADHD Self-Report Scale

**CFQ -** Cognitive Failures Questionnaire

**DCD -** Developmental Coordination Disorder

**HLJT -** Hand Laterality Judgment Task

**MWQ -** Mind Wandering Questionnaire

**MIQ -** Motor Imagery Questionnaire

**RT -** Response Time

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# Chapter 1: Introduction

Motor imagery is an excellent alternative to physical practice to achieve motor learning. Motor imagery is when one is imagining a movement, which can be used to practice and in-turn acquire new motor skills (Schuster et al., 2011, Di Rienzo et al., 2014). While motor imagery is understood to be a modality for motor learning, the mechanisms that facilitate learning are not fully understood (Hétu et al., 2013; O'Shea & Moran, 2019). Although motor imagery has been studied for years, there have been recent shifts in the direction of research and therefore, our understanding of how motor imagery works has changed. The first shift is that emerging theories of motor imagery have proposed perceptual/cognitive mechanisms may be more involved than previously thought (Hurst & Boe, 2022). The second is how motor imagery has been found to be multidimensional, meaning that there are multiple components (i.e., generation, maintenance and manipulation) to motor imagery that independently each reflect a person's ability to do motor imagery within each component (Collet et al., 2011; Kraeutner et al., 2020). With the shift in proposed motor imagery theories and being able to assess multiple components of motor imagery, we have a better opportunity to investigate how cognitive functions may influence motor imagery compared to previously.

It is well established that overt execution of movement and learning of skills that occurs through this relies on cognitive functions. Despite this knowledge, how cognitive functions are specifically involved in motor imagery has not been as extensively studied. Cognition, the processes in the brain responsible for learning and understanding, is seen as an essential part of motor learning (Saltzman & Garner, 1948). Considering the multi-dimensional nature of motor imagery, it is likely that cognitive functions are critical for performing motor imagery. When investigating cognitive processes, attention has been suggested as being required for the performance of motor imagery (Barhoun et al., 2019; Mullick et al., 2015; Rinne et al., 2017).

Attention can be defined as a complex control system with many processes to direct and maintain focus while disregarding distracting stimuli (Hommel et al., 2019). Specifically executive attention, the control of what one attends to, is likely to be especially critical for motor imagery performance. Once a task is attended to, working memory works with attention to ensure the goal of a task is achieved. Working memory has been looked at in motor imagery studies, but attention has not, making the gap of understanding attention's impact on motor imagery more glaring (Collet et al., 2011; Malouin et al., 2004).

The purpose of the proposed study is to investigate the relationship between cognitive function, namely executive attention, and performance of motor imagery. Multiple cognitive assessments were used to characterize one's attentiveness to predict how one performs on various motor imagery tasks involved with each component of motor imagery. Given the gap in motor imagery literature on how cognition affects motor imagery, to our knowledge this would be the first study to look at if an individuals' attentiveness might impact motor imagery. The study recruited healthy participants where it was expected that there would be a range of attentiveness across individuals. It was hypothesized that those who are more inattentive will have poorer performance on motor imagery tasks. The study findings did not confirm the hypothesis, as attentiveness did not significantly influence motor imagery performance, nor were any relationships between attentiveness and each of the motor imagery components found to be strong. The only significant relationship was the effect of attentiveness on the manipulation component of motor imagery, where working memory capacity was a significant predictor of manipulating a motor image. While the takeaway of this study is that one's attentiveness did not appear to influence motor imagery performance there is promise for how working memory might impact motor imagery specifically related to manipulating an image.

# Chapter 2: Background and Rationale

## Motor Imagery

Movement is critical to nearly all aspects of everyday life, and thus the ability to acquire and improve movements is just as critical. The ability to acquire or improve movement, termed motor learning, occurs through repetitive practice of the movement to be learned, whereby errors in performance can be identified and subsequently corrected, resulting in improved performance (Newell, 1991). The neural processes underlying motor learning are grounded in neuroplasticity. When a movement or skill is repetitively practiced, neural pathways in the brain are strengthened via plasticity, resulting in learning of the skill and optimized performance (Classen et al., 1998; Ruffino et al., 2017; Sanes & Donoghue, 2000). Typically, repetitive practice critical to motor learning is done through physical execution. Whereby a person executes the movement physically, which generates feedback related to performance that permits error detection and correction. While physically practicing a movement is the most common method for motor learning, there are other methods such as motor imagery (Jeannerod, 1995). Motor imagery, the mental performance of a movement without execution, has been shown to be a viable way of practicing and in turn learning new skills (Jeannerod, 1995). The use of motor imagery can result in behavioural improvements including acquiring new motor skills (Driskell et al., 1994; Toth et al., 2020). Motor imagery has been shown to be useful in many fields; for example, motor imagery has commonly been used in sports for athletes to work on improving a skill or when someone is injured (Toth et al., 2020). Another field that uses motor imagery is neurorehabilitation; here motor imagery can be used to relearn motor skills when physical movement is not possible (e.g., post-stroke) owing to severe impairments that preclude the use of the affected limbs (Barclay et al., 2020).

Contemporary theories of motor imagery attempting to explain why it is effective for motor learning can be placed into two broad schools of thought. The first suggests that motor imagery relies on motor processes and pathways in the brain, while the second suggests a reliance on perceptual/cognitive processes. The predominant motor-related theory, motor simulation theory, theorizes that motor imagery is functionally equivalent to physical performance (O'Shea & Moran, 2017). This theory suggests that motor imagery shares neural processes and pathways with physical performance up to the point of execution, which is inhibited in motor imagery (Solomon et al., 2019). Although it may appear that motor imagery achieves motor learning by simulating physical practice scenarios. There are several thoughts on the underlying learning mechanisms of motor imagery, that diverge from functional equivalence. One is how motor imagery facilitates the formation of motor planning pathways to be formed which can enhance the movements (Hurst & Boe, 2022). Theories that suggest motor imagery relies on more perceptual/cognitive processes, including the perceptual cognitive model and motor cognitive model, indicate that motor imagery only shares processes related to high level (perceptual) motor planning with physical performance. Therefore after the stage of motor planning, motor imagery diverges and is largely dependent on cognitive resources and processes to generate abstract representations of movement (Glover & Baran, 2017). As a full review of theories of motor imagery is outside the scope of this thesis, the reader is directed to Hurst and Boe (Hurst & Boe, 2022) for a detailed review and discussion of imagery theory.

Recent theories have shifted toward the idea that motor imagery may be less motoric and therefore more perceptual/cognitive (Glover et al., 2020). Thus, the effectiveness of motor imagery may depend on an individual's capacity to concentrate and mentally encode their imagery to improve the coordination and control of motor skills (Glover et al., 2020). However, there is a lack of empirical studies that have probed the cognitive elements of motor imagery, and thus a key piece of evidence supporting these theories is lacking (O'Shea & Moran, 2017). Furthermore, despite the understanding that cognitive functions are critical for motor performance and learning, there is a lack of studies examining cognitive skills in relation to motor imagery. Even fewer studies have looked at how a person's cognitive abilities might influence their motor imagery performance (Collet et al., 2011; Munzert & Zentgraf, 2009). While the importance of cognition in motor learning has been acknowledged, previous studies have not been specific to motor imagery (Cauchoix et al., 2018).

**Cognition**

Cognition refers to the mental processes involved in thoughts, perspectives and expectations which are the mechanisms behind learning, decision-making and communication (Verburgh et al., 2014). Cognition is an integral part of everyday life and is involved in everything humans do, including motor function and learning. Motor learning relies heavily on cognitive functions as evidenced in research examining cognitive deficits in stroke (Schmidt et al., 2017). For instance, a meta-analysis examining the relationship between cognitive deficits after stroke looked at how cognition may impact motor improvement (Mullick et al., 2015). This analysis included six studies that found different relationships between three cognitive functions (executive function, attention, and working memory) and motor improvement (Mullick et al., 2015). While there was a moderate association of cognition and overall motor improvement, the individual cognitive functions showed a moderately strong relation between executive function and motor recovery, a weak positive correlation between attention and motor recovery, and no correlation between memory and motor recovery. This meta-analysis shows how cognitive deficits negatively impact motor improvement, furthermore, showing the importance of cognitive function to motor learning. As well, with the individual cognitive functions this meta-analysis reflects how more research is needed to better understand the role of different cognitive functions including attention, working memory and executive function in relation to motor improvement and learning.

The importance of cognitive functions to motor learning and motor imagery is evident in children with developmental coordination disorder (DCD) (Fong et al., 2016). Developmental coordination disorder is a neurodevelopmental disorder that impacts motor function and coordination in children. It is indicated by a delay in the development of motor skills but is thought to be an issue in the acquisition and learning of movements. Fong et al.'s cross-sectional study looked further into how the motor-cognitive relationship was negatively impacted in children with DCD. Specifically, the study looked at how executive functions including attention influence motor performance in children with only DCD, DCD with ADHD, and children who were developing typically. The results of the study concluded that both children with DCD (with and without ADHD) had impaired attention and motor skills (Fong et al., 2016). Furthermore, there have been numerous studies that looked at the effect of DCD on motor imagery performance (Adams et al., 2016; Barhoun et al., 2019; Williams et al., 2013). Barhoun et al. (2019) completed a meta-analysis that included eight studies that compared children with and without DCD in their ability to do motor imagery. The findings overall show that while children with or without DCD can engage in motor imagery, they had higher reaction times and poorer accuracy on motor imagery tasks relative to the typically developing children. This finding indicates poorer motor imagery performance in children with DCD compared to typically developing children (Barhoun et al., 2019). The findings from these studies suggest that different cognition functions are critical to motor function and learning, as deficits in cognition have a negative impact on motor performance.

**Motor Imagery Components**

Motor imagery is multidimensional, being comprised of multiple components. The idea that motor imagery consists of multiple components was initially proposed by Cumming & Eaves (2018) and subsequent research by Kraeutner et al. (2020) concluded that motor imagery has three primary components: generation, maintenance, and manipulation. It is believed that cognitive skills may influence the performance of each component. These components may draw from specific cognitive functions that if impaired would likely affect motor imagery ability or performance.

The first component, generation, is the process of creating an initial image in your mind. The generation component includes using information derived from past experiences (e.g., sensory information) from long-term memory to create the image (Cumming & Eaves, 2018). For someone to generate an image one must attend to the task of creating that image which can include both visual and kinesthetic perspectives. Generation is considered the first component as it is the first step in motor imagery. Overall, the generation component is crucial for motor imagery as the maintenance and manipulation of an image are not possible without it first being generated.

The second component, maintenance, is the process by which an image is continuously held in one's head. When 'performing' a movement using motor imagery, an image must be maintained long enough to then imagine the movement. This means one must retain the image for a long period of time (Kosslyn, 1994). Maintaining images is also essential to be able to build and add more details to the movement being imagined. Therefore, the maintenance component can help hold some information while new aspects of an image are generated. As well, the maintenance component ensures an image is held long enough to manipulate it (Cumming & Eaves, 2018).

The third component, manipulation, is the process of changing the image that is in one's head. This is done by adjusting the content the person is imagining (Cumming & Eaves, 2018). This includes the ability of manipulating the orientation of the body in one's mind to complete a movement via motor imagery. Often a type of manipulation that has been looked at is mental rotation, but manipulation can include other changes such as scanning and zooming (Kosslyn, 1994). Manipulation is key to motor imagery as imagining movements is greatly reliant on imagining the changes occur, which is done by manipulating the image.

Recent research from our lab has looked at how assessments of motor imagery ability measure the different components of motor imagery (Kraeutner et al., 2020), with the findings providing support for how different motor imagery assessments measure the different components (Figure 1). The assessments that best measured the generation component was self-report questionnaires including the Kinesthetic and Visual Imagery Questionnaire (KVIQ) and the Motor Imagery Questionnaire (MIQ). These questionnaires involve a person first physically performing a movement and then imagining the movement, and finally rating the vividness and sensation of the imagery (Gregg et al., 2010; Malouin et al., 2007). For the maintenance component, the best assessment was mental chronometry (Kraeutner et al., 2020). Mental chronometry is a measure of the congruence between an overt action and an imagined action where the difference in the time required to complete the action is calculated (Guillot & Collet, 2005). As mental chronometry is a measure of the difference in completion time, this can be applied to many tasks. In the Kraeutner et al., 2020 study the mental chronometry was embedded in the MIQ. The manipulation component was found to be best assessed by the Hand Laterality Judgment Task (HLJT). In the HLJT participants are presented an image of a left or right hand that in different orientations, with the goal of responding as quickly and accurately (determining if it is a right or left hand) as possible. As the means of completing the task is to imagine and rotate their own hand, the HLJT is considered to be an implicit task, as participants are not told to use imagery to complete it. This logically fits the manipulation component as the main skill in the HLJT is the ability to rotate the hand, which is a type of manipulation (Kraeutner et al., 2020). Overall, a better understanding of different tasks assessing different motor imagery components can help researchers to probe and look at the components individually.

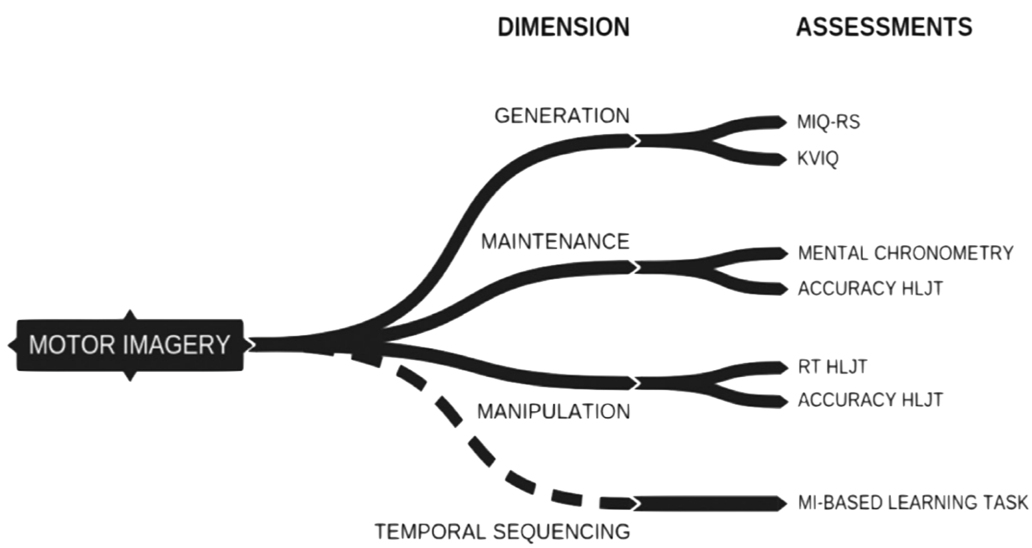


Figure 1. Diagram of results from the Kraeutner et al., 2020 study demonstrating how different motor imagery assessments relate to different components of motor imagery. Note, the temporal sequencing dimension was an additional component of the Kraeutner.

Furthermore, the generation component of motor imagery has been found to be the best predictor of overall motor imagery ability and performance (Kraeutner et al., 2020). This means that the generation component along with the self-report assessments (KVIQ and MIQ) best predict motor imagery ability. This includes predicting the performance in other motor imagery assessments and subsequently in the other components of maintenance and manipulation. Furthermore, for the generation component, research has shown the visuospatial pathway is essential (Collet et al., 2011; Oostra et al., 2016). This has been shown in lesion-based studies where damage impacting the visuospatial pathway impairs the ability to generate an image (Oostra et al., 2016). Overall, this means that generation is an important component to be able to assess when people perform motor imagery. Also, if someone is unable to generate an image that overall motor imagery performance including maintaining and manipulating images is greatly impacted.

**Cognitive and Executive Functions**

Multiple studies that have looked at the different components that comprise motor imagery have alluded to cognitive processes likely being linked to the components (Cumming & Eaves, 2018; Guillot & Collet, 2008; Kosslyn, 1994). However, there is a lack of research directly examining how the cognitive functions impact motor imagery performance or ability. The recent research from Kreautner et al., 2020 examining the constituent components of motor imagery makes the lack of research on cognitive functions of motor imagery even more glaring, as the components identified no doubt depend on cognitive functions for their successful execution (Cumming & Eaves, 2018, S. N. Kraeutner et al., 2020). When comparing cognitive functions to the components of motor imagery, there are two that would appear to link with the components, attention and working memory.

When reviewing attention and working memory as cognitive functions, it is important to understand their relation to executive functions. Executive functions are the cognitive abilities that underlie goal achievement and behavioural control. There are thought to be many executive functions including attention, working memory, cognitive flexibility, set-shifting, planning and inhibitory control (Diamond, 2013; Piek, 2004; Verburgh et al., 2014), although the most accepted model for executive functions includes inhibition (interference control), shifting (cognitive flexibility), and updating (working memory) (Miyake & Friedman, 2012; Wiebe & Karbach, 2017). Attention is a complex concept as it has been conceptualized as its own executive function but also it is thought to be embedded within the main accepted executive functions (inhibition, shifting, updating). (Hommel et al., 2019). Inhibition for instance involves the attentional process of selectively choosing what information to focus on. As well, in shifting, attention can play a role in being able to refocus attention (Garon et al., 2008; Wiebe & Karbach, 2017). Unlike attention, working memory is often considered one of the executive functions, sometimes called updating. The updating executive function is the process of updating the mental representations in working memory (Friedman et al., 2008; Piek, 2004). Overall, in different ways both attention and working memory are a part of the executive functions.

**Attention**

The main cognitive function being focused on in the present work is attention. There appears to be a link between attention and motor imagery performance, and this cognitive function has not been extensively studied in relation to motor imagery. Attention is made up of cognitive processes that enable individuals to allocate mental resources (Baghdadi et al., 2021). Attention is a control system that includes multiple networks and different types of attention all interacting to ultimately direct one's focus and thoughts (Baghdadi et al., 2021). As attention is complex, the literature consists of multiple definitions, as well, there are many models or frameworks for attention (Hommel et al., 2019). Owing to this variation in definitions and models of attention, providing a singular definition of attention is essential to understanding it's influence on motor imagery.

Posner and Petersen originally developed a model of attention in 1990 that was revisited in 2012 which proposed that attention has three subsystems (Figure 2) that includes the alerting, orienting, and the executive control networks (Petersen & Posner, 2012; Posner & Petersen, 1990). The Petersen & Posner model has helped to link behavioural and anatomical fields to attention research and thus was considered an appropriate model to define attention in the present work (Petersen & Posner, 2012). With the model, the alerting network is related to the arousal and sensitivity to incoming stimuli, whilst the orienting network is related to the selection of stimuli, and finally the executive control network is related to monitoring and resolving conflict. While each of these networks play a role in overall attention, the executive control network best relates to the skills required for motor imagery. The executive control network monitors thoughts to ensure there is no conflict. The term can also be referred to as executive attention or attention control. The executive control of attention manages what is being attended to and being able to shift that focus when needed to engage concentration and retain information (Rinne et al., 2017). As previously mentioned, inhibition uses executive attention to help ensure attention is on a particular task of interest (Miyake & Friedman, 2012; Wiebe & Karbach, 2017). Conflict includes the ability to disregard irrelevant information to ensure there is control on the intended information. Therefore, while proposed in different models, executive control can be considered the overall control of thoughts and behaviours, and through allocating of resources, inhibiting irrelevant information and maintaining attention. Throughout this paper when the term attention is used it will refer to executive attention as defined here.

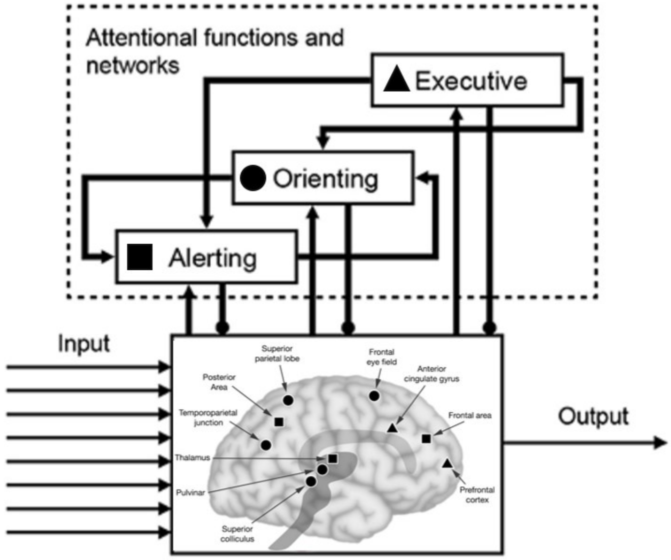


Figure 2. The attention network model originally proposed by Posner & Peterson 1990 based on figures by Posner & Rothbart 2007 and Fan 2014. The figure demonstrates the anatomical regions underlying the attention networks and how the functioning and feedback between networks occurs.

Executive control, as a cognitive function, has been shown to impact motor performance. For example, one study looked at motor dexterity and strength in stroke versus healthy participants to see if attentional control impacted their motor performance. The study used motor tasks including simple-tracking, precision-holding and maximum force generation while introducing distractors (Rinne et al., 2017). The increase in distractors was used to see if there was a negative impact on motor performance. The overall findings of the study showed that impaired attentional control did co-exist with decreased motor performance. Furthermore, for with stroke attention control was found to be vital for their motor performance (Rinne et al., 2017). This finding shows the importance of attention and motor function, specifically how impairment of attention can impact motor performance.

Despite its importance, the effect of attention and impairment in attention specifically, on motor imagery performance has not been fully explored in the literature. To perform motor imagery effectively, there must be attention on the task being imagined, as demonstrated in previous literature showing the impact of attention deficits on motor performance (Barhoun et al., 2019; Mullick et al., 2015; Rinne et al., 2017). The reason why executive attention is key is that without the ability to control one's focus and thoughts on the task being imagined the encoding of the information can be disrupted or not as efficient (Munzert & Zentgraf, 2009). Few studies to date have empirically tested the role of attention on motor imagery. Studies of motor imagery have suggested attention as being a factor in determining motor imagery performance primarily in the context of understanding the components that comprise motor imagery (Collet et al., 2011; Kosslyn, 1994). Attention has been mentioned in relation to motor imagery, with terms such as visual attention and sustained attention to explain the mental resources required for motor imagery (Cumming & Eaves, 2018; Guillot & Collet, 2008). Overall, while there is research supporting the role cognitive functions play in motor imagery, there is currently little information regarding the role of attention in motor imagery performance.

### Working Memory

Working memory is the second cognitive function of interest to the proposed work as it is closely related to executive attention, as once a task is attended to the thoughts and concepts are held in working memory (Moraru et al., 2016). Working memory involves holding information in one's mind including procedures, sequences, and facts (Luck & Vogel, 2013, A. Baddeley, 2003). Working memory then, while holding the information, allows one to process and work with the information to achieve the goal of the task. This process is vital for performance on any task as when someone is attending to a task there is a goal that needs to be met (Fougnie, 2008). As there are multiple types of information working memory holds, certain working memory functions may be more related to motor imagery than others. The most accepted model of working memory is the functional components model (Figure 3) which includes the central executive, which acts as a control system responsible for manipulation within work memory (A. D. Baddeley & Hitch, 1974). The central executive is directly related to the executive control of attention as both work towards overall control of thoughts and behaviour. There are also storage systems controlled by the central executive which includes a phonological loop which works to store and rehearse verbal information, primarily language. The phonological loop can be used in many tasks or goals as it can verbalize steps and abstract thoughts. The episodic buffer is another storage system that was added to the original model, as a limited capacity storage system for integrating different information including from long-term memory (LTM) (A. Baddeley, 2000). Lastly, the visuospatial sketch pad works to store and manipulate visual and spatial information (A. D. Baddeley & Hitch, 1974). The visuospatial sketchpad conceptually heavily relates to motor imagery, as both involve visual and spatial information.

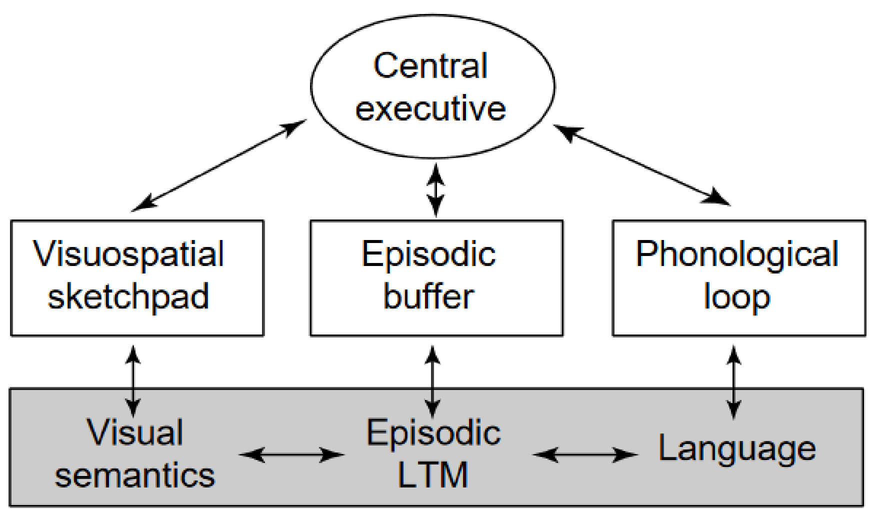


Figure 3. Schematic of Baddeley's model, where the central executive acts as the overarching control of the visuospatial sketchpad, the episodic buffer, and the phonological loop. Each are different storage systems that are able to work with the different types of information, visual semantic, episodic LTM and Language. (A. Baddeley, 2000).

As indicated above, working memory has been shown to be related to motor imagery (Gabbard et al., 2013; Helene & Xavier, 2006). The impact of deficits in working memory on motor imagery performance has been looked at in clinical populations such as stroke (Malouin et al., 2004; Schott, 2012). The Malouin et al., 2004 study looked at patients post stroke with motor impairment and healthy participants completing a single session of combined motor imagery and physical practice. Motor imagery ability was assessed along with a training procedure using motor imagery and physical practice. Importantly, working memory was assessed in three domains, including visuospatial, verbal, and kinesthetic. The results showed that patients after stroke had different levels of impairment of working memory and that the impairment in working memory impacted the results of training. As well, improvement from training was correlated to all domains of working memory, with the strongest correlation relating to visuospatial (Malouin et al., 2004). This is one example that shows the importance of working memory, primarily visuospatial, for motor imagery, specific to when there may be impairment (Malouin et al., 2004).

**Linking Motor Imagery Components and Cognitive Functions**

Ultimately, while looking at the cognitive functions of executive attention and working memory, there is overlap between the attention and working memory models. The executive control network for attention and the central control in working memory both focus on the goal of being able to attend to a task and control one’s thoughts. Attention, specifically the executive control, is crucial for generating an image and therefore is best linked with the generation component of motor imagery (Kosslyn, 1994). This attentional control is the process of ensuring thoughts are on the motor imagery task therefore creating an image while ignoring any conflicting stimuli or thoughts. Since the generation component was found to be the most predictive of overall motor imagery performance, it is believed that without the generation of an image one cannot move into the other components of maintaining or manipulating an image

(Kraeutner et al., 2020). Therefore, if someone is not able to attend to generating an image first then motor imagery may not occur making attention vital (Kraeutner et al., 2020). Generating an image can also relate to the central executive component of working memory as it relates to the executive control proposed in attention. The episodic buffer component of attention may also likely link to the generation component as when originally generating an imagine information stored in long term memory may be used. Therefore, the episodic buffer can bridge the persons prior knowledge to the motor imagery task at hand to generate an image.

For the maintenance component, working memory can be seen to play a vital role as holding any information in one’s memory is key to holding an image in one’s mind. The visuospatial sketchpad is especially relevant to the maintenance of an image as it would contain the visual information of the movement being imagined. The phonological loop may also be involved in verbalizing the steps of the action being imagined such as direction (e.g., thinking of the words, left, right, down, and up) or likely sounds to occur. Attention is also related to the maintenance component of motor imagery. For instance, to be able to generate and then maintain an image, one must focus their attention on generating the image, and then keep their attention on the image to maintain it. Maintaining an image specifically relates to sustained attention, as this is the act focusing on one thing over a longer period (Guillot & Collet, 2008).

Like its role in the maintenance component, working memory would play a key role in image manipulation as it provides the ability to ‘work’ with the image as changes are made throughout the process of imagery. Therefore, the manipulation component is also attributed to working memory, and more specifically the visuospatial sketchpad for working memory (Gu et al., 2018). Therefore, the visuospatial sketchpad would be essential to visualizing the changes of the movement that are occurring. As indicated previously, the phonological loop may also relate to verbalizations such as sounds related to the movements.

While working memory is no doubt important, it is likely that the cognitive function that is most crucial to motor imagery performance is attention, and specifically executive attention, as this relates to the overall control of one focusing on the task they are completing. Working memory should also be looked at as another essential function specifically for the maintenance or manipulation components and from a visuospatial perspective. Ultimately, generation of an image can only occur when there is attention to the motor imagery task to create the image. Without generation of an image there would then be no image to maintain or manipulate. Therefore, looking at executive attention along with working memory is a viable direction to look at how cognitive function are critical for motor imagery (Figure 4).

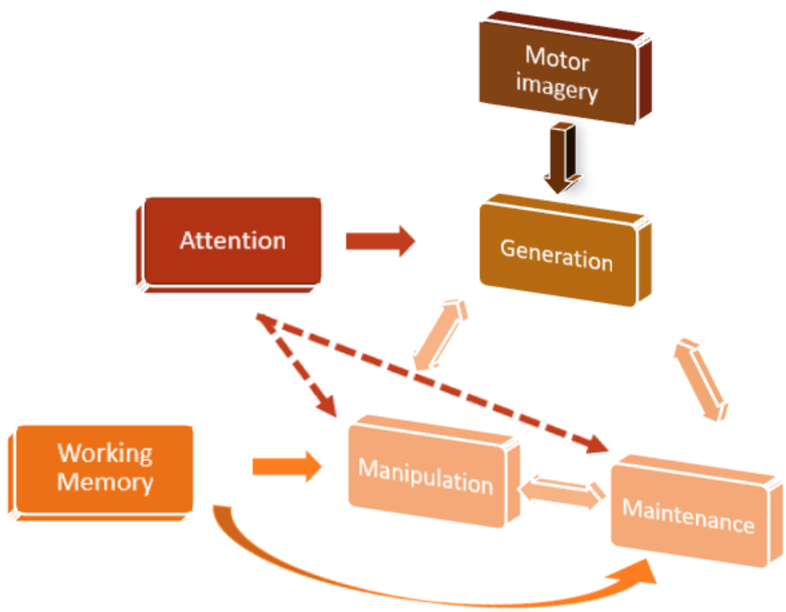


Figure 4. Diagram of the proposed links between the cognitive functions attention and working memory with the components of motor imagery.

Cognitive Deficits

As shown in the studies detailed above, an overall finding is that deficits in cognitive function can impact motor performance and learning such as in stroke, aging, and DCD (Biederman et al., 2019; Das et al., 2015). That attention is likely critical for motor imagery performance means that deficits in attention will negatively impact motor imagery. One reason for looking at attention along with working memory is that while 'healthy' participants are used in most motor imagery studies, some of these participants could potentially have an attention deficit, particularly in today's society where inattention has become a concern (Waite et al., 2020). Inattentiveness, which is when someone does not pay attention, can arise from a lack of motivation or an inability to concentrate, which can hinder performance (Rosario Rueda et al., 2015).

When inattentiveness occurs, this can result in phenomena such as mind wandering. Mind wandering, also known as daydreaming, is a concept related to attention. Mind wandering is where someone is supposed to be doing one thing, but they are actively thinking about something else, with the frequency of mind wandering varying based on how easily the individual can be distracted (Randall et al., 2014, Smallwood & Schooler, 2015). In a review, mind wandering was found to occur during everyday activities such as reading and driving and can occur in specialized occupations like aviation, although it can be minimized as seen with trained pilots (Smallwood & Schooler, 2015). Therefore, during mind wandering, a person's thoughts will not align with the task they are completing. For some people this may occur frequently and quickly during a task. While others may be able to initially focus easily, their thoughts will then shift to something other than the task (Boogert et al., 2018). While currently there is little research on mind wandering in relation to motor imagery, some studies have looked at mind wandering with motor performance of other tasks (Bock & Hagemann, 2010; McVay & Kane, 2009). One study looked at the negative impact mind wandering had on fine movements, and specifically how attention ensures optimal control of movements and that during mind wandering that would be disrupted (Dias Da Silva & Postma, 2022). Participants completed a visuomotor task where throughout the task participants would be asked if they had been mind wandering. The results showed that when participants reported mind wandering their movements were more variable and unpredictable, with the change attributed to reduced attentiveness to the task (Dias Da Silva & Postma, 2022). Overall, this study demonstrates the importance of mind wandering to attention, especially during motor tasks, where likely a similar impact would occur during motor imagery.

In general inattentiveness along with mind wandering can occur in anyone even when not considered a clinical deficit. A clinical deficit or issue with one's working memory can often be behaviourally observed as an attention deficit such as in attention-deficit hyperactivity disorder (ADHD) (Gu et al., 2018). If someone is not paying attention, their working memory can be unable to then hold information if the focus is not on it, which has been shown in ADHD (Cowan et al., 2005, Gu et al., 2018). While if someone has issues holding information in their working memory, the learning that occurs during motor imagery is not as efficient (Malouin et al., 2004). Attention-deficit hyperactivity disorder diagnoses have increased, but it's unclear whether there's an actual increase in incidence or better detection methods. Ultimately there are now more adults with ADHD symptoms, and the use of motor imagery in the population may be impacted given the rise in prevalence (Castellanos et al., 2005; Jonkman et al., 2017; Waite et al., 2020). Given this, we need to better understand how ADHD or inattentiveness in general impacts on motor imagery performance (Zhang & Markon, 2021; Waite et al., 2020). As mind wandering has been shown to be linked with ADHD, attention deficits are also likely to be related to working memory (Biederman et al., 2017). Overall, it is important for us to have a better understanding of how attention (or deficits in attention) impact on motor imagery performance.

The importance of attention to motor imagery is a notable relationship that needs to be further researched. As highlighted previously, the theories attempting to explain motor imagery have shifted towards more perceptual/cognitive mechanisms yet cognitive functions themselves have not been heavily studied regarding motor imagery (Cumming & Eaves, 2018; Guillot & Collet, 2008). The research that has occurred does show that deficits in cognitive function(s) impact motor learning and in certain cases, such as with DCD, there does appear to be an impact of deficits in cognitive function on motor imagery performance. Researchers studying motor imagery now have a better understanding of the components (i.e., generate, maintain, and manipulate) that make up motor imagery and the motor imagery assessments that measure the different components. By investigating the cognitive functions to determine how each contributes to the components of motor imagery, an overall better understanding of the cognitive resources required for motor imagery can be determined. Attention is one cognitive function that should be looked at as it has been suggested as being required for motor imagery, yet little research has investigated how attention, or more specifically deficits in attention, impact motor imagery performance. As well, attention fits with the generation component of motor imagery, if one cannot attend to a motor imagery task the image will likely not be generated therefore the other motor imagery components would also not occur. Another cognitive function, working memory, has been investigated in some motor imagery studies but is thought to better relate to the maintain and manipulation components of motor imagery. Ultimately by looking at attention along with working memory we can gain a better understanding of the role of these cognitive functions in motor imagery. Consequently, how we prescribe, and use motor imagery would be better informed – for instance, the use of motor imagery in people with inattention, mind wandering, or ADHD may not be preferred given motor imagery performance would be negatively impacted.

Assessment Psychometric Properties

In this study, the cognitive functions being assessed were defined based on the following constructs. Attention refers to executive attention as defined in the Petersen & Posner model. Likewise, working memory refers to visual working memory based on the visuospatial sketchpad of Baddeley's model. Furthermore, attentiveness refers to the observable trait of someone being attentive, with the opposite being inattentiveness. As attention and working memory both appear to be critical for motor imagery performance, both were investigated in the present work. To assess attention and working memory, assessments were chosen that best characterize attentiveness. Attentiveness (and its opposite, inattentiveness) are terms used throughout the study to address each of the cognitive assessments and measures that look at executive attention and working memory. Mind wandering, cognitive failures, and attention deficits (ADHD) were chosen as the measures for the constructs within the observable trait of attentiveness. The assessments looking at attentiveness included self-reported measures related to mind wandering and ADHD, as these were identified in the literature as part of cognitive deficits above.

The Mind Wandering Questionnaire (MWQ) was chosen to reflect the inattentiveness that can occur due to the frequency of mind wandering, as mind wandering was demonstrated above to be related to inattentiveness. The MWQ has been shown to be a valid tool for assessing an individual's propensity (i.e., trait level) for mind wandering in both adolescent and adult populations (Mrazek et al., 2013). The MWQ has been specifically validated against scales such as the Mindful Attention and Awareness Scale and the working memory capacity task, the Operation Span Task for convergent validity (Mrazek et al., 2013). While this scale was more recently developed, the goal of this scale is to combat face validity as prior scales being used to look at mind wandering focused on the construct of daydreaming. Reliability was also assessed, where good internal consistency was found with a Cronbach's analysis and inter-item correlations. The MWQ continues to be a reliable measure for other studies including but not limited to, Gionet et al., 2023; Liu et al., 2023; Pereira et al., 2020.

The Cognitive Failures Questionnaire (CFQ) is a self-report measure designed to assess everyday attentional lapses or cognitive failures in individuals' daily lives (Broadbent et al., 1982). The questionnaire reflects the subjective perception of cognitive failures rather than objectively measuring attentional performance. A factor analysis of the questionnaire has demonstrated that the CFQ consists of three factors, forgetfulness, distractibility, and false triggering. Forgetfulness directly relates to memory, including working memory. Distractibility and false triggering relate to attention. Specifically, distractibility is described as absentmindedness, particularly in social situations, and false triggering is the interrupted processing of sequences of cognitive and motor actions (Wallace, et al., 2004). This questionnaire was originally created to measure cognitive failures from a trait perspective where trait would be an underlining attribute that would not vary over time. This is opposed to state measures that could change as circumstances change. The CFQ was therefore tested for reliability to ensure scores were consistent over time with the same individuals completing the CFQ multiple times (Broadbent et al., 1982). The CFQ was initially tested for convergent and discriminant validity against multiple assessments including the Middlesex Hospital Questionnaire (MHQ), Slips of Action Form & Absent-mindedness questionnaire (Broadbent et al., 1982). More recently, this questionnaire has been revisited and found to also be related to the concept of mind wandering, furthering the concurrent validity of the assessment (Lopez et al., 2021).

The Adult ADHD Self-Report Scale (ASRS-V1.1) measures the presence and frequency of ADHD symptoms. These symptoms, which are commonly associated with attention problems, include difficulties with attention, distractibility, and impulsivity. Validity and reliability have been thoroughly assessed for use in the general population to measure symptomology of ADHD in research settings (Kessler et al., 2005, 2007; Silverstein et al., 2018). To improve face validity when developing the ASRS, clinicians looked at ADHD symptom criteria as well as the ASRS showed criterion validity in comparison to other diagnostic gold standards for diagnosing ADHD, which is a clinical interview (Kessler et al., 2005). The assessment was also found to have good test-retest reliability and internal consistency using the Cronbach's Alpha, and finally interrater consistency using interrater correlations (Silverstein et al., 2018, Adler et al., 2006).

The partial change detection task primarily measures attention and visual working memory processes. Researchers use the partial change detection task to explore various aspects of attention, such as the effects of attentional load, the role of selective attention, attentional capture, and the impact of distractors on change detection performance. By manipulating different factors, researchers can gain insights into attentional processes and cognitive mechanisms involved in change detection. This task has been shown to be valid and have good reliability (Luck & Vogel, 1997, 2013). Reliability for the specific structure (trial, and block length) was calculated using the Spearman-Brown corrected correlation (Harris et al., 2020).

**Objectives and Hypotheses**

Given the above, the objective of this project was to examine the role cognitive functions, and specifically executive attention and working memory, have on motor imagery performance. Therefore, the question asked was, does the level of attentiveness predict performance of motor imagery? As attention and working memory are linked, both were investigated as the behavioural skill of attentiveness. It was hypothesized that higher levels of inattentiveness will predict poorer performance on motor imagery tasks. The findings can generate knowledge on how an individual's inattentiveness may influence their motor imagery performance, and if this should be a consideration for determining if someone is a good candidate for motor imagery.

# Chapter 3: Methods

## Participants

Fifty-six participants between the ages of 17 and 60 who self-report having normal or corrected to normal vision as well as, no neuromuscular or musculoskeletal issues that would impede their ability to complete the tasks were recruited. The selected age range is based on previous research showing age-related changes in reaction time in participants over 60 years of age (Kray & Lindenberger, 2000). It is important to note that this study involves the first use of a comparison between the chosen motor imagery assessments and the chosen cognitive assessments. As such, there is little previous literature that exists to estimate expected effect sizes for a power analysis. Effect size was estimated based on a previous study of motor imagery assessments performed in our laboratory (Kraeutner et al., 2020). A power analysis was performed for a multiple linear regression (G*Power 3.1.9.7) using a small-moderate effect size ($f^2 = 0.15$) with results showing 43 participants would be needed to achieve power (type 1 error rate = 0.05, power ($1 - \beta$) = 0.8) for the proposed statistical analysis (details below under Experimental Design). The study was approved the Dalhousie University Health Sciences Research Ethics Board (REB # 2022-6137). Prior to taking part, each participant provided written, informed consent.

## Tasks and Materials

### Demographic Assessments

Sex, age, and handedness were the only demographic data recorded and reported on.

### Attention Assessments

Information related to attention was collected with the following research instruments and used to measure one's inattentiveness. To do so, participants completed three different questionnaires: the mind wandering questionnaire, the cognitive failures questionnaire and an

ADHD symptomology self-report. Participants also completed one computerized task called the Change Detection task.

*Mind Wandering Questionnaire (MWQ) (Appendix A)*

The Mind Wandering Questionnaire (MWQ) consists of 5 questions, with responses provided on a 6-point Likert scale (anchored by 1- almost never to 6- almost always) (Mrazek et al., 2013). The MWQ measures one's frequency of mind wandering, with higher scores meaning that the individual is more likely to mind wander (Pereira et al., 2020).

*Cognitive Failures Questionnaire (CFQ) (Appendix B)*

The Cognitive Failures Questionnaire (CFQ) consists of 25 questions, with responses provided on a 5-point Likert scale (anchored by 0- never to 4- very often) (Broadbent et al., 1982). The CFQ measures the number of cognitive failures or mistakes a person has made, with higher scores on the CFQ indicative of a greater tendency for cognitive failures (Broadbent et al., 1982). This questionnaire assesses multiple components of cognition, including attention. Specifically, in relation to attention, the CFQ assesses the likeliness of outcomes or missteps that may occur due to inattentiveness. Other components of the CFQ include memory and absentmindedness which directly relate to the constructs of attention that are of interest in this study (i.e., working memory and mind wandering).

*Adult ADHD Self-Report Scale (ASRS-V1.1) (Appendix C)*

This is a modified version of an ADHD adult self-report comprised of six questions with responses on a 5-point Likert scale (anchored by 0-never to 4- very often). The ASRS measures the frequency of ADHD symptoms one has experienced with higher scores indicating ADHD tendencies. Specifically, the first four questions assess inattentiveness while the last two assess hyperactivity.

*Change Detection Task*

The Change Detection Task is a visual working memory task where participants were asked to indicate if there is any difference or changes between an array of stimuli initially shown, compared to a single test stimulus (Alvarez & Cavanagh, 2004; Awh et al., 2007; Brady et al., 2011; Luck & Vogel, 1997). The version of the Change Detection Task used here is a computerized partial change detection task where participants watch a screen where squares of different colours appear briefly in different locations. This presentation of squares is followed by a blank screen and then the presentation of one square that may or not be the same as one of the squares shown previously (Figure 5). Participants are asked to identify if the square is the same or different. The task consists of 180 trials (Harris et al., 2020) where a change was present on 50% of the trials, and the number of squares changes every 60 trials from 4 to 6 to 8. Working memory capacity is calculated from the accuracy of identification (i.e., square is same or different) along with the response times are averaged. The Change Detection Task assesses working memory capacity through how well the participant can hold the visual stimuli in their mind and be able to recognize if there was a change.

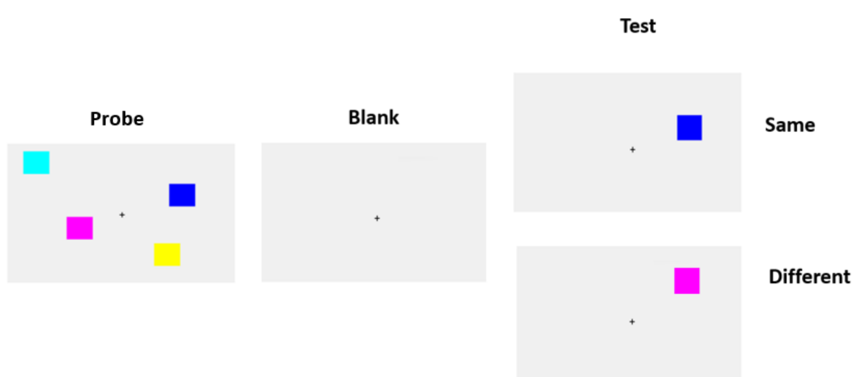


Figure 5. One trial of the change detection task which includes an arrayof squares appearing, followed by a blank screen and the test screen of either a square that is the same or different as one of the previous squares. This change detection task was specifically adapted from the Harris et al., 2020 study.

Motor Imagery Assessments

The motor imagery data collected with the following research instruments was used to measure different components of motor imagery (i.e., generate, maintain, manipulate). To do so, the motor imagery assessments included are the Movement Imagery Questionnaire, the Hand Laterality Judgment Task, and TraceLab (a tracing learning task).

*Movement Imagery Questionnaire- Revised Second Version (MIQ-RS) (Appendix D)*

The MIQ-RS consists of seven items for the visual and kinesthetic dimensions of motor imagery, for a total of 14 items. Each of the 14 items includes a movement involving the whole body (e.g., picking up a cup off the table) described to the participant which they are asked to perform. This is followed by the participant then being asked to imagine the movement (see Figure 6 for the set-up). Half of the questionnaires assess the visual dimension where they are asked to attempt to see the movement and the other half of the question, they are asked to attempt to feel the movement through imagery. Finally, they are asked to rate the imagery on a scale based on where it was a visual or kinesthetic question. Within the visual dimension, a self-report rating of 7 indicates the individual can very easily see the movement, while a score of 1 is reflective of the movement being very hard to see. Within the kinesthetic dimension, a self-report rating of 7 indicates the individual can very easily feel the movement, while a score of 1 is reflective of the movement being very hard to feel. The MIQ-RS has high reliability and has been shown to be predictive of high motor imagery ability (Gregg et al., 2010; Kraeutner et al., 2020). The MIQ was computer-based; participants used the keyboard to indicate when they began and finished both physical and imagery performance. Therefore, movement time was recorded, and mental chronometry could be calculated by comparing physical and imagery movement times.

Figure 6. Set up for the Motor Imagery Questionnaire (MIQ) including a screen with the instructions and the participant seating in a starting position for a movement.

*Hand Laterality Judgment Task (HLJT)*

The HLJT is a mental rotation task intended to assess implicit motor imagery ability (Boonstra et al., 2012). Participants are presented with pictures of the back or palm of a hand in different orientations and are asked to indicate if it is a right or left hand. The current study employs HLJT consistent with that reported in Kraeutner et al., 2020 in which 216 total stimuli (pictures of hands) are presented (Figure 7). Seventy-two different stimuli were created using the back and palms of a single hand, presented at 0, 60 and 300 degrees rotated. Each stimulus is presented to the participant three times, for a total of 216 trials (Kraeutner et al., 2020). Following the presentation of each stimulus, the participant is asked to respond as quickly and accurately as possible by pressing the left button ('z' on the keyboard) when a left hand appears, and the right button (‘m’ on the keyboard) when a right hand appears. Performance on the HLJT is measured via response time and error rate (Kraeutner et al., 2020). The task has been shown to be a reliable and valid measure of rotational motor imagery skills (Conson et al., 2015; ter Horst et al., 2010).

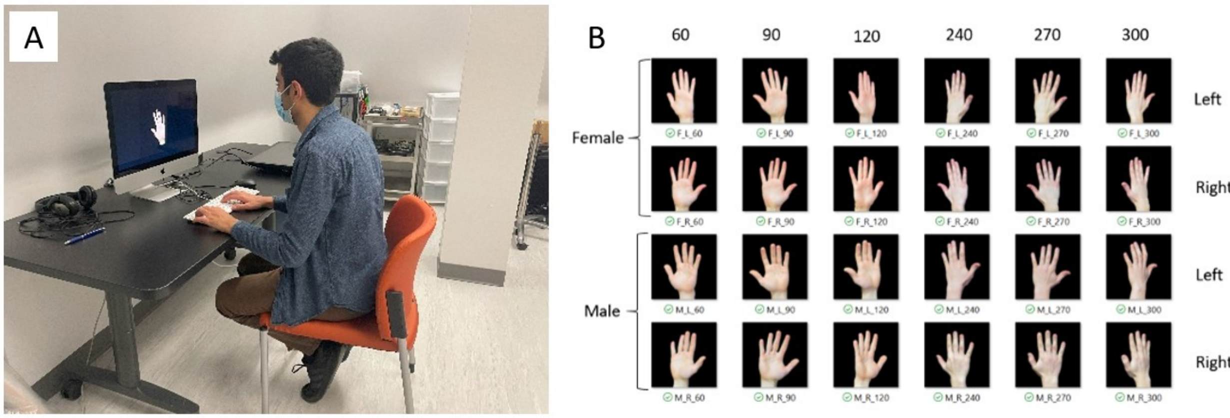


Figure 7. Images for the HLJT Task.Panel A shows the set up for the HLJT where the participant is seated comfortable with their hands on the keyboard with a hand on the screen. Panel B shows the possible images of hands that were presented to participants. Each image was shown in three different orientations ($0^{\circ}$, $60^{\circ}$, $300^{\circ}$) for a total of 72 potential trial types.

*TraceLab Task*

This task requires participants to reproduce complex trajectories on a touch screen. In this study, participants observe a trajectory as it is animated on a touchscreen, then practice reproducing the trajectory via motor imagery (Figure 8). Trajectories are either randomly generated or a repeated trajectory that the participant learns with practice. Practice consists of 100 trials (80 motor imagery followed by 20 physical practice trials). Performance is assessed in a final block of trials performed physically, where error (difference between stimulus trajectory and the reproduction) is calculated for the random trajectories and the repeated trajectory (to be learned). Importantly, learning via motor imagery has been demonstrated for the task (developed by our research group) in our prior work (Ingram et al., 2019).

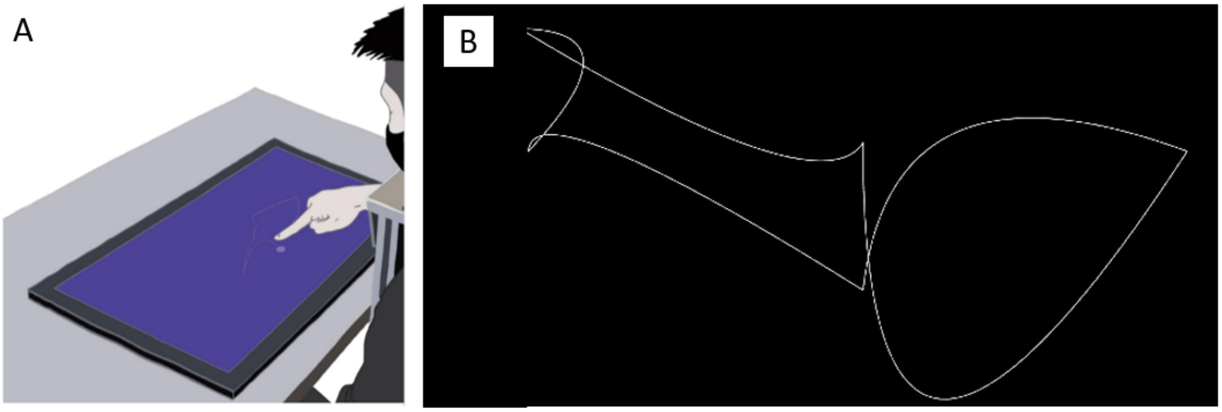


Figure 8. Images of TraceLab (a learning task). Panel A image shows the set up for a participant interaction with a touch screen for the tracing task. Panel B shows the repeated shape for all participants.

**Experimental Procedures**

The study consisted of a single session lasting approximately 120 minutes (Figure 9). Initial preparation for the study included verbally being instructed on what the participant would be asked to do, obtaining consent, and collecting the demographic information including the person's age, biological sex, and self-reported handedness. Participants were set up in a private, quiet room, comfortably seated with a computer in front of them.

Participants were first asked to complete the three attention-based questionnaires: the Mind Wandering Questionnaire (MWQ), the Cognitive Failures Questionnaire (CFQ), and the Adult ADHD Symptomology Self-Report (ASRS). Each participant completed these questionnaires in a randomized order. The questionnaires were completed by the participants on paper copies of each where the participants were told they can complete the tasks at their own pace or take a break at any point but that they needed to complete the questionnaires in the order the questionnaires were received. Completion of the questionnaires was private as the experimenter was unable to see their answers as they completed the questionnaires. Scores on questionnaires were calculated after the participants experimental session was completed.

Once the questionnaires were completed, participants were asked to complete the computer-based assessment of working memory, the Change Detection Task. The experimenter set up the computer to run this task which consisted of three blocks with 6 practice trials and 60 trials each. Once the change detection task was completed the participants transitioned to the motor imagery assessments. This component of the study began with a familiarization script that described how to perform motor imagery (Appendix E). The script was read out to the participant by the experimenter. The script specifies that motor imagery was to be completed in the first-person perspective (imagining themselves performing the movements) and provided direction on what sensations to focus on while imaging. The familiarization script has been used previously in the lab.

Following the familiarization to motor imagery, the participant began the motor imagery tasks. This consisted of the three tasks to assess motor imagery ability, including the Movement Imagery Questionnaire (MIQ), the Hand Laterality Judgment Task (HLJT), and the TraceLab task. Like the order of the questionnaires, the order of completion for the motor imagery assessments was randomized across participants. Each task was completed on the computer located in front of the participant. The MIQ involves full body movements where the participant completed movements from both sitting and standing positions where the participant moved through the questionnaire on the computer using the keyboard and mouse. This included having participants indicate when they would start and finish each movement as well as provide a rating after each movement. For the HLJT the participant was seated in front of the computer. The TraceLab Task was completed on a separate screen that is flat on the table where the participant interacts with the touch screen instead of a keyboard.

For each motor imagery task, the experimenter set up the computer for the next task. The participant followed and completed any instructions for the motor imagery task with the experimenter present to answer any questions. Once the participant reported being comfortable with the task the experimenter left the room noting they were available to the participant if they needed anything. For all the tasks participants were free to take breaks between blocks as long or as often as needed. At the conclusion of the study participants were invited to ask any questions about the study.

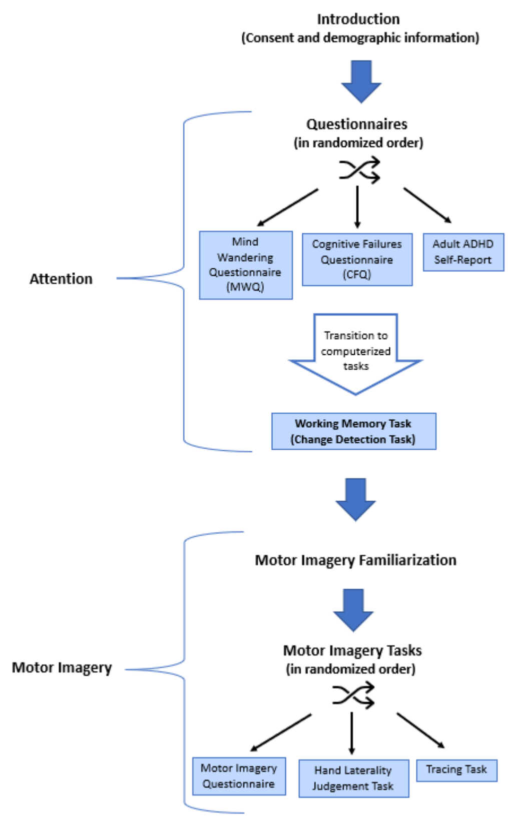


Figure 9. Flow chart detailing the study procedures, all tasks are indicated in each of the blue boxes with attention tasks followed by motor imagery tasks.

**Data Analysis**

The statistical analysis used modelling to determine if attentiveness predicted overall motor imagery performance. Regressions were used to predict overall motor imagery performance along with performance on tasks related to each of the motor imagery components using the attentiveness measures as the independent variables. Data processing and statistical analysis was completed using R (R project for statistical computing) with an a priori alpha of $p<0.05$.

All the attention and motor imagery measures were calculated for each participant prior to analysis. Each attention task resulted in a score that measured a different aspect of the individuals' attentional skills. Mean score on the Mind Wandering Questionnaire were calculated across all 6 questions, where a higher mean score reflects more inattentiveness. Total score on the Cognitive Failures Questionnaire is out of 100 with a higher score meaning the person is more inattentive. For the ASRS (the ADHD Symptomology Self-Report) possible scores are 1-6, with averages calculated for inattentiveness questions and impulsivity questions where a score of 2 or less indicates being less inattentive or impulsive and a score of 3 or more being more inattentive or impulsive. Lastly, for the Change Detection Task, working memory capacity was calculated with the equation, $K=n(HR+CR-1)$, where K is the standardized working memory capacity scores, n is the array number, HR is the hit rate (number correct when stimuli were the same) and CR is the correct rejection (number correct when stimuli were different). A lower working memory capacity score on the Change Detection Task reflects higher inattentiveness. Mean response times on the Change Detection task for the trials with a correct response were also included as a variable, where a higher time means someone may be more inattentive.

The motor imagery tasks each included a time-based measure. For the MIQ and the Tracing Task mental chronometry was calculated as the difference between the time needed to physically perform the task vs. the time needed to imagine it. For the HLJT the mean response times across all trials where the participant responded correctly were included. As well, the self-reported scores from the kinesthetic and visual components of the MIQ-RS (each out of 49) were calculated as a measure of ability to generate a mental image. The error rate on the HLJT, as a proportion of when the correct hand was identified, was also calculated. Lastly the difference in error for physical trials between repeated and random shapes on the tracing task was calculated. This is calculated by finding the difference in pixels between the shape that was animated and the shape the participant drew. Motor imagery performance was represented as a rank order of participants determined by summing scores across the motor imagery tasks used (see below for details).

Regression Modeling

The measures of attention detailed above were used as independent variables to predict motor imagery performance. The attention measures had assumptions checked prior to analysis including multicollinearity. For the multiple regressions the dependent variable was the ranked sum score of each motor imagery measure. An overall motor imagery score was calculated for each participant across the motor imagery measures following a similar process to Kraeutner et al., 2020. Each measure was ranked among the participants (i.e., best performing participant ranked number one and so forth), then each participants' rank across the motor imagery tasks was summed to create an overall rank for each participant.  For the MIQ visual and kinesthetic scores and the accuracy score from the HLJT, higher scores were associated with better motor imagery performance, and participants with the highest scores were ranked 1 (best performer), while those with the lowest scores were ranked 53 (worst performer). For mental chronometry (MIQ and TraceLab), HLJT RT (Response Time) and the error score from TraceLab, smaller values indicated better motor imagery performance, and thus participants with the smallest values were ranked one (best performer), while those with the highest values were ranked 53 (worst performer). After calculating the ranks for each motor imagery measure the individual ranks were summed for each participant. The sums were then re-ranked to create an overall motor imagery performance rank which represents the cumulative performance of each participant across all motor imagery measures completed in the study.

In addition to the model that used the attention measures to look at overall motor imagery performance, analyses were performed to examine how the attention measures related to the different components of motor imagery based on the results of Kraeutner et al., 2020. Ranked scores were therefore motor imagery measures summed based on the motor imagery component they were determined to be related to (Table 6). For the generation component of motor imagery, the dependent variable was determined by summing the ranks for the scores on the visual and kinesthetic component of the MIQ. For the maintenance component of motor imagery, the dependent variable was the sum of the ranks for mental chronometry for the MIQ and tracing task and the accuracy score from the HLJT. Finally, for the manipulation component of motor imagery, the outcome variable was realized by summing the ranks from the accuracy score of the HLJT and the average RT from the HLJT. The performance measure, difference in error (between random and repeated trajectories), derived from the TraceLab task was not included in the Kraeutner study and therefore was not fit to a motor imagery component. We thus performed an additional regression outside the motor imagery performance model described above to look at this measure independently. Each regression was performed using the forced entry method to look at how six different variables related to one's attentiveness predict overall ranked motor imagery performance.

Table 1. Outcome variables for each motor imagery components model

| Outcome Variable (Motor Imagery Component | Motor Imagery Measure |
|---|---|
| Generation | MIQ Visual Score |
| | MIQ Kinestic Score |
| Maintenance | MIQ Mental Chronometry |
| | TraceLab Mental Chronometry |
| | HLJT Accuracy |
| Manipulation | HLJT Accuracy |
| | HLJT RT |
| ? | TraceLab Difference in Error |

## Chapter 4: Results

### Participants

Of the 56 participants recruited, 53 were included in the final analysis. One participant's data was removed due to technical errors, and following preliminary data cleaning data, two additional participants was removed due to passing the threshold for the number of mistrials on the TraceLab. Of the 53 participants 40 were female, 45 were right-handed, and the mean age was 21.9 ± 3.7.

### Attention Data

Table 2 shows summary data for each of the attentiveness measures and a visualization of this data is shown in Figure 10. There appeared to be a range in the data obtained for the Mind Wandering Questionnaire, where the mean value was 3.9 (± 0.9) and a range of 2 to 5.7, where possible scores would range from 1 to 6 (Figure 10A). Similar variability was found for the Cognitive Failures Questionnaire, where a mean value of 45.1 (± 14.1) was observed and a range of 17 to 73, where possible scores range from 0 to 100 (Figure 10B). For the inattentiveness portion of the ASRS a mean score of 1.7 (± 0.7) was observed, while the mean score on the impulsivity portion of the ASRS was 2.4 (±1.0). The scores on the ASRS can range from 0 to 4 for both the inattentiveness and impulsivity componenets, with the range for inattentiveness found to be 0 to 3.75 and the range for impulsivity found to be 1 to 4 in the present study. Visual inspection of the ASRS data (Figure 10) for inattentiveness (C) and impulsivity (D) suggest that innattentiveness scores were skewed towards lower inattentiveness (i.e., participants were more attentive). Lastly, for the change detection task, the mean score for working memory capacity was 3.0 (± 1.2) with a mean RT of 980.5 ms (± 208.9). Visual inspection of this data (Figure 10) for both working memory capacity (E) and average RT (F) suggest working memory capacity has a  positive skew, therefore more particpants hadhigher working memory capacity scores and average RT has a negative skew, therefore more particpants had faster times.

Table 2. Descriptives for the Attentiveness Measures

| Measure | Outcome | Mean | SD | Variance | Min | Max |
|---|---|---|---|---|---|---|
| Mind Wandering Questionnaire | Average Mind Wandering Score | 3.9 | 0.9 | 0.8 | 2 | 5.8 |
| Cognitive Failures Questionnaire | Total Cognitive Failures Score | 45.1 | 14.1 | 199.0 | 17 | 73 |
| ADHD Self-Report Scale | Inattentiveness Score | 1.7 | 0.7 | 0.5 | 0 | 3.8 |
| | Impulsivity Score | 2.4 | 1.0 | 0.9 | 1 | 4 |
| Change Detection Task | Working Memory Capacity | 3.0 | 1.2 | 1.5 | -0.2 | 5.3 |
| | Average RT (ms) | 980.5 | 208.9 | 43651.8 | 527.4 | 1550.1 |

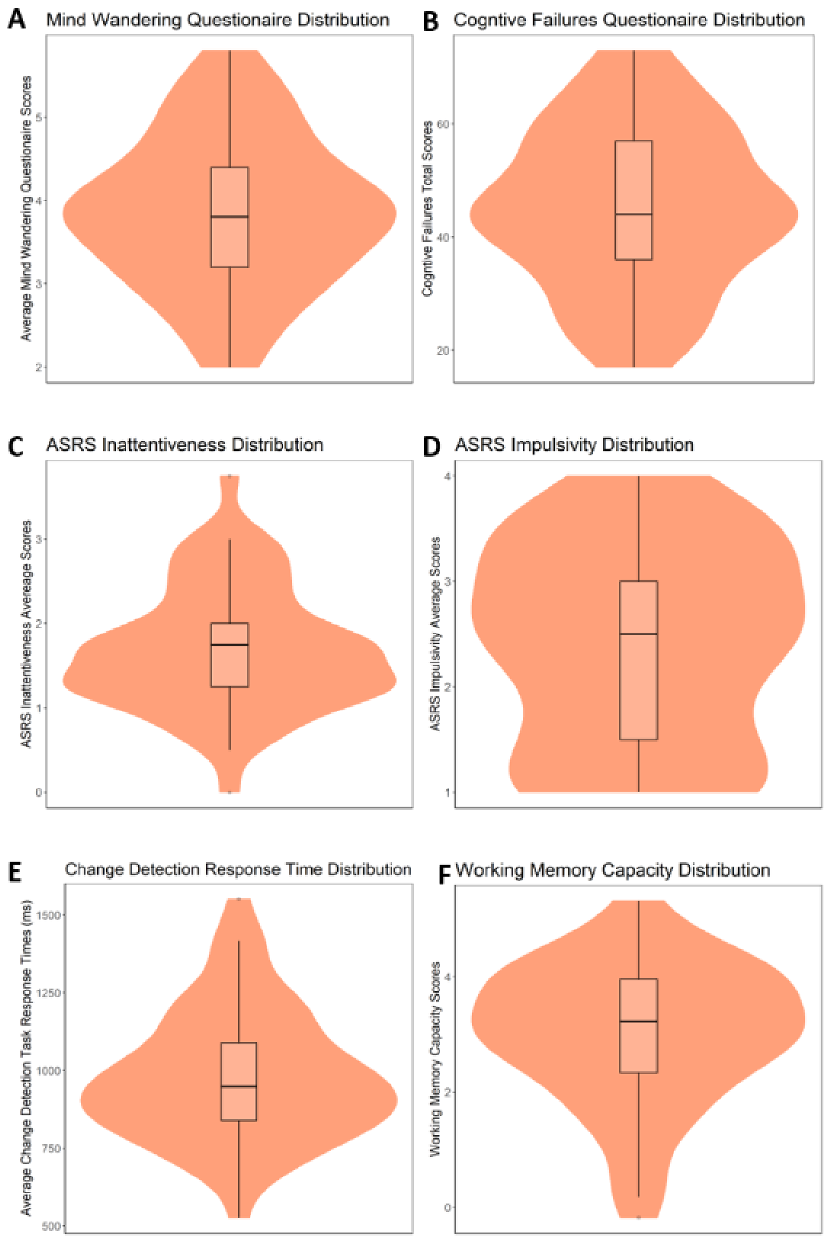


Figure 10. Violin plots of the attentiveness measures displaying the distribution of the scores for the Mind Wandering Questionnaire (A), Cognitive Failures Questionnaire (B), inattentiveness (C) and impulsivity (D) from the ASRS, and the working memory capacity (E) response times (F) from the Change Detection Task.

## Motor Imagery Data

For each of the three motor imagery tasks, a performance score and a time-based score (average RT or mental chronometry) were calculated. Summary data for the motor imagery measures are reported in Table 3. For the MIQ, mean score on the visual and kinesthetic components were 37.5 (± 8.6) and 35.2 (± 9.2) with a range of 14 to 49 and 8 to 48 out of a possible range of 7 to 49 (Figure 11A and B). The mean mental chronometry score for the MIQ was found to be 1.2 (± 0.8; Figure 11C). The scores on the visual and kinesthetic component of the MIQ appeared to be skewed towards representing better motor imagery ability (i.e., higher scores), with a similar finding for mental chronometry, albeit being skewed towards smaller differences between the time to physically and mentally perform the tasks. Average accuracy on the HLJT was 0.86 (± 0.65) and average RT was1307.2 ms (± 306.7). Visual inspection of the HLJT data (Figure 11) for both accuracy (D) and average RT (E ) show that accuracy appeared to be skewed towards higher values (i.e., better motor imagery ability) and average RT skewed towards faster response times. For TraceLab, the average difference in error between the repeated and random shape was -31.6 (± 26.2) and average mental chronometry score was 0.43 (± 0.55). Plots produced for both the difference in error and mental chronometry scores (Figure 11F and G) show the difference in error score is not normally distributed and many scores are negative, indicating that performance did not improve while mental chronometry was skewed towards smaller differences between physical and mental performance times indicating congruence in their RT for physical and motor imagery trials.

Table 3. Descriptives for the Motor Imagery Tasks

| Measure | Outcome | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| MIQ | Visual Score | 37.5 | 8.6 | 14 | 49 |
| | KinestheticScore | 35.2 | 9.2 | 8 | 48 |
| | Mental Chronometry | 1.2 | 0.8 | 0.004 | 3.4 |
| HLJT | Accuracy | 0.86 | 0.1 | 0.7 | 0.9 |
| | RT (ms) | 1307.2 | 306.7 | 648.8 | 1989.6 |
| TraceLab | Difference in Error (Pixels) | -31.6 | 26.2 | -106.5 | 15.4 |
| | Mental Chronometry | 0.4 | 0.5 | 0.005 | 2.9 |

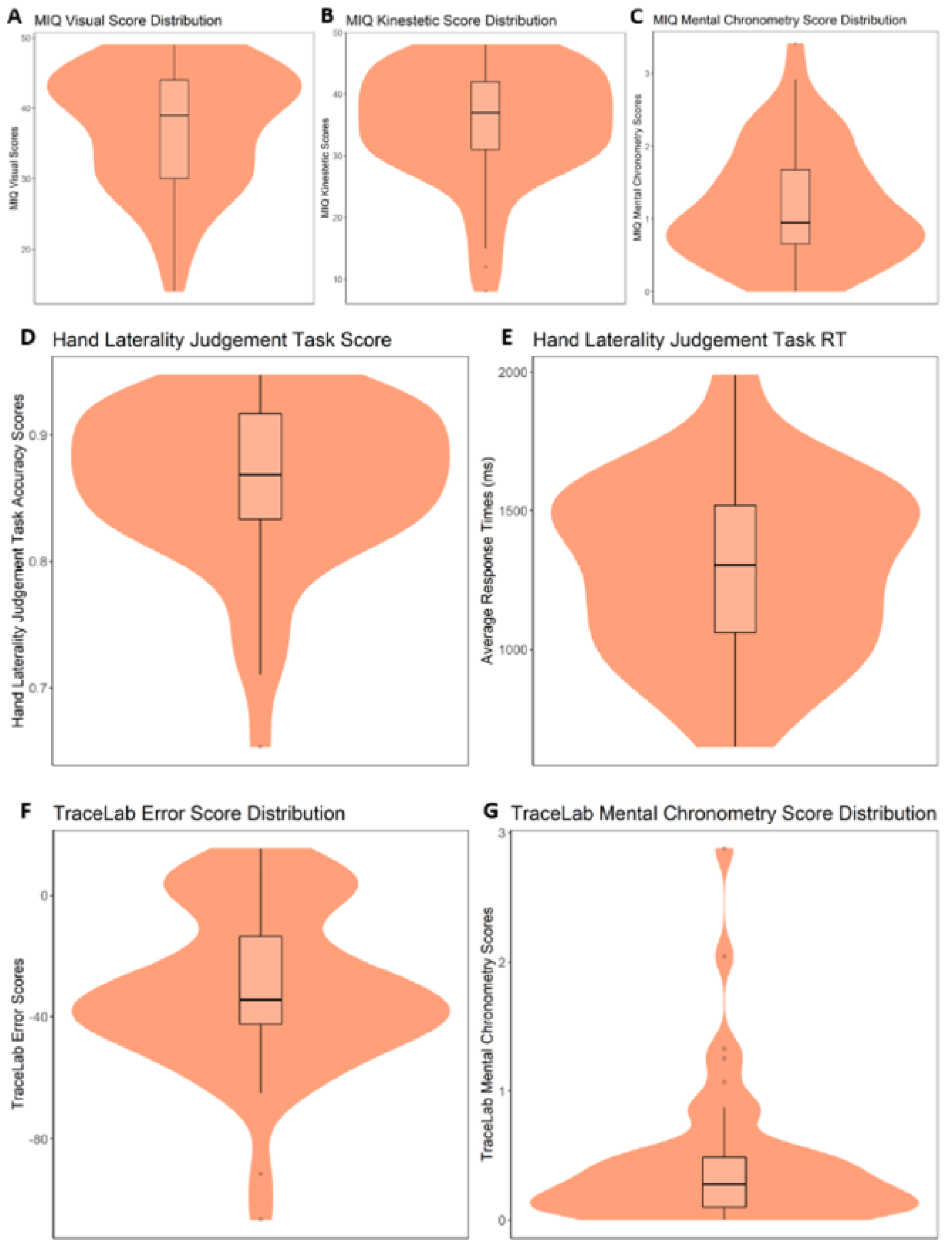


Figure 11. Violin plots of the motor imagery measures displaying the distribution of the visual (A), kinesthetic (B), and mental chronometry scores (C) from the MIQ, accuracy scores (D), and average response times (E) from the HLJT, the Difference in Error (F) and the mental chronometry score (G) from the TraceLab Task.

## Regression Modeling

Assumptions

Prior to the analysis being performed, the attentiveness measures were checked to ensure all assumptions were met. The attentive measures were found to have a non-zero variance (Table

2) and were found not to be related based on the results for multicollinearity (Table 4). Table 4 shows the attentiveness measures have variance inflation factor (VIF) scores of < 10 and Tolerance Scores should be > 0.2 confirming that the assumption of no multicollinearity is met.

Table 4. Variance inflation factor (VIF) and Tolerance values of the predictor variables

| Measure | Outcome | VIF | Tolerance |
|---|---|---|---|
| Mind Wandering Questionnaire | Average Mind Wandering Score | 2.241 | 0.446 |
| Cognitive Failures Questionnaire | Total Cognitive Failures Score | 2.278 | 0.439 |
| Adult Self-Report Scale ADHD | Inattentiveness Score | 1.526 | 0.655 |
| | Impulsivity Score | 1.332 | 0.751 |
| Change Detection Task | Working Memory Capacity | 1.079 | 0.926 |
| | Average RT (ms) | 1.046 | 0.956 |

For each of the predictor variables scatterplots were generated with the summed ranked values to examine the linearity of the predictor variables (Figures 8 through 15). For each relationship it was determined that while the relationship was not strong, it was linear in nature.

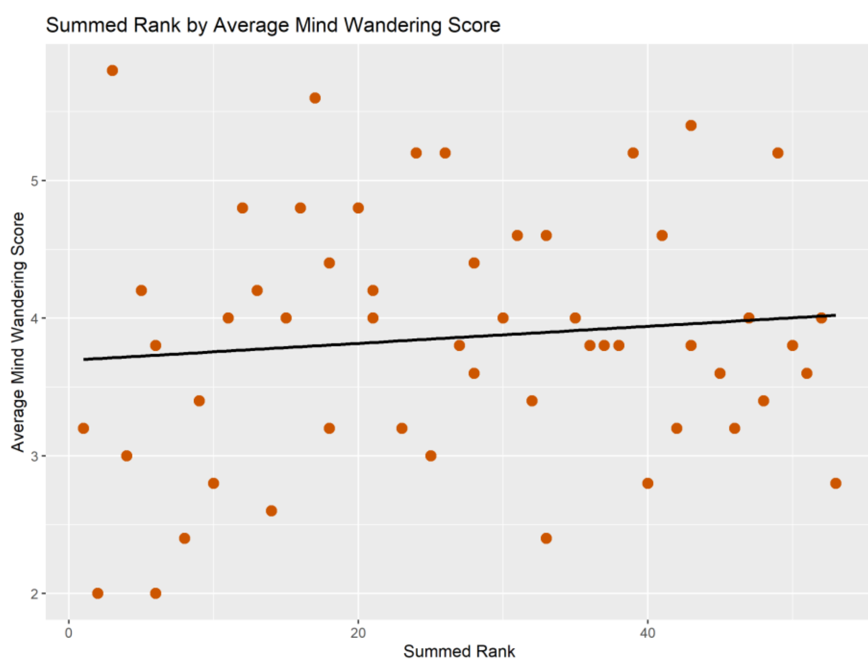


Figure 12. Scatter plot of a correlation between summed rank of motor imagery performance and mind wandering score, where summed rank is on the x-axis and mind wandering score is on the y-axis.

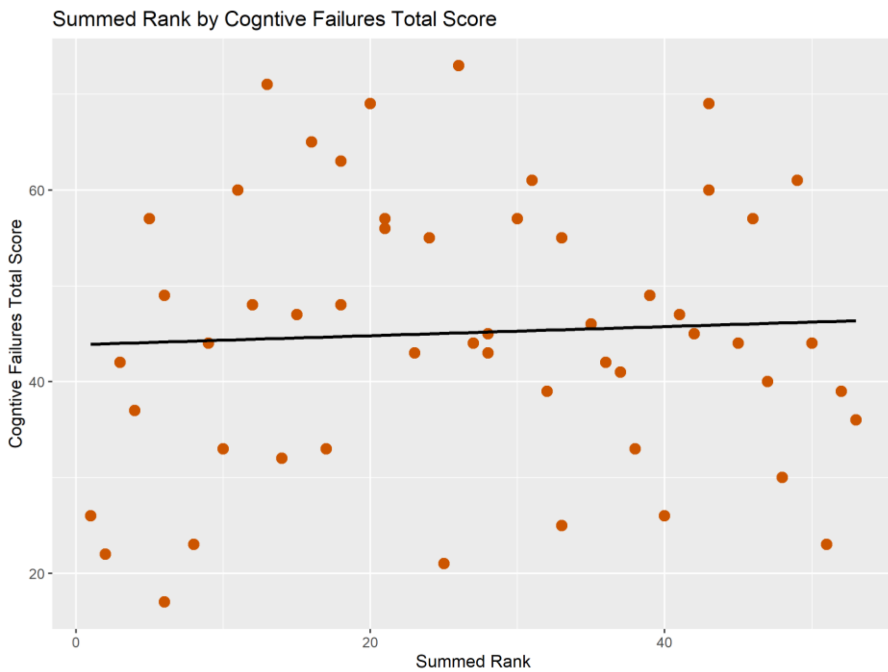


Figure 13. Scatter plot of a correlation between summed rank of motor imagery performance and cognitive failures score, where summed rank is on the x-axis and cognitive failures score is on the y-axis.

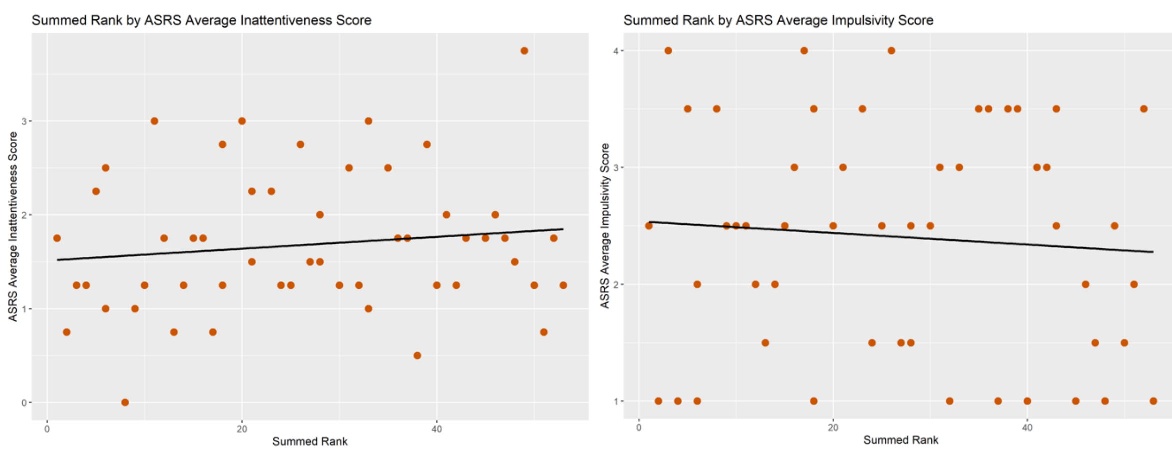


Figure 14. Scatter plot of a correlations between summed rank of motor imagery performance and ASRS scores,where summed rank is on the x-axis for both. The left image is the ASRS inattentiveness scores on the y-axis and the right image is the impulsivity scores on the y-axis.

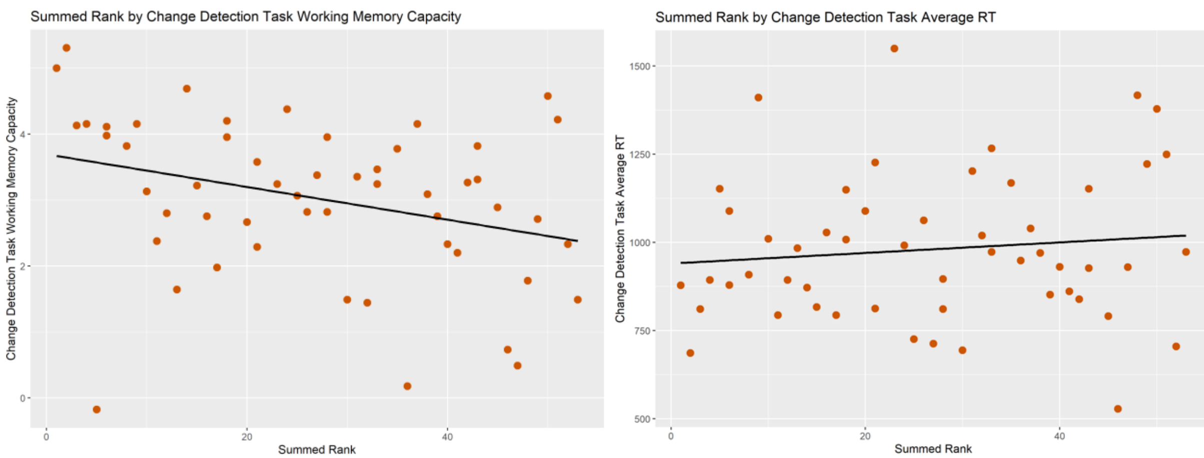


Figure 15. Scatter plots of correlations between summed rank of motor imagery performance and measures from the change detection task, where summed rank is on the x-axis for both. The left image is the working memory capacity scores on the y-axis, and the right image is the average response time on the y-axis.

Effect of Attentiveness on Motor Imagery Performance

As per our primary objective we performed a regression to determine if one's attentiveness predicted overall motor imagery performance. There were six predictor variables which included average scores for the Mind Wandering Questionnaire, ASRS ADHD Inattentiveness, ASRS ADHD Impulsivity and RT from the Change Detection Task and total score on the Cognitive Failures Questionnaire and Working Memory capacity while the outcome variable was the overall summed rank of motor imagery Performance. Results of the regression indicated one's overall attentiveness was not a significant predictor of overall motor imagery performance (F (6,46) = 1.549, p=0.184, $r^2$=0.168) (Table 5).

Table 5. Model summary of forced entry model predicting Overall Motor Imagery Performance

| | | | Change Statistics | | | |
|---|---|---|---|---|---|---|
| $R^2$ | Adjusted $R^2$ | Std. Error of the Estimate | F Change | df1 | df2 | p-value |
| .168 | .060 | 14.988 | 1.549 | 6 | 46 | .184 |

A residual plot was generated to further examine the residuals for the effect of attentiveness on motor imagery performance model and to confirm assumptions of linearity and homoscedasticity (Figure 12). The residual plot shows no clear pattern with even distribution around the y-intercept meaning the linearity and homoscedasticity assumptions were met, although one outlier is noted.

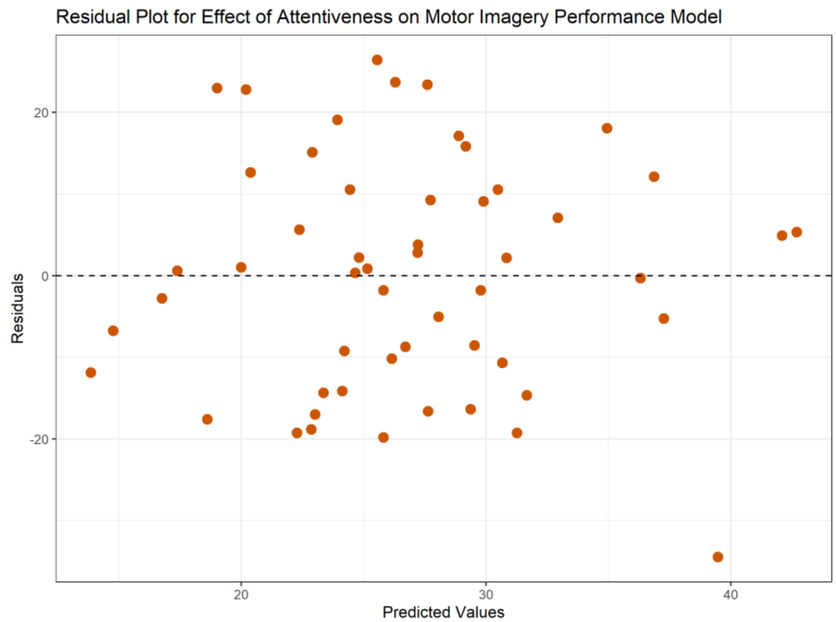


Figure 12. A residuals plot for the model that looks at the effect of attentiveness on motor imagery performance. Predicted values of the model are on the x-axis and the residuals are on the y-axis.

The coefficients for each of the attentiveness predictors for looking at motor imagery performance are summarized in Table 6. There was a significant negative relationship between Working Memory Capacity and Overall Ranked Motor Imagery Performance (b= -4.403, 95% CI [-8.007, -0.799], *t* (46) = -2.459, p= 0.018). All other predictors were not significant in accounting for variability in motor imagery performance including total score on the Cognitive Failures Questionnaire (b= -0.218, 95% CI [-0.665, 0.230], *t*(46) = -0.979, p= 0.333), Impulsivity Average Score on the ASRS (b= -3.085, 95% CI [-8.108, 1.938], *t*(46) = -1.236, p= 0.223), average score on the Mind Wandering Questionnaire (b= 3.776, 95% CI [-3.13, 10.715], *t*(46) =1.095 , p=0.279), Inattentiveness Average Score on the ASRS (b= 2.233, 95% CI [-4.823, 9.289], *t*(46) =0.637 , p=0.527), and average RT on the Change Detection task (b= 0.011, 95% CI [-0.009, 0.031], *t*(46) =1.081 , p=0.285).

Table 6. Coefficients of force entry model predicting Overall Motor Imagery Performance

| Model | Unstandardized Coefficients B | Std. Error | t | Sig. | 95.0% Confidence Interval for B Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|
| (Constant) | 28.353 | 14.350 | 1.976 | .054 | -.532 | 57.237 |
| Average Mind Wandering Score | 3.776 | 3.447 | 1.095 | .279 | -3.163 | 10.715 |
| Total Cognitive Failures Score | -.218 | .222 | -.979 | .333 | -.665 | .230 |
| Inattentiveness Score | 2.233 | 3.505 | .637 | .527 | -4.823 | 9.289 |
| Impulsivity Score | -3.085 | 2.496 | -1.236 | .223 | -8.109 | 1.938 |
| Change Detection Working Memory Capacity | -4.403 | 1.790 | -2.459 | .018* | -8.007 | -.799 |
| Change Detection Average RT (ms) | .011 | .010 | 1.081 | .285 | -.009 | .031 |

Regression Modeling for Motor Imagery Components

Assumptions were checked for all the following regression models, which included residuals plots. The residual plots (Figure S1 -S4)

*Effect of Attentiveness on Generation of a Motor Image*

For the generation component of motor imagery, the regression model is summarized in Table 7 and shows that one's attentiveness is not a significant predictor of the generation component of motor imagery (6,46) = 1.311, p=0.272, $r^2$=0.146. The coefficients for each of the attentiveness predictors for looking at the generation of a motor image are summarized in table S1. There were no significant relationships between the predictors and the outcome variable.

Table 7. Model summary of force entry model predicting Ranked Generation Component

| $R^2$ | Adjusted $R^2$ | Std. Error of the Estimate | Change Statistics F Change | df1 | df2 | p-value |
|---|---|---|---|---|---|---|
| .146 | .035 | 15.139 | 1.311 | 6 | 46 | .272 |

*Effect of Attentiveness on Maintenance of a Motor Image*

For the maintenance component of motor imagery, the regression model is summarized in Table 8 and shows that one's inattentiveness is not a significant predictor of the maintenance component of motor imagery F (6,46) = 1.520, p=0.193, $r^2$=0.165. The coefficients for each of the attentiveness predictors for looking at the maintenance of a motor image are summarized in Table S2. There was a significant negative relationship between Working Memory Capacity and maintenance motor imagery component; b= -4.218, 95% CI [-7.834, -0.603], *t* (46) = -2.349, p= 0.023. There were no significant relationships between the rest of the predictors and the outcome variable.

Table 8. Model summary of force entry model predicting Ranked Maintenance Component

| | | | Change Statistics | | | |
|---|---|---|---|---|---|---|
| $R^2$ | Adjusted $R^2$ | Std. Error of the Estimate | F Change | df1 | df2 | p-value |
| .165 | .057 | 15.036 | 1.520 | 6 | 46 | .193 |

*Effect of Attentiveness on Manipulation of a Motor Image*

For the manipulation component of motor imagery, the regression model is summarized in Table 9 and shows that one's inattentiveness is a significant predictor of the manipulation component of motor imagery F (6,46) = 3.308, p=0.009, $r^2$=0.301.

Table 9. Model summary of force entry model predicting Ranked Manipulation Component

| | | | Change Statistics | | | |
|---|---|---|---|---|---|---|
| $R^2$ | Adjusted $R^2$ | Std. Error of the Estimate | F Change | df1 | df2 | p-value |
| .301 | .210 | 13.681 | 3.308 | 6 | 46 | .009* |

The coefficients for each of the attentiveness predictors for looking at the manipulation of a motor image are summarized in Table 10. There was a significant negative relationship between Working Memory Capacity and Ranked Manipulation Component; b= -5.752, 95% CI [-9.042, -2.462], *t* (46) = -3.520, p< 0.001. There was a significant positive relationship between Average RT on Change Detection and Ranked Manipulation Component; b= 0.022, 95% CI

[0.003, 0.041], *t* (46) = 2.369, p= 0.022. The rest of the predictors did not have a significant relationship with the outcome of manipulation ranked score.

Table 10. Coefficients of force entry model predicting Ranked Manipulation Component

| | Unstandardized Coefficients | | | | 95.0% Confidence Interval for B | |
|---|---|---|---|---|---|---|
| Model | B | Std. Error | t | Sig. | Lower Bound | Upper Bound |
| (Constant) | 28.099 | 13.099 | 2.145 | .037* | 1.732 | 54.465 |
| Average Mind Wandering Score | -1.384 | 3.147 | -.440 | .662 | -7.718 | 4.950 |
| Total Cognitive Failures Score | .186 | .203 | .916 | .364 | -.223 | .595 |
| Inattentiveness Score | -1.390 | 3.200 | -.434 | .666 | -7.831 | 5.051 |
| Impulsivity Score | -2.531 | 2.278 | -1.111 | .272 | -7.117 | 2.055 |
| Change Detection Working Memory Capacity | -5.752 | 1.634 | -3.520 | <.001* | -9.042 | -2.462 |
| Change Detection Average RT (ms) | .022 | .009 | 2.369 | .022* | .003 | .041 |

*Effect of Attentiveness on the Performance of the TraceLab Task*

The regression model for the ranked score of difference in error on the TraceLab task is summarized in Table 11 and shows that one's attentiveness is not a significant predictor of the difference in error score on the TraceLab task F (6,46) = 1.511, p=0.196, $r^2$=0.165. The coefficients for each of the attentiveness predictors for looking at the TraceLab difference in error are summarized in Table S3. There was a significant positive relationship between Mind Wandering Questionnaire Score and Ranked Score on TraceLab b= 8.868, 95% CI [1.920, 15.816], *t* (46) = 2.569, p= 0.013. There was a significant negative relationship between Total Cognitive Failures Score and ranked score on TraceLab; b= -0.539, 95% CI [-0.988, -0.091], *t* (46) = -2.422, p<=0.019. The rest of the predictors did not have a significant relationship with the outcome of manipulation ranked score.

Table 11. Model summary of force entry model predicting performance on TraceLab Task

| | | | Change Statistics | | | |
|---|---|---|---|---|---|---|
| $R^2$ | Adjusted $R^2$ | Std. Error of the Estimate | F Change | df1 | df2 | p-value |
| .165 | .056 | 15.007 | 1.511 | 6 | 46 | .196 |

# Chapter 5: Discussion

## Overview

This study aimed to examine the role cognitive functions, and specifically the influence attention and working memory, have on motor imagery performance. The goal was to address gaps in the literature, related to cognitive functions and motor imagery. Specifically, the influence of attentiveness on motor imagery performance had yet to be examined despite it seemingly being critical to motor imagery. Related to this gap is the importance of looking at how potential deficits in attentiveness impact on practical applications of motor imagery given the prevalence of such issues in society. Therefore, executive attention along with working memory were chosen, as the literature would suggest that they would subserve the components of motor imagery previously identified, generation, maintenance, and manipulation. To achieve our goal, participants completed a single session in which attention, working memory and motor imagery ability were assessed. Subsequent analysis sought to predict overall motor imagery performance using each participant's attentiveness outcomes.

It had been hypothesized that attentiveness would predict motor imagery performance, and more specifically that higher levels of inattentiveness would be predictive of poorer motor imagery performance. The results of the study show that the attentiveness predictors, including likeliness to mind wander, cognitive failures, ADHD symptomatology and working memory capacity did not significantly predict overall motor imagery performance. This is based on the multiple regression with the model being non-significant and having a low $r^2$ value (0.168) showing the model to be a poor fit and leading to rejection of the study hypothesis.

Examination of the coefficients in the model looked at the individual attentiveness predictors to the outcome of motor imagery performance. Overall, the Change Detection Task was more predictive of performance than the other measures. Specifically, the Working Memory Capacity was calculated from the accuracy of hits and correct rejections on the Change Detection Task. While the overall model was insignificant, the relationship between Working Memory Capacity and motor imagery performance was a negative significant relationship, so the better someone's Working Memory Capacity was, the higher ranked they were for motor imagery performance (see Figure 15 for the general relationship). As the model looking at the influence of attentiveness on motor imagery performance was non-significant it cannot be definitively determined if working memory capacity predicts motor imagery performance.

Regression models were also performed that sought to predict the influence of attentiveness on the individual components of motor imagery. These analyses showed that attentiveness was not found to predict performance on the motor imagery tasks that reflect the generation, maintenance, or manipulation components. The model looking at the generation component was not significant and had a low $r^2$ value (0.146). As it was thought attention would be best linked to the generation component, it does make sense that if the main model with overall motor imagery performance was non-significant that the generation model would also be non-significant. The model examining the maintenance component was also found to be non-significant, with a low $r^2$ value (0.165), indicating it was a poor fit. Like the main model, examination of the coefficient for Working Memory Capacity was a significant predictor. Although again as the model itself was not significant so conclusions related to the predictive value of working memory capacity cannot be drawn.

The only significant model was that examining the manipulation component which summed the HLJT accuracy and RT ranks, although the $r^2$ value was low (0.301) indicating a weak relationship between the attentiveness measures and the manipulation component. Like the other models, working memory capacity predicted the most variance in the regression model suggesting that working memory capacity may predict ability to maintain an image (i.e., the maintenance component). Further investigation of this relationship is certainly warranted given this finding. The RT on the Change Detection Task was also a significant predictor of manipulation, which further suggests that working memory is an important contributor to the ability to manipulate a motor image. A fourth regression model was completed with the outcome variable being the ranks scores for the TraceLab difference in error scores. This score determines if learning (or, in the case of a single session, an improvement in performance) occurred during the TraceLab task. As indicated previously measures associated with TraceLab have not previously been linked to a motor imagery component. Therefore, it was examined independent of the other motor imagery measures, with the model found to be non-significant. This model, however, showed that there was a significant predictor of the Mind Wandering Questionnaire and the Cognitive Failures Questionnaire. While conclusions cannot be drawn as the model was not significant, this is the first model that showed these variables were predicting the outcome.

## Implications

### Implications for Inattentiveness Impacting Motor Imagery

While the results did not demonstrate that attentiveness influenced motor imagery performance (or more specifically a negative impact of *in*attentiveness on motor imagery performance), the findings do offer valuable insights into the relationship between cognitive functions and motor imagery performance. In this study it was found that regardless of someone's attentiveness skills, as assessed by the attentiveness measures, participants were still able to complete the motor imagery tasks. The only noteworthy finding suggests the significance of working memory specifically on manipulation, which was indicated by the predictor variable ‘working memory capacity’ from the Change Detection task. The finding suggests that working memory does play a role in the manipulation of a motor image. Therefore, further investigation into the impact of working memory on motor imagery performance, potentially involving different working memory tasks is needed. The results here suggest that working memory is more vital to motor imagery performance, but as demonstrated (see Figure 3), working memory itself is complex and made up of different systems that should be further explored.

The findings do conflict with the expectations for how the motor imagery components were likely linked to cognitive functions. The predicted relationships between attention and working memory to the motor imagery components, as originally illustrated in Figure 4 and revised in Figure 16, suggested a link for how attention was thought to impact the generation component of motor imagery. Furthermore, it was theorized that if attention was important for the generation component and a lack of attention impacted on image generation this would impact overall motor imagery performance as without an image maintenance and manipulation are not possible. However, the findings show that attention skills did not have an impact on motor imagery performance. Therefore, at least in the present study, despite someone having some degree of inattentiveness, there was no impact on motor imagery performance. The exception to this finding being that working memory may influence one’s ability to manipulate an image. The results do support the theorized link between cognitive functions and the motor imagery components as working memory was a significant predictor of the manipulation component, however no conclusion can be drawn regarding the influence of working memory on the maintenance component (see Figure 16). Thus, while the findings did not show that attentiveness more broadly influences motor imagery performance, it is likely that cognitive functions (or a subset of cognitive functions) have an influence.

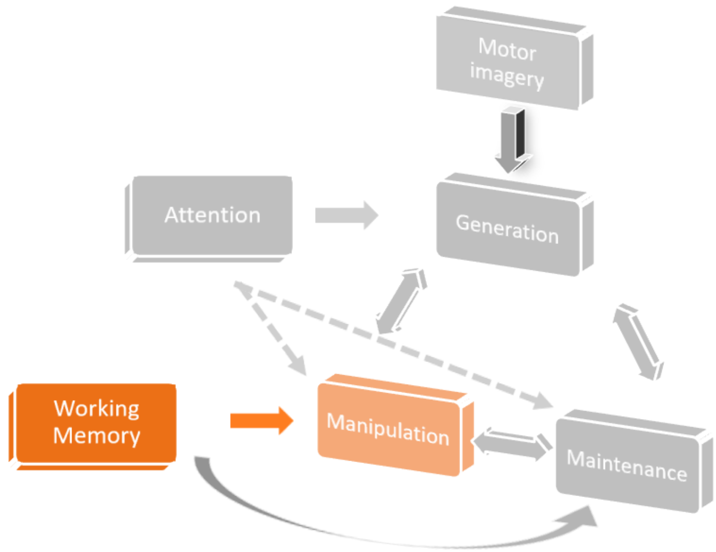


Figure 16. Revised image (from Figure 3) of the possible relationships between attention and working memory to the motor imagery components.The image now shows the only possible relation found based on the results of working memory and manipulation in colour.

While the results of the study indicate limited or no relationship between attentiveness and motor imagery performance, based on the literature and our understanding of motor imagery as a cognitive phenomenon, it is improbable that there is no link between attentiveness (i.e., attention and working memory more specifically) on motor imagery performance. This raises the question as to why the present work did not uncover such a relationship and begs a further question of whether there is a link that was not revealed in this specific study. Reasons for this study not finding a link between attentiveness and motor imagery performance may include the approach to defining and measuring attention. Indeed, it may well be that an alternate approach is needed, with such an approach including a broader representation of cognitive function, such as looking at the executive functions (collectively) instead of executive attention. Another possibility is to include each of the networks within the Peterson & Posner model, including alerting and orienting. With the finding of working memory capacity being a predictor of manipulation of a motor image, another direction could focus on working memory. Specifically, research in this area could focus on each of the working memory systems (i.e., the central executive, visuospatial sketchpad, episodic buffer, and the phonological loop) and their role in motor imagery.

The rationale for including the selected measures was to look at inattentiveness from an executive attention perspective. While the measures chosen do reflect inattentiveness, three of the four assessments (Mind Wandering Questionnaire, Cognitive Failures Questionnaire, ASRS) have potential to be biased as they are self-reported. Specifically, research suggests that a social desirability bias could be present, where participants may answer a question based on what they believe is the most desirable answer. Additionally, there may be confirmation bias where participants answer based on the beliefs of the researcher (Althubaiti, 2016). In this case, participants may not have wanted to report they had challenges with attentiveness, or they may believe that in today's society people are becoming less attentive and that includes themselves being less attentive (Gray et al., 2014; Waite et al., 2020). Conversely, the Change Detection Task, which is not a questionnaire and as such is not self-reported, had more promising results in showing an influence on motor imagery performance. As noted above, the possibility of using the Attention Network Test (ANT) or other cognitive tasks, mind wandering probes, or other assessments that yield behavioural or neurophysiological outcomes (or ideally both) may better illuminate the link between cognitive functions and motor imagery performance.

In addition to potential issues with the assessments used, the participants included in the study may not have reflected the variability in attentiveness skills that was assumed present in the population. Alternatively, if the participant group was reflective of attentiveness in the population, it suggests that the degree of deficits in attentiveness was not sufficient to impact on motor imagery performance. Rather, to have an impact on motor imagery performance, attentiveness deficits must be on the order found in clinical populations, such as those observed in individuals' post-stroke or those with DCD as documented in the literature. Ultimately these results do show that attentiveness skills in a healthy (self-reported) population that motor imagery is a tool that can be used and that research on this population is viable as they are able to do motor imagery.

**Limitations and Future Directions**

While the study sought to select and use assessments that were reflective of executive attention and working memory it is possible that the assessments chosen did not adequately capture the cognitive functions critical to motor imagery performance. Certainly, it was challenging to select assessments given the limited research on the impact of cognitive function (or more specifically dysfunction) on motor imagery performance. As indicated previously, other elements of attention should be looked, including, executive functions, and the networks in the Peterson & Posner model (i.e., Orienting, Alerting, and Executive Control), which could be accomplished using a measure such as the Attention Network Test (ANT) (de Souza Almeida et al., 2021; Fan et al., 2002). Furthermore, investigating working memory by looking at the entirety of Baddeley's model (i.e., the central executive, visuospatial sketchpad, episodic buffer, and the phonological loop) would represent an area for future research (Petersen & Posner, 2012, A. Baddeley, 2000, Miyake & Friedman, 2012). There have been previous studies that examined working memory and motor imagery (Malouin et al., 2004; Schott, 2012). Based on the results of this study, as well as the conclusions that have been made in previous studies, looking at how working memory interacts with motor imagery is a logical next step. Specifically, future work should look at each aspect of working memory and expand into the other working memory subsystems including the phonological loop and episodic buffer. Additionally, looking at working memory and each subsystem in relation to motor imagery components is advised, as this approach showed promise in this study with the relationship observed between working memory and the manipulation component. Such an approach may ultimately help to further the understanding of the importance of working memory for motor imagery. Alternatively, how the tasks were presented to participants could be considered a limitation. For instance, better understanding the learning style of the participants may be key, as the manner in which a given assessment was presented (e.g., audio vs. written instructions) could influence a participant understanding of the task influencing their performance.

In a study examining cognitive functions including attention, it is likely important to control (or assess) external variables such as sleep, anxiety, and motivation of the individual participants. While control or assessment of these variables was considered outside the scope of the present work, future studies that better account for such external factors may help in understanding the link between cognitive functions and motor imagery performance. Another variable that may have impacted the results is that within the sample there was a much higher proportion of females. This distribution may have impacted the results; sex and gender differences should be considered in future studies. Finally, a more thorough assessment of variables that may impact performance could aid in ensuring participants did not have other conditions that precluded them from full participation. For instance, screening for eligibility was completed via self-reporting and no further checks were completed. It is possible participants could have perceptual (tactile or visual) deficits or a learning disability that was unreported. Given the range of scores on the attentiveness measures this is unlikely, however not impossible.

## Conclusions

Overall, the results show that while attentiveness did not have an impact on motor imagery performance it is likely that cognitive functions, including working memory, influence motor imagery performance. The finding that levels of inattentiveness in a sample of participants randomly drawn from the university student population did not impact motor imagery performance suggest its prescription in this group and their use in studying motor imagery is warranted. The findings contribute to having a better understanding of motor imagery in relation to cognitive functions. While the degree of attentiveness did not impact motor imagery performance, the findings provided avenues for future research including further investigation of working memory and other cognitive functions including the executive functions. Such detailed investigation of cognitive functions and motor imagery will help uncover this this intricate relationship to optimize motor imagery research and its practical application.

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## Appendix A: Research Instruments- Mind Wandering Questionnaire

The Mind-Wandering Questionnaire (MWQ), along with the original article validating the MWQ, are freely available. Please cite the following reference when using this scale:

Mrazek, M. D., Phillips, D. T., Franklin, M. S., Broadway, J. M., & Schooler, J. W. (2013). Young and restless: Validation of the Mind-Wandering Questionnaire (MWQ) reveals disruptive impact of mind wandering among youth. *Frontiers in Perception Science, 4*, 560.

Scoring Instructions: Average responses from the five items. No reverse scoring is necessary.

Using the 1-6 scale below, please indicate how often you currently have each experience.

**1. I have difficulty maintaining focus on simple or repetitive work.**

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Almost Never | Very Infrequently | Somewhat Infrequently | Somewhat Frequently | Very Frequently | Almost Always |

**2. While reading, I find I haven't been thinking about the text and must therefore read it again.**

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Almost Never | Very Infrequently | Somewhat Infrequently | Somewhat Frequently | Very Frequently | Almost Always |

**3. I do things without paying full attention.**

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Almost Never | Very Infrequently | Somewhat Infrequently | Somewhat Frequently | Very Frequently | Almost Always |

**4. I find myself listening with one ear, thinking about something else at the same time.**

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Almost Never | Very Infrequently | Somewhat Infrequently | Somewhat Frequently | Very Frequently | Almost Always |

**5. I mind-wander during lectures or presentations.**

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Almost Never | Very Infrequently | Somewhat Infrequently | Somewhat Frequently | Very Frequently | Almost Always |

## Appendix B: Research Instruments- Cognitive Failures Questionnaire

The following questions are about minor mistakes which everyone makes from time to time, but some of which happen more often than others. We want to know how often these things have happened to your in the past 6 months. Please circle the appropriate number.

| | Never | Very Rarely | Occasionally | Quite Often | Very Often |
|---|---|---|---|---|---|
| 1. Do you read something and find you haven't been thinking about it and must read it again? | 0 | 1 | 2 | 3 | 4 |
| 2.Do you find you forget why you went from one part of the house to the other? | 0 | 1 | 2 | 3 | 4 |
| 3.Do you fail to notice signposts on the road? | 0 | 1 | 2 | 3 | 4 |
| 4.Do you find you confuse right and left when giving directions? | 0 | 1 | 2 | 3 | 4 |
| 5.Do you bump into people? | 0 | 1 | 2 | 3 | 4 |
| 6.Do you find you forget whether you've turned off a light or a fire or locked the door? | 0 | 1 | 2 | 3 | 4 |
| 7.Do you fail to listen to people's names when you are meeting them? | 0 | 1 | 2 | 3 | 4 |
| 8.Do you say something and realize afterwards that it might be taken as insulting? | 0 | 1 | 2 | 3 | 4 |
| 9.Do you fail to hear people speaking to you when you are doing something else? | 0 | 1 | 2 | 3 | 4 |
| 10.Do you lose your temper and regret it? | 0 | 1 | 2 | 3 | 4 |
| 11.Do you leave important letters unanswered for days? | 0 | 1 | 2 | 3 | 4 |
| 12.Do you find you forget which way to turn on a road you know well but rarely use? | 0 | 1 | 2 | 3 | 4 |
| 13.Do you fail to see what you want in a supermarket (although it's there)? | 0 | 1 | 2 | 3 | 4 |
| 14.Do you find yourself suddenly wondering whether you've used a word correctly? | 0 | 1 | 2 | 3 | 4 |
| 15.Do you have trouble making up your mind? | 0 | 1 | 2 | 3 | 4 |
| 16.Do you find you forget appointments? | 0 | 1 | 2 | 3 | 4 |
| 17.Do you forget where you put something like a newspaper or a book? | 0 | 1 | 2 | 3 | 4 |
| 18.Do you find you accidentally throw away the thing you want and keep what you meant to throw away -- as in the example of throwing away the matchbox and putting the used match in your pocket? | 0 | 1 | 2 | 3 | 4 |
| 19.Do you daydream when you ought to be listening to something? | 0 | 1 | 2 | 3 | 4 |
| 20.Do you find you forget people's names? | 0 | 1 | 2 | 3 | 4 |
| 21.Do you start doing one thing at home and get distracted into doing something else (unintentionally)? | 0 | 1 | 2 | 3 | 4 |
| 22.Do you find you can't quite remember something although it's "on the tip of your tongue"? | 0 | 1 | 2 | 3 | 4 |
| 23.Do you find you forget what you came to the shops to buy? | 0 | 1 | 2 | 3 | 4 |
| 24.Do you drop things? | 0 | 1 | 2 | 3 | 4 |
| 25.Do you find you can't think of anything to say? | 0 | 1 | 2 | 3 | 4 |

**Appendix C: Research Instruments- Adult ADHD Self-Report Scale (ASRS-V1.1)**

| Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, place an X in the box that best describes how you have felt and conducted yourself over the past 6 months. | Never | Rarely | Sometimes | Often | Very often |
|---|---|---|---|---|---|
| **PART A** | | | | | |
| How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done? | | | | | |
| How often do you have difficulty getting things in order when you have to do a task that requires organization? | | | | | |
| How often do you have problems remembering appointments or obligations? | | | | | |
| When you have a task that requires a lot of thought, how often do you avoid or delay getting started? | | | | | |
| How often do you fidget or squirm with your hands or feet when you have to sit down for a long time? | | | | | |
| How often do you feel overly active and compelled to do things, like you were driven by a motor? | | | | | |

## Appendix D: Research Instruments- Movement Imagery Questionnaire
## Movement Imagery Questionnaire – Revised second version

**MIQ-RS**

This questionnaire concerns two ways of mentally performing movements that are used by some people more than by others and are more applicable to some types of movements than others. The first is attempting to form a visual image or picture of a movement in your mind. The second is attempting to feel what performing a movement is like without actually doing the movement. You are requested to do both of these mental tasks for a variety of movements in this questionnaire, and then rate how easy/difficult you found the tasks to be. The ratings that you give are not designed to assess the goodness or badness of the way you perform these mental tasks. They are attempts to discover the capacity individuals show for performing these tasks for different movements. There are no right or wrong ratings or some ratings that are better than others. Each of the following statements describes a particular action or movement. Read each statement carefully and then actually perform the movement as described. Only perform the movement a single time. Return to the starting position for the movement just as if you were going to perform the action a second time. Then, depending on which of the following you are asked to do, either (i) form as clear and vivid a visual image as possible of the movement just performed, or (ii) attempt to feel yourself making the movement just performed without actually doing it. After you have completed the mental task required, rate the ease/difficulty with which you were able to do the task. Take your rating from the following scales.
Rating scales:

**Visual Imagery Scale**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to see | Hard to see | Somewhat hard to see | Neutral (not easy not hard) | Somewhat easy to see | Easy to see | Very easy to see |

**Kinesthetic Imagery Scale**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to feel | Hard to feel | Somewhat hard to feel | Neutral (not easy not hard) | Somewhat easy to feel | Easy to feel | Very easy to feel |

Be as accurate as possible and take as long as you feel necessary to arrive at the proper rating for each movement. You may choose the same rating for any number of movements “seen” or “felt” and it is not necessary to utilize the entire length of the scale.

1. ***Starting Position:*** Stand with your feet and legs together and your arms at your sides.
   ***Action:*** Raise your one knee as high as possible so that you are standing on one leg with your other leg flexed (bent) at the knee. Now lower your leg so that you are again standing on two feet.
   ***Mental Task:*** Assume the starting position. Attempt to **feel** yourself making the movement just performed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to feel | Hard to feel | Somewhat hard to feel | Neutral (not easy not hard) | Somewhat easy to feel | Easy to feel | Very easy to feel |

***Rating:*** _________

2. ***Starting Position:*** While sitting, put your hand on your lap and make a fist.
   ***Action:*** Raise until hand above your head until your arm is fully extended, keeping your fingers in a fist. Next, lower your hand back to your lap while maintaining a fist.
   ***Mental Task:*** Assume the starting position. Attempt to **see** yourself making the movement just performed with as clear and vivid a visual image as possible. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to see | Hard to see | Somewhat hard to see | Neutral (not easy not hard) | Somewhat easy to see | Easy to see | Very easy to see |

***Rating:*** _________

3. ***Starting Position:*** Extend your arm straight out to your side so that it is parallel to the ground, with your fingers extended and your palm down.
   ***Action:*** Move your arm forward until it is directly in front of your body (still parallel to the ground). Keep your arm extended during the movement and make the movement slowly. Now move your arm back to the starting position, straight out to your side.
   ***Mental Task:*** Assume the starting position. Attempt to **feel** yourself making the movement just performed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to feel | Hard to feel | Somewhat hard to feel | Neutral (not easy not hard) | Somewhat easy to feel | Easy to feel | Very easy to feel |

***Rating:*** _________

4. ***Starting Position:*** Stand with your arms fully extended above your head.
   ***Action:*** Slowly bend forward at the waist and try and touch your toes with your fingertips. Now return to the starting position, standing erect with your arms extended above your head.
   ***Mental Task:*** Assume the starting position. Attempt to **see** yourself making the movement just performed with as clear and vivid a visual image as possible. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to see | Hard to see | Somewhat hard to see | Neutral (not easy not hard) | Somewhat easy to see | Easy to see | Very easy to see |

***Rating:*** _________

5. ***Starting Position:*** Put your hand in front of you about shoulder height as if you are about to push open a swinging door. Your fingers should be pointing upwards.
   ***Action:*** Extend your arm fully as if you are pushing open the door, keeping your fingers pointing upwards. Now let the swinging door close by returning your hand and arm to the starting position.
   ***Mental Task:*** Assume the starting position. Attempt to **see** yourself making the movement just performed with as clear and vivid a visual image as possible. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to see | Hard to see | Somewhat hard to see | Neutral (not easy not hard) | Somewhat easy to see | Easy to see | Very easy to see |

***Rating:*** _________

6. ***Starting Position:*** While sitting, put your hand in your lap. Pretend you see a drinking glass on a table directly in front of you.
   ***Action:*** Reach forward, grasp the glass and lift it slightly off the table. Now place it back on the table and return your hand to your lap.
   ***Mental Task:*** Assume the starting position. Attempt to **feel** yourself making the movement just performed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to feel | Hard to feel | Somewhat hard to feel | Neutral (not easy not hard) | Somewhat easy to feel | Easy to feel | Very easy to feel |

***Rating:*** _________

7. ***Starting Position:*** Your hand is at your side. Pretend there is a door in front of you that is closed.
***Action:*** Reach forward, grasp the door handle and pull open the door. Now gently shut the door, let go of the door handle and return your arm to your side.
***Mental Task:*** Assume the starting position. Attempt to **feel** yourself making the movement just performed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to feel | Hard to feel | Somewhat hard to feel | Neutral (not easy not hard) | Somewhat easy to feel | Easy to feel | Very easy to feel |

***Rating:*** _________

8. ***Starting Position:*** Stand with your feet and legs together and your arms at your sides.
***Action:*** Raise your one knee as high as possible so that you are standing on one leg with your other leg flexed (bent) at the knee. Now lower your leg so that you are again standing on two feet.
***Mental Task:*** Assume the starting position. Attempt to **see** yourself making the movement just performed with as clear and vivid a visual image as possible. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to see | Hard to see | Somewhat hard to see | Neutral (not easy not hard) | Somewhat easy to see | Easy to see | Very easy to see |

***Rating:*** _________

9. ***Starting Position:*** While sitting, put your hand on your lap and make a fist.
***Action:*** Raise your hand above your head until your arm is fully extended, keeping your fingers in a fist. Next, lower your hand back to your lap while maintaining a fist.
***Mental Task:*** Assume the starting position. Attempt to **feel** yourself making the movement just performed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to feel | Hard to feel | Somewhat hard to feel | Neutral (not easy not hard) | Somewhat easy to feel | Easy to feel | Very easy to feel |

***Rating:*** _________

10. ***Starting Position:*** Extend your arm straight out to your side so that it is parallel to the ground, with your fingers extended and your palm down.
***Action:*** Move your arm forward until it is directly in front of your body (still parallel to the ground). Keep your arm extended during the movement and make the movement slowly. Now move your arm back to the starting position, straight out to your side.
***Mental Task:*** Assume the starting position. Attempt to **see** yourself making the movement just performed with as clear and vivid a visual image as possible. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to see | Hard to see | Somewhat hard to see | Neutral (not easy not hard) | Somewhat easy to see | Easy to see | Very easy to see |

***Rating:*** _________

11. ***Starting Position:*** Stand with your arms fully extended above your head.
***Action:*** Slowly bend forward at the waist and try and touch your toes with your fingertips. Now return to the starting position, standing erect with your arms extended above your head.
***Mental Task:*** Assume the starting position. Attempt to **feel** yourself making the movement just performed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to feel | Hard to feel | Somewhat hard to feel | Neutral (not easy not hard) | Somewhat easy to feel | Easy to feel | Very easy to feel |

***Rating:*** _________

12. ***Starting Position:*** Put your hand in front of you about shoulder height as if you are about to push open a swinging door. Your fingers should be pointing upwards.
***Action:*** Extend your arm fully as if you are pushing open the door, keeping your fingers pointing upwards. Now let the swinging door close by returning your hand and arm to the starting position.
***Mental Task:*** Assume the starting position. Attempt to **feel** yourself making the movement just performed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to feel | Hard to feel | Somewhat hard to feel | Neutral (not easy not hard) | Somewhat easy to feel | Easy to feel | Very easy to feel |

***Rating:*** _________

13. ***Starting Position:*** While sitting, out your hand in your lap. Pretend you see a drinking glass on a table directly in front of you.
***Action:*** Reach forward, grasp the glass and lift it slightly off the table. Now place it back on the table and return your hand to your lap.
***Mental Task:*** Assume the starting position. Attempt to **see** yourself making the movement just performed with as clear and vivid a visual image as possible. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to see | Hard to see | Somewhat hard to see | Neutral (not easy not hard) | Somewhat easy to see | Easy to see | Very easy to see |

***Rating:* _________**

14. ***Starting Position:*** Your hand is at your side. Pretend there is a door in front of you that is closed.
***Action:*** reach forward, grasp the door handle and pull open the door. Now gently shut the door, let go of the door handle and return your arm to your side.
***Mental Task:*** Assume the starting position. Attempt to **see** yourself making the movement just performed with as clear and vivid a visual image as possible. Now rate the ease/difficulty with which you were able to do this mental task.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very hard to see | Hard to see | Somewhat hard to see | Neutral (not easy not hard) | Somewhat easy to see | Easy to see | Very easy to see |

***Rating:* _________**

## Appendix E: Motor Imagery Familiarization Script

Motor imagery is the mental performance of a movement – this means that you don't physically perform the movement. Instead, you imagine yourself doing it by creating a picture of it in your head. There are two ways you can do motor imagery. The first is by picturing yourself performing the movement, and the second is by picturing someone else doing the movement. For this study we want you to imagine yourself doing each of the movements throughout the motor imagery tasks.

Doing motor imagery can be difficult at first, but there are a few things that can help you get better at it. One thing you can do is to try and relax – take a couple of slow, deep breaths. If you are sitting you can think about how the chair feels, and the position of your body. Another thing you can do is to think about how it feels when you actually perform the movement. How is each body part moving? How long does each movement take? All these sensations can be used to make the picture in your head more vivid.

## Appendix F: Supplementary Materials

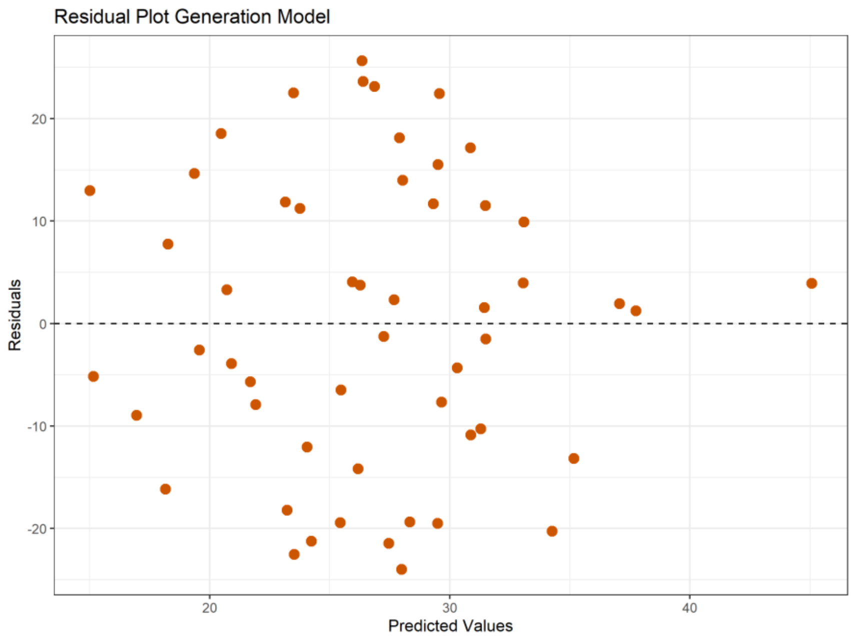


Figure S1. A residuals plot for the model that looks at the effect of attentiveness on generation of a motor image. Predicted values of the model are on the x-axis and the residuals are on the y-axis.

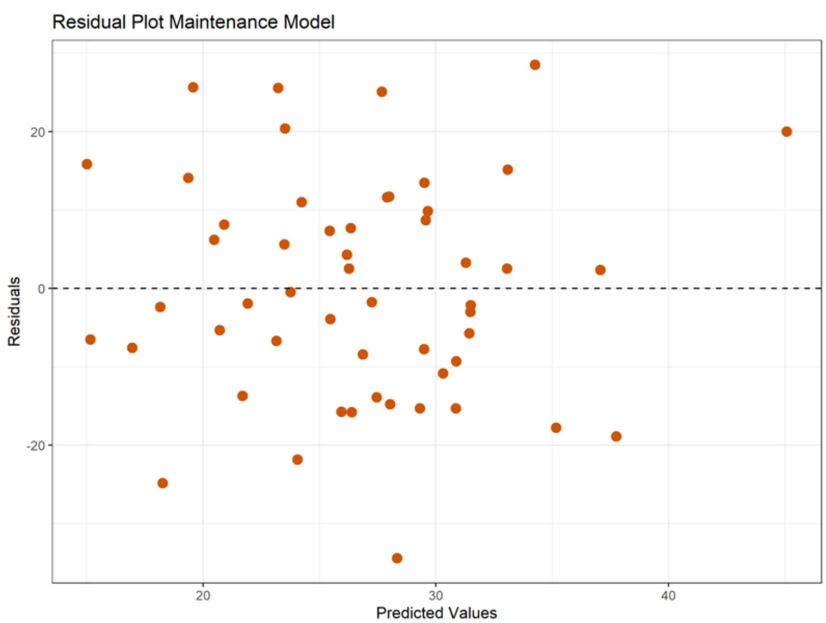


Figure S2. A residuals plot for the model that looks at the effect of attentiveness on maintenance of a motor image. Predicted values of the model are on the x-axis and the residuals are on the y-axis.

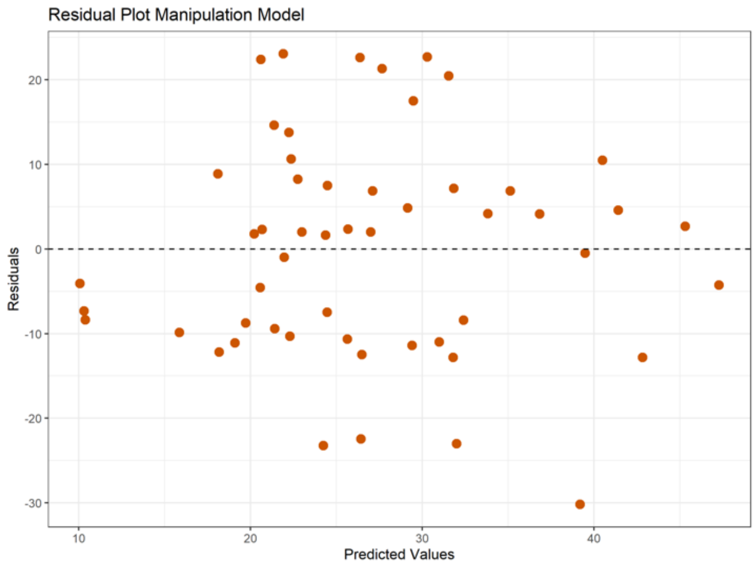


Figure S3. A residuals plot for the model that looks at the effect of attentiveness on manipulation of a motor image. Predicted values of the model are on the x-axis and the residuals are on the y-axis.

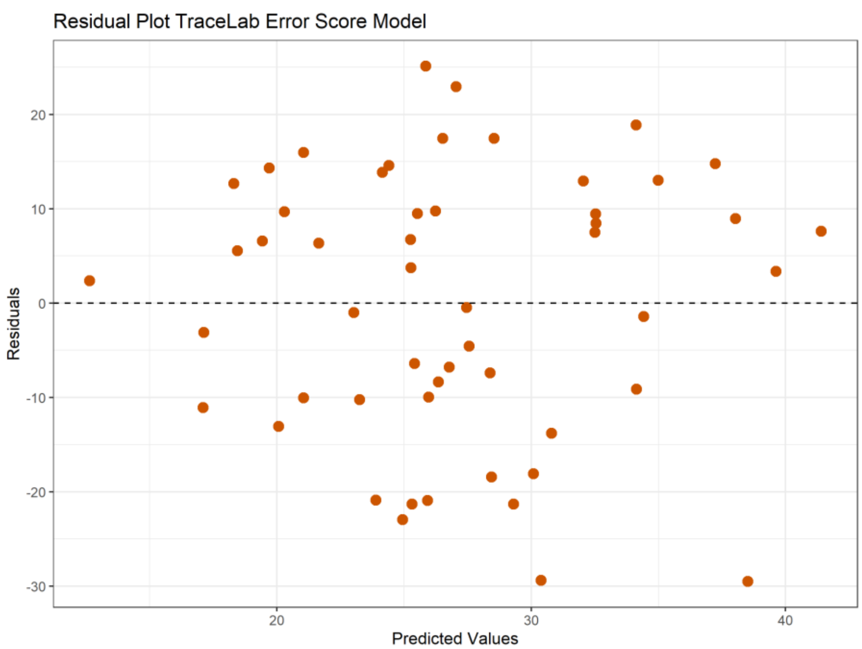


Figure S4. A residuals plot for the model that looks at the effect of attentiveness on TraceLab performance measure by difference in error. Predicted values of the model are on the x-axis and the residuals are on the y-axis.

Table S1. Coefficients of forced entry model predicting Ranked Generation Component

| | Unstandardized Coefficients | | | | 95.0% Confidence Interval for B | |
|---|---|---|---|---|---|---|
| Model | B | Std. Error | t | Sig. | Lower Bound | Upper Bound |
| (Constant) | 52.8 | 14.495 | 3.644 | <.001 * | 23.6 | 81.999 |
| Average Mind Wandering Score | -3.3 | 3.482 | -.939 | .353 | -10.3 | 3.740 |
| Total Cognitive Failures Score | .312 | .225 | 1.389 | .171 | -.140 | .764 |
| Inattentiveness Score | .125 | 3.541 | .035 | .972 | -7.003 | 7.252 |
| Impulsivity Score | -2.419 | 2.521 | -.960 | .342 | -7.494 | 2.655 |
| Change Detection Working Memory Capacity | -1.446 | 1.809 | -.800 | .428 | -5.087 | 2.194 |
| Change Detection Average RT (ms) | -.018 | .010 | -1.741 | .088 | -.039 | .003 |

Table S2. Coefficients of forced entry model predicting Ranked Maintenance Component

| | Unstandardized Coefficients | | | | 95.0% Confidence Interval for B | |
|---|---|---|---|---|---|---|
| Model | B | Std. Error | t | Sig. | Lower Bound | Upper Bound |
| (Constant) | 17.939 | 14.395 | 1.246 | .219 | -11.038 | 46.915 |
| Average Mind Wandering Score | 4.092 | 3.458 | 1.183 | .243 | -2.869 | 11.053 |
| Total Cognitive Failures Score | -.196 | .223 | -.878 | .385 | -.645 | .253 |
| Inattentiveness Score | -.123 | 3.517 | -.035 | .972 | -7.201 | 6.956 |
| Impulsivity Score | -.809 | 2.504 | -.323 | .748 | -5.849 | 4.231 |
| Change Detection Working Memory Capacity | -4.218 | 1.796 | -2.349 | .023* | -7.834 | -.603 |
| Change Detection Average RT (ms) | .017 | .010 | 1.687 | .098 | -.003 | .038 |

Table S3. Coefficients of forced entry model predicting Complex Movement Learning Task

| | Unstandardized Coefficients | | | | 95.0% Confidence Interval for B | |
|---|---|---|---|---|---|---|
| Model | B | Std. Error | t | Sig. | Lower Bound | Upper Bound |
| (Constant) | 10.513 | 14.368 | .732 | .468 | -18.408 | 39.434 |
| Average Mind Wandering Score | 8.868 | 3.452 | 2.569 | .013* | 1.920 | 15.816 |
| Total Cognitive Failures Score | -.539 | .223 | -2.422 | .019* | -.988 | -.091 |
| Inattentiveness Score | 2.121 | 3.510 | .604 | .549 | -4.944 | 9.186 |
| Impulsivity Score | -2.558 | 2.499 | -1.023 | .311 | -7.588 | 2.473 |
| Change Detection Working Memory Capacity | -.482 | 1.793 | -.269 | .789 | -4.091 | 3.126 |
| Change Detection Average RT (ms) | .011 | .010 | 1.065 | .292 | -.010 | .031 |