ABSTRACT

Title of Dissertation: A PSYCHOPHYSIOLOGICAL INVESTIGATION OF VISUALIZING SUCCESS: THE INFLUENCE OF MENTAL IMAGERY ON PERFORMANCE AND NEURAL EFFICIENCY IN A TARGETED MOTOR TASK IN SPORT

Kiersten Janjigian, Doctor of Philosophy in Kinesiology, Specialization Cognitive Motor Neuroscience, 2025

Dissertation directed by: Professor & Chair, Athletic Council, Dr. Bradley D. Hatfield, Department of Kinesiology

Existing literature has laid the theoretical groundwork positing that mental imagery of a motor task is beneficial to performance. Other variables held constant, individuals tend to engage in more optimal motor performance after using mental imagery, especially that which follows the Physical, Environment, Task, Timing, Learning, Emotion, Perspective (PETTLEP) model, mimicking real experience with the involvement of all sensory modalities. Psychological data suggest that imagery's effect on performance may be mediated by internal emotions and cognitions, such as confidence and anxiety. Physiological data suggest that imagery primes and activates muscles similar to actual execution of a motor event. Neurological data suggest that imagery acts as mental practice and activates similar regions in the brain as executing an actual motor event, and like the muscles, primes the brain by strengthening neural pathways for efficient movement. Although previous efforts have examined cerebral cortical dynamics *during* mental imagery, the resulting adaptations in psychomotor efficiency made in the brain are not well defined. Therefore, the present investigation compared the effects of neurological (i.e., neural correlates of activation) and psychological constructs (i.e., confidence and anxiety) as mediators of the imagery-performance relationship as well as their interactions, exploring how the brain is affected *after* imagery use. As such, the present multi-level research aimed to explore the effectiveness of mental imagery from a psychophysiological lens. The present study examined the extent to which a single guided, programmatic mental imagery intervention and application of a practiced imagery script influenced the neural correlates of activation and performance of free throw shooters. Using a pretest-posttest mixed-model design, participants (N = 26) were randomly assigned to either a mental imagery (MI) or control (CON) group. Electroencephalography (EEG) was used to assess neural activation, including temporal alpha power, fronto-midline theta power, central mu rhythm, and alpha coherence, while self-reported confidence and anxiety were examined as potential psychological mediators. Subjective cognitive workload and conscious motor processing were also examined. A series of repeated-measures ANOVAs and Hayes' PROCESS analyses were conducted to evaluate the direct and indirect effects of mental imagery on performance through neural and psychological pathways. Results indicated that mental imagery did not significantly enhance free throw performance compared to the control condition. While confidence significantly increased following imagery, this did not translate into improved performance, nor did anxiety demonstrate a meaningful mediating role. Similarly, EEG measures of neural efficiency did not show significant changes attributable to imagery. Neural activation patterns such as increased left temporal alpha and decreased coherence did, however, support expectations of engagement during a motor task. Although the overall moderated-mediation models were not significant, a more specific examination of the elements of the model revealed that confidence moderated the relationship between mental imagery and change in performance, such that imagery was associated with more stable performance only when confidence was high. However, anxiety did not significantly moderate the effects of mental imagery on neural efficiency. These findings suggest that while mental imagery can enhance confidence, its effectiveness in improving motor performance is highly dependent on individual psychological states. The absence of significant neural adaptations further calls into question the role of psychophysiological mechanisms in short-term imagery interventions. Future research should explore individual differences in response to imagery and examine the long-term effects of repeated imagery training on motor performance and neural efficiency.

A PSYCHOPHYSIOLOGICAL INVESTIGATION OF VISUALIZING SUCCESS: THE INFLUENCE OF MENTAL IMAGERY ON PERFORMANCE AND NEURAL EFFICIENCY IN A TARGETED MOTOR TASK IN SPORT

by

Kiersten A. Janjigian

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Advisory Committee:
  Professor Dr. Bradley D. Hatfield, Chair
  Dr. Hyuk Oh
  Dr. David Klossner
  Dr. Min Qi Wang
  Dr. Carson Smith

Preface

Conceptually, the psychology of sport has been part of my life since I was very young. I had a natural inclination towards trying to better understand the thoughts, emotions, and behaviors, and their interaction, in those within the sporting context. When I began to study sport psychology at university, my passion for the concepts were only fueled more. After years of work in the business side of sports, it became increasingly evident that one way to effectively help people while incorporating my love for sports was to dive even further into sport and performance psychology. As I began to develop my evidence-based practice as a mental performance consultant, it became clear to me very early in my journey towards competence and mastery in the field that more research was needed to inform the biological bases of sport psychology. In graduate school I was properly introduced to the brain – the most powerful organ in our body. I fell in love with it fast and hard and deeply resonated with the psychophysiological perspective, the brain-body connection, and how it influenced what we do as human beings. The brain is a constant source of "awe" for me. Part of this obsession was a consequence of my love for puzzles – the brain is the greatest puzzle we have in the universe and many pieces of it have continued to be a mystery as science has progressed. Attending the University of Maryland under the Cognitive Motor Neuroscience laboratory was an important step in allowing me the opportunity to contribute to the field and develop a much greater understanding and expertise on the topic. The science conducted in this dissertation project is a testament to my attempt to add a tiny piece of information that might add to that puzzle: the mystery of the brain, in conjunction with my love for sport psychology. It combines the perspective I come with as an applied practitioner in the field with my ideals as a researcher. Oftentimes in sport psychology, we see a prominent research-practice “gap.” Researchers are unaware of how to apply or communicate their work to those who actually use it in the real-world, and practitioners lack the feasibility to put interventions to the test in a controlled manner, often looked down upon by academia’s “exclusive club” culture. I currently sit in the middle of this junction and have used my experience as a practitioner to inform the current science.

I had a very strong idea of the research route I wanted to take when I began this doctoral degree. Though I strayed away from it at times to fulfill requirements and the opinions of others, I eventually made it back to the true interests of mine. An important lesson to learn: your research interests should be interesting and fulfilling to *you*. This will help you maintain at least a little joy and motivation when it gets hard. A degree like this is all about traveling along this ambiguous path from ‘not knowing’ to ‘knowing.’ It’s a learning process, most of which is done on your own. The most prominent feeling associated with this path? Frustration. Those of us who make it to the end inevitably demonstrate our ability for frustration tolerance. Can you push the wall back when it’s not budging? Can you even figure out how to do that? Do you want to? You have to find *something* that makes this work worth doing.

The particular goals of this research included (1) to combine the findings from psychological and physiological sport psychology and human performance research to investigate the neural underpinnings of mental skills *and* expand our knowledge of the effects of mental skills on cortical dynamics with the ambition of improving <u>**both**</u>

performance and *well-being* of athletes/performers; and (2) to explore the biological or neurological bases to why the mental side of sport or performance is equally as important as the physical side. Or if not *as* important, how important might it be? The premise of the present study is a fresh idea that has sparsely been explored, especially using the paradigm of a motor task from a sport so widely accepted and enjoyed by many: basketball. It was very important to me to study a particular movement that would be highly relatable when communicating about the findings post-hoc and, as another goal of mine, increase the contributions of the project to practitioners, other sport-related figures (i.e., coaches) and the public.

Completing this dissertation has been one of the most challenging and rewarding of my academic career, and honestly my life to this point. Only 1.8% of the U.S. population earns a Ph.D. in their lifetime. This does not surprise me. The amount of perseverance and pure resilience that it requires to overcome constant problem-solving is not for the faint of heart. I often felt like Harry Potter on a wild adventure, many times alone and feeling like I did not know what to do next, but still able to find a way to kill each Horcrux…and right after, of course, a new one would present itself. In a darker or truer sense, it was like sitting in a burning building completing a puzzle, while having to remain as calm as possible. Again, not for the faint of heart. And in the vein of the subject at hand, it took extreme amounts of mental fortitude. When you chase big things, though, you inevitably become bigger through the process of chasing them. A life lived correctly is brutally difficult by default – not because the world is unfair or cruel, but because genuine growth requires continuously confronting the unknown. Most people see friction and obstacles as signals they’re off track. The reality: that friction is the very proof that you’re stepping into new territory. If you’re not regularly feeling out of your depth, you’re coasting – stagnant. I am now the most capable I have ever been in my life and I am a changed person from where I was when I started this journey four years ago.

Read on to explore the project that lies within. Not only do these findings inform the practices currently used in the high-performance environment, but I hope this dissertation also provides inspiration of what’s possible for the current and future Ph.D. students who take a read.

Foreword

"If the brain were simple enough for us to understand it, we would be so simple that we couldn't."

- George Pugh; nuclear physicist

I stand
on the sacrifices
of a million women before me
thinking
what can I do
to make this mountain taller
so the women after me
can see farther

-*legacy* by Rupi Kaur

Dedication

This work is dedicated to anyone who has ever felt the need to prove doubters wrong. This work is dedicated to anyone who has completed astonishing tasks while separated from their main support system. This work is dedicated to those who figured out how to build a support system within themselves. This work is dedicated to every female who has ever felt the need to earn the highest degree possible in her field of work so that she may be respected at the level of her male peers. This work is dedicated to any individual who has ever felt that their intelligence and abilities have been judged based on the way they look. This work is dedicated to anyone who has experienced breathtaking heartbreak and found a way to keep going. This work is dedicated to me and my ability to fight through hard things and do my best, to succeed, and to teach other people how to do it too.

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I would like to acknowledge my advisor, Dr. Hatfield. Doc: you have been a rock for me from beginning to end and served as the voice of reason and guiding light at the end of the tunnel when things got hard. The amount of information, in both science and life, that I learned from you over the past four years is incomparable to anything I've received from any other mentor in my life. I consider you family. To my true 'team,' the undergraduates who mean more to me than they will ever know: Erin Tebbe, Rachel Gunter, Aislinn Sax, Tyler Spielman, Anthony Rotello, Reese Marsallis, and Jake Muma. As the last 'real' doctoral student in our lab, *you* made my experience at UMD what it was. Thank you for your help on the days when it was just us in the burning room. Thank you for showing up for me. You never cease to amaze me and I can't wait to see where you all make it because you are some of the sharpest, kind, and curious people I know. To my undergraduate student support at GW: Duru Ciftci. Thank you for everything you've done and helped build with me over the past 2.5 years. You've provided incredible support to make a lot of this work possible. To all the other students I've had, in sport psychology, or otherwise, thank you. Thank you for showing up, your energy and effort, and for allowing me to teach you something I am so passionate about.

To Dr. Jay (Goldstein): Thank you for everything. You showed me what it looks like to truly care about your students and to create a classroom that made everyone feel welcome. You acted as a chip of support for me through every step of this process. There are many days that I have felt your consistent belief in me and that has kept me going. To my other committee members: Dr. Hyuk Oh, Dr. David

Klossner, Dr. Min Qi Wang, Dr. Carson Smith, and Dr. Seppo Iso-Ahola, thank you for your input and support throughout this process. To my other mentors who supplemented my knowledge base in neuroscience, biofeedback, and neurofeedback: Dr. Jay Wiles, Dr. Manuel Halter, Dr. Inna Khazan, David Ims, Dr. Sandy Molle, and Dr. Leslie Sherlin. Thank you also to Dr. Jette, for inviting me into this program, being a backbone of this department, an advocate for graduate students, and a trusted voice of advice when needed.

Thank you, James Goedeke, for being my partner in crime through this all. I can't believe we did this sh*t. Remember how this started – all the classes we took together (…statistics…) and golf putts measured. I'll never be able to truly express how much I appreciate you just being "in it" with me. Thank you, Kyle Pietro, for teaching me more tangible skills than almost anyone here. You were the first to show me how EEG equipment works, provided theoretical guidance for so many research decisions, and lended your time and knowledge to put out fires along the way. There were many moments when I felt lost and I turned to you. Thank you, Jayesh Jayashankar for the unbelievable support you've provided me, especially in learning how to process EEG. This project would not be finished without your help. When it was just you and I alone in EEG class our first and second years, who knew we would be figuring it out side-by-side for the final round. Thank you to the rest of the CogMo graduate students – we are the only ones who will ever understand how this experience really feels. Even if all we did was work countless hours side-by-side in silence or were sounding boards of pure venting to each other, there's no one else I would have rather done it with.

Lastly, thank you to my family and friends. My parents, Mike and Susie helped me move across the country for this dream. My brothers, Michael and Thomas, are the ones who have played a huge role in developing my love for sport psychology across their whole lives. My best friends have checked in on me and provided comic relief during the times of struggle. I have been far, far away for a long time to do this really big thing. Thank you for your constant support. Thank you for reminding me why I was doing it. Thank you for believing in me, always.

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Chapter 1: The Evolution of Psychophysiological Research: From Foundations to Applied Sport Psychology with Implications for Mental Imagery

From Brainwaves to Behavior: The Role of Psychophysiology in Performance

Historically, the study of psychophysiology was rooted in the desire to quantify how mental states manifest in the body, as seen in early work linking emotional responses to physiological changes, such as heart rate and muscle tension. These foundational explorations provided the basis for modern tools and techniques, such as electroencephalography (EEG), that now allow researchers to observe and analyze brain activity in real-time, opening up a far deeper ability to explore the mind-body connection. This evolution has not only deepened our understanding of human behavior but also positioned psychophysiological research as a cornerstone in performance contexts, including applied sport psychology.

In the realm of sport, psychophysiological research has demonstrated its utility in examining how athletes respond to high-pressure situations and optimize performance at the neural level. For instance, the ability to regulate arousal and manage cognitive workload during competition is crucial for success, particularly in high-stakes scenarios. Many studies have also contributed to identification of the neural patterns of activation associated with elite level performance, often referred to as psychomotor efficiency. Uncontested moments of skill and finesse across sports can often be considered as crucial “game-winning” junctures in the battle of a competitive match. In soccer, the penalty kick is a game-situation of the highest pressure, often determining a win or a loss. In tennis, the serve – good or bad – can determine the winner of each set. In golf, each swing on the course is important for the final outcome of the tournament. Swing better than anyone else on every hole, and you win. In basketball, the free throw allows for a moment of predictability in a game that is typically anything but predictable. All of these moments are examples of what psychological and sport literature refer to as closed skills. Closed skills are those that occur in a fixed and predictable environment or manner and the athlete is (1) in control of what happens next, and (2) generally can predict the exact movements he/she needs to execute (Goldschmied, Raphaeli, Moothart, & Furley, 2021). These *closed-skill* tasks provide an ideal framework for studying the interaction between psychological states and physiological responses given the limitations of modern neuroimaging equipment (Hatfield et al., 2020). The findings from cornerstone psychophysiological studies using these refined motor tasks to observe the brain have provided a mechanistic foundation for practical applications, such as mental imagery training, neurofeedback, and interventions to enhance focus and resilience under pressure.

Within sport psychology, mental imagery is a widely employed psychological skill, consistently shown to be both efficacious and effective for performance enhancement. The biological mechanisms underlying mental imagery have been extensively studied, primarily from the traditional neuroscience perspective, which focuses on identifying neural patterns that emerge during mental rehearsal of a motor task (Jeannerod, 1995). It is well-established that functional equivalence exists between mental imagery and actual physical movement, meaning that imagining an action recruits many of the same neural pathways as physically performing it (Kosslyn et al., 2001; 1978). However, these functional equivalence theories, which emphasize how imagery activates overlapping sensorimotor networks, autonomic responses, and efferent motor pathways, do not fully explain the broader brain processes involved in the mental imagery-performance relationship.

A promising alternative explanation lies in the theory of psychomotor efficiency, which suggests that more skilled performers exhibit streamlined neural activation, allowing for optimal performance with reduced cognitive and physiological effort (Hatfield & Hillman, 2001; Deeny et al., 2003). By incorporating EEG as a measure of brain activity, researchers may be able to further explore how mental imagery contributes to performance enhancement via changes in neural efficiency and consequent reduction of interference with essential motor processes underlying intended actions. This perspective extends beyond traditional functional equivalence models to consider how imagery may refine underlying neural processes that support elite motor performance.

This chapter traces the journey of psychophysiological research from its inception to its current applications, particularly in the field of sport psychology. It will first explore the historical foundations and pivotal discoveries that established the field, then discuss advancements in tools and methodologies that have propelled it forward. Finally, the chapter will examine how these insights are being applied today, with a focus on their relevance for athletes – including how psychophysiological methods are used to study mental imagery as a performance-enhancing tool – and implications for future research. Through this exploration, we aim to illuminate the transformative potential of psychophysiological research and its enduring impact on both science and practice.

Historical Foundations of Psychophysiological Research

Psychophysiology, as a field of study, emerged from an enduring quest to understand the dynamic interplay between mental and physical processes. Early thinkers, such as William James, an American philosopher and psychologist, were instrumental in shaping foundational ideas about how emotions and thoughts influence the body, laying the groundwork for the scientific exploration of these connections (James, 1890). James and Carl Lange proposed the James-Lange Theory of Emotion which proposed that emotions arise as a result of physiological changes in the body. For example, a person feels afraid because his or her heart races and the muscles tense in response to a threat (James, 1884). This era marked the beginning of efforts to quantify subjective experiences through observable and measurable physiological changes, setting the stage for the development of psychophysiology as a distinct scientific discipline.

The initial descent into psychophysiological research continued to be marked by philosophical inquiries into the nature of human behavior and its biological underpinnings. Scholars in the 19th century speculated on how psychological phenomena, such as stress or focus, could manifest in physiological responses like heart rate variability, muscle tension, or respiratory patterns. Walter Cannon later critiqued the James-Lange Theory and emphasized the role of the autonomic nervous system in preparing the body for emotional and physical responses (e.g., increased heart rate during fear or excitement) (Cannon, 1927). The Two-Factor Theory of Emotion, proposed by Schachter and Singer in 1962 demonstrated that physiological arousal (e.g., changes in heart rate) interacts with cognitive interpretation to produce emotional experiences (Schachter & Singer, 1962). John Cacioppo then introduced extensive empirical evidence suggesting a link between emotions and physiological processes, specifically demonstrating that emotions are reflected in physiological markers, such as heart rate, skin conductance, and muscle tension (Cacioppo & Tassinary, 1990; Fridlund & Cacioppo, 1986). These early observations hinted at a bidirectional relationship: not only do mental states influence physiological functions, but physiological conditions can also shape psychological experiences.

The field began to solidify in the 20th century with the introduction of tools and methodologies that allowed for the precise measurement of physiological responses. One pivotal development was the invention of the electroencephalogram (EEG) in 1929 by Hans Berger, which provided researchers with a means to study brain activity in real-time (Berger, 1929). This breakthrough technology opened new avenues for understanding how the brain operates during mental tasks and physical activities. Early studies utilizing EEG laid the groundwork for contemporary investigations into neural efficiency and motor performance, highlighting the brain's capacity to adapt and optimize its processes in response to training and environmental demands (Busk & Galbraith, 1975).

Another significant milestone in the evolution of psychophysiological research was the emergence of biofeedback techniques in the mid-20th century. These methods provided individuals with real-time feedback about their physiological states, such as heart rate or muscle activity, empowering them to exert conscious control over processes once thought to be involuntary. Biofeedback was particularly influential in the realms of stress management and performance enhancement, as it allowed researchers and practitioners to demonstrate the tangible effects of psychological interventions on physiological functioning (Schwartz & Andrasik, 2003).

The advent of psychophysiological research in high-performance contexts, including sports, marked another critical turning point. As competitive environments became more structured and data-driven, researchers sought to understand how athletes could optimize performance through the regulation of their psychological and physiological states. Early work in this domain revealed that elite athletes often exhibited distinct psychophysiological patterns, such as lower heart rates and reduced cortical activation in task-irrelevant regions of the brain during high-pressure tasks, compared to their less experienced counterparts (Hatfield & Landers, 1984). These findings underscored the potential for psychophysiology to inform strategies for enhancing performance and resilience in high-stakes scenarios.

The historical trajectory of psychophysiological research reflects a steady progression from philosophical musings to empirical investigations supported by advanced technologies. Each milestone in this journey has expanded our understanding of the intricate connections between the mind and body, setting the stage for contemporary applications in sport psychology and beyond. By integrating insights from early pioneers with modern methodologies, the field has not only deepened its scientific foundations but also paved the way for practical innovations that continue to shape our understanding of human potential.

Advances in Psychophysiological Research

The field of psychophysiology has undergone significant evolution, driven by advancements in technology, methodology, and theoretical understanding. From the early studies focusing on observable physiological responses to mental states, the field has expanded to explore the intricate neural mechanisms underlying human behavior. These developments have not only deepened our scientific knowledge but also enhanced the applicability of psychophysiology to real-world contexts, including performance in sport.

Neural Efficiency and Performance

One of the most influential contributions to psychophysiology is the concept of neural efficiency, or the theory of psychomotor efficiency, which posits that skilled performers exhibit optimized brain activity patterns during task execution. Research suggests that as individuals become more proficient in a skill, they demonstrate reduced cortical activation in task-irrelevant regions, allowing for more efficient use of cognitive and neural resources (Hatfield & Kerick, 2007). For example, elite athletes performing closed-skill tasks, such as free throws in basketball or putting in golf, display distinct EEG patterns which translate into subjectively lower cognitive workload and enhanced focus compared to novices (Hatfield et al., 2020).

The neural efficiency hypothesis highlights the role of automaticity in performance. Skilled individuals transition from conscious, effortful control to more automatic processes, reducing the cognitive load required for execution and increasing the attention reserve available to focus on the task (Deeny et al., 2003). EEG studies have demonstrated that this transition is marked by increased alpha power in the left temporal region, reflecting the inhibition of verbal-analytical processes, and greater synchronization, or coherence, between frontal and motor areas, indicative of task-relevant cortical activity (Babiloni et al., 2008). These findings have advanced our understanding of how the brain adapts to repeated practice, emphasizing the importance of deliberate training in achieving peak performance.

Integration of EEG and Performance Research

The integration of high-resolution EEG technology has allowed researchers to examine the real-time dynamics of brain activity during performance. This has been particularly impactful in studying how individuals manage cognitive workload and arousal under pressure. EEG markers such as an increase in left-hemispheric temporal (T7) alpha power (8-13 Hz), desynchrony of alpha in the right temporal (T8) region (i.e., temporal asymmetry), and increased frontal midline theta power during the preparatory period leading up to motor execution have been linked to attentional control, with alpha activity reflecting task-irrelevant inhibition and beta activity associated with increased alertness, awareness, and readiness during motor preparation (Babiloni et al., 2008; 2011; Baumeister et al., 2008; Klimesch et al., 1997).

When comparing the cortical dynamics of experts and novices, findings suggest that experts exhibit greater psychomotor efficiency than novices. The expert's brain seems to quiet as manifested by an increase in alpha power (i.e, inhibition) in the left temporal lobe and decrease in alpha power over the central regions. Experts also display decreased cortico-cortical communication, between the left temporal and frontal regions as seen using a measure of alpha coherence, suggesting that they experience less "cross-talk" between brain regions during skill execution (i.e., displaying a reduction in "overthinking") (Deeny et al., 2009; Deeny, Hillman, Janelle, & Hatfield, 2003). Experts also exhibit increased frontal midline theta power which is associated with effortful engagement of working memory and processing multitasks (Hatfield et al., 2020). The established cortical dynamics of experts suggest that they engage in an increased state of automaticity compared to novices, allowing for less impedance in performance (Deeny et al., 2003). The novice's brain typically exhibits cortical dynamics of motor learning, associated with the stage of learning that psychophysiologist's Fitts and Posner (1967) termed the 'cognitive stage' during which the prefrontal cortex and anterior cingulate region are highly recruited during motor performance (Jueptner et al., 1997). In novices, more attention is necessary for the task at hand and more cognitive resources, both task-relevant and irrelevant will be used during skill execution.

It is important to recognize that sport and performance typically occur in a stressful environment of competition, evaluation, time-demands, and other forms of pressure. Stress was first defined by Hans Selye in 1936 as "the non-specific response of the body to any demand for change" (Selye, 1936, p. 138). In the psychophysiological literature, this definition of stress has better allowed researchers to understand how 'demand' changes the system and causes the body to adapt. Clinically, stress is defined as a "physical or emotional response to a situation, feeling or an event that interferes with the sense of general well-being" and can be categorized as negative stress or positive stress (Prathaban, Sumondo, & Puthusserypady, 2019). This stress can affect cognitive and attentional capacity and ultimately performance, leading to performance decrements or even choking (Beilock, Berenthal, McCoy, & Carr, 2004; Beilock & Carr, 2001). In these high-pressure scenarios skilled performers exhibit increased alpha power in task-irrelevant regions, suggesting an inhibition of those regions and reduced interference from competing cognitive processes (Gallicchio et al., 2017) allowing them to maintain peak performance. Research by Beilock, et al. (2004) measuring the stress-performance relationship using the expert-novice paradigm found that experts tend to perform better under dual-task conditions that are designed to distract attention as well as under conditions of speed, while novices perform better under conditions of skill-focused instruction and accuracy. Experts' established abilities may actually benefit from a more pressurized environment, allowing them to limit 'overthinking' of procedural knowledge that is already automatic, while novices tend to exhibit an increase in verbal-analytical processing under pressure (Zhu, Poolton, Wilson, Maxwell, & Masters, 2011). This phenomenon might be described as stress reversing the effect of automaticity in the expert (Hatfield et al., 2020). Psychophysiological explanations of stress' effect on performance are tied to the theory of psychomotor efficiency previously outlined. As stress increases, cognitive workload increases and attentional reserve decreases, thereby reducing psychomotor efficiency (Hatfield, et al., 2020; Hatfield et al., 2013). Due to the effects on cortical efficiency, the neuromuscular and respiratory systems also respond in a less-efficient manner leading to detrimental effects on performance (Cooke et al., 2010). These findings support the idea that neural efficiency is not just a byproduct of skill acquisition but a dynamic process that can be influenced by situational demands.

The ability to monitor and analyze cortical dynamics has also provided valuable insights into the role of psychophysiology in managing performance anxiety. Studies have shown that individuals with greater right compared to left temporal-premotor coherence, as measured by 4–7 Hz theta coherence between temporal (T7/T8) and premotor (Fz) cortex, are better able to regulate their arousal levels, maintaining composure under stress and report higher instances of "flow" experience (Wolf et al., 2015). These insights have informed interventions aimed at enhancing emotional resilience and focus in athletes, demonstrating the practical applications of EEG research in performance contexts.

Cognitive Neuroscience Perspectives on Psychophysiology

Advancements in cognitive neuroscience have further enriched the field of psychophysiology by identifying the neural mechanisms that underpin psychological skills such as mental imagery, and other cognitive-affective constructs such as attention and motivation. Mental imagery, for instance, has been shown to activate neural networks involved in motor control, memory, and emotion, highlighting its role as a form of mental practice (Jeannerod, 1995). Functional neuroimaging studies have revealed that visualizing a motor task engages the same cortical regions as performing the task, supporting the idea of functional equivalence between imagery and physical practice (Kosslyn et al., 2001). These findings have significant implications for psychophysiological research, particularly in understanding how the brain prepares for and executes motor tasks.

More research is needed (1) to explore the potential neural refinement that occurs via the practice of psychological skills and (2) to explore the neural correlates related to psychological constructs important for performance such as confidence, mindset, presence, and perceived control, as well as neural mechanisms underlying the effectiveness of other psychological skills such as self-talk, goal setting, mindfulness, and other energy management and attentional control techniques. With greater understanding of where these 'mental constructs' lie in the brain and frameworks for the neural activation underlying these states, we can begin to design better informed psychophysiological training techniques (e.g., neurofeedback training protocols).

Current Applications in Applied Sport Psychology

The practical applications of psychophysiological research in sport psychology have significantly advanced in recent decades. These applications focus on enhancing athletic performance, managing arousal, and fostering resilience under pressure. By integrating findings from neuroscience, psychology, and physiology, practitioners have developed tools and interventions that translate scientific discoveries into real-world strategies for athletes.

Mental Imagery and Psychophysiological Benefits

One of the most well-established applications of psychophysiological research in sport psychology is the use of mental imagery. Mental imagery, often referred to as visualization, involves creating vivid, controlled mental representations of movements, events, or scenarios in one's mind without physical execution. Research has demonstrated that mental imagery activates neural and muscular circuits similar to those engaged during actual motor execution, making it an effective tool for performance enhancement (Jeannerod, 1995; Kosslyn et al., 2001). Specific to psychophysiological outcomes, mental imagery has been linked to reductions in state anxiety and improvements in focus. For example, basketball players using mental imagery before free throws demonstrated improved shot accuracy and decreased physiological markers of stress, such as heart rate variability (Robin et al., 2019). This begs the question, does mental rehearsal also lead to neural refinement predictive of enhanced performance similar to physical practice?

The PETTLEP model of mental imagery, which emphasizes the integration of physical, environmental, task, timing, learning, emotion, and perspective elements, has been widely adopted as a framework for optimizing imagery-based interventions (Holmes & Collins, 2001). This model emphasizes creating a highly realistic and multisensory experience that closely mimics actual performance conditions. Studies utilizing this model have demonstrated its effectiveness in enhancing performance and arousal control, improving motor skill acquisition, reducing anxiety, and improving focus, particularly in high-pressure contexts (Wakefield & Smith, 2012). The PETTLEP model provides a framework for future research and application involving mental imagery.

Neurofeedback as a Training Tool

Neurofeedback, a method of training individuals to regulate their brain activity, has also emerged as a powerful tool in applied sport psychology. By providing real-time feedback on neural states, neurofeedback enables athletes to fine-tune their focus, arousal, and relaxation levels. This approach is grounded in psychophysiological research showing that optimal performance is associated with specific patterns of brain activity, such as increased alpha power and reduced beta activity during high-pressure tasks (Cooke, 2013).

Recent research underscores the efficacy of neurofeedback in enhancing performance during closed-skill tasks, such as golf putting and archery, with particular emphasis on the role of sensorimotor rhythm (SMR; 12-15 Hz) training. Cheng et al. (2015) demonstrated that athletes trained to increase alpha power and enhance SMR activity in specific brain regions, such as the central (Cz) region, exhibited greater neural efficiency and improved accuracy under pressure. Ghaziri et al. (2013) further highlighted that neurofeedback targeting SMR facilitates functional connectivity changes, promoting self-regulation and focus during high-stakes scenarios. Additionally, Hung and Cheng (2018) provided evidence that neurofeedback interventions significantly reduce pre-competition anxiety, allowing athletes to maintain composure and execute with precision. These findings suggest that neurofeedback is a promising tool for optimizing both mental and motor performance in competitive settings. Continuing research on neural patterns associated with psychomotor efficiency, acquired through physical *or* mental practice, may also provide empirical support for neurofeedback protocols most effective for performance optimization. Practitioners can use these identified neural patterns of refinement to train performers to engage in optimal readiness states.

Though there is still much room for improvement and a need for increased education regarding this technique, the accessibility of neurofeedback has also improved, with portable devices and user-friendly software making it more feasible for coaches and practitioners to integrate this technology into training programs. These advancements underscore the potential of neurofeedback to revolutionize mental training by providing athletes with tangible, data-driven insights into their psychophysiological states.

Relevance to Applied Sport Psychology and Future Research

Psychophysiology’s Contribution to the Applied Practitioner

The application of psychophysiological research in sport psychology bridges the gap between science and practice. This field provides a comprehensive framework for addressing the unique demands faced by athletes. By translating findings from laboratory studies into real-world interventions, practitioners can equip athletes with the evidence-based tools to optimize their performance and manage the demands of competition. One key implication is the ability to provide real-time feedback to athletes. Tools such as biofeedback and neurofeedback systems empower athletes to observe their psychophysiological states and make adjustments in the moment. This is particularly valuable in high-pressure situations, where the ability to regulate arousal and maintain composure can be the difference between success and failure. These advancements underscore the relevance of psychophysiology in shaping the future of sport psychology and performance enhancement.

Techniques such as mental imagery, neurofeedback, and psychophysiological monitoring provide actionable strategies for athletes and coaches. These interventions not only improve physical performance but also foster mental resilience, enabling athletes to thrive under pressure. For practitioners, these tools offer a scientific basis for designing personalized training programs that address individual needs. By leveraging psychophysiological insights, practitioners can help athletes build the mental skills necessary to excel in competitive environments, from regulating arousal to maintaining focus during critical moments.

Future Directions for Research

The future of psychophysiological research lies in its potential to address emerging questions and challenges in applied sport psychology. One promising area of investigation is the use of advanced neuroimaging techniques to explore how individual differences in neural dynamics influence performance outcomes. For instance, future studies could examine how genetic predispositions (e.g. polymorphisms in the human serotonin transporter gene (Hariri et al., 2002)), training history, or environmental factors shape an athlete's neural efficiency and resilience, specifically incorporating the alpha peak frequency as a marker of unique cortical dynamics in the individual among other established cortical patterns (Parr et al., 2023).

Another critical direction is the development of portable and cost-effective psychophysiological tools. While EEG and neurofeedback systems have traditionally been confined to laboratory settings, recent innovations have made these technologies more accessible for field use. Future research should focus on validating the reliability and efficacy of these tools in real-world environments, ensuring that practitioners and athletes can benefit from accurate and actionable data (Cheng & Tsung-Min, 2021).

Additionally, interdisciplinary collaborations between psychophysiologists, sport psychologists, and neuroscientists hold the potential to deepen our understanding of the brain-body connection. By combining insights from multiple fields, researchers can develop more holistic models of performance, integrating cognitive, emotional, and physiological factors into a unified framework.

Broader Implications for Performance and Well-Being

Beyond the athletic arena, psychophysiological research has broader implications for performance and well-being in diverse domains. In occupational settings, for example, the ability to manage stress and maintain focus is critical for productivity and decision-making. Psychophysiological interventions such as biofeedback and mindfulness training have shown promise in improving these skills, highlighting their relevance beyond sports (Schwartz & Andrasik, 2003). Similarly, the principles of psychophysiology can be applied to rehabilitation and recovery. Techniques such as mental imagery and neurofeedback have been used to support motor learning and neuroplasticity in individuals recovering from injury or illness (Mulder, 2007; Lotze & Halsband, 2006). These applications demonstrate the versatility of psychophysiological research and its potential to improve quality of life across various contexts.

In the context of sport psychology, these broader implications emphasize the need for continued exploration and innovation. By expanding the scope of psychophysiological research, practitioners can address not only performance optimization but also holistic well-being, ensuring that athletes thrive both on and off the field.

Conclusion

Psychophysiological research has traveled an extraordinary journey, from its philosophical roots exploring the mind-body connection to its current role in optimizing human performance. This evolution has been marked by significant advancements in tools and methodologies, such as EEG and neurofeedback, which have provided unprecedented insights into the neural dynamics of behavior and performance. The foundational studies of psychophysiology, which sought to quantify the physiological correlates of mental states, laid the groundwork for today's applications in sport psychology. By identifying the distinct psychophysiological patterns associated with skilled performance, researchers have provided a roadmap for developing interventions that foster focus, resilience, and consistency. As the field advances, future research has the opportunity to further explore how techniques like mental imagery may enhance neural efficiency, potentially unlocking new methods for optimizing performance and expanding the applications of psychophysiology in sport psychology.

Looking ahead, the future of psychophysiological research holds tremendous potential. Advances in portable and accessible technology will likely bring psychophysiological tools into the hands of more practitioners, coaches, and athletes, making these insights more actionable and impactful in real-world settings. Furthermore, interdisciplinary research integrating neuroscience, psychology, and physiology will continue to deepen our understanding of the complex interactions that drive human performance.

Beyond sports, the principles of psychophysiology have broader implications for well-being and performance across multiple domains. Whether it's aiding individuals in managing stress, improving cognitive focus in the workplace, or facilitating motor recovery in rehabilitation settings, psychophysiological research provides a versatile and powerful framework for addressing human challenges.

The relevance of psychophysiological research in applied sport psychology is a testament to the importance of bridging science and practice. By translating rigorous research into actionable strategies, practitioners and researchers have created a foundation for athletes to thrive not only in their sports but in their lives. The journey of psychophysiological research is far from over, and its future promises to offer even greater contributions to the understanding and optimization of human potential.

Chapter 2: "Visualize the Swish": A Psychophysiological Investigation of the Influences of a Mental Imagery Intervention

on Performance and Psychomotor Efficiency During a Free Throw Shot

Applied Sport Psychology

Applied sport psychology is a field that attempts to facilitate and maximize performance enhancement and optimal enjoyment of athletes using evidence-based techniques, sport science, and counseling skills. Examples of these evidence-based performance enhancing techniques include goal setting, self-talk, arousal control, team building, efficacy management, attention control, emotion regulation, and mental imagery (Mellalieu & Hanton, 2008). Comprehensive amounts of previous research have recognized mental imagery as efficacious for aiding in performance enhancement, arousal control, affective and cognitive modification, and rehabilitation (Jones & Stuth, 1997; Martin et al., 1999). Simply, mental practice can improve performance. Cohn's (1990, p. 304) official definition of mental imagery is "the process of imagining the performance of a skill with no related overt actions." It is often referred to as visualization and acts, in the mind, as a way to simulate and embody some sort of movement, occurrence, or event in a very controlled way without it actually occurring.

Mental Imagery

Mental imagery in sport is a skill that can be learned. Modern applied sport psychology literature suggests that teaching athletes how to better use mental imagery in the context of their sport and to better address their needs within the sport, can significantly benefit their performance. Using mental imagery in combination with motor practice seems to have the greatest effect on performance across many modalities, sports, and motor tasks, but imagery has also been shown to have significant performance enhancing effects when used alone or with other cognitive strategies compared to no imagery use (Feltz & Landers, 1983; Jones & Stuth, 1997). Therefore, mental imagery is an important tool used in a basketball context. John Calipari, current basketball coach at the University of Kentucky, and NCAA Hall of Fame Coach, said, "The only thing I pay attention to with free throws is what a guy does in the final four minutes of a game. If you can improve players' self-esteem and confidence, get them to relax, teach visualization and routine, they will shoot as well, or better, with the pressure on." The importance of mental imagery for preparation for superior performance is highly applicable to free-throw shooting, both by science and coaching accounts.

Specific to basketball, research has again revealed that mental imagery can exert a powerful and positive impact on athletic performance. The results from previous experiments investigating the effects of mental imagery on free throw shooting have shown a prevailing positive effect on performance (Hall, 1983; Peynircioglu et al., 2000; Robin et al., 2019). Research also suggests that the more an athlete partakes in imagery practice, the better the performance outcomes will be (Cannon, 2008). It is widely acknowledged that mental imagery can effectively improve skill learning and enhance performance of free throws.

An established protocol for learning, practicing, and executing efficacious mental imagery is known as the PETTLEP (physical, environment, task, timing, learning, emotion, perspective) model. The PETTLEP model is the common recommendation for applying mental imagery in a sport context in order to mimic a real experience using a combination of different sensory modalities and has shown effective for performance enhancement (Holmes & Collins, 1999; Smith et al., 2007; Wakefield & Smith, 2012). Traditional mental performance techniques also suggest that imagery include vividness and controllability of the situation to be visualized, along with personalization of perspective used and consideration of speed of the activity or sport. Imagery practice should have high functional equivalence, be systematically implemented, and be well matched to the intended outcome (Gregg et al., 2011). An athlete can build a personalized imagery script to help mentally practice for any situation needed, whether experienced first-hand or imagined, visualizing superior performance, fixing past mistakes, or rehearsing potential obstacles he or she might face in the future.

There are a number of theories that inform mental imagery's effect on performance. The psychological theoretical approach to imagery's effectiveness is predominantly represented by Paivio's (1985) analytic framework for imagery effects. Paivio's theory, often regarded as more encompassing than the subsequently discussed physiological theories, posits that "imagery influences motor behavior through its impact on both cognitive and motivational response systems" (Martin, Moritz, & Hall, 1999, p. 246). This approach assumes that the imagery of motor skill components does not occur without simultaneous imagery of goal-directed behaviors and achievement of the intended movement. The physiological arousal and emotions invoked by visualizing success and/or failure of a certain movement or performance may therefore affect the actual performance or motivation to execute that particular motor task (Paivio, 1985).

In the psychological literature, suggested mechanisms between imagery and performance include anxiety regulation and confidence management. Mental imagery allows athletes to effectively increase, or "psych up" their arousal state or, on the other hand, induce relaxation to decrease their arousal state, depending upon their optimal state of arousal. It can also better allow athletes to manage stress and anxiety (Jones & Stuth, 1997). This regulatory control over arousal state and anxiety has therefore been shown to improve performance. In Vadoa, et al.'s (1997) study examining the relationship between competitive anxiety and imagery use, results suggested that imagery can effectively help control anxiety levels and boost confidence in a sport context. Mental imagery has also been shown to effectively increase athletes' self-confidence (Jones & Stuth, 1997; Callow & Hardy, 2001; Hall, et al., 2009). To address possible mediation effects, the present study explored the effectiveness of mental imagery at modifying these psychological variables.

It is thought that mental imagery both psychologically primes an individual to engage in a motor task and physically primes the muscles/motor units that will be recruited during actual performance (Feltz & Landers, 1983) while also influencing cognitive and motivational responses (Martin, et al., 1999). The physiological theoretical approaches include psychoneuromuscular theory (Jacobson, 1930) and symbolic learning theory (Sackett, 1934). Psychoneuromuscular theory postulates that imagined events produce muscle innervation comparable to that produced by actual physical movement of the muscle. In this sense, an individual can purely imagine a movement and the muscles used in that movement will fire, priming and strengthening that muscle for actual execution of the movement. Symbolic learning theory presumes that imagery acts as a cognitive coding system that allows athletes to create "mental blueprints" for patterns of movement. These mental blueprints are strengthened by imagery allowing movements to become more automatic (Martin, Moritz, & Hall, 1999). These two theories highlight the interaction between imagery and the physical motor skill acquisition components of the body. Given the psychological and physiological theoretical rationale for imagery's effectiveness, we can then ask, what do these mind-body effects appear as in the brain – that which controls both the mind and body?

Neural Underpinnings of Mental Imagery

With the advent of neuroimaging techniques, such as PET and fMRI, the field of cognitive neuroscience has identified some of the neural underpinnings of mental imagery in the brain. In fMRI studies, mental imagery has been shown to involve many areas of the brain that resemble actual movement and perception, including the frontal cortex and sensory areas, and primary visual and motor cortices, overlapping with the default mode network (Pearson, 2019). In 1978, research by Kosslyn, Ball, and Reiser set the precedent of how the brain works during mental imagery. Their research established functional equivalence, showing that the brain behaves in exactly the same way during imagery as during an actual task itself. The processing speed and spatial relationship of imagined experiences are highly similar to the processing speed of real experiences. Essentially, visualization at the neural level is identical to real-world events (Kosslyn, Ball, & Reiser, 1987; Borst & Kosslyn, 2008).

Recently, the field of neuroscience has studied the parts of the brain that are activated *during* imagery, as well as when and to what extent. It appears that mental imagery draws upon similar neural mechanisms used in perception and motor control and can activate the brain in a similar pattern used in memory, emotion, and movement. It is suspected that similar cortical recruitment may allow for neural adaptations or plasticity that result in motor refinement and performance optimization (Hetu et al., 2013; Mulder, 2007). Specifically during mental imagery of a motor task, mental imagery seems to activate a pattern of cortical activity in areas of the brain devoted to motor control (i.e., the supplementary and primary motor cortices, cingulate and parietal cortical areas, the basal ganglia, and the cerebellum) that resembles activity seen during actual execution of the motor task (Jeannerod, 1995; Porro et al., 1996; Roth et al., 1996; Ehrsson et al., 2003; Meister et al., 2004; Hugdahl, 2009; Olsson et al., 2008). A study by Williamson and Kaufman (1989) showed suppression of alpha activity in the occipital cortex, indicating visual attention and the task of visual memory search, suggesting alpha oscillations may be a "cortical signature of representations shared between mental imagery and perception"

(Xie et al., 2020, p. 2621). From these findings, one might assume visual cortex involvement in mental imagery, specifically in engaging visual attention (i.e., “seeing” the basketball go in the net) and visual memory (i.e., using what an athlete has already seen to influence what he or she is currently visualizing) (Andreassi, 2000). Monany et al. (2022) recently identified functional connectivity between the cerebellum and the primary motor cortex during imagery, indicating less inhibition from the cerebellum to result in enhanced speed and accuracy performance of a motor task. Their findings suggest that mental imagery supports neuroplastic changes in regions of the brain associated with the visualized movement, such as the cerebellum (Monany et al., 2022).

Jeannerod (2001) proposed the simulation hypothesis to explain the neurophysiological effects of imagery which suggests that the motor system is part of a simulation network in the brain that is activated under conditions related to action without actual execution (i.e., imagining actions). Humans have the ability to experimentally access cognitive or mental states in the absence of overt behavior by using imagery. Naito et al. (2002) added to this hypothesis by postulating that the kinesthetic sensations or elements prompted by mental imagery may be a substitute for sensory feedback that would typically arise during movement execution, adding to its effectiveness at a neural level. Furthermore, there is evidence suggesting that imagery of emotional events may cortically activate the autonomic nervous system, the body’s control center for bodily functions not consciously detected, and the amygdala, resulting in physiological outcomes such as skin conductance increases and changes in heart rate and breathing rate (Kosslyn, Ganis, & Thompson, 2001). However, there is an ongoing debate regarding the exactness of the neural correlates of imagery with those of actual execution. Some researchers suggest that mental imagery may induce a distinct set of cortical activation unlike actual motor execution (Bartolomeo, 2008). These findings are indicative a neural foundation for cognitive and physiological outcomes after mental imagery.

Psychomotor Refinement, Neural Efficiency, and the Skill Acquisition Model

Logical reasoning might suggest that if imagery tends to strengthen performance through psychological and physiological mechanisms and correlates with a clear cortical activation of the brain, then it will also strengthen performance through neurological mechanisms. In the neuroscience literature (Hatfield & Kerick, 2007), psychomotor refinement is defined as suppression of irrelevant cognitive processes and cortico-cortical communication, with a very clear decrease in analytical thinking and added quiescence in the brain. This phenomenon is often referred to as “neural efficiency” or “automaticity,” as it implies that the brain is in its most effective state to perform well. The predominant theory of psychomotor efficiency posits that practice results in less complexity in the neural processes associated with motor control, suppression of irrelevant cognitive processes, less variability in the lead-up to a movement, and greater consistency of the resultant motor performance (Hatfield & Kerick, 2007). The efficient brain executes what it intends without the interference from nonessential processes. In a similar vein, Fitts and Posner (1967) proposed the skill acquisition model in which skilled motor performance is no longer under conscious and explicit control and becomes automatic. Historically, there has been a clearly accepted link between automaticity and performance; greater automaticity tends to contribute to better performance, especially in experts compared to novices (Hatfield & Kerick, 2007; Wolf, et al., 2015). The research suggests that a brain experiencing automaticity will exhibit an increase in left-hemispheric temporal (T7) alpha power (8-13 Hz), desynchrony of alpha in the right temporal (T8) region (i.e., temporal asymmetry), and increased frontal midline theta power during the preparatory period leading up to motor execution, all of which have been associated with highly focused attention, less self-instruction, and less disturbing ruminative thoughts.

Elite performers also show decreased cognitive workload and increased attentional reserve, two components of the psychomotor efficiency equation, in practiced, refined motor skills within their sports. They move efficiently within task constraints due to the brain's efficient use of task-relevant resources (i.e., those most important for task-performance) and quieting of task-irrelevant resources (i.e., those with limited relevance for the task) (Hatfield, Landers, & Ray, 1984; Wolf et al., 2015; Gallicchio et al., 2017). There also seems to be a particular quieting of the verbal-analytical regions of the brain associated with verbal information, language, and early motor learning, along with a reduction in cortico-cortical communication between different brain regions leading up to execution of a refined motor skill (Deeny et al., 2003; Rebert, Low, & Larsen, 1984). In this sense, an efficient brain will show cortical dynamics indicating a decrease in what is subjectively identified as "overthinking."

Temporal Alpha & Alpha Connectivity

Temporal alpha was considered as an a-priori marker for neural activation in the present study. Within the literature, the alpha wave is given significant focus in determining cortical efficiency due to its inhibitory nature. Greater alpha in a given brain region indicates greater inhibition in that region. Therefore, when alpha power increases in the left temporal lobe (T7) immediately before skill execution, one can assume that region is inhibited (Klimesch, 2012). If the brain is exhibiting reduced neural activation (i.e., increased neural efficiency), then we would expect to see increased left temporal alpha compared to baseline and increased left temporal alpha compared to right temporal alpha leading up to or during the task. Separate from its use in identifying the state of activation, the alpha wave also allows identification of functional connectivity between two brain regions (e.g., the left temporal region (T7) and the frontal region (Fz) (Gallicchio, Cooke, & Ring, 2017). Alpha-band activity is especially suited to moderate to long-range cortico-cortical communication. The synchronization of alpha rhythms is important for gating information between distributed areas, especially frontal and temporal regions during motor tasks (Jensen & Mazaheri, 2010). Therefore, if the brain is exhibiting reduced neural activation (i.e., increased neural efficiency), we would expect to see decreased fronto-temporal alpha coherence (i.e., alpha coherence from sites Fz-T7 and Fz-T8), indicative of less cross-talk between the frontal cortex and temporal association areas of the brain. The alpha band can further be divided into "low alpha" (8-10 Hz) which is inversely associated with general arousal (i.e., as low alpha increases, general arousal decreases), and “high alpha” (10-13 Hz) which is inversely associated with task-relevant attentional processes (i.e., as high alpha increases, task-related attentional processes decrease) (Hatfield, Jaquess, Lo, & Oh, 2020). One model to explain this difference in alpha activity is that of alpha gating inhibition where an inhibition of non-essential brain regions or conflicting processing is reflected by an increase in alpha in those regions (Jensen & Mazaheri, 2010). More recent literature (Parr et al., 2023) has questioned the relationship between left temporal alpha, fronto-temporal connectivity and verbal-analytical processing, suggesting that efficacy of these EEG indices of verbally-guided conscious motor processing is lower than initially reported. While the present experiment was designed on the premise of the historically proposed indices of neural activation (i.e., neural efficiency) and the mental states they assume to represent, Parr et al.’s suggestions were applied to data processing and will be discussed in the context of limitations and future research. Additionally, the individualized alpha frequency (IAF) was not used as a marker of alpha band definition in this study due to the other supplementary neural indices chosen to measure neural activation. Future studies may consider use of the IAF for increased specificity.

Fronto-midline Theta

Fronto-midline theta (Fm θ) was another marker of neural activation considered for the present study. Fronto-midline theta (4-7 Hz at Fz and Cz) is a well-established neural marker of cognitive control, attention, and performance monitoring originating primarily from the medial prefrontal cortex (mPFC) and anterior cingulate cortex (ACC), making it particularly relevant for psychomotor efficiency during motor task execution. Increased activity in this frequency band also tends to reflect adaptive control mechanisms, including error monitoring, cognitive effort allocation, optimizing responses, cognitive processing using working memory, and performance optimization (Cavanagh & Frank, 2014; Chuang et al., 2013; Holroyd & Coles, 2002). For example, in high-level athletes (i.e., experts), increased fronto-midline theta tends to rise as cognitive demand increases and predicts better real-time adjustments to movement errors, improving motor learning and adaptation (Cheron et al., 2016; Baumeister et al., 2008) and performance (Chuang et al., 2013). Fronto-midline theta also increases when individuals must correct errors, regulate movement, and sustain attention on a task (Cohen & Cavanagh, 2011). If the brain exhibits less neural activation (i.e., increased neural efficiency), we would expect to see an increase in fronto-midline theta across the midline region (Fz, Cz, Pz).

Central Mu Rhythm

Lastly, within this study, central mu rhythm was also used as a marker of neural activation. The mu rhythm (8-13 Hz), originating from the sensorimotor cortex, plays a critical role in motor preparation, execution, and observation. Studies have established that efficient motor performance is characterized by appropriate modulation of mu rhythm, specifically mu suppression (i.e., desynchronization or decreased mu power) during movement-related tasks, suggesting the greater engagement of the sensorimotor and motor cortices (i.e., task-relevant regions for motor-execution) (Pineda, 2005; Neuper & Pfurtscheller, 2001). As a skill becomes more automatic, mu suppression patterns become more stable, reflecting increased neural efficiency in motor execution (Babiloni et al., 2008). Mu rhythm is primarily measured over the sensorimotor cortex, specifically at C3, C4, and Cz. While C3 mu rhythm might have been measured due to right-handedness of all participants (i.e., the contralateral site), mu rhythm was measured at Cz for the present study in order to gauge bilateral movement and whole-body coordination rather than left or right alone and because of its direct correspondence with the supplementary motor area (SMA) and primary motor cortex (Pfurtscheller et al., 1997). With decreased neural activation (i.e., increased neural efficiency) we would expect a decrease in mu power at Cz, indicating more engagement with the task.

Methodological Considerations of Research in Neuroscience

It is important to note that neuroimaging data is only correlational, showing a particular set of brain areas activated when an individual is engaged in a particular task (Kosslyn, Ganis, & Thompson, 2001). Because of this lack of specificity and sensitivity, it is important for researchers to consider using different neuroimaging methods in their experiments so to better compare results and draw stronger conclusions regarding neural correlates. Here, electroencephalography (EEG) was used. Within methodological constraints, EEG measurements have been shown to be valid and reliable for inference of various psychological processes related to the observed power of specific frequency bands matched with spatial topography (Thatcher, 2010). Additionally, much of the previous research in this domain has used EEG to study cortical refinement in athletes of low-movement, predominantly steady-state sports. Modern paradigms for analyzing EEG data and controlling for motion artifact have allowed us the ability to elegantly analyze the data and expand application of these methods to practically-relevant settings and activities. To control for weaknesses presented by use of the EEG, such as low spatial resolution due to volume conduction and limitations of reverse inference, the present study followed methodological recommendations by Parr et al. (2023) to identify and reject non-neural components in the data set including band-pass filtering, waveform inspection to discard noisy channels/trials, and advanced denoising techniques (such as Independent Component Analysis (ICA)).

The Importance of the Free Throw: A Measure of Performance

NCAA Basketball Hall of Fame Coach, Rick Majerus said, “to win the big games you must get to the free throw line, and then you must make them.” Pat Summit, one of the greatest collegiate women’s basketball coaches of all time said, “If you want to be in the game, you better shoot 75% from the [free throw] line.” In the game of basketball there is a clear anecdotal perception that free throws matter, big time. When it comes to collegiate and professional basketball, if free throws win games, they also correlate to monetary benefits collected from those wins, whether it be from direct win compensation or secondary income from fans and sponsors (Elkins, 2020; Gough, 2022; Hobson, 2014).

Statistically, the most valuable shot in college basketball is the free throw attempt, according to data collected from 2001 to 2018 across Division I NCAA men's basketball seasons (Wilco, 2018). The most notable finding from this study: "teams that shot more free throws won more games" compared to any other shot, including 3-pointers or two-point field goals. In the National Basketball Association (NBA), as of data collected in 2014, there was only one champion in the 21 years prior that allowed more free throw attempts against them than of their own foul shots (Young, 2014). While this data suggests that good defense and limited fouling of the opponent is most trivial, we still have to ask, is *taking* more free throws the most important factor in a win or is *making* them just as important? With that in mind, there is further evidence that NBA teams with average free throw percentages (FTPs) can still win games when they matter. In collegiate basketball, *however*, it is clear that teams with higher free throw percentages more frequently win games and go farther in the post-season (Wilco, 2018). Previous research also suggests that the free throw contributes to approximately 20-25% of the overall number of scored points in a basketball game (Cabarkapa, Fry, Poggio & Deane, 2021; Hays & Krause, 1987, Kozar et al., 1994; Merskey, 1987). It seems then, that free throws matter in the outcome of a game; both taking more and making more is a determinant of a win.

One striking factor is that the success of free throw shooting is the one shot in basketball that has consistently remained about the same. From 1999 to 2010, the NCAA FTP hovered around 70% and the NBA FTP hovered around 75-77%, while overall field-goal percentage and 3-point percentages improved (Branch, 2009). In the 2024-2025 NBA season, point guards shoot an average 82% from the foul line while centers remain around 71%. What is it about the free throw that hasn't allowed for significant longitudinal performance enhancement? The present study used the free throw shot as the motor skill of interest in an effort to model similar self-paced closed-skill, fine-motor tasks reliably used in the psychophysiological research (Chuang, Huang, & Hung, 2013; Wu, Lo, Lin, Shih, & Hung, 2007; Bellomo et al., 2020) and to offer a more pragmatic translation of this research to the population interested in applying its findings. Furthermore, to date, there is little scientific literature addressing key psychophysiological characteristics during the preparatory phase of free throw shooting that allow basketball players to achieve success.

Chapter 3: Purpose of the Present Study

Significance and Uniqueness of Proposed Effort

Prevailing theories in various scientific disciplines indicate and acknowledge that mental imagery serves as a potent tool within psychological skills training (PST), fostering the optimization of motor performance (Feltz & Landers, 1983; Jones & Stuth, 1997; Martin et al., 1999; Jeannerod, 2001; Mulder, 2007; Hall et al., 2009; Hetu et al., 2013). This enhancement in performance is attributed to physiological mechanisms involving muscle activation, cognitive and emotional regulation, and neural activation akin to those observed during actual motor tasks. Thus, it is reasonable to infer that the efficacy of imagery results from the intricate interplay of these factors, each exerting influence on the others in a synchronous manner. While the cortical dynamics *during* imagery have been densely studied, it has yet to be explored whether mental imagery interventions lead to the neural correlates of activation predictive of improved performance (i.e., patterns of neural efficiency). Additionally, the neuroscience and psychology literature has neglected to meaningfully explore the biological bases of perceived psychological states and how these states dynamically interact with neural efficiency to influence motor performance. The mediated-moderation relationship explored here remains unresolved, representing a "chicken-or-the-egg" question in psychophysiology. Does confidence, anxiety or any sort of psychological state drive neural activation, or does neural activation create the psychological state?

To expand upon these psychophysiological theories of imagery and psychomotor efficiency, this investigation aimed to explore the effects of psychological variables (i.e., confidence and anxiety) and neurological variables (i.e., neural correlates of activation) as mechanisms of the mental imagery-performance relationship. Do psychological constructs, neurological constructs, or both mediate the imagery-performance relationship? This study attempted to bridge a knowledge gap between what is known about the effectiveness of the psychological skill of mental imagery and resulting brain activity while investigating underlying mechanisms. This relationship was explored with a focus on expanding our understanding of the psychomotor processes facilitated by mental imagery during movement and identifying the neural activity occurring in the brain during the preparatory period of "just prior to the execution" of a motor task with and without formal guided imagery rehearsal.

Purpose

The purpose of the present study was to examine the effect of a mental imagery intervention on the neural correlates of activation and performance during the preparatory period of a basketball free throw shot. The primary aim of the present study was to investigate whether a mental imagery intervention was related to a) changes in performance, b) changes in neural activation, and c) changes in perceived psychological states. More specifically, the research questions addressed were twofold: (1) To what extent does mental imagery completed before a basketball free throw shooting task facilitate more efficient neural correlates of activation and performance compared to a control group? (2) Do psychological states of (a) confidence and (b) anxiety mediate this relationship?

Hypotheses

H_1: Performance is expected to improve from pre-test to post-test after imagery intervention compared to control.

H_2: Hypotheses related to the neural correlates of activation variable during the preparatory period are as follows:

(a) Left temporal alpha will increase after the mental imagery intervention compared to control.
    ǂ Tested by the Condition × Time × Hemisphere × Region × Epoch interaction in the ANOVA model.
(b) Fronto-midline theta will increase after the mental imagery intervention compared to control.
    ǂ Tested by the Condition × Time × Site × Epoch interaction in the ANOVA model.
(c) Central (Cz) mu rhythm will decrease after the mental imagery intervention compared to control.
    ǂ Tested by the Condition × Time × Epoch interaction in the ANOVA model.
(d) Coherence between the frontal region and temporal regions of the brain will decrease after the mental imagery intervention compared to control.
    ǂ Tested by the Condition × Time × Region × Epoch interaction in the ANOVA model.

H_3: Subjective cognitive workload and conscious motor processing are hypothesized to decrease from pre-test to post-test in the mental imagery group compared to control.

H_4: Self-confidence is hypothesized to increase from pre-test to post-test in mental imagery intervention compared to control.

H_5: State anxiety is hypothesized to decrease from pre-test to post-test in mental imagery intervention compared to control.

The study conceptualization and variables can be seen in *Figure 1.* including hypothesized moderated-mediation models. In other words, we explored whether mental imagery improves performance *because* it changes confidence, anxiety, or brain activity (i.e., mediation) and whether the effectiveness of mental imagery depends on how confident or anxious an athlete is (i.e., moderation). Overarchingly, mental imagery is expected to have an effect on performance via all three variables: neural correlates of activation, confidence, and anxiety. Mental imagery may also interact with confidence and/or anxiety to therefore affect neural activation, resulting in improved performance (*Figure 2.*). The moderated-mediation models suggest that mental imagery may affect neural activation and performance, but not always directly. The effect of mental imagery may be partly explained by confidence and anxiety and at the same time, confidence and anxiety also change how much mental imagery affects neural activation.

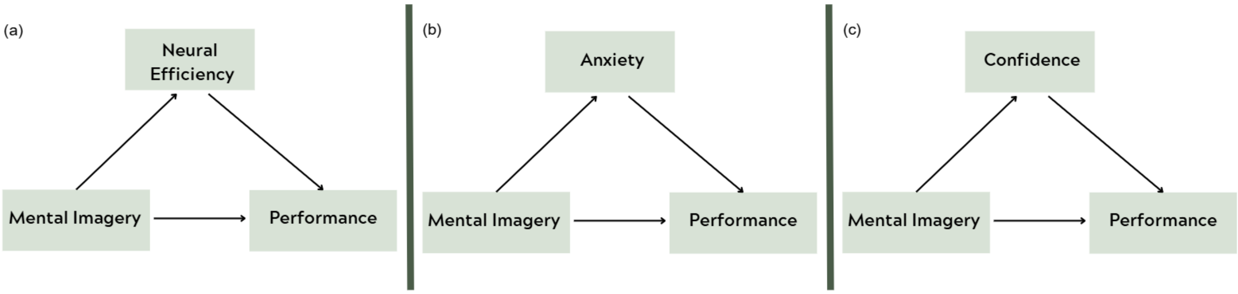


Figure 1. (a) Mediation model with psychomotor efficiency as mediator of mental imagery and performance; (b) Mediation model with anxiety as mediator of mental imagery and performance; (c) Mediation model with self-confidence as mediator of mental imagery and performance.

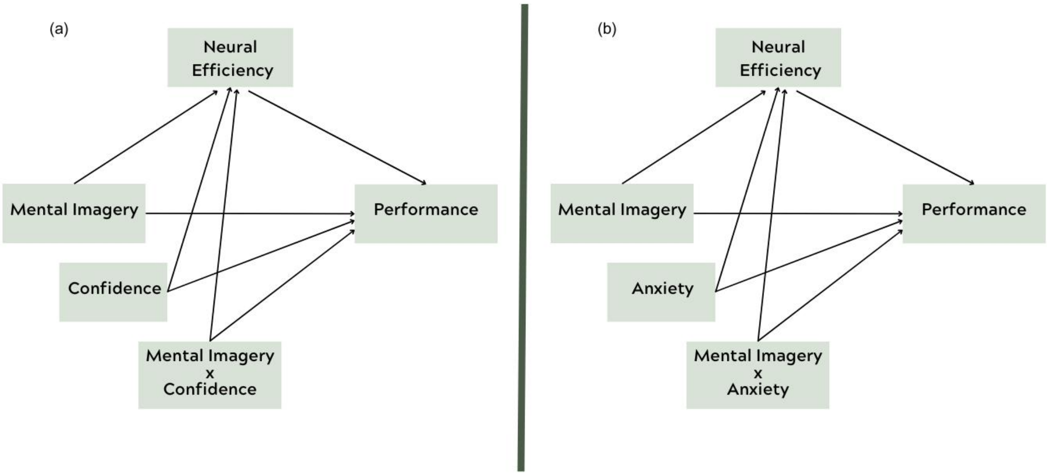


Figure 2. (a) Proposed moderated-mediation model with Mental Imagery x Self-Confidence; (b) Proposed moderated-mediation model with Mental Imagery x Anxiety
**Neural activation in model was tested using alpha.*

Chapter 4: Research Design and Methods

Participants

A total of 26 right-handed (Edinburgh Handedness Inventory ≥ +70, Oldfield, 1971) male and female (18 males, 8 females) basketball players from a pool of undergraduate students from an East Coast university were recruited through convenience and snowball sampling (M age = 21.4, SD age = 5.2). Given the focus on detecting a Condition × Time interaction and that previous EEG research has seen a medium effect in precision sports performance (Cohen's d ≈ 0.462, which approximates f ≈ 0.23) (Wu et al, 2023), it was determined that a smaller sample size would be adequate to achieve a power estimate of 0.8, assuming $\alpha=0.05$. Power was estimated for a repeated-measures within-between interaction. The analysis indicated that a sample size of approximately N = 28 would be needed to detect a 2-way interaction. However, within EEG research there is a constraint of burden of the data collection and for practical reasons it was determined that a sample size of approximately 20-30 total participants would be adequate to conduct this study, operating under the assumption that there would be a medium to small effect size. As such, the study was likely underpowered to detect 3-way and higher interactions with small-to-medium effects ($f < .25$), and non-significant results for these higher-order interactions should be interpreted with caution.

Inclusion criteria wer determined during initial recruitment and included: (1) right-handedness; (2) a current self-reported FTP of 50-75%; and (3) an average score of ≤ three on the mental imagery (MI) experience-specific questions on the Test of Performance Strategies (TOPS). The FTP range of 50-75% was determined in order to identify participants who have some experience with basketball, but also show room for improvement. The average upper limit of college and professional FTP average is about 75%, with the best in the world shooting about 90%. Therefore, the participants in this study were not considered novice or expert, but rather 'experienced.'

The TOPS, previously determined as valid and reliable (Thomas, Murphy, & Hardy, 1999), was used to gauge participants' use of MI at baseline, in order to control for current MI use. The TOPS asks questions regarding use of a variety of mental skills, not just imagery, allowing the nature of the present study to be kept undercover in order to limit ironic processes. Previous research indicates that athletes with high imagery ability tend to improve in performance of a sport task significantly more than athletes with low imagery abilities, regardless of skill level (Isaac, 1992). Athletes with high imagery ability also tend to use imagery more often (Gregg et al., 2011). In the present study, researchers decided to control for this possible confounding variable by excluding those participants who scored high on MI experience and use. Therefore, participants were only included if they scored an average of ≤ three on the MI experience-specific questions.

Participants determined eligible for the study were randomly assigned to an experimental (i.e., MI intervention) or control group. Both groups were initially kept blind to the purpose of the study and informed that it was a study to investigate "performance, brain, and basketball skills." All participants provided written consent to participate after the study procedures were explained. Ethical approval was obtained from the University of Maryland’s IRB.

Design

The study employed a 2 (Condition) between-subjects x 2 (Time) within-subjects factorial pre-test, post-test design. The experimental design is pictured in *Figure 3*.

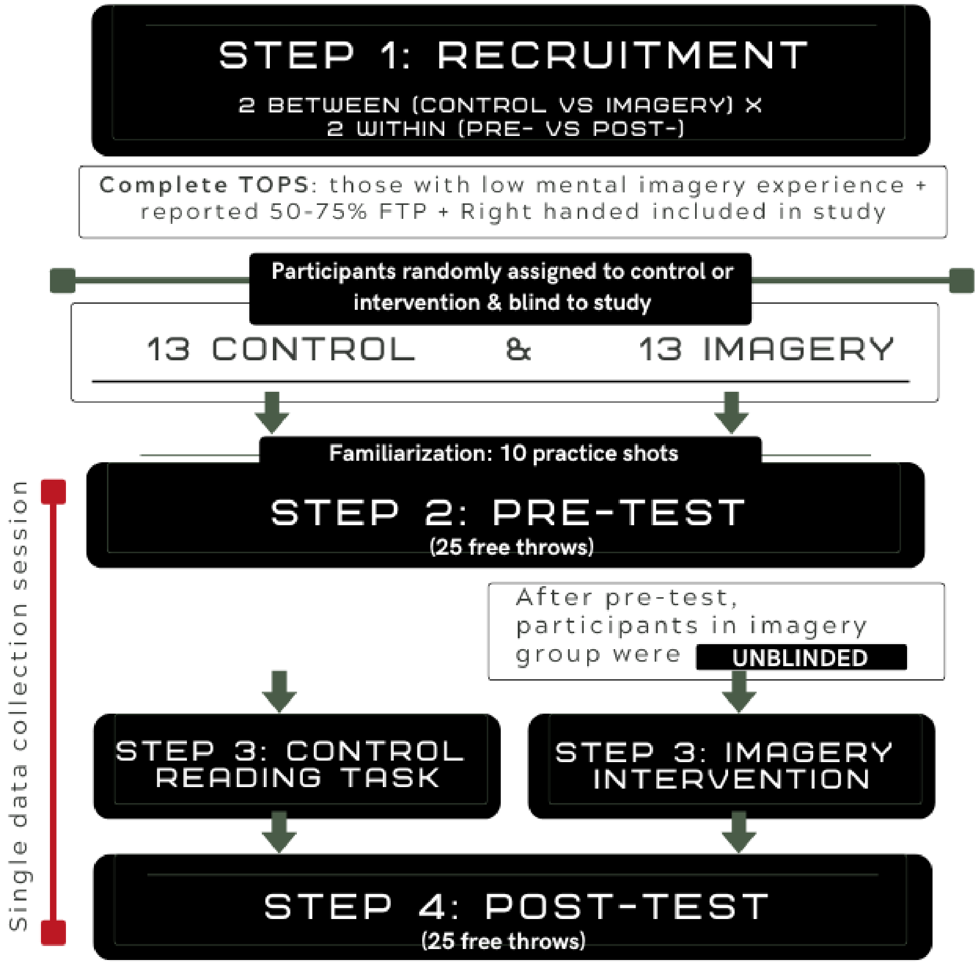


Figure 3. Study Protocol.

Independent Variables

The independent variables in the present study were: (1) Intervention (i.e., MI intervention and no-imagery intervention); and (2) Time (i.e., pre-test and post-test).

The MI condition was defined by one MI training session and use of a MI script. As discussed in the *Measurement* section of this paper, the imagery training and script underwent pilot testing to determine appropriate timing, conciseness, and clarity of instruction and use.

Dependent Variables

The dependent variables measured in the present study were performance, neural correlates of activation, cognitive workload, conscious motor processing, self-confidence, and state anxiety. Performance was measured by made free throws, or FTP, out of 25 shots. Data on rim backboard touch was collected via a point system to gauge how close each shot came to a "make."

Neural correlates of activation were measured by EEG. Neural activation is typically operationalized as widespread event-related synchronization (ERS) of theta, alpha, and lower beta bands more generally (Sommer, Werthner, & Bertollo, 2019). Four of the most consistently demonstrated cortical dynamics associated with efficiency are an increase in alpha power in the left temporal lobe, an increase in fronto-midline theta power, decreased coherence between the frontal and temporal regions, and decreased mu rhythm power in the central region. Therefore, to measure neural activation in the present study, four components of the electrical brain activity were measured:

(a) Temporal alpha (8-13 Hz at T7 & T8) – does it increase pre-test to post-test?
(b) Fronto-midline theta (4-7 Hz at Fz, Cz, & Pz) – does it increase pre-test to post-test?
(c) Alpha coherence (8-13 Hz) between Fz and T7 and Fz and T8 – does coherence decrease pre-test to post-test?
(d) Central (Cz) mu rhythm (8-13 Hz) – does it decrease pre-test to post-test?

Neural correlates of activation also serve as mediators within the relationship being explored.

Subjective Cognitive Workload was measured by the NASA Task Load Index (NASA-TLX). Subjective Conscious Motor Processing was measured by the Conscious Motor Processing Inventory. Self-Confidence was measured by a score on the State Sport-Confidence Inventory (SSCI). State anxiety was measured using the Sport Anxiety Scale-2 (SAS-2). Self-Confidence and anxiety also served as mediators within the relationship being explored.

Measures

Brain Imaging Measures and EEG Data Acquisition

The common agreement amongst current researchers is that spontaneous cortical activity, as measured by EEG, does in fact reflect global states and functional properties of brain function (Nunez, 2000; Fingelkurts, et al., 2006). Across studies, the reported reliabilities of EEG parameters range high from 0.81 and 0.86 for theta and alpha bands (Burgess & Gruzelier, 1993), test-retest reliability for EEG power about 0.80 for absolute and relative power (Stassen et al., 1987), and even over longer time intervals between measurements, reliability has been found to be over 0.70 (Gasser et al., 1985; Stassen et al., 1988; Fingelkurts et al., 2006). Additionally, test-retest reliability of EEG used to assess cognitive status changes was found to be between 0.80 to 0.90 (McEvoy, Smith, & Gevins, 2000). According to Napflin, et al. (2007), the test-retest reliability of resting EEG was sufficiently established. Using 2,960 pairwise comparisons, sensitivity was found to be 88% and specificity 99.5%. They concluded that any external factors on EEG data could be contrasted against their normal variability over time to adequately identify the statistical signature of an individual's brain activity (Napflin et al., 2007). This experiment used EEG to measure brain oscillations across the cortex.

NASA Task Load Index (NASA-TLX)

The NASA-TLX has been employed as a measure of cognitive workload in numerous psychophysiological studies. The index assesses workload on six dimensions: "Mental Demand," "Physical Demand," "Temporal Demand," "Performance," "Effort," and "Frustration" on a scale from 0-100. In the neuroscience literature, cognitive workload is often paired with neural correlates of activation as a subjective indicator of effort. The present study determined cognitive workload would contribute as a measurement of interest supporting the neurological data. Overall validity and reliability of the assessment scales have been shown to be of high magnitude, though construct validity has been questioned (McKendrick & Cherry, 2018). Specifically, split-half reliability and Cronbach's alpha are more than 0.80 and there is high internal consistency between scales. Factor analyses have also shown "good structure validity" (Devos, et al., 2020; Xiao, Wang, Wang, & Lan, 2005, pp. 178).

Conscious Motor Processing Inventory

Versions of the Conscious Motor Processing Inventory of the Movement Specific Reinvestment Scale (Orell, Masters, & Eves, 2009) have also been employed throughout the psychophysiology literature, particularly in the sport domain. This study employed a basketball-specific version. Six items are scored on a 5-point Likert scale and then averaged to generate a single scale score. The measure has been shown to exhibit high predictive validity and a Cronbach's alpha coefficient of approximately 0.89, as well as adequate test-retest reliability ($r = 0.67$, $p < .05$) (Jackson, Kinrade, Hicks, & Wills, 2013).

State Sport-Confidence Inventory (SSCI)

The State Sport-Confidence Inventory (SSCI; Vealey, 1986) was employed to measure participants' confidence just prior to pre-test and post-test free throw shooting. Previous research has reported an internal consistency of 0.95 and sufficient concurrent validity, criterion validity, and predictive validity (Gayton & Nickless, 1987) of the SSCI (Martin & Gill, 1991).

Self-efficacy measures such as the Perceived Self-Efficacy Scale in Sports (PSES) (Aizava, Codonhato, & Fiorese, 2023) and the General Self-Efficacy Scale (GSE) (Schwarzer & Jerusalem, 1995) were also considered for similar purpose within the experiment, however, the questions within these assessments do not contextually fit the intended purpose of collecting confidence and anxiety scores *before* free throw performance.

Sport Anxiety Scale-2 (SAS-2)

The Sport Anxiety Scale-2 was employed as a relevant measure of state anxiety before the free throw task at pre-test and post-test. An acceptable reliability (Cronbach's alpha coefficients between 0.74 and 0.92) and factorial and construct validity (r = 0.90) of the SAS-2 have been established by previous research (Smith, Smoll, Cumming, & Grossbard, 2006).

Motor Task

In the present study the motor task of shooting free throws was suitable to measure underlying cortical dynamics along with self-confidence, anxiety, and performance, conveniently because of the limited body movement one makes during a standing free throw shot. Previous studies in psychophysiology have successfully used the free throw shot as the motor task of interest (Keshvari et al., 2024; Chuang et al., 2013). As previously discussed, the free throw is also a closed skill in basketball, must be completed individually, and is an important and seemingly crucial component to the sport. It is also evidently clear how a successful free throw shot is measured, as it must be made (go through the rim and net) to count for points.

Biomechanics research has established the movement patterns of the free throw shot. The "motions of the legs, trunk, and upper arm are prerequisite movements to reach an adequate release speed and position," while ball release is generated from wrist and finger flexion (Mullineaux & Uhl, 2010, pp. 1022). The three movement phases of a free throw are the preparatory, transition, and launch phases. These phases represent a "generalized framework of the movement pattern," (pp. 29) so while every shooter may exhibit small individual motions that do not adhere to the defined phases, this template is a way to define the motor preparatory to execution stage epoch for the purpose of this study.

During the preparatory phase, the shooter is passed the ball by the referee and "goes through an individual-specific pre-shot routine that commonly consists of spinning the ball, dribbling the ball, moving the feet or other body parts or some combination of these movements" (Williams, 2021, pp. 30). Previous research with free throw shooting has determined that allowing participants to engage in their typical pre-shot routine is important to maintain a consistent behavioral sequence (Mack, 2001), therefore the present study allowed participants to engage in their typical pre-shot routines leading up to each free throw.

After this routine, the player will use both hands to stabilize the ball "at or near the level of the waist with his/her fingers spread as the primary contact points for the ball" (Williams, 2021, pp. 30; Okazaki et al., 2015).

The beginning of the transition phase is indicated by simultaneous knee and hip extension and the rise of the body's center of mass. The trunk may begin to extend towards neutral and shoulder flexion will occur. "The primary function of this phase is to transition from the lower extremity (LE) flexion positions into an extension pattern to generate an initial upward impulse similar to a countermovement jump" (Williams, 2021, pp. 30). The kinematic chain of the shot, confirmed by the shoulder, elbow, and hand will occur during this phase (Gutierrez & Castellanos, 2018).

The launch phase begins with elbow extension and wrist flexion. During this phase, the knee and hip will reach their maximum extension for the movement. "Adequate wrist flexion and subsequent finger flexion provide backspin to the ball as it is released," therefore ball release from the fingertips dictates the end of this phase (Williams, 2021, pp. 31). *Figure 2.* (Williams, 2021) illustrates the phases of a free throw shot, including the 10-sec mental preparation period employed in the present study.

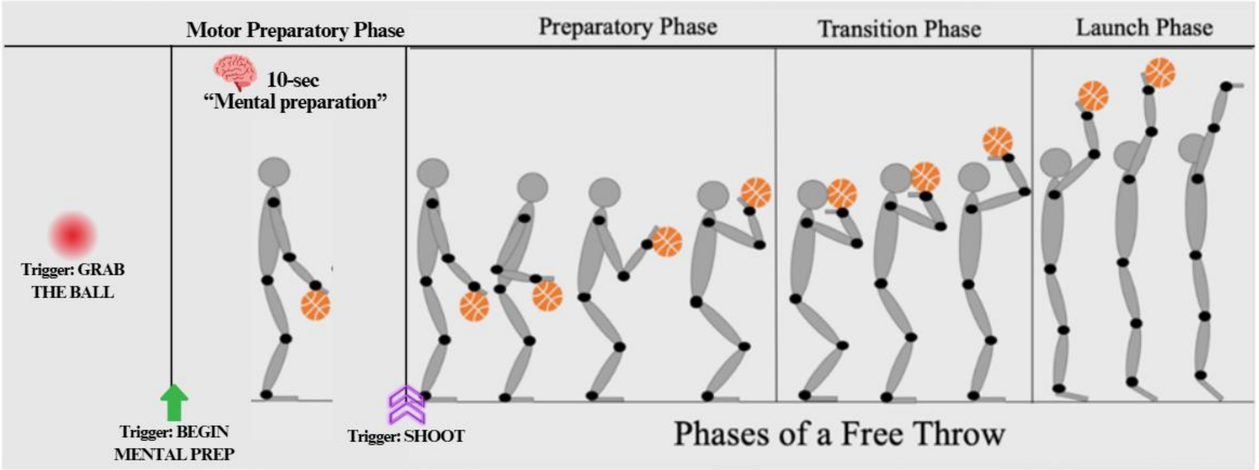


Figure 4. Phases of a free throw shot, including 10-sec mental preparatory period and EEG triggers used in the present study before execution of shot. Participants began gross motor movement involving free throw shooting routine and resulting shot after signal to "shoot." During the mental preparatory period, participants stood quietly at the free throw line holding the basketball, eyes directed toward the basket.

Following methodology used by Wallace and Hagler (1979) and modified by Mack (2001), the present study used a rating system to measure free throw performance. Four points were given for a "swish in which the ball goes through the basket without touching the rim" (pp. 569), three points were given for a ball hitting the rim and going in, two points were given to a ball for hitting the backboard and going in, one point was given to a ball that hit the front, back, or side of the rim or backboard but does *not* go in, and zero points were given to misses that did not touch anything ("airballs").

Mental Imagery Intervention

The MI intervention included an (1) educational component and (2) an imagery script component. The educational component consisted of a brief ten-minute asynchronous video about the uses and effectiveness of imagery use in sport. The content of the imagery education was mirrored off of imagery interventions developed in previous sport psychology research (Koehn, Morris, & Watt, 2014; Jordet, 2005; Callow, Hardy, & Hall, 2001), though it was reduced in time for practical application in the context of the present study.

The script component consisted of introduction and rehearsal of a guided imagery script for a free throw shot. Research on MI in sport suggests that imagery scripts are an effective means of preparing an athlete for visualization of a chosen motor task or situation (Wakefield & Smith, 2012). The imagery script used in the present study was designed by the lead researcher who is a Certified Mental Performance Consultant (CMPC), as designated through the Association for Applied Sport Psychology (AASP). Previous research suggests that imagery scripts "weighted with response proposition evoking physiological-emotional-movement reactions (e.g., imagine being in control of the situation) are more likely to produce vivid images than those weighted with stimulus propositions, which describe content of the scenario (e.g., imagine the physical details of an object)" (Callow, Hardy, & Hall, 2001, p. 393; Lang, Kozak, Miller, Levin, & McLean, 1980). Therefore, using the PETTLEP model of imagery (Holmes & Collins, 2001; Wakefield & Smith, 2012), consultation from NBA Coach Hal Wissel's (2004) free throw imagery script, and guidelines outlined by Williams, et al. (2013) and Cooley et al. (2013), the current script (*see Appendix A)* was created to induce a realistic free throw practice environment and realistic shooting movements and handling of a basketball during a free throw task, involving all of the senses in a generic way open for athletes to personalize.

In this case, the imagery script was the stimulus for examining neural activity in the brain, so it was important to gauge its effectiveness. Rather than allow participants to create their own personalized imagery script, which is the most highly recommended means of creating an effective script, researchers decided to create a basic basketball free throw descriptive imagery script presented across all participants to attenuate the practical challenges that individual scripts would introduce. The entire imagery intervention was pilot tested to gauge engagement and practicality during the testing period. It was determined that 20 minutes total was appropriate to maintain participants' attention. At the end of imagery script practice, participants were also asked to rate on a scale of 1-10 how well they could visualize a free throw using the script.

Control Group

Participants in the control condition were given a basketball magazine titled "The NBA Goat: There Can Only Be One," featuring stories about Michael Jordan, Lebron James, and Kobe Bryant, in between pre-test and post-test and were instructed to read for approximately 20 minutes while sitting.

EEG Protocol

EEG and EOG Recording

Using the Brain Vision wireless LiveAmp (Version 2.2.0) [Software] (2019), EEG was recorded from 30 active gelled electrodes positioned within a stretchable lycra cap onto the scalp according to the 10 –20 system (Jasper, 1958) at FP1, FP2, Fz, F3, F4, F7, F8, FT9, FT10, FC1, FC2, FC5, FC6, Cz, C3, C4, T7, T8, CP1, CP2, CP5, CP6, TP9, TP10, Pz, P3, P4, P7, P8, Oz, O1 and O2 referenced to FCz. Additionally, one active electrode was placed at the bottom (TP9) and one at the outer canthus (TP10) of the left eye using an electrode contact stickers. Although an upper limit of 10 kΩ was used for inclusion, impedance levels were generally below 5 kΩ at all sites of interest. The ground electrode was located at the frontal pole (FPz). Vertical and horizontal electro-oculograms (VEOG and HEOG, respectively) were recorded with bipolar configurations of electrodes. VEOG was placed inferior to the left eye and HEOG was placed at the left orbital canthi. Online bandpass filters were disabled and the sampling rate was 1,000 Hz. The pre-session criteria required participants to (a) refrain from caffeine in the 2 hours preceding testing and (b) refrain from any other substances (i.e., alcohol or marijuana) in the 24 hours preceding testing.

An LED light trigger provided automatic time signals to the participant and researcher to mark initiation of the motor planning/mental preparation period and initiation of motor execution. The Arduino Nano microcontroller, programmed using the Arduino IDE (Arduino, 2023), controlled stimulus timing and LED activation. When the LED light turned red, the participant was instructed to “grab the ball.” When the participant was set, the LED light would then turn green, signaling the beginning of a 10-second mental preparatory period leading up to a purple light which signaled “shoot the ball” upon which the participant would initiate his or her free throw shot. The lead researcher employed the LED signals to indicate when to manually mark the EEG time series. The 10-second period during which the green light was active was marked on the EEG at start and end of the time series. Manual manipulation of the trigger holds the potential to compromise the timing of the EEG measures because of experimenter error, but considerable care was taken to avoid this. Furthermore, the specificity of the timing required of the event markers allowed for reasonable latitude as the precise timing of the preparatory period relative to “shoot the ball” was not essential due to the gross nature of the ensuing motor sequence/bodily movement.

EEG Processing

Using Brain Vision Analyzer 2.3 (Brain Products, 2022), the EEG signals were digitally bandpass filtered by employing a Zero Phase Shift Butterworth filter (1-Hz and 30-Hz cut-off frequencies and 48 dB/oct roll-off) with forward and reverse passes for zero phase shift. A raw data inspection of channel quality was then completed, and bad channels were labeled and interpolated when needed. Next, an ocular independent component analysis (ocular ICA) using an established algorithm

(Semlitsch et al., 1986) was conducted to remove blinks and eye movement artifact. As EEG data were originally recorded with FCz as the reference electrode, data were then re-referenced to the common average of all electrodes to minimize reference bias and improve spatial signal distribution. Additionally, the original FCz reference was retained with inverted polarity (negated new reference) to allow for later analyses that may require reference-dependent comparisons. Data were then exported to EEGLAB where Matlab scripts (MATLAB Release, 2016b; The MathWorks, Inc., Natick, MA) were used to complete preprocessing and compute spectral power and coherence. The following processing and analysis steps were implemented with the EEGLAB toolbox v2023.0 (Delorme & Makeig, 2004): (i) A visual inspection was conducted and any nonstereotypical components (e.g., motion artifact, line sway, etc.) were manually removed., (ii) the EEG time series was segmented into10-sec epochs based on the starting event trigger, (iii) The data were further segmented into five 1-sec epochs using the 5-sec window prior to initiation of movement to allow for stationarity of the spectral analysis and allow for an opportunity to examine the dynamic nature of the brain state up to the start of movement. An average of 22.84 (SD = 3.22) epochs per participant in the pre-test and 23.56 (SD = 1.68) epochs per participant in the post-test were retained and then averaged. The 1-sec EEG epochs were transformed into the frequency domain using a Fast-Fourier Transform and power spectral density was computed through a Hamming window across 1 Hz bins and integrated over the frequency bands of theta (4–7 Hz), alpha (8–13 Hz), and mu (8-13 Hz). The spectral power was log-transformed to decibels for subsequent statistical analyses. Coherence was defined as $C_{xy}(f)^2$ (Deeny et al., 2003), where $C_{xy}(f)$ is the coherence between two EEG channels xxx and yyy at frequency fff, computed across 1 Hz bins, and averaged across the frequency bandwidths of alpha (8-13 Hz) between T7 and T8 electrodes to Fz. The Fisher Transformation was applied to coherence values to tend towards a normal distribution.

For the mediation and moderation analyses, the neural efficiency variable was defined as normalized T7 alpha which was calculated as the percent of change from the baseline EO condition to the preparatory period of post-test. EEG data from the EO condition was handled identical to preprocessing of the data described above. A 5-sec period from the EO data was used and the entire 5-sec epoch before motor execution was used within post-test data.

Procedure

Following recruitment, informed consent and completion of the Edinburgh Handedness Inventory, participants completed a one hour and 30-minute testing session. The testing session was conducted in the university's practice gymnasium in which a basketball hoop at standard height (10 feet) with a DI collegiate level key marked on the court floor reside. The basketball employed for the motor task was a Wilson Sporting Goods Co. official game ball in size 7 (29.5" circumference) for the male participants and size 6 (28.5" circumference) for the female participants, reflecting standard ball sizes used in the collegiate athletic setting. A cart full of basketballs was positioned to the left side of the participant during shooting.

Participants were fitted with a Brain Vision EEG cap by measuring head circumference and inion to nasion and set up with a portable, blue-tooth connected EEG amplifier after gelling with Omni-prep conducting gel and checking impedance. Acceptable levels of impedance were 10 kΩ or below. The wireless amp was placed in a fanny pack which was attached to the participants' waist, positioned toward the rear, and clear of their range of motion. Participants were instructed to blink as normal during the duration of the study and limit talking during EEG recording as prompted by the researcher. Next, 120 seconds of eyes-closed (EO) resting EEG was recorded, followed by 120 seconds of eyes-open (EO) resting EEG while standing in the free throw shot position with eyes fixated on their target (e.g., the back of the rim). This was done to establish a psychomotor baseline to be used during data analysis.

Task Instruction and 10-shot Familiarization Period

As participants were unfamiliar with the laboratory setting, they next performed ten free throw shots to familiarize with the experimental conditions. Before completing the 10 shots, the lead researcher instructed the shooting protocol to be used during the free throw task. The LED light signal was placed slightly to the left of the participant in eyesight. It was explained that when the red LED light turned on, the participant would turn and grab the ball from the cart. When the participant was set, the green light would then turn on signaling the beginning of a mental preparatory period, lasting 10-seconds. This was explained to the participant as a time to 'quiet the mind,' or often times in sports described as 'clear the mechanism.' The participant was instructed to shoot using his or her 'normal' free throw shooting routine when the purple light signaled. Additionally, the participant was instructed to maintain his or her spot on the free throw line for the duration of the study unless prompted to sit down to complete questionnaires. All researchers were positioned behind the participant during shooting trials. All shots were rebounded by the researchers at natural pauses throughout data collection that did not interfere with the participants' shooting trials. This limited movement by the participant throughout the duration of the study.

Pre-Test

After familiarization, participants completed the SSCI and SAS-2 in the context of the 25-shots they were about to take. They were directed back to the free throw line and told that they were being tested on their free throw performance directed to give their best effort at making as many shots as possible, given 25 shots. Participants proceeded by taking 25 free throw shots. Immediately after, participants completed the NASA-TLX and Conscious Motor Processing assessments, and asked to report how they felt about the 25 shots just completed.

Intervention

After pre-test, the experimental group was guided through the MI intervention. The participant watched an educational video about MI with details about how to effectively engage in mental imagery for sport and theoretical orientation as to why imagery is effective. The participant was then introduced to the MI script for a free throw shot used for the duration of the study. First, the lead researcher read the script aloud to the participant as he or she visualized along. Second, the participant was given five minutes to read the script him or herself. Third, the participant was told to stand holding a basketball at the free throw line and listened to a recording of the script while he or she visualized along with it once more. The control group read a basketball magazine for the duration of the intervention period. EEG was not recorded during intervention.

Post-Test

After control or MI intervention, participants completed the SSCI and SAS-2 in the context of the next 25-shots. All participants received the same instructions as used in the pre-test. They then completed 25 free throw shots. In the MI group, participants were paused after their 12th shot and engaged in visualization along with the MI script one additional time while standing at the free throw line holding the basketball. Once the free throw task was complete, participants completed the NASA-TLX and Conscious Motor Processing assessments, and asked to report how they felt about the 25 shots just completed. During the debrief period, participants were probed to determine whether they engaged in the MI as instructed, though the guided nature of the imagery acted as a manipulation check of the intervention.

Statistical Analysis

All statistical analyses were conducted using JASP (JASP Team, 2023) and SPSS 26 (SPSS, Chicago, IL). A series of mixed-design ANOVAs were conducted to examine behavioral and performance data and repeated-measures analyses of variance (rmANOVAs) were conducted to examine changes in EEG activity, including alpha power, fronto-midline theta power, mu power, and alpha coherence across conditions. Condition (Imagery vs. Control) was included as the only between-subjects factor.

Prior to hypothesis testing, all variables were assessed for normality, sphericity, and homogeneity of variances. Specifically, Mauchly’s test of sphericity was conducted for all within-subject factors with more than two levels. If the assumption of sphericity was violated, the Greenhouse-Geisser correction was applied, and adjusted degrees of freedom were reported. The Holm-Bonferroni correction method was employed to determine the significance for post-hoc comparisons of means. The *p*-values reported are based upon the corrected degrees of freedom. Effect sizes were reported using partial eta squared (η^2) and omega squared (ω^2) where appropriate.

To investigate the relationships between mental imagery, neural efficiency, confidence, anxiety, and performance, a Hayes PROCESS macro (Models 4 and 8) was employed for mediation and moderated-mediation analyses. Change scores were used for the moderated-mediation analyses to control for baseline differences in skill level. Directional changes, rather than absolute changes, were used. Change scores were calculated by subtracting baseline (pre-test) values from post-test values:

- Confidence: Post-test SSCI score – Pre-test SSCI score
- Anxiety: Post-test SAS-2 score – Pre-test SAS-2 score
- Alpha power: Post-test alpha power – Baseline EO (eyes open) alpha power

Therefore, in the models, positive beta values suggest that the predictor variable is associated with a greater percent change (i.e., larger increases or smaller decreases), while negative beta values indicate that the predictor is associated with a lower percent change (i.e., smaller increases or greater decreases, meaning more stability over time). Indirect effects were tested using 5,000 bootstrap resamples, with bias-corrected 95% confidence intervals (CIs). A significant mediation or moderated mediation was inferred if the bootstrap CI did not include zero.

All participants were included in the analyses of psychological and performance variables (N = 26). However, one participant's EEG data was excluded due to excessive artifacts and poor signal quality. As a result, this participant was also excluded from the mediation-moderation analysis, which required complete data across all variables, including EEG. Given the sample size of 25, the mediation-moderation analysis was conducted with bootstrapped confidence intervals to account for the small sample. However, results should be interpreted with caution due to the potential for limited statistical power. All statistical significance was set at $\alpha = 0.05$, and descriptive statistics were reported as means ± standard deviations (SDs) unless otherwise stated.

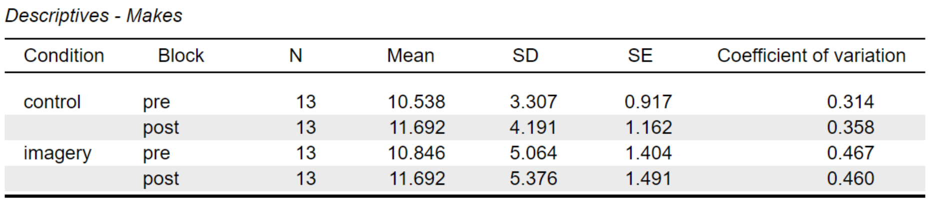
Chapter 5: Results

Behavioral Data

Performance: Successful Shots

The mean number of successful free throws across all conditions was 11.19 (SD = 4.45) or 45%. *Table 1.* provides the descriptive statistics categorized by Condition (Imagery vs. Control) and Time (Pre-test vs. Post-test). The number of successful shots varied widely across participants across conditions and time, with minor increases observed from pre-test to post-test for both groups. In both imagery and control groups, there was an increasing trend of successful makes from pre- to post-test (*Figure 5.*).

Table 1. Descriptive statistics for the number of successful free throws across condition (Imagery vs. Control) and time (Pre-test vs. Post-test).



Descriptives - Makes

Condition	Block	N	Mean	SD	SE	Coefficient of variation
control	pre	13	10.538	3.307	0.917	0.314
	post	13	11.692	4.191	1.162	0.358
imagery	pre	13	10.846	5.064	1.404	0.467
	post	13	11.692	5.376	1.491	0.460

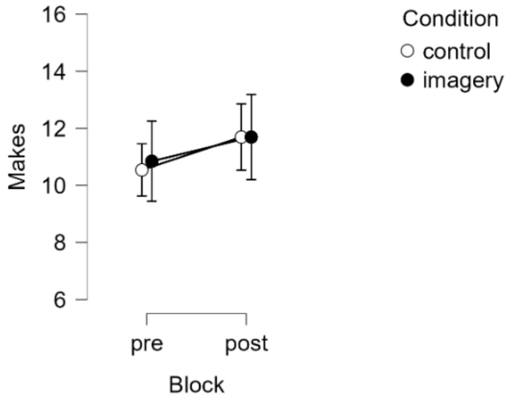


Figure 5. Trend of mean number of successful free throw attempts from pre-test to post-test across the imagery and control conditions. Error bars represent ±1 standard error of the mean (SEM). While both groups showed a slight increase in performance over time, no significant main effects or interactions were observed.

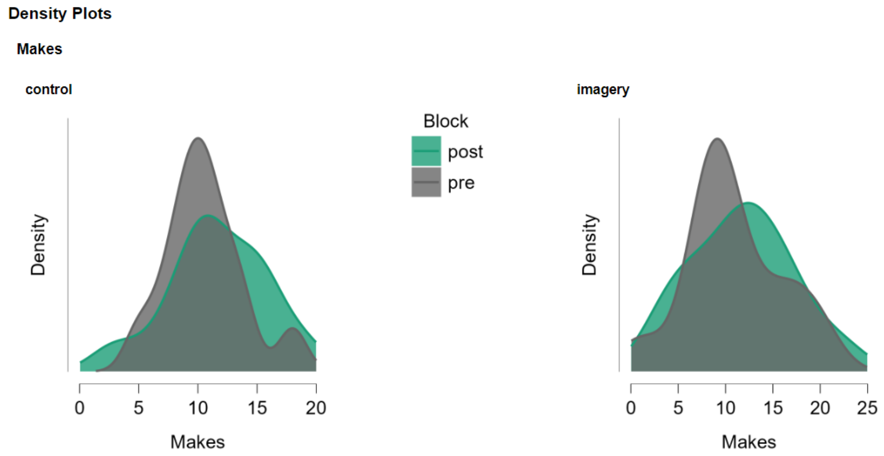


Figure 6. Density plots depicting the distribution of successful free throw attempts for the control (left) and imagery (right) groups across pre-test (gray) and post-test (green) conditions. While both groups show variability in performance, no systematic shift is observed, suggesting individual differences in response to the intervention.

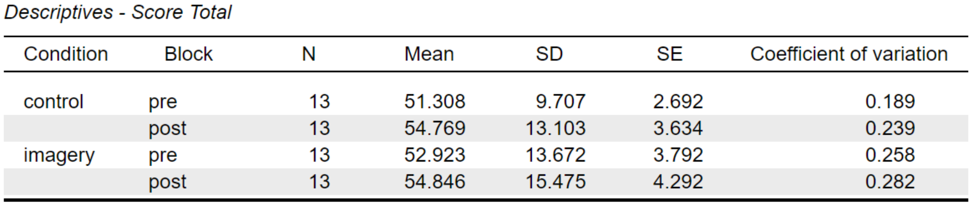
The density plots (*Figure 6.*) provide a visualization of the distribution of free throw makes across the pre-test and post-test blocks for both the control and imagery conditions. These plots offer insights into potential shifts in performance over time, as well as variability within each group. In both conditions, the distribution of free throw makes appears slightly different from pre-test to post-test. In the control group, the post-test distribution (green) appears to have a slightly wider spread, with some players improving but others staying around the same performance level. In the imagery group, post-test scores also show greater spread, suggesting some individuals improved, while others remained stable or even regressed. This increased variability in post-test scores suggests individual differences in response to the intervention, which could indicate that mental imagery had a differential effect across participants rather than a uniform benefit. Despite these observed changes in spread, statistical assumption testing confirmed that these differences did not violate the assumptions necessary for a valid ANOVA.

A 2x2 mixed-design ANOVA was conducted to examine the effects of Condition (between-subjects, Imagery vs. Control) and Time (within-subjects, Pre-test vs. Post-test) on the number of successful free throws. While successful shots increased in both the control and imagery conditions, and from pre- to post-test, the analysis revealed no significant main effects or interaction (*Figure 5.*). Specifically, the main effect of Condition was not significant, $F(1, 48) = 0.015$, $p = 0.904$, $\omega^2 = 0.000$, 95% CI [0.000, 0.000], indicating no overall difference in free throw performance between the imagery and control groups. Furthermore, there was no significant main effect of Time, $F(1, 48) = 0.626$, $p = 0.433$, $\omega^2 = 0.000$, 95% CI [0.000, 0.000], suggesting that free throw performance did not change significantly from pre-test to post-test regardless of the condition. Finally, contrary to expectations, the interaction between Condition and Time failed to achieve significance, $F(1, 48) = 0.015$, $p = 0.904$, $\omega^2 = 0.000$, 95% CI [0.000, 0.000], indicating that the change in performance over time did not differ between the two groups. All assumptions for the ANOVA were tested and met. Residuals were normally distributed (Shapiro-Wilk test, $p > 0.05$), and variances were homogeneous across groups (Levene's test, $p > 0.05$).

Performance: Quality of Shots

The highest performance score possible, indicating that a participant made every shot with a perfect "swish" every time, was 100. The lowest score possible was 0 indicating an airball every time. The mean free throw quality score (with higher scores indicating better shot quality) did not vary significantly between groups or across time. *Table 2.* provides the means and standard deviations for each Condition (Imagery vs. Control) and Time (Pre-test vs. Post-test).

Table 2. Descriptive statistics for free throw shot quality across condition (Imagery vs. Control) and time (Pre-test vs. Post-test).



Descriptives - Score Total

Condition	Block	N	Mean	SD	SE	Coefficient of variation
control	pre	13	51.308	9.707	2.692	0.189
	post	13	54.769	13.103	3.634	0.239
imagery	pre	13	52.923	13.672	3.792	0.258
	post	13	54.846	15.475	4.292	0.282

A 2x2 mixed-design ANOVA was conducted to examine the effects of Condition (between-subjects, Imagery vs. Control) and Time (within-subjects, Pre-test vs. Post-test) on free throw quality scores. While shot quality improved in both the control and imagery conditions, and from pre- to post-test, the analysis revealed no significance among the effects. There was no significant main effect of Condition, F(1,48) = 0.054, p = 0.818, ω2 = 0.000, 95% CI [0.000, 0.000], indicating no overall difference in shot quality between the imagery and control groups. Additionally, there was no significant main effect of Time, F(1,48) = 0.544, p = 0.464, ω2 = 0.000, 95% CI [0.000, 0.000], suggesting no improvement in shot quality from pre-test to post-test. Finally, the interaction between Condition and Time was not significant, F(1,48) = 0.044, p = 0.834, ω2 = 0.000, 95% CI [0.000, 0.000], indicating that changes in shot quality over time did not differ between the two groups. All assumptions for the ANOVA were met. Residuals were normally distributed (Shapiro-Wilk test, $p > 0.05$), and the variances were homogeneous across groups (Levene's test, $p > 0.05$).

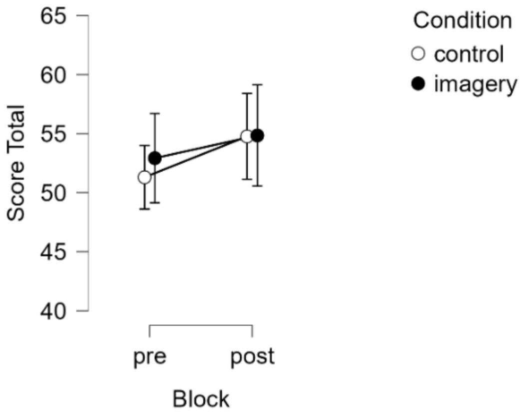
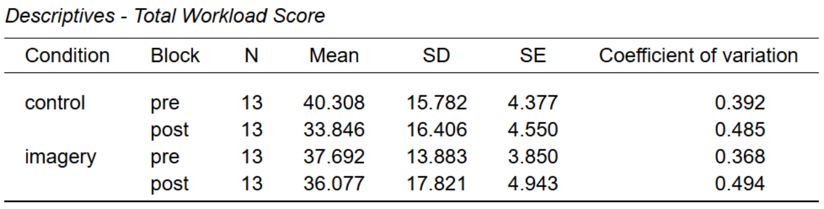


Figure 7. Trend of mean shot quality scores from pre-test to post-test across the imagery and control conditions. Error bars represent ±1 standard error of the mean (SEM). Both groups showed a slight increase in shot quality from pre-test to post-test, but no significant main effects or interactions were observed.

Cognitive Workload

Average workload score was calculated for each participant at pre- and post-test. Weighting of each dimension of workload was not used. Scores closer to 0 suggest a lower perceived workload (i.e., less demanding) and scores closer to 100 suggest a higher perceived workload (i.e., more demanding) (Hart & Staveland, 1988). Scores on the NASA-TLX, indicating a decrease in perceived cognitive workload, did not change significantly from pre-test to post-test for both the imagery and control groups. However, these reductions were not statistically significant. *Table 3.* provides the means and standard deviations for each group and block.

Table 3. Descriptive statistics for cognitive workload (NASA-TLX) across conditions and time.



Descriptives - Total Workload Score

Condition	Block	N	Mean	SD	SE	Coefficient of variation
control	pre	13	40.308	15.782	4.377	0.392
	post	13	33.846	16.406	4.550	0.485
imagery	pre	13	37.692	13.883	3.850	0.368
	post	13	36.077	17.821	4.943	0.494

A 2x2 mixed-design ANOVA was conducted to examine the effects of Condition (between-subjects, Imagery vs. Control) and Time (within-subjects, Pre-test vs. Post-test) on cognitive workload scores. The analysis revealed no significant main effect of Condition, F(1,48) = 0.02, p = 0.966, ω2 = 0.000, 95% CI [0.000, 0.000], indicating no overall difference in workload between the imagery and control groups. Additionally, the main effect of Time was not significant, F(1,48) = 0.825, p = 0.368, ω2 = 0.000, 95% CI [0.000, 0.000], suggesting no significant reduction in workload from pre-test to post-test. Finally, the interaction between Condition and Time failed to achieve significance, F(1,48) = 0.297, p = 0.588, ω2 = 0.000, 95% CI

[0.000, 0.000], indicating that changes in workload over time did not differ between the two groups. All assumptions for the ANOVA were met. Residuals were normally distributed (Shapiro-Wilk test, p > 0.05), variances were homogeneous across groups (Levene’s test, p > 0.05), and sphericity was not a concern for this two-level within-subjects factor.

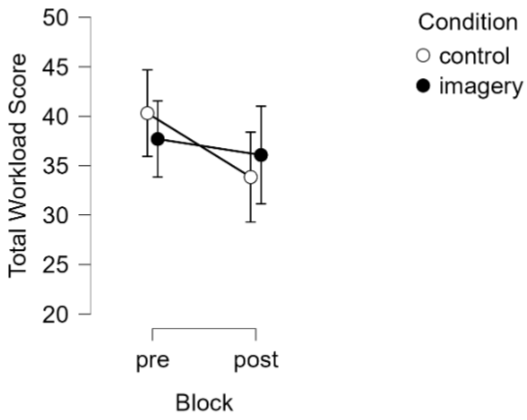
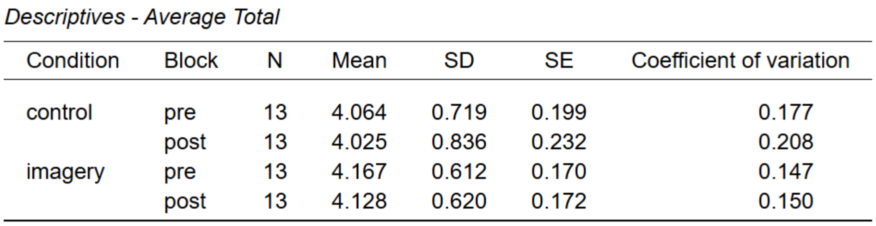


Figure 8. Trend of mean total cognitive workload (NASA-TLX scores) from pre-test to post-test across the imagery and control conditions. Error bars represent ±1 standard error of the mean (SEM). Both groups demonstrated a decrease in workload from pre-test to post-test, though no significant condition × time interaction was observed.

Conscious Motor Processing

An average score of five on the Conscious Motor Processing Inventory indicates high conscious processing, while a score of one indicates low conscious processing. The Conscious Motor Processing (CMP) scores ranged from approximately 4.01 to 4.18 across conditions and time, with minor changes observed from pre-test to post-test for both groups. ~~The control group exhibited a slight increase in scores, whereas the imagery group showed a slight decrease.~~ *Table 4*. provides the descriptive statistics, including means, standard deviations, and standard errors for each condition and time block.

Table 4. Descriptive statistics for Conscious Motor Processing Inventory scores across conditions and time.



Descriptives - Average Total

Condition	Block	N	Mean	SD	SE	Coefficient of variation
control	pre	13	4.064	0.719	0.199	0.177
	post	13	4.025	0.836	0.232	0.208
imagery	pre	13	4.167	0.612	0.170	0.147
	post	13	4.128	0.620	0.172	0.150

A 2x2 mixed-design ANOVA was conducted to examine the effects of Condition (between-subjects, Imagery vs. Control) and Time (within-subjects, Pre-test vs. Post-test) on CMP scores. The analysis revealed no significant main effect of Condition, F(1,48) = 0.278, p = 0.600, ω2 = 0.000, 95% CI [0.000, 0.000], indicating no overall difference in CMP scores between the imagery and control groups. Additionally, the main effect of Time was not significant, F(1,48) = 0.039, p = 0.844, ω2 = 0.000, 95% CI [0.000, 0.000], suggesting no significant change in CMP scores from pre-test to post-test. Finally, contrary to expectations, the Condition × Time interaction failed to achieve significance, F(1,48) = 0.000, p = 1.000, ω2 = 0.000, 95% CI [0.000, 0.000], indicating no differential change in CMP scores over time between the two groups. There was, however, a trend of lower CMP scores in both conditions (*Figure 9.*).

All assumptions for the ANOVA were tested. While the assumptions of homogeneity of variances (Levene's test, p > 0.05) and sphericity were met, the assumption of normality was violated (Shapiro-Wilk test, p < 0.001). Given this violation, the ANOVA results should be interpreted with caution. A non-parametric alternative (e.g., Wilcoxon Signed-Rank Test) yielded similar nonsignificant findings, supporting the robustness of these results.

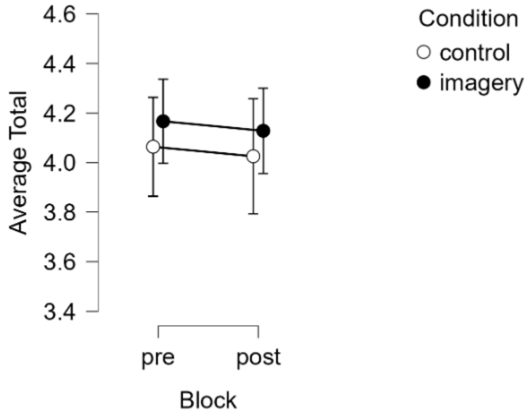
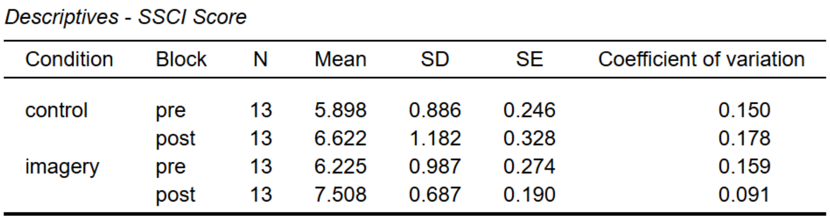


Figure 9. Trend of mean total conscious motor processing scores from pre-test to post-test for the imagery and control conditions. Error bars represent ±1 standard error of the mean (SEM). Both groups showed minimal changes over time, with no significant condition × time interaction observed.

Confidence

Confidence, as measured by the SSCI, ranged from one (low confidence) to nine (high confidence). Descriptive statistics for the control and imagery groups across pre-test and post-test blocks are shown in *Table 5*. At baseline (pre-test), confidence scores were comparable between the control group (M = 5.90, SD = 0.89) and the imagery group (M = 6.23, SD = 0.99). By the post-test, confidence scores increased for both groups, with a slightly more pronounced improvement in the imagery group (M = 7.51, SD = 0.69) compared to the control group (M = 6.62, SD = 1.18).

Table 5. Descriptive statistics for SSCI confidence scores across conditions and time.

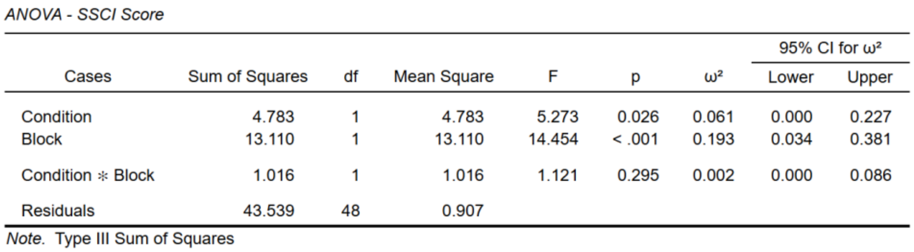


Descriptives - SSCI Score

Condition	Block	N	Mean	SD	SE	Coefficient of variation
control	pre	13	5.898	0.886	0.246	0.150
	post	13	6.622	1.182	0.328	0.178
imagery	pre	13	6.225	0.987	0.274	0.159
	post	13	7.508	0.687	0.190	0.091

A 2x2 mixed-design ANOVA was conducted to examine the effects of Condition (between-subjects, Imagery vs. Control) and Time (within-subjects, Pre-test vs. Post-test) on SSCI scores. The analysis revealed a significant main effect of Condition, F(1,48) = 5.27, p = 0.026, ω2 = 0.061, 95% CI [0.000, 0.227], indicating that the imagery group exhibited higher overall confidence compared to the control group. A significant main effect of Time was also found, F(1,48) = 14.45, p < 0.001, ω2 = 0.193, 95% CI [0.034, 0.381], with confidence scores increasing significantly from pre-test to post-test across both groups. However, the Condition × Time interaction failed to achieve significance, F(1,48) = 1.12, p = 0.295, ω2 = 0.002, 95% CI [0.000, 0.086], suggesting that the rate of improvement in confidence was similar for both groups over time. Refer to *Table 6.* for the ANOVA results and *Figure 10.* for illustration of the trends in confidence scores across the conditions and time points. The assumptions of homogeneity of variances (Levene's test, p > 0.05) and sphericity were met. However, the assumption of normality was violated (Shapiro-Wilk test, p = 0.027). Despite this violation, the ANOVA is robust to non-normality, particularly with equal group sizes, so the results are reported as is. A non-parametric alternative (e.g., Wilcoxon Signed-Rank Test) yielded consistent results.

Table 6. A 2 (condition) x 2 (time) ANOVA on SSCI scores.



ANOVA - SSCI Score

							95% CI for ω²	
Cases	Sum of Squares	df	Mean Square	F	p	ω²	Lower	Upper
Condition	4.783	1	4.783	5.273	0.026	0.061	0.000	0.227
Block	13.110	1	13.110	14.454	< .001	0.193	0.034	0.381
Condition ✻ Block	1.016	1	1.016	1.121	0.295	0.002	0.000	0.086
Residuals	43.539	48	0.907					

Note. Type III Sum of Squares

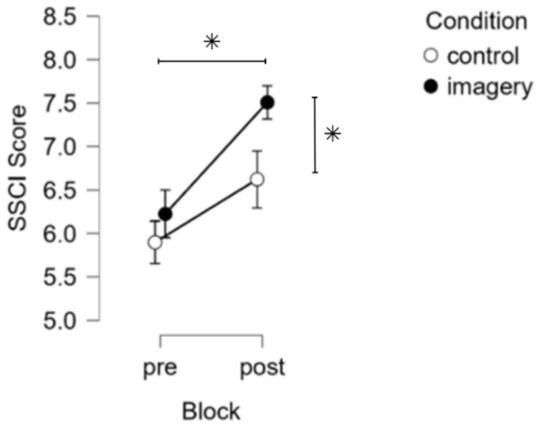
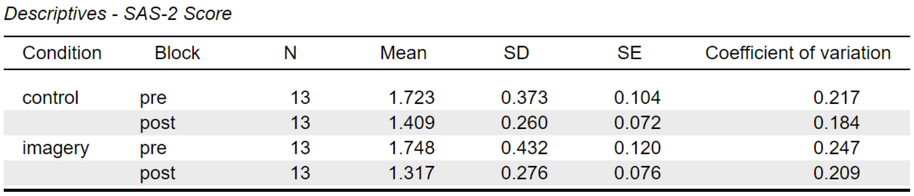


Figure 10. Mean Self-Confidence Scale for Sport (SSCI) scores from pre-test to post-test for the imagery and control conditions. Error bars represent ±1 standard error of the mean (SEM). Significant main effects of time and condition were observed. However, the interaction between time and condition was not significant, suggesting that both groups experienced similar rates of improvement in confidence over time.

State Anxiety

State anxiety, as measured by the SAS-2, ranges from one (low state anxiety) to four (high state anxiety). Descriptive statistics for the control and imagery groups across pre-test and post-test blocks are shown in *Table 7.* At baseline (pre-test), anxiety scores were comparable between the control group (M = 1.72, SD = 0.37) and the imagery group (M = 1.75, SD = 0.43). By the post-test, anxiety scores decreased for both groups.

Table 7. Descriptive statistics for SAS-2 state anxiety scores across conditions and time.



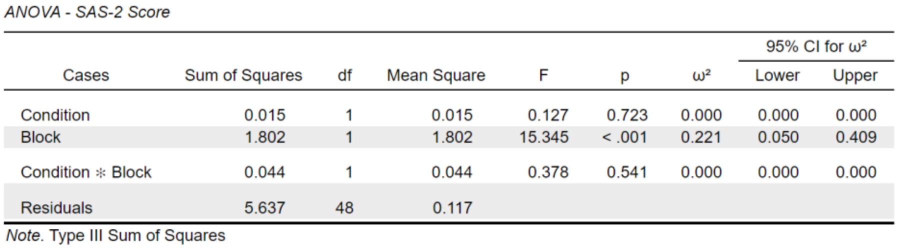
Descriptives - SAS-2 Score

Condition	Block	N	Mean	SD	SE	Coefficient of variation
control	pre	13	1.723	0.373	0.104	0.217
	post	13	1.409	0.260	0.072	0.184
imagery	pre	13	1.748	0.432	0.120	0.247
	post	13	1.317	0.276	0.076	0.209

A 2x2 mixed-design ANOVA was conducted to examine the effects of Condition (between-subjects, Imagery vs. Control) and Time (within-subjects, Pre-test vs. Post-test) on SAS-2 scores. The analysis revealed a significant main effect of Time, F(1,48) = 15.35, p < 0.001, ω2 = 0.221, 95% CI [0.000, 0.000], indicating a moderate-to-large effect (Cohen, 1988), where anxiety scores significantly decreased from pre-test to post-test across both groups (*Figure 11.*). However, the main effect of Condition was not significant, F(1,48) = 0.127, p = 0.723, ω2 = 0.000, 95% CI [0.050, 0.409], suggesting that overall anxiety levels did not differ between the imagery and control groups. Additionally, contrary to expectations, the Condition × Time interaction failed to achieve significance, F(1,48) = 0.378, p = 0.541, ω2 =

0.000, 95% CI [0.000, 0.000], indicating that the reductions in anxiety from pre-test to post-test were similar for both groups (*Table 8.*). The assumptions of homogeneity of variances (Levene's test, p > 0.05) and were met. However, the assumption of normality was violated (Shapiro-Wilk test, p < 0.001). Despite this violation, the ANOVA is considered robust to non-normality given the equal group sizes. A non-parametric alternative (e.g., Wilcoxon Signed-Rank Test) yielded consistent results, supporting the findings.

Table 8. A 2 (condition) x 2 (time) ANOVA on SAS-2 scores.



ANOVA - SAS-2 Score

							95% CI for ω²	
Cases	Sum of Squares	df	Mean Square	F	p	ω²	Lower	Upper
Condition	0.015	1	0.015	0.127	0.723	0.000	0.000	0.000
Block	1.802	1	1.802	15.345	< .001	0.221	0.050	0.409
Condition ✻ Block	0.044	1	0.044	0.378	0.541	0.000	0.000	0.000
Residuals	5.637	48	0.117					

Note. Type III Sum of Squares

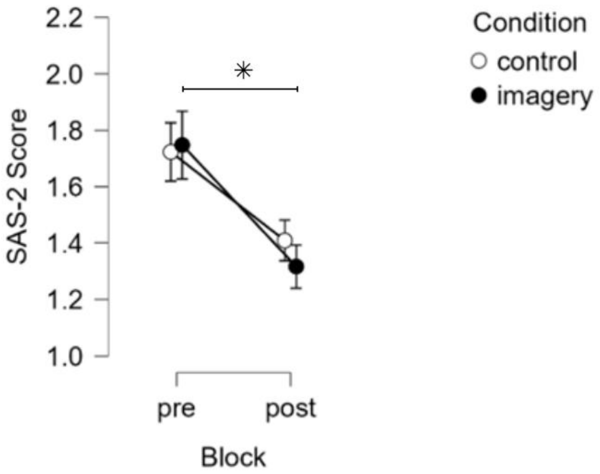


Figure 11. Mean SAS-2 scores for the control and imagery conditions at pre-test and post-test. Error bars represent ±1 standard error of the mean (SEM). Asterisk indicates a significant main effect of time (p < .05), showing a reduction in anxiety from pre-test to post-test across conditions.

<u>*Psychophysiological Data*</u>

Absolute Alpha Power

Due to the complexity of higher order interactions and difficulty in interpretation, a step-wise approach was taken when analyzing absolute alpha power to decrease the risk of Type I errors (false positives) due to multiple comparisons. To determine which within-subjects factors should be included in the final model, two separate 2 Time (within-subjects, Pre-test vs. Post-test) × 2 Hemisphere (within-subjects, Left vs. Right) × 5 Region (within-subjects, Frontal, Central, Temporal, Parietal, Occipital) × 5 Epoch (within-subjects, -5 to -1) repeated-measures ANOVAs were conducted separately for the Imagery and Control groups. When interpreting post hoc comparisons or simple effects, Holm-Bonferroni corrections were applied to control the family-wise error rate (FWER).

While this study tested higher-order interactions among EEG regions and time periods, the power analysis was based on detecting 2-way interactions of medium effect size. Therefore, the null results for higher-order interactions (e.g., Condition × Time × Region × Hemisphere × Epoch) should be interpreted with caution, as the study may not have been sufficiently powered to detect effects of this complexity.

In the Control group, a significant main effect of Region was observed, $F(4, 44) = 10.844$, $p < .001$, $\omega^2 = 0.166$, indicating that alpha power varied across cortical areas. Additionally, significant interactions emerged for Hemisphere × Epoch, $F(4, 44) = 6.902$, $p < .001$, $\omega^2 = 0.064$, Time × Region × Epoch, $F(16, 176) = 1.738$, $p = .043$, $\omega^2 = 0.009$, and Hemisphere × Region × Epoch, $F(16, 176) = 6.225$, $p < .001$, $\omega^2 = 0.092$, suggesting that alpha power variations were influenced by time, hemisphere, and epoch differently across regions. Though post-hoc tests did not reach statistical significance after correction, Parietal and Central regions tended to have the highest alpha power, while Temporal and Frontal regions showed lower values. Post-hoc comparisons also identified a slight decreasing trend in Left hemispheric alpha from epoch -4 to -1 ($t(96) = -2.22$, $pHolm = 1.000$). Left and right hemispheric alpha also reflected a fairly stable opposing pattern (i.e., when left increased, right decreased and vice versa) in all regions except occipital along epochs -5 to -1 leading to motor execution.

In the Imagery group, significant main effects of Hemisphere, $F(1, 12) = 7.487$, $p = 0.018$, $\omega^2 = 0.039$, and Region, $F(4, 48) = 9.095$, $p < .001$, $\omega^2 = 0.122$, were observed indicating that alpha power varied across hemispheres and regions. Post-hoc comparisons confirmed that alpha power was greater in the left hemisphere compared to right hemisphere and greater in parietal compared to all other regions. Additionally, significant interactions were found for Hemisphere × Epoch, $F(4, 48) = 5.643$, $p = 0.003$, $\omega^2 = 0.080$, and Hemisphere × Region × Epoch, $F(16, 192) = 3.468$, $p < .001$, $\omega^2 = 0.056$, suggesting that hemisphere-specific changes in alpha power varied across epochs and regions. Although the interaction between Hemisphere, Region, and Epoch was significant in the omnibus test, individual differences between specific hemisphere-region-epoch pairs were not strong enough to survive multiple comparison correction. There were trends suggesting that differences between the left and right hemisphere may fluctuate at specific epochs, but none were powerful enough to draw firm conclusions. However, the results from the two simplified models suggests that regardless of treatment and regardless of time, a logical activation of cortical dynamics occurred.

Given these results, all significant main effects and interactions were retained in the final 2 Condition (between-subjects, Imagery vs. Control × 2 Time (within-subjects, Pre-test vs. Post-test) × 2 Hemisphere (within-subjects, Left vs. Right) × 5 Region (within-subjects, Frontal, Temporal, Central, Parietal, Occipital) × 5 Epoch (within-subjects, -5 to -1) mixed-model ANOVA to test for between-group differences and potential interactions with Condition. Mauchly’s test of sphericity was conducted for all factors with more than two levels. The assumption of sphericity was violated for the main effect of Epoch ($p < .001$) and the Hemisphere × Epoch interaction ($p < .001$). Therefore, Greenhouse-Geisser corrections were applied for these effects.

Main Effects. Using the final model, a significant main effect of Region was found, $F(3.005, 69.122) = 3.283$, $p = 0.015$, $\eta^2\omega = 0.027$, indicating differences in absolute alpha power across cortical regions. A significant main effect of Hemisphere emerged, $F(1, 23) = 27.567$, $p < 0.001$, $\eta^2\omega = 0.070$, suggesting that alpha power was distributed differently between the left and right hemispheres. There was also a significant main effect of Epoch, $F(4, 92) = 18.614$, $p < 0.001$, $\eta^2\omega = 0.144$ (*Greenhouse-Geisser corrected*), indicating that alpha power varied systematically across time points leading up to movement execution. No significant interactions involving Condition were found, indicating that mental imagery did not differentially affect alpha power across time, hemisphere, epoch, or region.

Interaction Effects. A significant Hemisphere × Epoch interaction was observed, $F(4, 92) = 12.096$, $p < 0.001$, $\eta^2\omega = 0.084$ (*Greenhouse-Geisser corrected)*, suggesting that changes in absolute alpha power over epochs were dependent on hemisphere. All other main effects and interactions were non-significant ($p > .05$) and were not further explored.

Post-hoc Comparisons. Post-hoc comparison for the significant main effect of Region revealed that alpha power significantly differed between cortical areas. Alpha power was significantly higher in the parietal region compared to the frontal region ($t = -2.851$, $pHolm = 0.081$, $d = -0.267$, 95% CI [-0.583, 0.048]). Alpha power was significantly higher in the parietal region compared to the temporal region ($t = -2.962$, $pHolm = 0.395$, $d = -0.256$, 95% CI [-0.549, 0.037]) (*Figure 12*.). These findings suggest that alpha power suppression was strongest in the parietal region, which aligns with literature indicating greater sensorimotor processing demands in this area. However, while these differences were notable, they did not reach statistical significance after correcting for multiple comparisons.

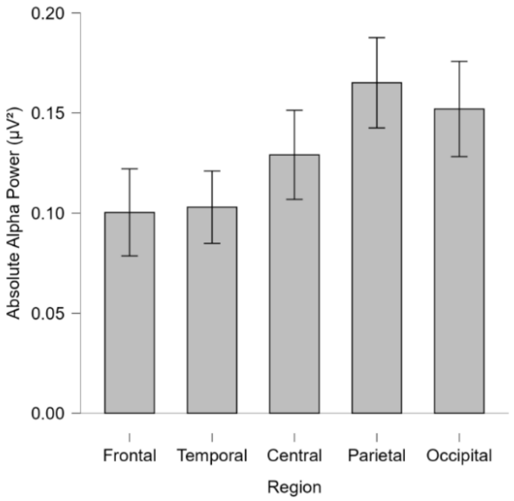


Figure 12. Trend of mean alpha power (µV²) across five brain regions (Frontal, Temporal, Central, Parietal, Occipital). Error bars represent standard error of the mean (SEM). Asterisks indicate significant pairwise comparisons between regions (p < .05, corrected).

A post-hoc comparison for the main effect of Hemisphere indicated that alpha power was significantly greater in the left hemisphere compared to the right (t = 5.250, *pHolm* < .001, d = 0.260, 95% CI [0.131, 0.390]). This finding suggests hemispheric asymmetry in alpha power, indicating greater inhibition in the left hemisphere, potentially reflecting greater neural engagement in movement preparation. The effect size of d = 0.260 suggests a small to moderate effect.

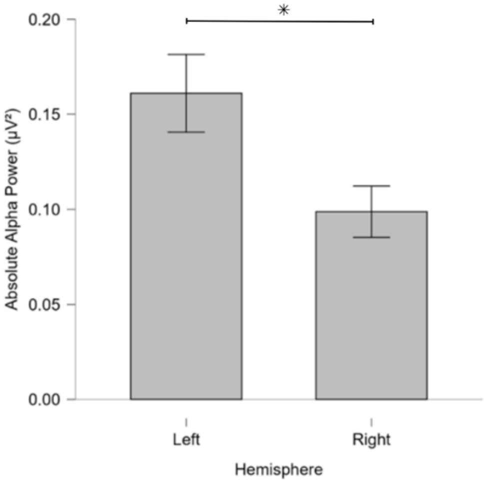


*Figure 13. Mean alpha power (µV²) for the left and right hemispheres. Error bars represent ± standard error of the mean (SEM). A significant main effect of hemisphere was observed (**p** < .001, **d** = 0.260), with alpha power significantly greater in the left hemisphere compared to the right hemisphere.*

A post-hoc comparison for Epoch indicated a significant increase in alpha power at -2s relative to earlier time points (-5s, -4s, -3s, all $p < .001$, d > 0.2). Alpha power then dropped significantly from -2s to -1s ($p = .002$, $d = 0.423$), indicating a preparatory desynchronization of alpha leading into movement execution.

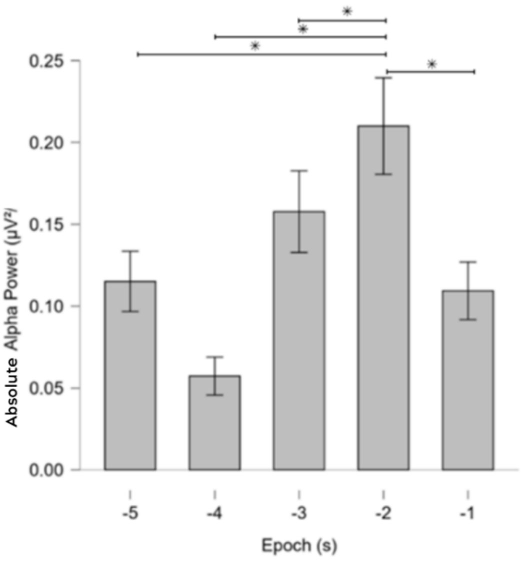


Figure 14. Mean alpha power (μV²) across epochs (-5 to -1 seconds) during movement preparation. Error bars represent ± standard error of the mean (SEM). A significant main effect of epoch was observed ($p < .001$, $\eta^2\omega = 0.144$), with alpha power peaking at -2 seconds before movement execution.

Post-hoc comparisons were conducted to examine the significant Hemisphere × Epoch interaction, using Bonferroni-adjusted p-values to control for multiple comparisons. The analysis revealed several notable findings. As expected, alpha power was significantly higher in the left hemisphere than in the right hemisphere at multiple time points preceding movement execution, consistent with the literature in EEG and motor behavior. Specifically, left hemisphere alpha power was significantly greater than right hemisphere alpha power at Epoch -4 ($p < .001$, $d = 0.714$), Epoch -3 ($p < .001$, $d = 0.766$), and Epoch -2 ($p < .001$, $d = 0.448$). At these time points, the left hemisphere exhibited stronger alpha activity, suggesting greater cortical inhibition or disengagement relative to the right hemisphere. Within-hemisphere comparisons further revealed that left hemisphere alpha power exhibited a significant increase from Epoch -5 to Epoch -2 ($p < .001$, $d = 0.448$) before declining significantly at Epoch -1 ($p = .002$, $d = 0.214$). A similar pattern was observed in the right hemisphere, where alpha power peaked at Epoch -2 and then decreased at Epoch -1 ($p = .008$, $d = 0.386$).

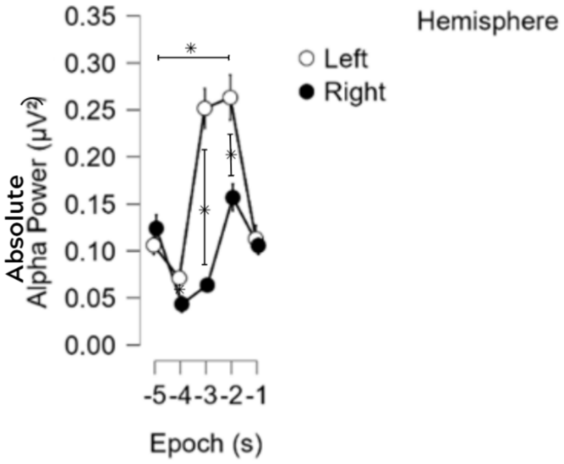


Figure 15. Hemisphere x epoch interaction demonstrating hemispheric changes in neural activity across epoch leading to motor execution differing in left and right hemispheres. Error bars represent ± standard error of the mean (SEM).

Fronto-midline Theta

A 2 Condition (between-subjects, Imagery vs. Control) × 2 Time (within-subjects, Pre-test vs. Post-test) × 3 Site (within-subjects, Fz, Cz, Pz) × 5 Epoch (within-subjects, -5 to -1) mixed-model ANOVA was conducted to examine differences in fronto-midline theta (fmTheta) power.

Main Effects. Contrary to expectations, the main effect of Condition failed to achieve significance, $F(1, 23) = 0.709$, $p = 0.409$, $\eta^2\omega = 0.000$, indicating no overall difference in fmTheta power between the groups. The main effect of Time was not significant, $F(1, 23) = 0.183$, $p = 0.673$, $\eta^2\omega = 0.000$, therefore there was no overall difference in fmTheta power between pre- and post-testing sessions. The main effect of Epoch was significant, $F(4, 92) = 3.450$, $p = 0.011$, $\eta^2\omega = 0.028$, indicating that fmTheta power significantly varied across epochs, suggesting temporal fluctuations in neural activity. The main effect of Site was significant, $F(2, 46) = 5.865$, $p = 0.005$, $\eta^2\omega = 0.021$, indicating fmTheta power differed across electrode sites (Fz, Cz, Pz), suggesting spatial variations in theta activity.

Two- Way Interactions. Contrary to expectations, the Condition × Time interaction was not significant, $F(1, 23) = 1.040$, $p = 0.318$, $\eta^2\omega = 0.000$, indicating the change in fmTheta power from pre- to post- did not differ between the control and imagery groups. The Condition × Epoch interaction was not significant, $F(4, 92) = 0.306$, $p = 0.873$, $\eta^2\omega = 0.000$, indicating the way fmTheta power changed across epochs was similar for both control and imagery groups. The Condition × Site interaction was not significant, $F(2, 46) = 0.123$, $p = 0.885$, $\eta^2\omega = 0.000$, indicating the differences in fmTheta power across electrode sites were not condition-dependent. The Time × Epoch interaction was not significant, $F(4, 92) = 2.253$, $p = 0.069$, $\eta^2\omega = 0.018$. The

Time × Site interaction was not significant, *F*(2, 46) = 1.309, *p* = 0.280, η²ω = 0.002, indicating the change in fmTheta power over time was not significantly different across electrode sites. The Site × Epoch interaction was not significant, *F*(8, 184) = 1.906, *p* = 0.061, η²ω = 0.008, indicating that site-dependent changes in fmTheta power across epochs were not significant.

Three- and Four-Way Interactions. The Condition × Time × Epoch interaction was not significant, *F*(4, 92) = 0.882, *p* = 0.478, η²ω = 0.000, indicating that the manner in which time and epoch influenced fmTheta power was not different between control and imagery. The Condition × Time × Site interaction was not significant, *F*(2, 46) = 1.807, *p* = .0176, η²ω = 0.005, indicating that the manner in which time and site influenced fmTheta power was not different between control and imagery. The Condition × Site × Epoch interaction was not significant, *F*(8, 184) = 0.898, *p* = 0.519, η²ω = 0.000, indicating that changes in fmTheta power across epochs and sites were not influenced by condition. The Time × Site × Epoch interaction was not significant, *F*(8, 184) = 1.374, *p* = 0.244, η²ω = 0.003, indicating that the combination of time, epoch, and site did not significantly impact fmTheta power. The Condition × Time × Site × Epoch interaction was not significant, *F*(8, 184) = 1.227, *p* = 0.285, η²ω = 0.002, indicating that the full combination of all four factors did not produce a significant effect.

Post-hoc Comparisons. Post hoc tests for the main effect of site indicated that fmTheta power was significantly greater at Pz compared to Fz, *p* = .023, while no significant differences were found between Fz and Cz (*p* = 0.087) or Cz and Pz (*p* = 0.825). Therefore, fmTheta power was strongest at Pz, moderate at Cz, and lowest at Fz across groups and time (*Figure 16.*). Post hoc tests for the Epoch effect did not reveal significant pairwise differences after Bonferroni correction (*p*s > .05), but the overall trend suggests fmTheta increased from epoch -5 to epoch -1 (*Figure 17.*).

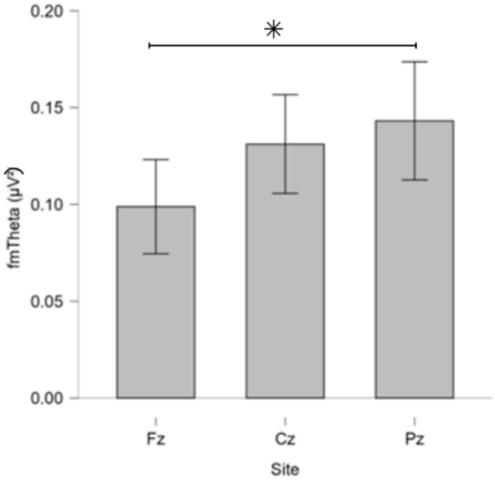


Figure 16. Mean fronto-midline theta (fmTheta) power (µV²) at electrode sites Fz, Cz, and Pz. Error bars represent standard error of the mean (SEM). Asterisk indicates a significant difference between Fz and Pz (p < .05, corrected).

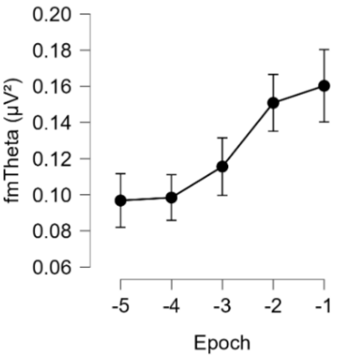


Figure 17. Mean fronto-midline theta (fmTheta) power (µV²) across epochs (-5 to -1 seconds) during movement preparation. Error bars represent ± standard error of the mean (SEM). A significant main effect of epoch was observed (p = 0.011), indicating temporal fluctuations in neural activity. However, post hoc pairwise comparisons did not reach significance after Bonferroni correction (p > .05), suggesting that while fmTheta showed an increasing trend leading up to movement execution, specific time points did not significantly differ from each other.

Mu Rhythm

A 2 Condition (between-subjects, Imagery vs. Control) × 2 Time (within-subjects, Pre-test vs. Post-test) × 5 Epochs (within-subjects, -5 to -1) mixed-model ANOVA was conducted to examine the effects of mental imagery on mu absolute power.

Main Effects. The main effect of Time was not significant, *F*(1, 23) = 0.050, *p* = 0.825, $\eta^2\omega = 0.000$, indicating that overall mu power did not significantly differ between pre-test and post-test. The main effect of Epoch was not significant, *F*(4, 92) = 1.819, *p* = 0.132, $\eta^2\omega = 0.013$, suggesting that mu power did not significantly change across the five 1-second bins leading up to motor execution. The effect of Condition was not significant, *F*(1, 23) = 2.011, *p* = 0.170, $\eta^2\omega = 0.021$, indicating no overall difference in mu power between the control and imagery groups.

Two-Way Interactions. The Condition × Time interaction was not significant, *F*(1, 23) = 1.908, *p* = 0.180, $\eta^2\omega = 0.014$, indicating that changes in mu power over time did not differ between the control and imagery groups. The Condition × Epoch interaction was not significant, *F*(4, 92) = 1.993, *p* = 0.102, $\eta^2\omega = 0.016$, suggesting that mu power changes across epochs were not different between groups. The Time × Epoch interaction was not significant, *F*(4, 92) = 0.238, *p* = 0.916, $\eta^2\omega = 0.000$, indicating no interaction between time and specific epochs.

Three-Way Interaction. Contrary to expectations, the Condition × Time × Epoch interaction was not significant, *F*(4, 92) = 1.299, *p* = 0.276, $\eta^2\omega = 0.005$, suggesting that changes in mu power over epochs and time did not depend on condition.

Although the repeated-measures ANOVA did not yield statistically significant effects, examination of descriptive statistics and trends suggests potential differences in mu absolute power between the imagery and control groups across epochs.

Alpha Fz-T7 and Fz-T8 Coherence

A 2 Condition (between-subjects, Imagery vs. Control) × 2 Time (within-subjects, Pre vs. Post) × 2 Region (within-subjects, Fz-T7 vs. Fz-T8) × 5 Epoch (within-subjects, -5 to -1) mixed-model ANOVA was conducted to examine differences in alpha-band coherence.

Main Effects. The main effect of Time was significant, $F(1, 24) = 16.236$, $p < 0.001$, $\eta^2\omega = 0.102$, indicating that alpha coherence significantly changed from pre-test to post-test. The main effect of Region was not significant, $F(1, 24) = 2.887$, $p = 0.102$, $\eta^2\omega = 0.025$, suggesting no strong evidence that alpha coherence differed between the Fz-T7 or Fz-T8. The main effect of Epoch was not significant, $F(4, 96) = 0.783$, $p = 0.539$, $\eta^2\omega = 0.000$, indicating that alpha coherence did not systematically change across the five epochs. The effect of Condition was not significant, $F(1, 24) = 0.648$, $p = 0.429$, $\eta^2\omega = 0.000$, suggesting that overall alpha coherence did not differ between the control and imagery groups.

A post hoc comparison confirmed that alpha coherence significantly decreased from pre-test to post-test, $t(24) = 4.029$, $p < 0.001$, $d = 0.238$. The mean difference was -0.031, 95% CI [-0.046, -0.015], indicating that alpha coherence was lower in the post-test compared to pre-test across conditions, regions, and epochs. This effect was small to moderate in magnitude and supports established expectations of cortical dynamics before motor execution (see *Figure 18.*) (Busk & Galbraith, 1975).

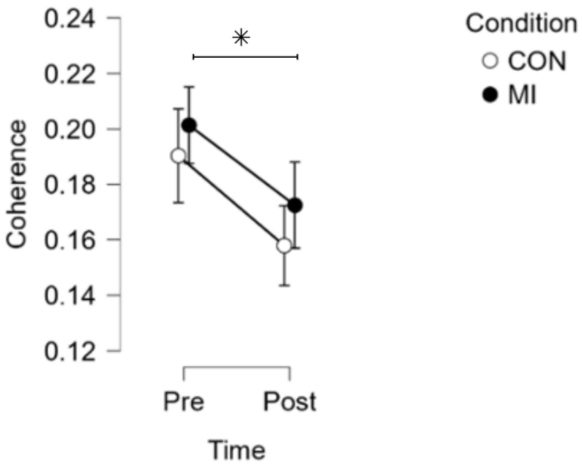


Figure 18. Mean alpha coherence from pre-test to post-test for the imagery and control conditions. Error bars represent ±1 standard error of the mean (SEM). A significant main effect of time (p < .001) was observed, indicating that alpha coherence decreased from pre-test to post-test across both groups., collapsed across region (Fz-T7 & Fz-T8) and epochs indicating main effect of time.

Two-Way Interactions. The Condition × Time interaction was not significant, $F(1, 24) = 0.055$, $p = 0.817$, $\eta^2\omega = 0.000$, indicating that changes in alpha coherence from pre- to post-test were similar between the control and imagery groups. The Condition

× Region interaction was not significant, *F*(1, 24) = 0.100, *p* = 0.755, η²ω = 0.000, indicating that alpha coherence differences across brain regions were similar between groups. The Condition × Epoch interaction was not significant, *F*(4, 96) = 0.427, *p* = 0.789, η²ω = 0.000, suggesting that alpha coherence changes across epochs did not depend on condition. The Time × Region interaction was not significant, *F*(1, 24) = 2.100, *p* = 0.160, η²ω = 0.017, meaning the change in alpha coherence over time was not different between the two regions. The Time × Epoch interaction was not significant, *F*(4, 96) = 0.464, *p* = 0.762, η²ω = 0.000, indicating that alpha coherence over epochs did not vary significantly by time. The Region × Epoch interaction was also not significant, *F*(4, 96) = 0.333, *p* = 0.855, η²ω = 0.000.

Three- and Four-Way Interactions. The Condition × Time × Region interaction was not significant, *F*(1, 24) = 3.998, *p* = 0.057, η²ω = 0.044, suggesting a trend toward significance, but not enough evidence to conclude that the effect of time on region depended on condition. The Condition × Time × Epoch interaction was not significant, *F*(4, 96) = 0.728, *p* = 0.575, η²ω = 0.000. The Condition × Region × Epoch interaction was not significant, *F*(4, 96) = 2.147, *p* = 0.081, η²ω = 0.031, showing a trend toward significance, suggesting potential differences in how alpha coherence changed across epochs depending on region and condition, but it did not reach statistical significance. The Time × Region × Epoch interaction was not significant, *F*(4, 96) = 0.557, *p* = 0.695, η²ω = 0.000. The Condition × Time × Region × Epoch interaction was not significant, *F*(4, 96) = 0.709, *p* = 0.588, η²ω = 0.000.

Post-hoc Comparisons.

Exploratory post-hoc analyses of the Condition × Time × Region interaction did not reveal any statistically significant effects following correction for multiple comparisons (Bonferroni and Holm) (*p*s > 0.05). However, numerical trends indicated that, contrary to our hypothesis, coherence in the imagery group increased from pre-test to post-test, particularly at the Fz-T8 region (*d* = 0.513 before correction). Meanwhile, coherence in the control group showed a slight decline over time. Given that these effects were not statistically significant, they should be interpreted cautiously. Future studies with larger sample sizes and additional functional connectivity measures may help clarify whether mental imagery differentially affects alpha coherence across brain regions.

Post hoc comparisons for the Condition × Region × Epoch interaction did not reveal any statistically significant differences (*pHolm* > .05). However, exploratory trends suggested that coherence at Fz-T7 was slightly higher in the imagery group compared to control at later epochs (-2 to -1), while coherence at Fz-T8 showed a slight decrease in the imagery group relative to control at earlier epochs (-3 to -2). These effects, though small to moderate in magnitude (*d* = 0.306 at Epoch -1, *d* = -0.253 at Epoch -3), did not reach statistical significance and should be interpreted cautiously. Again, future studies with larger sample sizes may clarify whether these trends reflect meaningful differences in interregional connectivity during mental imagery.

Moderated-Mediation Analyses

Despite the lack of a significant main effect between mental imagery and performance (i.e., the primary path) in the following mediation analyses, a decision was made to analyze these pathways for exploration of partial mediation.

Mediation: Neural Efficiency

A mediation analysis was conducted using Hayes PROCESS Model 4 to examine whether Neural Efficiency mediates the relationship between Mental Imagery Condition (X) and Performance (Y). The analysis was conducted using 5,000 bootstrap samples and a 95% confidence interval. Results indicated that Condition did not significantly predict Neural Efficiency, *b* = 100.3003, *t* = 1.1978, *p* = 0.242, nor did Condition significantly predict Performance, *b* = -0.1205, *t* = -0.2954, *p* = 0.839. Furthermore, Neural Efficiency did not significantly predict Performance, *b* = -0.5404, *t* = -0.1339, *p* = 0.748. The indirect effect of Condition on performance via Neural Efficiency was not significant (BootCI [-2.2071, 1.6007]), indicating that neural efficiency does not mediate the relationship between condition and performance. These results suggest that mental imagery does not significantly influence neural efficiency, nor does neural efficiency explain variance in performance outcomes in this dataset.

Mediation: Confidence

A mediation analysis was conducted using Hayes PROCESS Model 4 to examine whether Confidence mediates the relationship between Mental Imagery Condition (X) and Performance (Y). The analysis was conducted using 5,000 bootstrap samples and a 95% confidence interval. Results indicated that Mental Imagery significantly predicted Confidence, b = 0.5750, t = 2.3884, p = 0.025, but Confidence did not significantly predict Performance, b = -1.7912, t = -1.3499, p = 0.191. Additionally, Mental Imagery did not significantly predict Performance, b = -0.7094, t = -0.4142, p = 0.683. The indirect effect of Mental Imagery on Performance via Confidence was also not significant (BootCI [-3.7442, 1.0880]), indicating that confidence did not mediate the relationship between mental imagery and performance. These results suggest that while mental imagery increased confidence, this increase in confidence did not translate to improved performance.

Mediation: Anxiety

A mediation analysis was conducted using Hayes PROCESS Model 4 to examine whether Anxiety mediates the relationship between Mental Imagery Condition (X) and Performance (Y). The analysis was conducted using 5,000 bootstrap samples and a 95% confidence interval. Results indicated that Mental Imagery did not significantly predict Anxiety, *b* = -0.1074, *t* = -0.8594, *p* = 0.399. Similarly, Anxiety did not significantly predict Performance, *b* = 1.6922, *t* = 0.6419, *p* = 0.526. Additionally, Mental Imagery did not significantly predict performance, *b*

= -0.1387, *t* = -0.0864, *p* = 0.931. The indirect effect of Mental Imagery on Performance via Anxiety was not significant (BootCI [-1.9945, 0.3418]), indicating that anxiety did not mediate the relationship between mental imagery and performance. These findings suggest that mental imagery does not significantly influence anxiety, nor does anxiety play a mediating role in the relationship between mental imagery and performance.

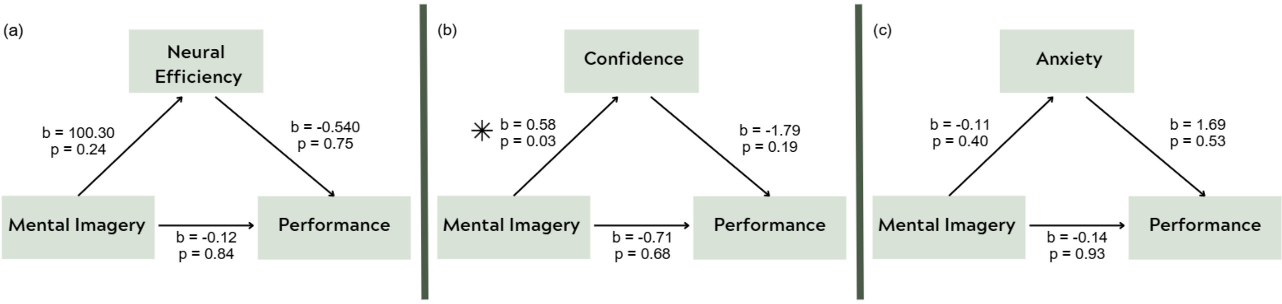


Figure 19. Mediation Analyses for (a) Neural Efficiency, (b) Confidence, and (c) Anxiety as mediators between Mental Imagery and Performance.

Moderated-Mediation: Confidence

A moderated mediation analysis was conducted using Hayes' PROCESS Model 8 to examine whether Neural Efficiency mediates the relationship between Mental Imagery Condition (X) and Performance (Y), and whether this mediation is moderated by Confidence (W). The model predicting Performance was not significant (F(4, 20) = 2.62, p = 0.0658), meaning that while individual paths may show significant effects, the full model does not explain a meaningful amount of variance in performance. Neither Mental Imagery (b = 0.3343, t = -1.2766, p = 0.216) nor Neural Efficiency (b = -0.0542, t = -1.4037, p = 0.164) significantly predicted Performance. However, as the results were trending towards significance with this small sample size, the information on model coefficients is reported as follows. Results indicated that Mental Imagery did not significantly predict Neural Efficiency (b = -26.3153, t = -1.166, p = 0.259), and the interaction between Mental Imagery and Confidence was also not significant (b = 33.7153, t = 2.286, p = 0.815), suggesting confidence did not moderate the effect of mental imagery on neural efficiency. There was no predictive effect of Mental imagery Condition (*b* = 0.3343, t = -1.28, *p* = 0.216) nor Neural Efficiency (b = 0.0054, t = 1.45, p = 0.1628) on performance. There was, however, a significant predictive effect of Confidence (*b* = -6.27, t = -3.16, *p* = 0.0049), which suggests that for each 1 unit increase in Confidence change score, percent of change in Performance is expected to decrease by 6.27% (i.e., more confidence is associated with less fluctuation in performance, meaning performance remains more stable). The interaction between Mental Imagery and Confidence was also significant (b = 5.7408, t = 2.3702, p = 0.0279), indicating that confidence positively moderated the relationship between mental imagery and performance. Simple slopes analysis revealed that Mental Imagery was positively associated with Performance only at high levels of Confidence (b = 1.6177, t = 2.3190, p = 0.047, 95% CI [0.033, 3.805]), but not at low or moderate levels. Thus, participants in the Imagery Condition with high levels of Confidence had higher positive change in performance levels than Control participants with high levels of confidence.

The indirect effect of Mental Imagery on Performance via Neural Efficiency was not significant at any level of confidence (all BootCIs included zero). These findings suggest that neural efficiency does not mediate the relationship between mental imagery and performance, but confidence plays a moderating role, such that mental imagery is associated with improved performance only when confidence is high.

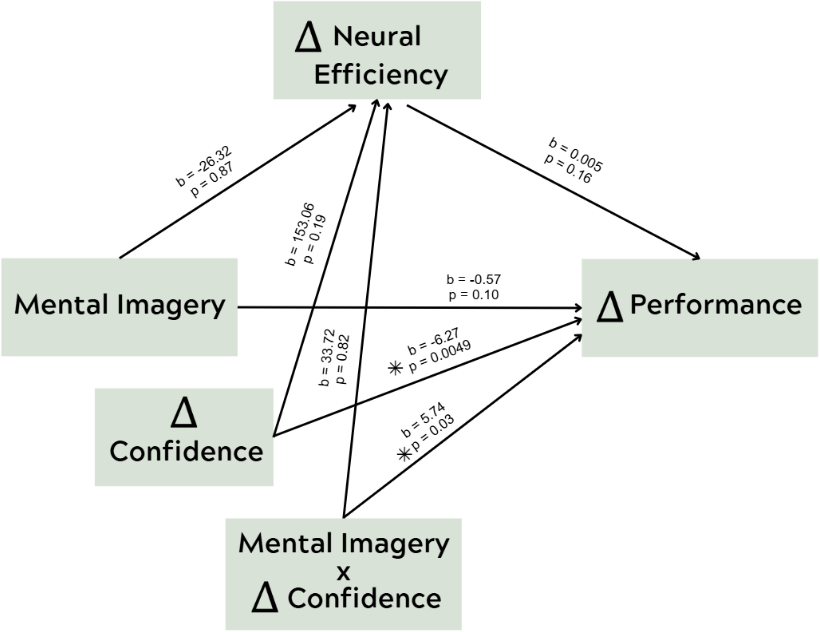


Figure 20. Moderated-Mediation Analyses with variables Neural Efficiency (M), Mental Imagery Condition (X), Performance (Y), and Confidence (W).

Moderated-Mediation: Anxiety

A moderated mediation analysis was conducted using Hayes’ PROCESS Model 8 to examine whether Neural Efficiency mediates the relationship between Mental Imagery condition (X) and Performance (Y), while Anxiety moderates the effect of Condition on Neural Efficiency. Results indicated that the interaction between Condition and Anxiety did not significantly predict Neural Efficiency, $b = 81.6308$, $t = 0.2685$, $p = 0.7909$, suggesting no significant moderation effect. Additionally, Condition did not significantly predict Neural Efficiency, $b = 133.2446$, $t = 0.902$, $p = 0.3761$, nor did Anxiety significantly predict Neural Efficiency, $b = -59.7543$, $t = -0.2783$, $p = 0.7835$. When predicting Performance, neither Anxiety ($b = 1.7105$, $t = 0.4404$, $p = 0.6644$) nor Neural Efficiency ($b = -0.0022$, $t = -0.5507$, $p = 0.5880$ were significant predictors. The direct effect of Condition on Performance was also not significant, $b = -0.3437$, $t = -0.1267$, $p = 0.9004$. The index of moderated mediation was not significant, $b = 0.1771$, BootCI[−0.9513, 3.2972], indicating that the mediation of neural efficiency between mental imagery and performance was not conditional on anxiety levels. These results suggest that anxiety does not moderate the effect of mental imagery on neural efficiency, and neural efficiency does not mediate the relationship between mental imagery and performance. In this model, neither anxiety nor neural efficiency significantly explained variance in performance outcomes.

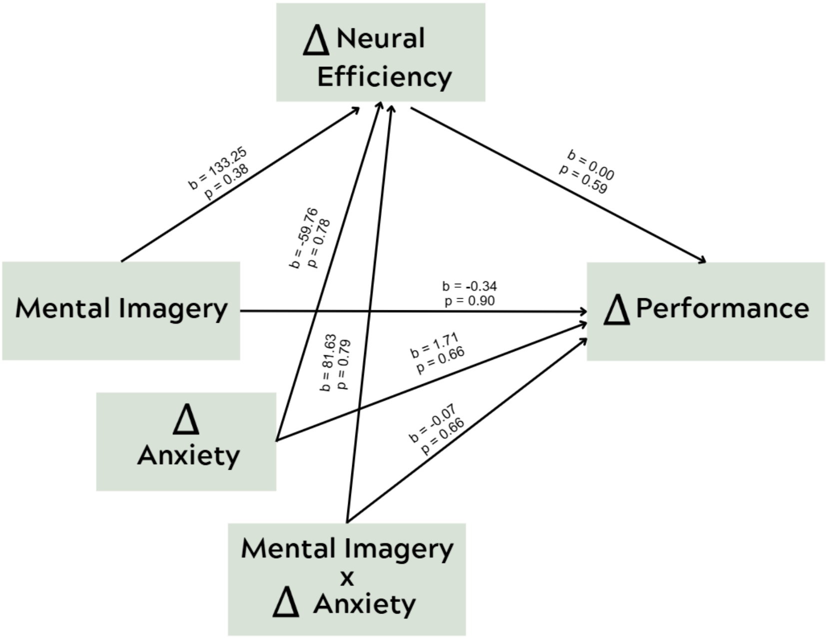


Figure 21. Moderated-Mediation Analyses with variables Neural Efficiency (M), Mental Imagery Condition (X), Performance (Y), and Anxiety (W).

Chapter 6: Discussion

The present study provided a multi-level assessment of human performance that examined the impact of a mental imagery intervention on free throw performance, neural correlates of activation, and psychological states of confidence and anxiety. The results provide mixed support for the hypotheses, with some findings aligning with theoretical frameworks and others challenging existing assumptions regarding the psychophysiological mechanisms underlying the effectiveness of mental imagery.

Contrary to expectations (H1), mental imagery did not significantly enhance free throw performance relative to the control group. While both groups exhibited minor improvements from pre- to post-test, no significant main effects or interactions were observed, suggesting that physical practice effects may be a better predictor of short-term performance change. These findings align with prior research suggesting that the effectiveness of mental imagery on performance may depend on additional factors such as skill level, imagery quality, or contextual pressure (Munroe-Chandler & Morris, 2011). It is also possible that a single-session intervention was insufficient to produce measurable performance improvements, highlighting the need for more extended or repeated imagery practice sessions to yield performance benefits. Furthermore, by quantifying performance as successful shots, some information, such as kinematic alterations in skill execution, that may convey efficiency is still unknown.

The results also did not support H2, which posited that mental imagery would lead to increased left temporal alpha power, increased fronto-midline theta, decreased central mu rhythm, and decreased frontal-temporal coherence. No significant group differences in neural activity were observed, suggesting that the intervention did not systematically alter neural efficiency, as measured by these variables. However, significant main effects of region and time emerged for alpha power, indicating that alpha power varied across cortical areas and epochs leading up to movement execution. Specifically, the findings that elevated alpha was observed in the left relative to the right hemisphere and a significant decrease in alpha power was detected in the epoch before motor execution may be indicative greater engagement in movement preparation. This pattern of hemispheric alpha activity has typically been observed in trained individuals (Hatfield et al., 2020). These results suggest that while alpha power exhibits dynamic changes during motor preparation, these changes were not differentially influenced by mental imagery. The decrease in alpha coherence over time suggests refinement of cortical dynamics implying that the brain was engaged with less cortico-cortical communication (i.e., cross-talk between the frontal and temporal cortices) from pre- to post-test. This finding supports the existing literature, however, with the lack of effect of the imagery condition, this decrease in coherence is likely attributable to physical practice effects rather than mental imagery.

The subjective assessments of cognitive workload and conscious motor processing employed to complement the neural findings exhibited trends supporting hypotheses (H3), however, demonstrated no significant differences between imagery and control groups. The significant reduction in overall workload ratings from pre-test to post-test across both groups likely reflects increased task familiarity and improved motor planning efficiency with repeated execution. Similarly, the decrease in conscious motor processing in both groups suggests that imagery does not uniquely contribute to a shift to automaticity or even acceleration of these processes.

One possible explanation for the lack of significant group differences in neural activation is that neural efficiency effects require extended imagery training or individualized protocols tailored to participants' baseline neural states. Another consideration is that the neural measures employed, particularly EEG-derived indices of efficiency, may require finer temporal resolution or alternative analytical techniques such as wavelet analyses to detect any subtle changes associated with imagery practice.

Hypotheses regarding the psychological mediators of performance (H4 and H5) were partially supported. Mental imagery significantly increased self-confidence, supporting prior research that highlights its role in enhancing belief in one’s ability (Feltz & Landers, 1983). However, increased confidence did not translate into improved performance, suggesting that confidence alone may not be a sufficient mechanism for motor execution benefits. Additionally, the absence of a significant Condition × Time interaction suggests that while confidence increased from pre-test to post-test in both groups, the rate of improvement was consistent across conditions. This indicates that the imagery intervention may not have significantly enhanced confidence beyond what was observed in the control condition. Similarly, while state anxiety decreased significantly from pre- to post-test across both groups, there was no condition-specific effect, indicating that imagery did not differentially impact anxiety reduction. These findings may simply be due to repeated testing, exposure to the experimental setting, or the natural component of physical practice and feedback gained from completing the pre-test.

The mediation models revealed that neither confidence nor anxiety significantly mediated the imagery-performance relationship, challenging the notion that these psychological factors serve as primary conduits for performance enhancement. This finding diverges from studies demonstrating that psychological states can shape motor performance (Jekauc et al., 2022; Lazarus, 2000) and suggests that additional factors, such as attentional control or physiological arousal, may play a more critical role.

The moderated-mediation analyses tested whether neural efficiency mediated the imagery-performance relationship while accounting for confidence and anxiety as moderators. The overall model predicting performance was not significant, suggesting that neural efficiency did not mediate the relationship between mental imagery and performance. No significant moderation effects were detected for anxiety. However, confidence significantly moderated the relationship between mental imagery and performance, such that the influence of mental imagery was positively associated with performance only when confidence was elevated. This finding suggests that while mental imagery alone may not consistently enhance performance, it may be beneficial when an athlete’s confidence is already high. While confidence was significantly increased by imagery, its moderating role in neural efficiency was non-significant, implying that confidence alone does not necessarily enhance neural efficiency. These findings highlight the complex role of psychological states in motor performance and suggest that future research should explore whether targeted interventions to increase confidence could enhance the effectiveness of mental imagery.

As for the "chicken-or-the-egg" question of whether neural bases drive psychological states or psychological states drive neural activation, it's likely bidirectional. Psychological states can influence brain activity, but brain activity can also generate those states. Furthermore, the environmental context, particularly the level of stress or pressure a performer is under, plays a crucial role in this dynamic. Psychophysiological research on stress has shown that under high-pressure conditions, performers not only experience increased anxiety but also exhibit greater right-hemispheric frontal alpha power, a neural signature associated with cognitive control and emotional regulation (Hatfield & Hillman, 2001). These findings suggest that performance outcomes are not solely dictated by either psychological states or neural mechanisms in isolation but rather by the interaction between brain, mind, and situational demands. Understanding this interplay will be essential for advancing both theoretical models of performance and practical applications in sport and high-performance environments.

Limitations & Future Research

While this study provided valuable insight into the cortical dynamics of mental imagery, several limitations should be acknowledged to contextualize the findings and guide future research. Future studies should consider exploring additional psychological and physiological variables that may drive imagery benefits. Potential directions include examining attentional control, motor preparation dynamics, and the role of task complexity in moderating imagery effects. Participant experience level, trial duration and intervention duration and robustness, and the independent sensitivity of brain dynamics are other notable limitations in the present study.

The participants recruited were all experienced basketball players, however there was a wide range of skill-levels. Given the inclusion criteria of a self-reported FTP of 50-75%, the resulting performance was variable between participants. It should also be noted that participants were poor at rating their own FTP before the study began and often inflated their abilities. Future research might consider increasing determinants reflective of level of expertise in participants, for example, confirm FTP with a shooting test before acceptance into the study. Adding the traditional expert-novice paradigm would also contribute to future findings. The sample size may also not have been large enough to detect small effects, especially in EEG data and future studies might consider recruiting a larger participant group.

Another methodological limitation includes the trial duration period of 10-sec of motor planning which may limit the amount of relevant data obtained in the frequency domain. Ten seconds was deemed ecologically valid because of the same time limit to take a free throw in a real basketball game and ensured a significant amount of data (e.g., more than 3-sec). However, 10-sec may feel quite long for some participants and may have increased between-subjects variability. For reliable EEG data, future studies should consider adding a longer motor planning period or including more trials if attention of the participant can be better controlled for. This would also allow for additional analyses related to the exploration of ERPs tied to motor execution. The control group served as a comparison to account for practice effects, but inherent to many psychophysiological studies that use motor tasks, some degree of physical practice effects may be unavoidable.

Intervention duration may have also played a role on the results. Though there is limited research suggesting that brief PST interventions are effective for increasing mental toughness (Stamatis, 2002), most research in sport psychology suggests that psychological skills interventions are most effective over the course of approximately ten or more weeks (Vella-Fondacaro & Romano-Smith, 2023). Participants in this study received only brief mental imagery training and practice. Future studies may consider using a longitudinal design and more in-depth mental imagery training.

Compared to other neuroimaging techniques, the nature of EEG lends itself well to tasks involving movement, but brain dynamics overall are quite sensitive and can vary significantly between time and person. Techniques to reduce this variability were used in this study, but additional measures may be considered in the future. This includes measures of coherence which "may reflect large scale changes in cortical activation that are projected to many electrodes simultaneously, as opposed to inter-regional communication." The results of coherence indicating solely significance based on the factor of time and no influence of region or epoch in this study may reflect this type of large-scale activation and should be interpreted with caution (Parr et al., 2023, pp. 418).

Inherent to the nature of work with EEG, there are various paths along the data processing pipeline that a researcher can choose as the most feasible and effective for analyzing the data given the overarching research question(s). While the present study analyzed a more traditional time period of 5-sec preceding motor execution, future research might consider using signal behavior in the time-frequency domain to identify patterns of interest and analyzing a channel-time-frequency period of interest by using wavelet or spectrogram-based analyses. Applying wavelet transforms or spectrogram analysis in EEG research allows for a more dynamic and temporally sensitive approach to understanding neural activity, particularly in short trial motor tasks where frequency patterns may shift rapidly. Unlike traditional Fourier-based approaches, which assume stationarity in the signal, wavelet transforms enable localized time-frequency decomposition, making them well-suited for analyzing transient, event-related oscillations that emerge in movement preparation and execution (Tallon-Baudry & Bertrand, 1999). Future studies employing wavelet analysis could gain finer temporal resolution in detecting pre-movement beta suppression, which has been widely linked to motor readiness and sensorimotor processing (Pfurtscheller & Lopes da Silva, 1999). Additionally, spectrogram analysis could allow researchers to track dynamic spectral changes associated with motor learning and neuroplasticity, particularly in alpha and gamma band activity, which have been implicated in motor adaptation and skill acquisition (Cheyne, 2013). Incorporating time-frequency analyses like wavelets or spectrograms in future EEG studies could therefore provide deeper insights into the temporal evolution of neural oscillations and be valuable for examining individual differences in motor performance.

Lastly, a secondary subjective measure of conscious processing was used in this study, however future studies may introduce an additional measure specific to verbal-analytical processing in order to better determine the association between physiological data and behavioral data (Parr et al., 2023). Future research is also needed regarding the effectiveness of other psychological skills (i.e., mindfulness, self-talk, goal setting, etc.) using the theory of neural efficiency as a framework.

To summarize, components to consider for a future study with more sensitive detection of power for imagery effectiveness, include: (1) larger sample size, (2) manipulating experience level, (3) longer imagery intervention, (4) separate days for pre-test and post-test data collection, (5) measuring other psychological (i.e., attention or motivation) and physiological variables (i.e., movement kinematics, ECG, EMG, etc.), and (6) spectrogram analysis on EEG.

Practical Implications

Bridging research and application, this study demonstrated the effect of imagery on confidence, which we know plays a role in decision-making and execution during motor performance. While the single-session imagery intervention did not significantly improve performance itself, long-term imagery training might, as previous research would suggest. Practitioners should consider the duration, personalization, and integration of imagery into practice routines, applying as much precision and care to mental training as one would to physical training. Do not expect immediate effects from one imagery session. The present findings seem to highlight the importance of considering the uniqueness of the individual when developing a guided imagery script or programmatic intervention. An effective imagery script should closely align with an individual’s unique thoughts, emotions, and behaviors. In PST, mental imagery is often layered with other mental skills like self-talk, relaxation strategies, and focus cues learned by the performer. Practitioners should highlight combining use of these tools for performance enhancement.

It is important to highlight that the free throw shooting task used in this study was purely a vehicle to explore the psychophysiological state associated with readiness for motor execution. The implications of psychophysiological research like those presented here goes well-beyond basketball. Understanding the manner in which mental skills may affect psychological and neural states is important across domains of movement and skill in the performance realm. Military and tactical populations, medical personnel, and business executives can leverage psychological skills training for performance enhancement. Similarly, the everyday performers in any context, whether athletics, academics, work, or injury rehabilitation, for example, might consider how mental skills can affect their bodies *and minds* for performance and well-being optimization.

Conclusion

This study aimed to explore the psychophysiological underpinnings of mental imagery, particularly its effects on motor performance, neural activation, and psychological mediators like confidence and anxiety. While mental imagery boosted confidence, it did not significantly improve performance or neural efficiency. The null findings in mediation and moderated-mediation analyses suggest that the relationship between imagery and performance is more complex than previously assumed and that perhaps something else – potentially attention, physiological arousal, or task familiarity – might be at play. Further investigation into alternative explanatory mechanisms is needed. Despite these limitations, the study adds to the broader conversation about how mental imagery might work and points to the need for future research exploring individually-tailored imagery interventions for optimizing performance outcomes.

Appendix A: Imagery Script

Instructions: Make yourself comfortable in a relaxed position and allow yourself to relax. You may choose whether you feel more comfortable with your eyes open or closed at any time during the imagery session. Once a comfortable and relaxed state is obtained, we will begin.
(1) As this is read to you, imagine yourself experiencing and performing according to what is being described. (2) As you read this aloud, imagine yourself experiencing and performing according to what is being described. (3) As you listen to the recoding, imagine yourself experiencing and performing according to what is being described.

Imagine yourself standing confidently at the free throw line, ready to take your shot. Take a deep breath, inhaling calmness and focus, exhaling any tension.

As you prepare to shoot, feel the familiar texture of the basketball in your hands. Notice its weight and the comforting sensation of the seams beneath your fingertips.

Visualize yourself stepping up to the free throw line with confidence. You are calm, centered, and fully present in the moment. You have experienced these feelings in the past and have performed well . . . therefore you know that you are ready to perform well again today.

Set your feet firmly, aligning yourself perfectly with the hoop. You feel balanced and in control, with no pressure, only focus.

Fix your gaze on the target, the spot where the net and rim meet. Your eyes remain locked on this point, unwavering and determined.

Execute your pre-shot routine, dribbling the ball a few times, feeling the rhythm and timing of your shot. Your movements are smooth and deliberate.

With each breath you synchronize your motion, feeling your body relax and flow with effortless grace. As you exhale, you rise up, extending your arms with precision and confidence.

Release the ball with a flick of the wrist, the perfect arc carrying it toward the hoop. You hear the satisfying swish as it passes cleanly through the net.

In this moment, you feel unstoppable, like a well-oiled machine, capable of making this shot time and time again. You are in control of your free throw shot.

Rate how well can you visualize a free throw using this script:

1 2 3 4 5 6 7 8 9 10

References

Andreassi, J. L. (2000). *Psychophysiology: Human Behavior and Physiological Response*. Lawrence Erlbaum Associates, Inc. (4th Edition).

Aizava, P. V. S., Codonhato, R. & Fiorese, L. (2023). Association of self-efficacy and mental toughness with sport performance in Brazilian futsal athletes. *Frontiers in Psychology, 14*, 1195721. doi: https://doi.org/10.3389/fpsyg.2023.1195721

Arduino. (2023). *Arduino IDE (Version 2.3.3.) [Computer software]*. Arduino. https://www.arduino.cc/en/software

Arvinen-Barrow, M., & Walker, N. (2013). *Psychology of Sport and Injury.* Routledge: Abington.

Babolini, C., Infarinto, F., Marzano, N., Iacoboni, M., Dassu, F., Soricelli, A., Rossini, P. M., Limatola, C., & Del Percio, C. (2011). Intra-hemispheric functional coupling of Alpha rhythms is related to golfer's performance: A coherence EEG study. International *Journal of Psychophysiology, 82*, 260-268.

Babiloni, C., Del Percio, C., Iacoboni, M., Infarinato, F., Lizio, R., Marzano, N., Crespi, G. Dassu, F., Pirritano, M., Gallamini, M., & Eusebi, F. (2008). Golf putt outcomes are predicted by sensorimotor cerebral EEG rhythms. *Journal of Physiology, 586*(1), 131-139. doi: 10.1113/jphysiol.2007.141630

Bartolomeo, P. (2008). The neural correlates of visual mental imagery: An ongoing debate. *Cortex, 44*, 107-108. doi: 10.1016/j.cortex.2006.07.001

Baumeister, J., Reinecke, K., Liesen, H., Weiss, M. (2008). Cortical activity of skilled performance in a complex sports related motor task. Eur. *Journal of Applied Physiology, 104*, 625-631. doi: 10.1007/s00421-008-0811-x

Beilock, S. L., Bertenthal, B. I., McCoy, A. M., & Carr, T. H., (2004). Haste does not always make waste: Expertise, direction of attention, and speed versus accuracy in performing sensorimotor skills. *Psychonomic Bulletin & Review, 11*(2), 373-379.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology, 130*(4), 701-725.

Bellomo, E., Cooke, A., Gallicchio, G., Ring, C., & Hardy, J. (2020). Mind and body: Psychophysiological profiles of instructional and motivational self-talk. *Psychophysiology, 57*:e13586. doi: 10.1111/psyp.13586

Berger, H. (1929). \u00dcber das Elektrenkephalogramm des Menschen. *Archiv f\u00fcr Psychiatrie und Nervenkrankheiten*, 87, 527-570. (*Translation: "On the Electroencephalogram of Man." Archive for Psychiatry and Nervous Diseases.*)

Borst G. & Kosslyn, S.M. (2008). Visual mental imagery and visual perception: structural equivalence revealed by scanning processes. *Mem Cognit, 36*, 849–62.

Brain Products. (2022). *Brain Vision Analyzer (Version 2.3) [Computer software].* Brain Products GmbH.

Branch, J. (2009, March 3). For free throws, 50 years of practice is no help. http://www.nytimes.com/ 2009/03/04/sports/basketball/04freethrow.html

Burgess, A., Gruzelier, J. (1993). Individual reliability of amplitude distribution in topographical mapping of EEG. Electroencephalogr. *Clin. Neurophysiol. 86*, 219 – 223.

Busk, J., & Galbraith, G. C. (1975). EEG correlates of visual-motor practice in man. *Electroencephalography and Clinical Neurophysiology, 38*, 415-422.

Cabarkapa, D., Fry, A.C., Carlson, K.M., Poggio, J.P., & Deane, M.A. (2021). Key Kinematic Components for Optimal Basketball Free Throw Shooting Performance. *Central European Journal of Sport Sciences and Medicine*.

Cacioppo, J. T., & Tassinary, L. G. (1990). Inferring psychological significance from physiological signals. *American Psychologist*, 45(1), 16-28.

Cannon, Jamaal Edward. (2008). Effects of imagery use in basketball free throw shooting. *Theses Digitization Project. 3354*. https://scholarworks.lib.csusb.edu/etd-project/3354

Callow, N., Hardy, L., & Hall, C. (2001). The effects of a motivational general-mastery imagery intervention on the sport confidence of high-level badminton players. *Research Quarterly for Exercise and Sport, 72*(4), 389-400.

Callow, N. & Hardy, L. (2001). Types of Imagery Associated with Sport Confidence in Netball Players of Varying Skill Levels. *Journal of Applied Sport Psychology, 13(1)*, 1-17, doi: 10.1080/10413200109339001

Cannon, W. B. (1927). The James-Lange theory of emotions: A critical examination and an alternative theory. *The American Journal of Psychology*, 39(1/4), 106-124.

Cavanagh, J. F., & Frank, M. J. (2014). Frontal theta as a mechanism for cognitive control. *Trends in Cognitive Sciences, 18*(8), 414-421.

Chang, Y., Lee, J., Seo, J., Song, H., Kim, Y., Lee, H. Kim, H. J., Lee, J., Kime, W., Woo, M., & Kim, J. G. (2010). Neural correlates of motor imagery for elite archers. *NMR in Biomedicine, 24(2*), 366-372. doi: https://doi-org.proxy-um.researchport.umd.edu/10.1002/nbm.1600

Cheng, M., Huang, C., Chang, Y., Koester, D., Schack, T., & Hung, T. (2015). Sensorimotor rhythm neurofeedback enhances golf putting performance. *Journal of Sport and Exercise Psychology, 37*, 626-636.

Cheng, M.-Y., & Tsung-Min, H. (2021). Biofeedback and neurofeedback for mental skills training in sports. In M. Bertollo, E. Filho, & P. C. Terry (Eds.), *Advancements in mental skills training* (pp. 149–163). Routledge/Taylor & Francis Group.

Cheron, G., Petit, G., Cheron, J., Leroy, A., Cebolla, A., Cevallos, C., ... & Servais, L. (2016). Brain oscillations in sport: Toward EEG biomarkers of performance. *Frontiers in Psychology, 7*, 246. doi: 10.3389/fpsyg.2016.00246

Cheyne D. O. (2013). MEG studies of sensorimotor rhythms: a review. *Experimental neurology*, *245*, 27–39. https://doi.org/10.1016/j.expneurol.2012.08.030

Chuang, L., Huang, C., & Hung, T. (2013). The differences in frontal midline theta power between successful and unsuccessful basketball free throws of elite basketball players. *International Journal of Psychophysiology, 90*, 321-328. doi: https://doi.org/10.1016/j.ijpsycho.2013.10.002

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Routledge.

Cohen, M. X., & Cavanagh, J. F. (2011). Single-trial regression elucidates the role of prefrontal theta in learning and decision-making. *Psychophysiology, 48*(11), 1287-1293. doi: https://doi.org/10.3389/fpsyg.2011.00030

Cohn. P. J. (1990). Preperformance routines in sport: Theoretical support and practical applications. *Sport Psychologist, 4,* 301- 312.

Cooke, A., Kavussanu, M., McIntyre, D., & Ring, C. (2010). Psychological, muscular and kinematic factors mediate performance under pressure. *Psychophysiology, 47*, 1109-1118. doi: 10.1111/j.1469-8986.2010.01021.x

Cooley, S. J., Williams, S. E., Burns, V. E., & Cumming, J. (2013). Methodological variations in guided imagery interventions using movement imagery scripts in sport: A systematic review. *Journal of Imagery Research in Sport and Physical Activity, 8*(1), 13-44.

Deeny, S. P., Haufler, A. J., Saffer, M., & Hatfield, B. D. (2009). Electroencephalographic coherence during visuomotor performance: A comparison of cortico-cortical communication in experts and novices. *Journal of Motor Behavior, 41*(2), 106-116. doi: 10.3200/JMBR.41.2.106-116

Deeny, S. P., Hillman, C. H., Janelle, C. M., & Hatfield, B. D. (2003). Cortico-cortical communication and superior performance in skilled marksmen: An EEG coherence analysis. *Journal of Sport and Exercise Psychology, 25*, 188-204.

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*, 9–21. http://dx.doi.org/10.1016/j.jneumeth.2003 .10.009

Devos, H., Gustafson, K., Ahmadnezhad, P., Liao, K., Mahnken, J. D., Brooks, W. M., & Burns, J. M. (2020). Psychometric properties of NASA-TLX and index of cognitive activity as measures of cognitive workload in older adults. *Brain Sci.*, *10*(12), 994. doi: https://doi.org/10.3390/brainsci10120994

Elkins, K. (2020). How much money the winners of the NBA All-star game will earn. CNBC Money. Retrieved from https://www.cnbc.com/2020/02/15/nba-all-star-game-2020-how-much-money-the-winning-team-earns.html

Ehrsson, H. H., Geyer, S., & Naito, E. (2003). Imagery of voluntary movement of fingers, toes, and tongue activates corresponding body-part-specific motor representations. *J Neurophysiol, 90*(5), 3304-16. doi: 10.1152/jn.01113.2002

Feltz, D. L. & Landers, D. M. (1983). The effects of mental practice on motor skill learning and performance: A meta-analysis. *Journal of Sport Psychology, 5*, 25-57.

Fingelkurts, A. A., Ermolaev, V. A., & Kaplan, A. Y. (2006). Stability, reliability and consistency of the compositions of brain oscillations. *International Journal of Psychophysiology, 59(2*), 116-126. doi: https://doi.org/10.1016/j.ijpsycho.2005.03.014

Fitts, P.M., & Posner, M.I. (1967). *Human performance.* Brooks/Cole.

Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, 23(5), 567-589.

Gallicchio, G., Cooke, A., & Ring, C. (2017). Practice makes efficient: Cortical alpha oscillations are associated with improved golf putting performance. *Sport, Exercise, and Performance Psychology, 6*, 89–102. https://doi.org/10.1037/spy0000077

Gallicchio, G., Cooke, A., & Ring, C. (2016). Lower left temporal-frontal connectivity characterizes expert and accurate performance: High-alpha T7-Fz connectivity as a marker of conscious processing during movement. *Sport, Exercise, and Performance Psychology, 5*(1), 14–24. https://doi.org/10.1037/spy0000055

Gasser, T., Bacher, P., Steinberg, H., 1985. Test – retest reliability of spectral parameters of the EEG. *Electroencephalogr. Clinical Neurophysiology 60*, 312 – 319.

Gayton, W. H. & Nickless, C. J. (1987). An investigation of the validity of the trait and state sport-confidence inventories in predicting marathon performance. *Perceptual and Motor Skills, 65*, 481-482. doi: https://doi.org/10.2466/pms.1987.65.2.481

Ghaziri, J., Tucholka, A., Larue, V., Blanchette-Sylvestre, M., Reyburn, G., Gilbert, G., Levesque, J., & Beauregard, M. (2013). Neurofeedback training induces changes in white and gray matter. *Clinical EEG and Neuroscience*, 1-8. doi: 10.1177/1550059413476031

Goldschmied, N., Raphaeli, M., Moothart, S., & Furley, P. (2021). Free throw shooting performance under pressure: a social psychology critical review of research. *International Journal of Sport and Exercise Psychology, 20*(5), 1397-1415. doi: 10.1080/1612197X.2021.1979073

Gough, C. (2022). Teams of the NBA ranked by revenue 2020/21. Statista. Retrieved from https://www.statista.com/statistics/193704/revenue-of-national-basketball-association-teams-in-2010/

Gregg, M. J., Hall, C., McGowan, E. L., & Hall, N. (2011). The relationship between imagery ability and imagery use among athletes. *Journal of Applied Sport Psychology, 23*(2), 129-141. doi: 10.1080/10413200.2010.544279

Gutierrez, M. C. S., & Castellanos, P. M. V. (2018). Design and validation of a system for improving the effectiveness of basketball players: a biomechanical analysis of the free throw. Conference: 2018 IX International Seminar of Biomedical Engineering (SIB).

Hall, C. R., Rodgers, W. M., & Barr, K. A. (1990). The use of imagery by athletes in selected sports. *The Sport Psychologist, 4*(1), 1–10.

Hall, C. R., Munroe-Chandler, K. J., Cumming, J., Law, B., Ramsey, R., & Murphy, L. (2009). Imagery and observational learning use and their relationship to sport confidence. *Journal of Sports Sciences, 27(4)*, 327-337, doi: 10.1080/02640410802549769

Hall, E.G. & Erffmeyer, E.S. (1983). The effect of visuomotor behavior rehearsal with videotaped modeling on free throw accuracy of intercollegiate female basketball players. *Journal of Sport Psychology, 5*, 343-346.

Hart, S. G., & Staveland, L. E. (1988). Development of a multi-dimensional workload rating scale: Results of empirical and theoretical research. In P.A. Hancock & N. Meshkati (Eds.). *Human Mental Workload.* Amsterdam. The Netherlands: Elsevier.

Hatfield, B. D., Jaquess, K. J., Lo, L., & Oh, H. (2020). *The cognitive and affective neuroscience of superior athletic performance*. In Handbook of Sport Psychology, Fourth Edition, Volume I. John Wiley & Sons.

Hatfield, B. D., Costanzo, M. E., Goodman, R. N., Lo, L., Oh, H., Rietschel, J. C., Saffer, M., Bradberry, T., Contreras-Vidal, J., & Haufler, A. (2013). The influence of social evaluation on cerebral cortical activity and motor performance: A study of "Real-Life" competition. *International Journal of Psychophysiology, 90*, 240-249. doi: http://dx.doi.org/10.1016/j.ijpsycho.2013.08.002

Hatfield, B. D., & Hillman, C. H. (2001). The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. *International Journal of Sport Psychology, 32*(1), 3–22.

Hatfield, B. & Kerick, S. (2007). The psychology of superior sport performance: a cognitive and affective neuroscience perspective. In Tenenbaum, G., & Eklund, R. C. (2007). *Handbook of Sport Psychology* (3rd ed.). Hoboken, NJ: John Wiley & Sons, Inc.

Hatfield, B. D., Landers, D. M., & Ray, W. J. (1984). Cognitive processes during self-paced motor performance: An electroencephalographic profile of skilled marksmen. *Journal of Sport Psychology, 6*, 42-59.

Hardy, J., Comoutos, N., & Hatzigeorgiadis, A. (2018). Reflections on the maturing research literature of self-talk in sport: Contextualizing the special issue. *The Sport Psychologist, 32*, 1–8. doi: https://doi. org/10.1123/tsp.2017-0141

Hariri, A. R., Mattay, V. S., Tessitore, A., Kolachana, B., Fera, F., Goldman, D., et al. (2002). Serotonin transporter genetic variation and the response of the human amygdala. *Science, 297*, 400-403.

Hays, D., & Krause, J.V. (1987). Score on the throw. *The Basketball Bulletin, Winter*, 4-9.

Hetu, S., Gregoire, M., Saimpont, A., Coll, M., Eugene, F., Michon, P., & Jackson, P.

L. (2103). *Neuroscience and Biobehavioral Reviews, 37(5*), 930-949. doi: https://doi.org/10.1016/j.neubiorev.2013.03.017

Hobson, W. (2014). Fund and games. The Washington Post. Retrieved from https://www.washingtonpost.com/graphics/sports/ncaa-money/

Holmes, P.S., & Collins, D. J. (2001). The PETTLEP approach to motor imagery: A functional equivalence model for sport psychologists. *Journal of Applied Sport Psychology, 13*, 60-63. doi: https://doi.org/10.1080/10413200109339004

Holroyd, C. B., & Coles, M. G. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review, 109*(4), 679.

Hugdahl, K. (2009). Overlapping areas of neuronal activation after motor and mental imagery training. Front. *Neuroscience, 3*. doi: 10.3389/neuro.01.008.2009

Hutchinson, A. (2024, Mar 6). Sports Psychology Has an Evidence Problem. *Outside*. https://www.outsideonline.com/health/training-performance/sports-psychology-evidence/

Hung, T. & Cheng, M. (2018). Neurofeedback in sport: Theory, methods, research and efficacy. Handbook of Sport Neuroscience and Psychophysiology, 1st edition, Routledge.

IBM Corp. (2021). *IBM SPSS Statistics for Windows, Version 27.0* [Computer software]. IBM Corp.

Isaac, A. R. (1992). Mental practice – does it work in the field? *The Sport Psychologist, 6*, 192-198.

Jackson, R. C., Kinrade, N. P., Hicks, T., & Wills, R. (2013). Individual propensity for reinvestment: field-based evidence for the predictive validity of three scales. *Int. Journal of Sport Psychology, 44*. doi: 10.7352/IJSP 2013.00.000

Jacobson, E. (1930). Electrical measurement of neuromuscular states during mental activities. *American Journal of Physiology, 94*, 24-34.

James, W. (1890). *The Principles of Psychology* (Vols. 1 & 2). New York: Henry Holt.

James, W. (1884). What is an emotion? *Mind*, 9(34), 188-205.

JASP Team. (2023). *JASP (Version 0.17.2) [Computer software]*. https://jasp-stats.org/

Jasper, H. H. (1958). The ten-twenty electrode system of the International Federation. *Electroencephalography and Clinical Neurophysiology, 10*, 371–375.

Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. NeuroImage, 14, S103-S109. doi:10.1006/nimg.2001.0832 Jeannerod, M. (1995). Mental imagery in the motor cortex. *Neuropsychologia, 33(11*), 1419-1432. doi: https://doi.org/10.1016/0028-3932(95)00073-C

Jeannerod, M. (1995). Mental imagery in the motor context. *Neuropsychologia, 33*(11), 1419–1432. https://doi.org/10.1016/0028-3932(95)00073-C

Jekauc, D., Fiedler, J., Wunsch, K., Mülberger, L., Burkart, D., Kilgus, A., & Fritsch, J. (2023). The effect of self-confidence on performance in sports: a meta-analysis and narrative review. *International Review of Sport and Exercise Psychology*, 1–27. https://doi.org/10.1080/1750984X.2023.2222376

Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: Gating by inhibition. *Frontiers in Human Neuroscience, 4*(186), 1-8. doi: 10.3389/fnhum.2010.00186

Jones, L., & Stuth, G. (1997). The Uses of Mental Imagery in Athletics: An Overview. *Applied and Preventive Psychology, 6*, 101-115. doi: http://dx.doi.org/10.1016/S0962-1849(05)80016-2

Jordet, G. (2005). Perceptual training in soccer: An imagery intervention study with elite players. *Journal of Applied Sport Psychology, 17*(2), 140-156. doi: 10.1080/10413200590932452

Jueptner, M., Stephan, K. M., Frith, C. D., Brooks, D. J., Frackowiak, R. S. J., & Passingham, R. E. (1997). Anatomy of motor learning. I. Frontal cortex and attention to action. *The American Physiological Society, 77*(3), 1313-24. doi: 10.1152/jn.1997.77.3.1313

Keshvari, F., Farsi, A., & Abdoli, B. (2024). Investigating the EEG profile of elite and non-elite players in the basketball free throw task. *Journal of Motor Behavior, 56(*1), 91-102.

Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. Trends in *Cognitive Sciences, 16*, 606 – 617. doi: http://dx.doi.org/10.1016/j.tics.2012.10.007

Koehn, S., Morris, T., & Watt, A. P. (2014). Imagery intervention to increase flow state and performance in competition. *The Sport Psychologist, 28*, 48-59.

Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2001). Neural foundations of imagery. *Nature Reviews: Neuroscience, 2*, 635-642.

Kosslyn, S.M., Ball, T.M., Reiser, B.J. (1978). Visual images preserve metric spatial information: evidence from studies of image scanning. *J Exp Psychol Hum Percept Perform, 4*, 47–60.

Kozar, B., Whitefield, K. E., Lord, R. H., & Mechikoff, R. A. (1993). Timeouts before free-throws: do the statistics support the strategy? *Perceptual and Motor Skills, 76*, 47- 50.

Lang, P., Kozak, M., Miller, G.A, Levin, D. N., &McLean, A. (1980). Emotional imagery: Conceptual structure and pattern of somato-viseral response. *Psychophysiology,17*, 179-192.

Lazarus, R. S. (2000). How emotions influence performance in competitive sports. *The Sport Psychologist, 14*, 229-252. 10.1123/tsp.14.3.229

Lotze, M., & Halsband, U. (2006). Motor imagery. *Journal of Physiology-Paris, 99*(4-6), 386-395. https://doi.org/10.1016/j.jphysparis.2006.03.012

Mack, M. G. (2001). Effects of time and movements of the preshot routine on free throw shooting. *Perceptual and Motor Skills, 93*, 567-573.

Martin, J. J., & Gill, D.L. (1991). The relationships among competitive orientation, sport-confidence, self-efficacy, anxiety, and performance. *Journal of Sport and Exercise Psychology, 13(2*), 149-159.

Martin, K. A., Moritz, S. E., & Hall, C. R. (1999). Imagery use in sport: A literature review and applied model. *The Sport Psychologist, 13*, 245-268.

McKendrick, R. D., & Cherry, E. (2018). A deeper look at the NASA TLX and where it falls short. Proceedinings of the Human Factors and Ergonomics Society Annual Meeting, 62(1), 44-48. doi: https://doi.org/10.1177/1541931218621010

McEvoy, L. K., Smith, M. E., & Gevins, A. (2000). Test-retest reliability of cognitive EEG. *Clinical Neurophysiology, 111(3*), 457-463. doi: https://doi.org/10.1016/S1388-2457(99)00258-8

Meister, I.G., Krings, T., Foltys, H., Boroojerdi, B., Muller, M., & Topper R., Thron A. (2004). Playing piano in the mind — an fMRI study on music imagery and performance in pianists. *Cogn Brain Res, 19*, 219–228. doi: 10.1016/j.cogbrainres.2003.12.005

Mellalieu, S., & Hanton, S. (Eds.). (2008). *Advances in applied sport psychology*. Taylor & Francis.

Mersky, M. J. (1987). Coaching and teaching the free-throw shooter. *The Basketball Clinic, 19*(5), 8-11.

Monany, D.R., Lebon F., Dupont W., Papaxanthis C. (2022). Mental practice modulates functional connectivity between the cerebellum and the primary motor cortex. *iScience, 25*, 1–10.

Mulder, T. (2007). Motor imagery and action observation: Cognitive tools for rehabilitation. *J Neural Transm., 114(10*), 1265-1278. doi: https://doi.org/10.1016/j.neubiorev.2013.03.017

Mullineaux, D. R., & Uhl, T. L. (2010). Coordination-variability and kinematics of misses versus swishes of basketball free throws. *Journal of Sports Sciences, 28*(9), 1017-1024. doi: 10.1080/02640414.2010.487872

Munroe-Chandler, K. J., & Morris, T. (2011). Imagery and its effectiveness in the field. In T. Morris & P. C. Terry (Eds.), *The new sport and exercise psychology companion* (pp. 235–256). Fitness Information Technology.

Naito, E., Kochiyama, T., Kitada, R., Nakamura, S., Matsumura, M., Yonekura, Y., & Sadato, N. (2002). Internally simulated movement sensations during motor imagery activate cortical motor areas and the cerebellum. *J Neurosci, 22*, 3683–3691. doi: 10.1523/JNEUROSCI.22-09-03683.2002

Napflin, M., Wildi, M., & Sarnthein, J. (2007). Test-retest reliability of resting EEG spectra validates a statistical signature of persons. *Clinical Neurophysiology, 118(11*), 2519-2524. doi: https://doi.org/10.1016/j.clinph.2007.07.022

Neuper, C., & Pfurtscheller, G. (2001). Event-related dynamics of cortical rhythms: Frequency-specific features and functional correlates. *International Journal of Psychophysiology, 43*(1), 41-58.

Nunez, P.L., 2000. Toward a quantitative description of large-scale neocortical dynamic function and EEG. *Behav. Brain Sci. 23*, 371 – 437.

Okazaki, V. H. A., & Rodacki, A. L. F. (2012). Increased Distance of Shooting on Basketball Jump Shot. *Journal of Sports Science & Medicine, 11*(2), 231–237.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*, 71–113. https://doi. org/10.1016/0028-3932(71)90067-4

Olsson, C. J., Jonsson, B., & Nyberg, L. (2008). Learning by doing and learning by thinking: an fMRI study of combining motor and mental training. *Front. Hum. Neuroscience, 2*. doi: 10.3389/neuro.09.005.2008

Orrell, A. J., Masters, R. S. W., & Eves, F. F. (2009). Reinvestment and movement disruption following stroke. *Neurorehabilitation and Neural Repair, 23*, 177–183. http://dx.doi.org/10.1177/1545968308317752

Paivio, A. (1985). Cognitive motivational functions of imagery in human performance. Canadian *Journal of Applied Sport Sciences, 10*, 22-28.

Parr, J. V. V., Gallicchio, G., Wood, G. (2023). EEG correlates of verbal and conscious processing of motor control in sport and human movement: A systematic review. *International Review of Sport and Exercise Psychology, 16*(1), 396-427. doi: 10.1080?1750984X.2021.1878548

Pearson, J. (2019). The human imagination: the cognitive neuroscience of visual mental imagery. *Nature Reviews | Neuroscience, 20*, 624-634.

Peynircioglu, Z.F., Thompson, J.L.W., & Tanielian, T.B. (2000). Improvement strategies in free-throw shooting and grip-strength tasks. *Journal of General Psychology, 127(2*), 145-157.

Pineda, J. A. (2005). The functional significance of mu rhythm: Translating “seeing” and “hearing” into “doing.” *Brain Research Reviews, 50*(1), 57-68.

Pfurtscheller, G., & Lopes da Silva, F. H. (1999). Event-related EEG/MEG synchronization and desynchronization: Basic principles. *Clinical Neurophysiology, 110*(11), 1842–1857. https://doi.org/10.1016/S1388-2457(99)00141-8

Pfurtscheller, G., Stancák Jr, A., & Neuper, C. (1997). Event-related desynchronization (ERD) during motor behavior. *Neurology, 245*(1), 3-7.

Porro, C. A., Francescato, M. P., Cettolo, V., Diamind, M. E., Baraldi, P., Zuiani, C., Bazzocchi, M., di Prampero, P. E. (1996). Primary motor and sensory cortex activation during motor performance and motor imagery: a functional magnetic resonance imaging study. *Journal of Neuroscience, 16*(23), 7688-7698. doi: 10.1523/JNEUROSCI.16-23-07688.1996

Prathaban, S., Sumondo, V. S., Puthusserypady, S. (2019). Consequence of stress on cognitive performance: An EEG and HRV study. *2019 IEEE Region 10 Conference* (TENCON 2019), 1969-1974.

Rebert, C. S., Low, D. W., Larsen, F. (1984). Differential hemispheric activation during complex visuomotor performance: alpha trends and theta. *Biological psychology, 19*(3-4), 159-168.

Robin, N., Toussaint, L., Charles-Charlery, C., & Coudevylle, G. R. (2019). Free throw performance in non-expert basketball players: The effect of dynamic motor imagery combined with action observation. *Learning and Motivation, 68*, 101595. doi: https://doi.org/10.1016/j.lmot.2019.101595

Roth, M., Decety, J., Raybaudi, M., Masserelli, R., Delon-Martin, C., Segebarth, C., Morand, S., Gemignani, A., Decorps, M., & Jeannerod, M. (1996). Possible involvement of primary motor cortex in mental simulated movement: A functional magnetic resonance imaging study. *Neuroreport, 7*(7), 1280-1284. doi:

Sackett, R. S., (1934). The influences of symbolic rehearsal upon the retention of a maze habit. *Journal of General Psychology, 13*, 113-128.

Schachter, S., & Singer, J. (1962). Cognitive, social, and physiological determinants of emotional state. *Psychological Review*, 69(5), 379-399.

Schwarzer, R., & Jerusalem, M. (1002). Self-efficacy as a resource factor in stress appraisal processes. In R. Schwarzer (Ed.), *Self-efficacy: Thought control of action* (pp. 195-213). Washington, DC: Hemisphere.

Schwartz, M. S., & Andrasik, F. (2003). *Biofeedback: A Practitioner's Guide* (3rd ed.). Guilford Press.

Selye, H. (1936). A syndrome produced by diverse nocuous agents. *Nature*, 138, 32.

Semlitsch, H.V., Anderer, P., Schuster, P., Presslich, O., 1986. A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology 23*, 695–703.

Sommer, C., Werthner, P., & Bertollo, M. (2018). Exploration of event-related dynamics of brain oscillations in ice hockey shooting. *American Psychological Association: Sport, Exercise and Performance Psychology, 8(1)*, 38-52. doi: http://dx.doi.org/10.1037/spy0000134

Smith, D., Wright, C., Allsopp, A., & Westhead, H. (2007). It's all in the mind: PETTLEP-based imagery and sports performance. *Journal of Applied Sport Psychology, 19*, 80-92. doi: 10.1080/10413200600944132

Smith, R. E., Smoll, F. L., Cumming, S. P., & Grossbard, J. R. (2006). Measurement of multidimensional sport performance anxiety in children and adults: The sport anxiety scale-2. *Journal of Sport & Exercise Psychology, 28*, 479-501.

Stamatis, A. (2022). *Five minutes of psychological skills training intervention increase mental toughness levels in female athletes* [Poster presentation]. Retrieved from *https://www.researchgate.net/publication/375715705_*

Stassen, H.H., Bomben, G., Propping, P., 1987. Genetic aspects of the EEG: an investigation into the within-pair similarity of monozigotic and dyzigotic twins with a new method of analysis. *Electroencephalogr. Clin. Neurophysiol. 66*, 489 – 501.

Stassen, H.H., Lykken, D.T., Propping, P., Bomben, G., 1988. Genetic determination of the human EEG. Survey of recent results on twins reared together and apart. *Hum. Genet. 80*, 165 – 176.

Tallon-Baudry, C., & Bertrand, O. (1999). Oscillatory gamma activity in humans and its role in object representation. *Trends in Cognitive Sciences, 3*(4), 151–162. https://doi.org/10.1016/S1364-6613(99)01299-1

Thatcher, R. W. (2010). Validity and reliability of quantitative electroencephalography (qEEG). *Journal of Neurotherapy, 14*, 122-152.

Thomas, P. R., Murphy, S. M., & Hardy, L. (1999). Test of performance strategies: Development and preliminary validation of a comprehensive measure of athletes' psychological skills. *Journal of Sports Sciences, 17*(9), 697-711. doi: 10.1080/026404199365560

Vadoa, E. A., Hall, C. R., Mortiz, S. E. (1997). The relationship between competitive anxiety and imagery use. *Journal of Applied Sport Psychology, 9(2*), 241-253. doi: 10.1080/10413209708406485

Vealey, R. (1986). Conceptualization of sport-confidence and competitive orientation: Preliminary investigation and instrument development. *Journal of Sport Psychology, 8*, 221-246.

Vella-Brodrick, D. A., & MacRae, K. (2004), A review of mental imagery scales commonly used in sporting contexts. *Journal of Mental Imagery, 28(3 & 4*), 121-148.

Vella-Fondacaro, D., & Romano-Smith, S. (2023). *The Impact of a Psychological Skills Training and Mindfulness-Based Intervention on the Mental Toughness, Competitive Anxiety, and Coping Skills of Futsal Players—A Longitudinal Convergent Mixed-Methods Design*. Sports, 11(9), 162. https://doi.org/10.3390/sports11090162

Wakefield, C., & Smith, D. (2012). Perfecting practice: Applying the PETTLEP model of motor imagery. *Journal of Sport Psychology in Action, 3(1*), 1-11. doi: https://doi.org/10.1080/21520704.2011.639853

Wallace. S. A., & Hagler, R. W. (1979). Knowledge of performance and the learning of a closed motor skill. *Research Quarterly, 50*, 265-271.

Weinberg, R., Butt, J., & Knight, B. (2003). The relationship between the use and effectiveness of imagery: An exploratory investigation. *Journal of Applied Sport Psychology, 15*, 26-40.

Wilco, D. (2018). Why the free throw is the most important shot in college basketball. NCAA. COM. Retrieved from https://www.ncaa.com/news/basketball-men/article/2018-12-12/why-free-throw-most-important-shot-college-basketball

Williams, E. J. (2021). *Conquering the charity stripe: a literature review on the biomechanics of free throw shooting* (Doctoral dissertation).

Willimas, S. E., Cooley, S. J., Newell, E., Weibull, F., & Cumming, J. (2013). Seeing the difference: Developing effective imagery scripts for athletes. *Journal of Sport Psychology in Action, 4*: 109-121.

Williamson, S. J., & Kaufman, L. (1989). Advances in neuromagnetic instrumentation and studies of spontaneous brain activity. *Brain Topography*, 2, 129-139.

Wissel, H. (2004). *Basketball: Steps to Success.* Human Kinetics. Champaign, IL.

Wolf, S., Brolz, E., Keune, P. M., Wesa, B., Hautzinger, M., Birbaumer, N., & Streuhl, U. (2015). Motor skill failure or flow-experience? Functional brain asymmetry and brain connectivity in elite and amateur table tennis players. *Biological Psychology, 105*, 95-105.

Wu, J, Chueh, T., Yu, C., Wang, K., Kao, S., Gentili, R. J., Hatfield, B. D., & Hung, T. (2023). Effect of a single session of sensorimotor rhythm neurofeedback training on the putting performance of professional golfers. *Scand J Med Sci Sports, 34:e14540*. doi: https://doi.org/10.1111/sms.14540

Wu, C., Lo, L., Lin, J., Shih, H., & Hung, T. (2007). The relationship between basketball free throw performance and EEG coherence. *International Journal of Sport and Exercise Psychology, 5(*4), 448-450. doi: 10.1080/1612197X.2007.9671846

Xie, S., Kaiser, D., & Cichy, R. M. (2020). Visual imagery and perception share neural representations in the alpha frequency band. *Current Biology, 30*, 261-2627. doi: https://doi.org/10.1016/j.cub.2020.04.074

Xiao, Y. M., Wang, Z. M., Wang, M. Z., & Lan Y. J. (2005). The appraisal of reliability and validity of subjective workload assessment technique and NASA-task load index. *Chinese Journal of Industrial Hygiene and Occupational Diseases, 23*(3), 178-181. doi: 16124892

Young, S. (2014). NBA: How crucial are free throws to championship success?

Fansided. Retrieved from https://hoopshabit.com/2014/10/10/nba-free-throws-championship-success/

Zhu F. F., Poolton, J. M., Wilson, M. R., Maxwell, J. P., & Masters, R. S. W. (2011) Neural co-activation as a yardstick of implicit motor learning and the propensity for conscious control of movement. *Biological Psychology, 87*, 66-73. doi: 10.1016/j.biopsycho.2011.02.004