Contextual Interference in Motor Imagery Practice: How far can Functional Equivalence go?



Thesis submitted in accordance with the requirements of Liverpool Hope University for the degree of Doctor of Philosophy.

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Dedications and Epigraphs

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You will all, always be alive and well in my memories.

"If I have seen further, it is by standing on the shoulders of giants" - *Isaac Newton*

"A hundred times every day I remind myself that my inner and outer life are based on the labours of other men, living and dead, and that I must exert myself in order to give in the same measure as I have received and am still receiving" - *Albert Einstein.*

"I always got my work done before playing." - *Edwin Moses.*

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The Author's Declaration

This thesis is an original work composed solely by the undersigned candidate in fulfilment of the requirements for the degree of PhD at Liverpool Hope University and has not been submitted previously in support of any degree qualification or course. All sources of information therein have been specifically acknowledged, and the content of the thesis is legally allowable under copyright legislation. No generative Artificial Intelligence was used in the creation of this thesis.

Signed: 

Name: Maxime Robert Milego Ansell

Date: 06/03/2026

Thesis Format

This thesis comprises a literature review, three experimental chapters, and a general discussion. This thesis is presented in a manuscript style: the experimental chapters are written as standalone publications and therefore, because of their related nature, feature a degree of repetition. Abbreviations are defined anew in each chapter to facilitate readability. All chapters follow American Psychological Association (APA) Style (7th Ed.) guidelines on formatting and referencing (American Psychological Association, 2019). References for all chapters are listed at the end of the thesis. Figure, table, and appendix numbering is not restarted in each chapter.

Thesis Abstract

Functional equivalence proposes that imagined movements involve similar neural pathways as their physical counterparts. This has encouraged the use of imagery practice to enhance learning of movement skills, especially as imagery practice is also well suited to overcome issues associated with physical practice, such as dystonia, overloading, and tension stress (Ladda et al., 2021). While the literature on functional equivalence has largely focused on the neurological overlap between motor imagery and execution, little has been done to see how they compare functionally during skill acquisition. By replicating classic skill acquisition experiments, in an action observation and motor imagery (AOMI) intervention, this research aims to further test functional equivalence and to inform optimal practice structure in nonphysical interventions. Experiments one and two use a three day AOMI intervention test for the presence of the contextual interference effect in a dart throwing intervention without physical practice. Experiment one compares learning from a low contextual interference practice structure (blocked) with a high contextual interference structure (random). Experiment two compares a no practice variability (constant) to practice that does vary (variable). After the null findings in experiment one or two and third online experiment used a simple typing task as well as parallel imagery and physical groups (blocked physical, random physical, blocked imagery, and random imagery). This provided evidence of the contextual interference effect in physical practice but not in imagery. This supports functional divergence in practice structure effects, and the lack of generalisability of the contextual interference effect.

Chapter One

Literature Review

Motor Skill Acquisition

What is a Skill?

Guthrie (1952) defines skill as an ability to reach a goal with high certainty and minimal energy and time expenditure. Knapp (1963) expands on this, describing skill as "the learned ability to bring about pre-determined results with maximum certainty often with the minimum outlay of time or an act or whole collection of actions in which there is a clearly defined goal or set of goals" (p. 3). Despite these encompassing definitions there is great variance in what can be called a skill, with classifications for clarity (Yadav & Duque, 2023). Some classify the physical nature of the skill, for example skills that use large muscle groups, with less precision, and larger movements like crawling and running are known as 'gross' skills. Conversely 'fine' skills involve smaller muscle groups, involving more precision, and smaller movements, for example sewing and playing piano (Gonzalez et al., 2019). Another method of classification is to describe the environment, specifically the predictability of the environment, and a continuum between 'open' and 'closed'. Closed skills are those in a stable and predictable environment, for example archery, sprinting, and gymnastics. Open skills have a varying and unpredictable environment, where fast decision making becomes important, for example most team sports, racket sports, and combat sports (Schmidt & Lee, 2019). Discrete, serial, and continuous skills describe how defined the beginning, or the end of the skill is. In a discrete skill, like throwing a dart, there is a clear beginning and end. Many discrete skills are often involved in team sports, like shooting, passing, heading in football. On the opposite end of this spectrum are continuous skills which have no clearly defined beginning or end, for example the act of swimming, or steering while driving. In the middle of this spectrum is serial skills which can be thought of as a series of discrete skills performed one after the other to create a new, more complex, skill. An example would be a gymnastics routine where a series of distinct skills are linked together,

each one flowing into the next. These different types of skills require different processes for performance so must be learnt in different ways (Lee & Genovese, 1988; 1989).

Gentile (2000) created a classification system that can describe a given skill as an interaction between two dimensions (Schmidt & Lee, 2019). The first dimension considers whether the body is in motion or stationary during the skill, for example hockey where the individual is constantly moving around, versus golf in which the individual is stationary. Another consideration is whether the skill requires manipulation of an object, for example sprinting where no object is manipulated and badminton where a racket is used to manipulate a shuttlecock.

This thesis will be focused on how an individual can acquire motor skills, known as motor learning. Motor learning addresses the internal processes that create change in a learner's movement capabilities that can last for an extended period (Schmidt & Wrisberg, 2004).

Models of Motor Learning.

Motor learning is a process that requires practice, which can manifest in many ways. Practice is a crucial factor responsible for the permanent improvement of motor skill performance. Subsequently, a considerable amount of research has gone into improving practice (Adams, 1964; Fitts, 1964; Marteniuk, 1976; Newell, 1981; Schmidt & Lee, 1999; Magill, 2001). Much of this literature has been dedicated to creating theoretical approaches and models aimed at improving motor learning in a wide range of contexts.

Optimal Technique Approach

Schema theory. The theory outlines general motor programs; these are abstract representations aimed at describing classes of movements that share similar characteristics. For example, overarm throwing a tennis ball, football, or ping pong ball a variety of distances could

all be classed as involving the same general motor program. General motor programs have invariant features, characteristics that do not change between variations of that skill, these are relative timing, relative force, and the sequence order. This gives individuals a framework in which they can build upon to find motor solutions. For example, having a lot of experience throwing American footballs will give an individual a framework of motor commands to more quickly learn how to pitch a baseball.

Schmidt (1975) incorporated aspects of both open and closed loop control in Schema theory. Open loop control suggests that all the information required to perform a movement, the motor commands, can be represented within the central nervous system with no need for feedback (James, 1890; Woodworth, 1899, Lashley, 1917). Adams' (1971) closed loop theory instead proposed that feedback plays an important role in action. This theory suggests that information also flows back from the movement effectors to the movement executive providing sensory information, creating a feedback loop. Schema theory addresses one of the main criticisms of open and closed control explanations which assume that the central nervous system can store a huge number of representations for the many distinct movement patterns that humans require. For example, picking up a variety of handheld objects would require a distinct representation for each. For general motor programs, once the invariant features are learnt only the relatively superficial or surface features of the skill need to be processed to refine the general motor program for a specific skill. Open and closed models also struggle to explain high levels of novel motor performance that is also seen in humans. For example, many individuals can comfortably pick up and throw an object they have never experienced before. Schema theory, however, suggests that we would need time to make this throw accurate and reliable.

A schema is a group of learned rules that controls motor commands that more accurately guide a generalised motor program. Schemas are comprised of information concerning the effectors (the parts of the body responsible for the movement), the absolute force (the force used in the movement), the absolute timing (the timing used), and the outcome of the movement (which is used as feedback to inform future movements). Sensory feedback about the relationship of these four aspects is used to update the Schema to make it more accurate and reliable in future.

Schema theory addresses the issue of novelty; the ability to produce a correct motor response to novel variation of a task. Repeated and varied experience allows the individual to repeatedly test and update their schemas to make them more robust to varying conditions. Well-developed schemas can therefore generate accurate responses, in a variety of performance conditions. For example, accurately putting on a variety of golf courses from a variety of positions on the green, that are novel to the golfer. With practice, these schemas become more developed, and the learner becomes less reliant on feedback and instead relies more on open-loop control. Schmidt (1975) suggests that this reduces the cognitive burden and allows for the faster processing required in complex skills. Two types of schemas are identified to explain this shift from learning with feedback, to open-loop control. Recall schemas can select and initiate a specific motor response from a range of possible responses based on the requirements of the task. Recognition schemas use the sensory consequences to evaluate the response. Recall schemas are developed by using the stored information about the initial conditions (starting-point values), response specifications (what's needed), while recognition schemas are formed by the sensory consequences (how it felt) and response outcomes (results of the movement). Through practice, this information is linked together to develop schemas, allowing the learner to use the information in novel initial conditions.

Schema theory has received strong empirical support and has been widely used in clinical and applied teaching fields (for a review see Shea & Wulf, 2005). It is well established with newer models of motor learning basing themselves on schema theory predictions (Moxley, 1979; Shea & Morgan, 1979; Shea & Zimny, 1983; Lee & Magill, 1983; Lee et al., 1985). Evidence of prestructured motor programs have been demonstrated (Schmidt, 2003). Muscle activation sequences are still executed even when the movement of the limb is unexpectedly restrained (Wadman et al., 1979). This experiment demonstrated the body's reliance on recalling distinctive preplanned motor commands, rather than dynamically changing with the environment. However, Shea and Wulf (2005) caution that theories of motor learning and control should not be based solely on schema theory and the concept of motor programs. Schmidt (2003) also concludes that an explanation of motor learning can be achieved without schema theory.

Specificity of Practice. Proteau (1992) created the specificity of practice hypothesis based on earlier work that compared short and long durations of practice, with and without knowledge of results (Adams et al., 1972; Elliott & Jaeger, 1988; Proteau et al., 1987). The hypothesis predicts that learning develops from sensory information that is related to the skill. Specifically, information that is most likely to facilitate optimal accuracy. This addressed the debate over the way sensory feedback is used during motor learning. One argument centred around the belief that as a motor program becomes more developed, it has better control over movement in the absence of peripheral feedback (Keele, 1968). This is because well learned movements can rely solely on the motor command and become less dependent on sensory feedback as. The other argument believes that skill production requires effectively using sensory feedback, meaning the feedback becomes more important as skill increases (Adams, 1971). The specificity of practice hypothesis addresses this debate by suggesting that as an individual repeatedly performs a skill, a representation is developed of the expected sensory

feedback the individual will receive when performing. This representation of the expected sensory feedback is then compared to the actual sensory feedback received when performing, similar to the feedback loop described in the forward model (Sperry, 1950; Wolpert, 1997). Proteau et al. (1992) presented evidence where, during acquisition, participants were only shown the target, with the rest of the room being dark. They found that after the acquisition phase, increasing the visual information, by lighting up the rest of the room, would negatively affect performance. This effect became more pronounced if participants had experienced more practice trials during acquisition. This also explains the especial skills phenomenon, where specific variation, of a highly practised skill, becomes significantly better than other, closely related, variation of the skill (Keetch et al., 2005).

The specificity of practice hypothesis has since been developed to address criticisms. For example, Soucy and Proteau (2001) counter the proposal of a single sensory representation which contains information from all the different senses (multimodal). Instead suggesting that a representation is developed using information from the most task relevant sensory information, for example the visual information in darts. Tremblay and Proteau (2001) support this, suggesting that during practice the sensory information that results in the greatest success, will become progressively dominant over feedback from other senses. If this dominant source of sensory information is removed or interfered with, performance suffers. This is compounded if other task relevant sensory information (non-dominant) has been neglected and unused in practice. Elliott et al. (1995) suggested an alternate conceptualisation of the effect, instead of a sensory representation, practice results in motor commands that are triggered using the sensory information that is available in the practiced situation. This is used to explain how transfer performance is dependent on the similarity of the new procedures. The more the sensory information present during transfer is similar to that in acquisition, the more likely that the transfer task will trigger any successful motor commands learned during acquisition (Elliott et

al., 1997). Regardless of the debate surrounding the exact nature of the hypothesis, the specificity of practice hypothesis has been demonstrated using a wide range of tasks involving aiming (Elliott et al., 1997; Proteau & Cournoyer, 1990), precision walking (Proteau et al., 1998), balance (Robertson & Elliott, 1996a), gymnastics (Robertson & Elliott, 1996b), and powerlifting (Tremblay & Proteau, 1998). Coull et al. (2001) points out that the majority of this research only involves the removal of the visual information and that more research needs to be conducted that involves the other sensory information available during performance, like haptic and auditory information.

Repetitive Learning. The repetitive learning model, arguably as old as humankind, aims to change behavior or thinking by consistently attempting a task (Schöllhorn et al., 2022). It was first brought into the scientific literature with descriptions of how repeating cognitive content influences learning and forgetting curves (Ebbinghaus, 1885) and could condition behaviour (Pavlov, 1927). While this learning method has shown to be effective, especially in predicting performance during practice, the repetitive nature of it may be less optimal for retention or transfer performance (See contextual interference section, Jacoby, 1978; Cuddy & Jacoby, 1982; Lee & Weeks, 1987; Weeks et al., 1987). Repetitive learning requires the encoding context, at acquisition, to be the same as the context during retrieval or performance. This means transfer performance suffers as the context is different from acquisition (Tulving, 1979; Bransford et al. 1979; Battig, 1979). According to Deficient-processing theory (Callan & Schweighofer, 2010) repetitive practice leads to a high feeling of knowing (Zechmeister & Shaughnessy, 1980) which leads to a reduction in attentive maintenance rehearsal. Attentive maintenance rehearsal involves working memory processing, which is needed for long term storage of procedural knowledge about the task. Reducing the attentive maintenance rehearsal therefore had negative effects on retention (Callan & Schweighofer, 2010). For example, repetitive learning may be good for learning especial skills where the skill varies very little

each time, like a basketball free throw (see specificity of practice section Keetch et al., 2005), or if learners are novices to the skill (Del Rey et al., 1982). It is, however, rarely optimal for learning a slightly varied version of the skill (Gerson & Thomas, 1977; Moxley, 1979). For example, when learning a golf putt, repetitive learning would suggest repeating the same putt from the same place repeatedly to quickly learn the skill. However, as golf requires accurate putting from a range of distances, repetitive practice would be sub-optimal.

Challenge Point Framework. Guadagnoli and Lee (2004) looked at the interacting effects of two constraining variables: skill level and task difficulty. This aimed to investigate the notion of an optimal challenge point; a point where skill level and task difficulty are balanced so the level of challenge is optimal for learning gains. Practice at this optimal point is then specific to the individual's needs, so will account for individual differences in ability, experience and learning speed. Task difficulty had already been understood as a key, although often implicit, variable in motor learning research (Fleishman & Quaintance, 1984; Gentile, 1998). Guadagnoli and Lee (2004) suggest a two-part conceptualisation to task difficulty. Firstly, nominal task difficulty is the consistent amount of task difficulty, regardless of the characteristics of the performer (like experience) and conditions of the task being performed (like the weather). For example, a long distance putt from across the green is considerably more difficult than a short two meter putt, no matter the player or the environment. Functional task difficulty, on the other hand, is the task difficulty relative to the skill level of the performer and the conditions surrounding the performance. For example, a long-distance putt in high wind and rain would more negatively affect a novice player relative to a professional player who would be better able to cope with the conditions and the task.

The success of the theory has been demonstrated by many lab and field researchers (see Balali et al., 2019, for a comprehensive list). There have been successful applications in many

settings such as medical education, in understanding speech developments and disorders as well as in children's sports (Guadagnoli et al., 2012; Rvachew et al., 2016; Balali et al., 2019). This has led to the creation of measures, both physiological and self-report questionnaires, to aid interventions that use this theoretical approach (Akizuki & Ohashi, 2015). Frameworks for the application of the theory in coaching have also recently been developed (Hodges & Lohse, 2022). In golf putting, an individual could putt from various distances while recording their success and failure. Their optimal challenge point is where the task difficulty is highest (they are furthest away from the hole), just before the point where they are consistently missing. For example, the place on the green where an individual would make a putt 70-80% of the time.

Action Observation. It is well-documented that observing an action performed by another can improve the observer's subsequent performance of the same action (Castiello et al., 2002; Gianelli et al., 2008; Hardwick & Edwards, 2011; Ste-Marie et al., 2012). Action observation is used in neurorehabilitation (Buccino, 2014) and to improve sports performance (Polzien et al., 2019). Matching one's own movements to the movements of another (or a model) is known as modelling and is the basis of observational learning (Wohlschläger et al., 2003). The similarity hypothesis states that the model and observer should be as similar as possible to maximise the observer's learning (Braaksma et al., 2002; Rohbanfard & Proteau, 2011a; Calvo-Merino et al., 2005; Platow et al., 2008). While the support for this hypothesis is extensive it is not unanimous (Field et al., 2001; Groenendijk et al., 2013; Rohbanfard & Proteau, 2011b). The similarity hypothesis specifically suggests matching the model and learners' ability, gender, and physical characteristics to optimise observational learning. For example, matching dominant handedness (Braaksma et al., 2002; Rohbanfard & Proteau, 2011a), gender (Braaksma et al., 2002), and race (Kang et al., 2021). The suggestion of matching models and learners' perceived ability (Schunk, 1987, 1991, 1998), has been countered by suggestions that having models who are more skilled than learners is optimal

(Martens et al. 1976; McCullagh et al. 1989; Lee et al. 1994; Al-Abood et al. 2001; Heyes & Foster 2002; Hodges et al. 2003; Bird & Heyes 2005). More recently others have suggested that models with a range of abilities are best for observational learning (Rohbanfard & Proteau, 2011b).

The mechanism of the similarity hypothesis relies on the idea that action observation accesses the same motor representations used in planning and executing the given skill (Caspers et al., 2010). This allows the observer to better understand the intentions of the movements involved (Lacoboni et al., 2005; Rizzolatti & Sinigaglia, 2010). The overlap in neurons used in motor execution and observation, known as mirror neurons, also supports the idea that action observation accesses the same motor representations as physical execution (Rizzolatti et al., 1996; Grèzes & Decety, 2001; Rizzolatti & Sinigaglia, 2007). The same cognitive processes also appear in both observational and physical learning (Blandin & Proteau, 2000). Knowledge of the results is available during observational learning which also explains why action observation can lead to improved motor learning (Ste-Marie et al., 2012). There are, however, known differences between physical and observational practice. For example, reducing the knowledge of the results can have a more beneficial effect on observation learning when compared to physical learning (Badets & Blandin, 2004). Despite the similarities and differences between the two modalities, a combination of observational and physical practice is thought to be optimal (Shea et al., 2000). Specifically, doing physical practice after action observation improves movement accuracy. It is also clear that action observation can facilitate learning without physical practice, making it useful in applied situations (Zihlman, 2006). In golf for example, action observation could simply be achieved by watching professional golf players putt repeatedly on different courses with various third person camera angles or watching a first-person view of a golf putt with correct form.

Practice Variability. According to schema theory (Schmidt, 1975, see page 14), producing an accurate response to a novel variation of a task is achieved by developing a robust schema. This involves repeating the invariant elements of the skill (order of events, relative force, and timing of the movement), while varying the other elements (effector, absolute force, absolute timing, desired outcome, initial conditions, response specifications, sensory consequences and, response outcomes). Schmidt (1975) proposed that practicing variations of a task strengthened the schema, and improved transfer performance, as those with more variable experience will be better equipped to perform under new parameters. He cited evidence from earlier experiments that show increasing task variation leads to improved transfer performance (Duncan, 1958; Ellis, 1965). This prediction of schema theory, specifically the benefits of variable practice on transfer performance, was subsequently empirically supported (Gerson & Thomas, 1977; Moxley, 1979; Newell & Shapiro, 1976; Wrisberg & Ragsdale, 1979; Shea & Kohl, 1990; Landin et al., 1993; Wulf & Schmidt, 1997; Yao et al., 2009), some of which demonstrate the effect is more pronounced in young children with more novel tasks (Moxley, 1979; Shapiro & Schmidt, 1982). These predictions also seem most prominent in open, rather than closed, tasks (Barreiros et al., 2007).

An example of variable practice would be a basketball player practicing shooting from different points on the court (adding variability). Each shot uses the same generalised motor program, with the same invariant features. However, varying the distance and angle relative to the basket will produce a schema that can be used when shooting from anywhere on the court. Here the opposite of variable practice would be constant practice where all the elements of the skill remain the same, for example repeatedly shooting a basketball from the free throw line.

Much of the empirical support has been criticised for not factually addressing the variability hypothesis specifically in the context of schema theory. Schemas are described as taking considerable experience to develop, yet extended practice duration is not present in

much of the variable literature (Van Rossum, 1990). This criticism, however, does not undermine the empirical evidence that increasing variability during practice can improve learning. Specifically, the potential practical applications in real world learning contexts (Shea & Kohl, 1990; Travlos, 2010; Shoenfelt et al., 2002) when using different modalities of skill acquisition (like observational learning; Bird & Rikli, 1983). Recent research on the topic aims to explain more clearly the individual differences of variable and constant practice effects (Pacheco & Newell, 2018). This aims to address more recent criticisms that question the extent that variability of practice aids learning, by understanding the interacting effect that individual differences (for example relevant experience) have on the variable practice (Cardis et al., 2018; Hossner et al., 2016). A recent focus of this field is on a theoretical optimal variability of movements, providing the right amount of challenge for a given individual (see challenge point framework, Guadagnoli & Lee, 2004). This may also address ambiguity in practice variability research and further an individual differences approach (Stergiou et al., 2006; Ruano et al., 2022). This optimal level of variability can also be explained through an ecological dynamic's perspective (Harrison & Stergiou, 2015).

Another criticism of the research that compares variable and repetitive constant practice (with no variability) is that constant requires so little cognitive engagement that participants are susceptible to boredom (Davids, et al., 2008). Those in variable practice groups, however, often practice variations that are closer to the transfer task, giving them an unfair advantage (Davids, et al., 2008). If the transfer task is the same as the task performed during constant practice it has been shown that the especial skill effect can emerge, resulting in improved learning from constant practice when compared to variable practice (Breslin et al., 2012).

In the golf putting example used previously, variable practice could be elicited by asking the individual to putt from various distances from the hole, varying the gradient between the golfer and the hole would also work.

Contextual Interference Effect

In the real-world motor learning, it is rare that an individual is only concerned with learning one specific instance of skill, for example high jump. It is more common that multiple variations of a task are learnt, like golf putting from different distances. It is also common that a performer must learn multiple skills, for example passing, dribbling, shooting, and heading in football to successfully perform. When learning these skills together, the learner can experience interference, where the learning of one skill affects the learning of another skill. This was originally known as 'transfer effects' and could be positive, where learning one skill helps another, or negative, where one skill inhibits the learning of another skill. Positive transfer was named 'facilitation' and negative transfer was named 'interference' (Gagne et al., 1950; Battig, 1966). Facilitation usually occurs when the two skills involve similar features that can be transferred over. For example, a marathon runner with good aerobic capacity and muscular endurance in his legs, will likely take well to endurance cycling. However, a badminton player, who relies on wrist movements to generate power in their shots, may develop poor form when learning tennis which involves little wrist movement and generates power from larger shoulder movements.

One of the most researched and established theories of motor learning known as the contextual interference effect, shows how practice structure can lead to interference and facilitation. Contextual interference involves the practice of multiple skills in a randomised order, meaning that individual switches repeatedly between learning different skills. The contextual interference effect is a phenomenon where when practicing under higher levels of contextual interference, acquisition performance is inferior when compared to practice

involving lower levels of contextual interference. However, during subsequent retention and/or transfer performance, practice involving higher levels of contextual interference will outperform practice under lower levels of contextual interference. The contextual interference effect was originally put forward by Battig (1966), and subsequently expanded on (Battig, 1972; 1979; Shea & Morgan, 1979; for reviews see Magill & Hall, 1990; Brady, 1998; Ammar et al., 2023; 2024; 2025; Czyż et al., 2024a; 2024b). The effect was originally observed when learning several variations of a verbal task (Battig, 1966). Practicing the different variations of the verbal tasks was beneficial to learning when measured with retention and transfer tasks. Maslovat et al. (2004) showed that with enough practice, acquisition performance in a high interference group can reach superior levels of performance than acquisition performance from a low interference group. Jones et al. (2020) also showed that long-term cricket batting development is likely enhanced by more random and varied practice in earlier stages of their training (age 16 and younger). This style of practice acts to increase the nominal difficulty, helping them transition to elite level games, which involve a more varied style of play (batting against various spin and fast bowls).

Inter-task and Intra-task processing. In the original explanation for the contextual interference effect (Battig, 1966) two qualitatively different methods of processing were outlined, inter-task, and intra-task, also known as interitem and intraitem processing (Shea & Zimny, 1983). Inter-task processing, in the context of motor learning, involves comparing different tasks (between tasks) to improve distinctness of task information (or schema, see page 14). For example, kicking a football, dart throwing, and a badminton serve involve distinctly different general motor programs so practicing them together would elicit inter-task processing and subsequently the contextual interference effect. The multiple tasks reside simultaneously in working memory and so risk interfering with one another, requiring more distinction between tasks. Intra-task processing, however, involves developing associations between

features and characteristics within a specific task (the schema for a given generalised motor program). For example, developing associations between the different features of a golf shot. The same generalised motor program is used to perform a golf chip shot or a putt, but the different features and characteristics of those two shots must be distinguished. The same applies to the even more subtle differences between a shorter-range putt and a longer-range putt. Intra-task processing involves only processing one generalised motor program in working memory and so invokes lower levels of the contextual interference effect (Baddeley, 1981; Shea & Zimny 1983, 1988; Brady, 1998).

Blocked and Random Practice. To elicit inter-task processing, different tasks must be practiced in a random order; this elicits more interference when compared with a blocked practice structure. For example, if practicing a football free kick, a random structure would be one passing drill, one dribbling drill, a free kick, a dribbling drill, a passing drill, a free kick … and so on, with the same practice condition never repeating and in a randomised order. A blocked practice structure would involve ten repetitions of a dribbling drill, ten repetitions of passing drills, and then ten free kick practice shots. While this blocked structure had originally been proposed to be optimal (Pyle, 1919), Battig (1966) showed that randomising the structure of practice causes more interference and increases retention and transfer performance. Inter-task processing is more prominent when practicing tasks that involve distinctly different motor commands (schemas). There is also less intra-task processing as there is more time between similar trials in random practice. In random practice other tasks enter the working memory which will make it harder to draw upon the motor commands used in previously practised tasks (Baddeley & Hitch, 1974). Intra-task processing is more prevalent in blocked practice as the differences between each trial of the same task, within each block, are processed and understood. Previous trials of the same task can be easily held and compared in the working memory model, provided that the intertrial duration is kept to a minimum (Kim et al., 2015).

Explanations for the Contextual Interference Effect

Elaboration hypothesis. Originally proposed by Battig, (1966) but expanded on experimentally by Shea and Morgan (1979) and theoretically by Cuddy and Jacoby (1982) and Shea and Zimny, (1983). The hypothesis assumes that repeated experiences of a to-be-learnt task creates more features to the schema (Schmidt, 1975). Increasing its memorability by increasing the distinctiveness of the schema (Cuddy & Jacoby, 1982; Fisher, 1981; Hunt & Einstein, 1981; Winograd, 1981). Distinctiveness in schema theory refers to the degree that a specific schema shares features with other schemas. The fewer shared features the more distinctive and therefore increases the ease of selecting the correct schema during performance (Schmidt, 1975). The development of distinctive schemas is said to be aided by increasing the elaboration of the schema (Fisher, 1981; Winograd, 1981). Elaboration is increased by using multiple and varied learning experiences that involve different processing strategies (Shea & Zimny, 1983). For example, during random practice, the similarities and differences between the tasks are emphasised to a greater degree than blocked practice, facilitating elaboration and therefore increasing distinctiveness.

The elaboration hypothesis has been supported with experimental evidence that observes the effects of a varied number of related secondary tasks, on the learning of a primary task (Shea & Kohl, 1991). When the primary is paired with multiple secondary tasks, retention is shown to be superior than if there is no secondary task. However, only having one secondary task is shown to be most effective. Shea and Kohl (1991) explain that the presence of a secondary task facilitates learning, though elaboration. That having multiple items reside in working memory facilitates elaboration. However, they suggest that variation of the task is key to retention performance, suggesting elaboration is the driving force behind the benefits of contextual interference. The findings show that variable task experiences improved retention when compared to increasing additional trials of practice with the primary task or practice of

an unrelated task. Other similar work has supported this finding and the elaboration perspective in motor learning (Wright, 1991; Wright et al., 1992) and with verbal tasks (Shea & Zimny, 1998).

Elaboration has been supported by neuroscience by the finding that when adding perturbation to blocked and random practice, via transcranial magnetic stimulation (TMS) to the M1. TMS to the M1 aims to induce forgetting but does not improve blocked practice and deteriorates random practice when compared to no TMS (Lin et al., 2008). A review by Lage et al. (2015) concluded that different practice structures involve distinct neural processes. For example, the dorsolateral prefrontal cortex is associated with motor-skill retention and transfer in random practice, while the M1 is associated with retention in constant practice (Kantak et al., 2011, Kantak et al., 2010). The review concludes that to understand how different practice conditions invoke different neural processes, an integrated neurological and behavioural approach is needed. In the future this can help test which hypothesis better accounts for the contextual interference effect (Lage et al., 2015). It is, however, important to consider that multiple explanations for the contextual interference effect may interact. Some suggest elaboration works in isolation (Lin et al., 2008; Shea & Zimny, 1983), while others believe that multiple explanations collectively explain the contextual interference effect (Gabriele et al., 1989; Young et al., 1993; Yuhua, 1994).

Action plan reconstruction hypothesis. Lee and Magill (1983; 1985) highlighted that motor learning involves a process of problem-solving to find the best motor solution for the task goal (Adams, 1971; Bernstein, 1967). In the case of motor learning this involves developing an action plan to achieve the desired movement outcome. During blocked practice, the action plan is primarily acquired through recall, as it is still readily available in the short-term memory from the previous attempts. As the construction of the action plan is primarily created from recall it relies less on reconstruction. By using a random practice structure, the

action plan is ‘forgotten’ and no longer in the short term memory, as the action plan in short term memory is repeatedly replaced by the new alternating task. This means, according to the hypothesis, that the action plan must be reconstructed without as much assistance from short-term memory retrieval processes. This explains the poorer performance in blocked practice when compared to random in a similar fashion to deficient-processing theory (Callan & Schweighofer, 2010). During retention or retrieval however, where short term memory recall is unavailable, random practice groups outperform blocked practice groups. The suggestion is that learning through repetition is enhanced when short term memory is not relied upon. This has been established previously in verbal recall memory tests (Jacoby, 1978; Cuddy & Jacoby, 1982) and motor tasks (Lee & Weeks, 1987; Weeks et al., 1987) often being referred to as the spacing of repetitions effect. Lee et al. (1997) also found support for action plan reconstruction. Using an auditory cue that played just before performance during random practice, Lee et al. (1997) observed a reduction in the beneficial effects of random practice over blocked. Suggesting the auditory cue facilitated the reconstruction, assisting short term memory retrieval, and reducing the cognitive requirements of reconstruction during random practice.

As with the original interference effect, the action plans for the different skills interfere with one another, making the reconstruction of each one more difficult but more defined, aiding learning and retention performance (Lee & Magill, 1983; 1985). The action plan reconstruction hypothesis has also led to the ‘between-trial forgetting long-term retention hypothesis’ (Kim et al., 2015). Here the amount of between-trial forgetting during training, caused by the intertrial duration and interference, is the predictor of performance during acquisition and retention. Stating that if the intertrial duration is shorter, then training performance is improved but retention is poorer, than when compared to a longer or varied intertrial duration. A longer or varied intertrial durations leads to poorer performance during training but superior retention (Kim et al., 2015). The explanation for this hypothesis differs from action plan reconstruction

hypothesis, here forgetting between trials is suggested to increase errors during training, which can improve learning (Voelkel, 1924; Holding, 1970; Singer & Pease, 1976; Østergaard, 2016). This explanation uses a two-state model of learning processes, (Smith et al 2006), which states that there is a fast process to learning, which responds strongly to error but has poor retention, and a slow process which responds weakly to error but retains information well. The increase in error, that results from an increase in intertrial duration, results in more effectiveness of the slow process, through an increase in error feedback. This in turn leads to an increase in retention (Kim et al., 2015). This between-trial forgetting, long-term retention hypothesis also allows for other error-based explanations of learning, such as the 'elaboration hypothesis' (see page 27).This research demonstrates the importance of considering the 'intertrial intervals' during practice which, like interpolated tasks, can cause forgetting of previous motor solutions, and force the creation of a new solution for each new trial.

A critique of the original paper (Lee & Magill, 1983; 1985) was the lack of a detailed definition of an 'action plan'. Some criticize the use of this terminology (Newell, 1978) and prefer the use of generalised motor programs in the explanation of the model (Lee et al., 1992). The predictions from the action plan reconstruction hypothesis have received mixed empirical support, mostly supporting (Immink & Wright, 1998; Lee et al., 1997; Boutin & Blandin, 2010), while others counter it (Lin et al., 2008).

Error Processing Explanation. Much of current research in contextual interference focuses on learning perceptual-*motor* skills, where sensory information is used to generate movement (James, 1890; Woodworth, 1899, Lashley, 1917). Memmert et al. (2009) showed that the contextual interference effect could also be demonstrated in the learning of perceptual-*cognitive* skills. Perceptual-cognitive skills involve locating, identifying, and processing sensory information from the environment, while integrating it with previously stored knowledge in order to generate the appropriate action (Marteniuk, 1976). Broadbent et al.

(2017) investigated the elaboration and action plan reconstruction hypotheses, specifically in perceptual-cognitive skills learning, to test the generalisability of these explanations. In the first experiment in Broadbent et al. (2017) demonstrated an increase in cognitive effort during random practice, when compared to blocked practice. Using virtual tennis shots, participants were asked to predict the direction of three different types of shots performed by a virtual opponent: forehand groundstroke, forehand smash, and forehand volley. The accuracy of their prediction was measured by asking participants to verbally recall the anticipated direction of the shot (one: left short; two: right short; three left deep; four; right deep). After a pre-test, participants were split into two groups. A blocked group would practice predicting a block of the same type of shot (e.g. ground stroke) before moving on to a block of a different type of shot (e.g. forehand smash), and then a block of the final shot (e.g. forehand volley). Another group practice with a in a quasi-random order where none of the three shot-types was repeated more than twice in a row. A tone identification task was included as a secondary task, either a high (2,500 Hz) or a low frequency (300 Hz) tone was played for 240ms. Tones were presented at different points during each trial in acquisition, and participants were asked to respond verbally for both tasks as quickly as possible. During acquisition, reaction time in the tone identification task was significantly slower in the random group when compared to the blocked group. This suggests higher cognitive effort when contextual interference is increased, validating the predictions of both the action plan reconstruction and elaboration hypotheses. In the retention task the random practice group also outperformed the blocked group showing the contextual interference effect was present in the experiment.

The second experiment, in Broadbent et al. (2017), used the same task with four groups, a blocked and random group both with and without a secondary task. Instead of a tone identification secondary task, a more cognitively demanding stroop test was used as the secondary task (Stroop, 1935; MacLeod, 1991; Kane & Engle, 2003, see Appendix One for a

description of a stroop task). In the random group without a secondary task, they found the decision time was slower after an error in the previous trial, when compared to the other three groups. They suggested this was evidence that, during random practice, there is an increase in error processing that interferes with the next trial, an idea originally put forward by Lam et al. (2010). This increase in error processing in random practice explains why random practice results in superior learning effects, when compared to blocked practice. They also compared results of the blocked and random groups with the secondary (stroop) task, again after trials with and without an error in the primary tennis task. They found that for the random group, if there was an error in the primary task then secondary stroop performance was significantly poorer when compared to errorless instances of the primary task. Stroop performance after blocked practice was similar regardless of error. In the random group the decrease in secondary (stroop) task performance after an error also supports the suggestion that there is an increase in error processing during random practice. The contextual interference effect, however, was not found between these two groups. This may be a result of the participants struggling to cope with the additional cognitive load from the secondary stroop task, prioritising the primary task over this secondary task.

Blocked Practice Explanation. An alternate explanation for the contextual interference effect suggests that blocked practice results in retroactive interference or inhibition. This negatively affects performance after blocked practice, and results in random practice appearing to be superior. Poto (1988) first suggested that blocked practice negatively affected retention performance, critiquing other explanations of the contextual interference effect. For example, skill A is practiced ten times, then skill B is practiced ten times, and then skill C is practiced ten times. When measuring retention performance for skill A, an individual will likely underperform as not only was it practice further back in time but also there is the retroactive interference (more recent skill learning hindering previous learnt skills, Underwood, 1945)

which is caused by learning skill B and C. The opposite view of retroactive interference is proactive interference (previously learnt skills hindering current skill learning, Underwood, 1945) where the practice of skill C is negatively affected by the previous practice of skills A and B. By comparing experimental groups that would perform blocked practice of different skills in different orders, Poto (1988) showed that retroactive interference had a negative effect on retention performance. These findings were also supported by findings from Davis (1988) and Del Rey et al. (1994), who performed similar experiments. Meeuwsen (1987) also supported this explanation by assessing retention after every 'block' of blocked practice. Meeuwsen (1987) show that when secondary tasks were practiced after the primary task, it would negatively affect the retention performance of the primary task, demonstrating retroactive interference. Shea and Titzer (1993) and Shewokis et al. (1998) also support this explanation, however, they showed evidence that the retroactive interference explanation has a temporary nature, and that with more practice the effect of retroactive interference reduces.

Another model, that also used the low effectiveness of blocked practice as an explanation of the contextual interference effect, is the retroactive inhibition model (Shea & Graf, 1994). This extends Poto's (1988) original explanation, providing a deeper explanation as to the cognitive processing of the effect while integrating it with the elaboration hypothesis (see page 27). They propose a multiple level processing algorithm with three levels that can respond to the sensory input that generates the movement output. Firstly, execution, which is the fastest and most automatic processing level. Secondly, programming, which can perform additional processing on the input to modify the execution. Finally, planning which can modify programming. Each level assesses its success by comparing the movement output to an internal criterion. This internal criterion is the movement solution the individual creates to produce the desired movement. If at execution, performance is not satisfactory, then the programming level (a higher level than the execution) is subsequently used to correct the internal criterion to

produce better performance. If the internal criterion is still not met, then the planning level (the highest level) aims to improve the programming of the performance to further improve the internal criterion. The process of learning through error feedback, at each of these levels, is explained by a connectionist model. This model suggests that creating the correct movement output is dependent on how well connected the activation of the input (that triggers the generation of the movement) is to the activation of the different components (each known as a unit) required to achieve a successful output. Through repetition the weight of connection between each unit is updated to ensure that the required units are activated to respond to the input. Over time the input activation more consistently activates the units required which produces the output that best matches the internal criterion. The retroactive inhibition model explains that retroactive interference disrupts this multiple level processing algorithm, causing poorer retention. However, due to the dynamical nature of this system, during blocked practice the execution can quickly be modified to produce a desired outcome through lots of repetition. This explains why blocked practice leads to better performance. However, this does not develop as much distinctiveness (see elaboration hypothesis) or create as much error processing (see error processing explanation) as random practice. This causes random practice to outperform blocked practice in retention tests.

Like the retroactive interference explanation this model has received a great deal of empirical support (Meeuwsen, 1987; Shea & Titzer, 1993; Del Rey et al., 1994; Shewokis et al., 1998) In more recent years with the help of neuroimaging the effect of retroactive interference has been supported but also separated from the contextual interference effect, as contextual interference can still be observed when retroactive interference is controlled for (Thürer et al., 2019). This neuroimaging evidence supports an integrated explanation of contextual interference (Gabriele et al., 1989; Young et al., 1993; Yuhua, 1994).

The Task Similarity Debate. An aspect of Battig's (1966) original hypothesis that has been heavily debated is the effect of task similarity. This debate extends from the inter/intratask paradigm and focuses more specifically on the extent that the tasks practised in a random practice schedule should be similar or differ from one another (Lee et al., 1992). Battig (1979) observed that practicing tasks that were more similar to each other, increased confusion in the learner, thus promoting more interference, when compared to practicing tasks that were more different. Magill and Hall's (1992) review of the literature argued against Battig's hypothesis, finding the contextual interference effect is more evident when practicing tasks ruled by different generalised motor programmes. Lee et al. (1992) states that these predictions are contingent upon how one defines task similarity, suggesting the ambiguity of what constitutes as an action plan in Lee and Magill (1985) as a cause of confusion. This prevents the integration of the action plan reconstruction explanation of the contextual interference effect, and the predictions of schema theory. Specifically, the extent an action plan and a schema differ or overlap, is unclear. Issues with the term action plan have long been criticised (Newell, 1978). Lee et al. (1992) set out to address this debate regarding task similarity by comparing random and blocked groups that practiced different variations of a target movement timing task. Random and blocked groups practiced using different movements with the same relative timing (increasing intra-task processing). This was compared to random and blocked groups who practiced with different relative timings (increasing inter-task processing). As relative timing is an invariant feature according to Schmidt schema theory (see page 14) the different relative timing groups were using distinct generalized motor programs for each task. The groups that practice with the same relative timings were practicing only one generalised motor program at varying speeds. The results agreed with Magill and Hall's (1992) prediction that using distinct inter-task motor programs (i.e., the different relative timing groups,) the contextual interference effect is more pronounced due to the increased processing required (Quinn & Sherwood, 1983).

The contextual interference effect was not observed in the random and blocked groups that used more intra-task processing (using the same relative timings and therefore the same general motor program).

Sekiya et al. (1994) extends this line of thinking by dividing learning (measured through retention) into the acquisition of general motor programs and parameter learning. Parameter learning is the acquisition of task variations that share the same invariant features (so are using the same general motor program) but vary in terms of parameters or variant features (see schema theory and variable practice). Sekiya et al. (1994) found that the contextual interference effect only improves parameter learning when using single or multiple general motor programs. However, contextual interference did not improve the acquisition of general motor programs themselves. They also observed the contextual interference effect while using variation of the same general motor program, contrary to Magill and Hall (1992). Sekiya et al. (1994) also used tasks with different, and the same, relative timings and supported these findings. Then provided further support when using variable forces in practice (Sekiya et al., 1996). This is also in direct conflict with Wulf and Lee (1993) who found that contextual interference was more beneficial for learning general motor programs but hindered parameter learning. More recent finding suggests that if the tasks become too dissimilar, as in vastly different general motor programs are used, the contextual interference is not seen (Boutin & Blandin, 2010). This, however, disagrees with the action plan reconstruction hypothesis which suggests that using dissimilar tasks facilitates forgetting, which promotes reconstruction, which increases learning. The consensus in more recent years seems to be that using both variability of parameters (within a given general motor program) and varying practice between multiple different general motor programs, creates the most interference and is optimal for learning (Boutin & Blandin, 2010; Li & Lima, 2002; Maslovat et al., 2004; Ranganathan & Newell, 2010; Ruano et al., 2022; Sherwood, 1996).

Contextual Interference and Practice Variability. The use of variation of a single task to elicit the contextual interference effect (intra-task processing) is less frequently discussed in recent meta-analysis and literature reviews on contextual interference (Ammar et al., 2023; 2024; 2025; Czyż et al., 2024a; 2024b). Intra-task processing is, however, briefly mentioned in older research (Brady, 1998; Magill & Hall, 1990). This absence of discussion on intra-task processing effects in relation to contextual interference, may be due to the use of the term 'variable practice effects' to describe the same learning effect (Duncan, 1958; Ellis, 1965; Moxley, 1979, see page 23). Variable practice effects show more varied practice (where contextual interference, specifically intra-task processing, is higher) is superior to more constant practice (where contextual interference, specifically intra-task processing, is lower) for retention and transfer performance. However, during acquisition constant practice outperforms variable practice, just like with random and blocked practice (inter-task processing).

A clear and practical conceptualisation of both inter and intra task processing has been proposed by Reid et al. (2007) and is supported by Buszard et al. (2017). This involves a spectrum of inter-task variation, one end being random (high inter-task processing) the other blocked (low inter-task processing). Reid et al. (2007) conceptualised this as another spectrum with two ends: variable (high intra-task processing) and constant (low intra-task processing), that intersects the random/blocked continuum. Reid et al. (2007) also notes that the degree of intra-task processing involved in practice is originally described as the field of "practice variability" and "variable practice effects" (Duncan, 1958; Ellis, 1965; Moxley, 1979, see page 23).

In the field of contextual interference, variable practice is indicative of high intra-task processing and involves using similar general motor program or schema while varying the invariant features of the general motor program (see page 14) for example practicing the same

motor program at different distances (Dick et al., 2000; Ranganathan & Newell, 2010) and speeds (Del Rey et al., 1982; Magill & Hall, 1990). Reid et al. (2007) and Buszard et al. (2017) shows that their conceptualisation clearly shows the possibility of combining methods of practice associated with inter-task processing (blocked and random), with the method of practice associated with intra-task processing (constant, variable). For example, comparing the effects of blocked variable practice with random variable practice (Sherwood, 1996). Lee et al. (1985) have suggested that variable practice is only advantageous when using a random schedule. This aligns with the findings of experiments containing a variable practice group that also uses a random structure (Dick et al., 2000; Ranganathan & Newell, 2010; Ruano et al., 2022). Others have said that using random practice alone has a ceiling effect on retention performance as it does not invoke *enough* inter-task processing, what is instead important is the level of challenge the learner experiences (Boutin & Blandin, 2010, Albaret & Thon, 1998, Jarus & Gutman, 2001, Guadagnoli & Lee, 2004, Wulf & Shea, 2002). Some results have also indicated that blocked and constant practice groups do not differ much in their effectiveness on retention performance (Magill & Hall, 1990).

The terminology used when testing this paradigm is also inconsistent (see the variable parameter group in Dick et al., 2000, and random group in Lee et al., 1992; Thürer et al., 2019). Some have argued that the view of variability of practice as a single construct neglects the multiple ways the variability of practice affects learning through multiple mechanisms (Ranganathan & Newell, 2013). Alternatively, the conceptualisation of two intersecting dimensions of practice structure (random to blocked) and practice variability (variable to constant) has shown to be valuable in understanding the inter/intra-task paradigm, especially in applied settings (Reid et al., 2007). The combined use of inter/intra-task processing also seems to improve learning more than using them in isolation (Li & Lima, 2002; Ranganathan

& Newell, 2010; Boutin & Blandin, 2010; Ruano et al., 2022), again supporting this two-dimensional conceptualisation.

Individual Differences in Contextual Interference. There are many known individual differences in the effectiveness of variable and constant practice (Pacheco & Newell, 2018). For example, the effect can be seen more prevalent in young children (Moxley, 1979; Shapiro & Schmidt, 1982). There has also been research to discern if there are individual differences in the effectiveness of random or blocked practice. Specifically in individuals' level of experience (Del Rey, 1989b), and gender (Del Rey, 1983a). More experienced individuals seem to benefit from random practice than individuals with less experience (Del Rey, 1989b). This may be because high contextual interference may result in learning problems for complete beginners who need to grasp the basic idea of the task (Gentile, 1972; Magill & Hall, 1990; Wulf & Shea, 2002). However, as Magill and Hall (1990) argue, fine tuning a skill to acquire a variety of movement plans in response to a subtle change in demands, pointing to the inconsistent evidence from testing the effect experience has on contextual interference (Del Rey et al. 1982a; 1982b; 1983a; 1983b; 1987). Both Del Rey (1989) and Magill and Hall (1990) agree that the specificity of the previous experience is key to understanding the interaction between experience and the effectiveness of random and blocked practice. High levels of general physical activity likely also increase the effectiveness of the contextual interference effect, which may be due to improved cognitive functioning (Del Rey, 1982b).

The effectiveness of different practice structures can also vary depending on the age of the learner. During different stages of childhood development (five, seven, and 11 years old), Jarus and Goverover (1999) found that only the seven years olds performed as predicted by the contextual interference hypothesis. Pollock and Lee (1997) compared seven year old learners with university age learners. Finding that while the contextual interference was again found in

the 7-year-old group, it was more pronounced in the university age group. There are clear differences in how context-based interference affects processing, and therefore learning, in younger (18-28 years old) and older adults (60-82 years old). Older individuals show reduced use of bilateral dorsolateral prefrontal cortex and anterior cingulate relative to young, higher performing elderly individuals compensated by recruited additional middle and medial frontal regions which are not used by low-performing elderly or young adults (Gutchess et al., 2007). More recently, meta-analyses and systematic reviews by Ammar et al. (2024) and Czyż et al. (2024a; 2024b), show that age is a significant factor. Ammar et al. (2024) shows that the contextual interference effects seem to be more prominent in young adults than in children or older adults. Czyż et al. (2024a; 2024b) suggest instead that the effect is most prominent in older adults, then younger adults, while being non-existent in children. More research comparing multiple groups, with a large range of ages, needs to be done to address these discrepancies.

Regarding the effects of sex, Del Rey et al. (1983b) showed some evidence that for boys' random practice is more effective for learning than girls but there are no sex differences for blocked practice effects. These findings, however, are based on children no older than 10, so have limited generalisability. More research is needed to make any definitive statements about sex and contextual interference.

Edwards et al. (1986) compared random and blocked practice effectiveness on subjects with and without down's syndrome finding similar effects for both. The contextual interference effects are also seen in those with learning disabilities (Heitman & Gilley, 1989) suggesting that this effect is deeply ingrained and occurs regardless of neurodivergences. However, finding groups of individuals that do not demonstrate the contextual interference effect, would likely help us better understand contextual interference. For example, Jelsma and Van

Merrienboer (1989) showed that the cognitive style of an individual can vary the effectiveness of random or blocked practice. Specifically comparing the speed-accuracy trade off in those who favour reflective or impulsive processing. A more reflective individual will typically favour an accuracy approach to performing the task sacrificing speed. However, someone with higher impulsivity will favour responding quickly and sacrificing accuracy. While individuals high in either reflection or impulsivity demonstrated the contextual interference effect, the individuals high in impulsivity showed greater benefits from the random practice when compared to those with a more reflective cognitive style.

Applying Contextual Interference. Recent research on the contextual interference effect continues to find support for the benefits of random practice on learning (Ammar et al. 2024; Czyż et al., 2024a; 2024b; Wright et al., 2016), however, the exact mechanisms of the effect are still debated (Davids et al., 2008; Broadbent et al., 2015; Kim et al., 2015; Large et al., 2021; Thürer et al., 2019). Recently the generalisability of contextual interference to learning of skills, outside of highly controlled lab conditions, has been called into question (Ammar et al., 2024; Czyż et al., 2024a; 2024b) with a call for more field-based research comparing neurophysiological as well as performance measures with other models of motor learning (Ammar et al., 2025). It has been shown that the interactions of variables in field-based research, like the task difficulty, individuals' ability and changes in the performance conditions, can weaken the contextual interference effect (Ollis et al., 2005). In applied settings the contextual interference effect seems clearest in complex serial tasks, with several elements in a prescriptive order (Barreiros et al., 2007). Research continues to find ways of optimising contextual interference. For example, when choosing other tasks in a random practice structure it is important that the tasks are relevant and do not encourage participants to use redundant solutions (Ranganathan & Newell, 2010).

In the previously used golf putting example, contextual interference could be increased by doing the following. Blocked constant practice (lowest level of contextual interference), practicing a 5-meter putt on the same course with the same equipment over and over. Blocked variable practice would then be putting from five meters twenty times, six meters twenty times, four meters twenty times, seven meters twenty times and so on. This would increase the level of contextual interference slightly due to an increase in intra-task processing. Random constant practice would increase the level of inter-task processing and therefore increase the contextual interference, for example from five meters five times, then chipping from 10 meters five times, then driving from 50 meters five times before going back to putting, then driving, then chipping, then driving and so on. Keeping the distances the same but randomising the order in which the skills are practiced. Random variable practice would elicit the most contextual interference, for example putting from five meters, then chipping from two meters, then driving from 20 meters, then chipping from 15 meters, then putting from eight meters, then driving from 70 meters, then putting from six meters and so on. Here both the type of swings, clubs used, and the distances are randomised and constantly changing from trial to trial, eliciting high levels of inter-task and intra-task processing.

Recent Meta-Science on Contextual Interference. Recently there has been a series of systematic reviews and meta-analysis on contextual interference, from two research groups, which has resulted in much debate in the field (Ammar et al., 2023; 2024; 2025; Ammar & Schöllhorn 2024; Czyż & Wójcik et al., 2024; Czyż et al., 2024a; 2024b; Czyż, 2025). The first in this series of papers was Ammar et al. (2023), who questioned the effectiveness of contextual interference in gross motor skills, in sport settings. Showing that contextual interference could be confirmed in controlled lab experiments but not in field research. Also, that there are many inconsistencies in research findings, likely due to the context dependent nature of the effect. These findings extended and largely supported trends in previous meta-analysis (Brady, 1998).

Shortly after, Ammar et al. (2024), conducted another systematic review and meta-analysis on contextual interference. Aiming to further build on the previous work by using multilevel meta-analytic modelling and focusing on performance gains (pre to post), rather than isolated time-point measures. This was to focus on learning effects. Ammar et al. (2024) found similar findings to Ammar et al. (2023), suggesting there is very limited evidence for longer-term performance advantages from contextual interference. Again, questioning the generalization of the CI model in the field, suggesting it can only be observed reliably in laboratory experiments and again highlighting the context dependent nature of the effect, namely age, experience, and task.

Around the same time Czyż et al. (2024a) conducted a systematic review and meta-analysis on the effects of contextual interference, to see how practice structure effected transfer performance in motor learning. For laboratory experiments, they found a medium effect, suggesting high contextual interference is superior to low contextual interference for transfer task performance. Like Ammar et al. (2023; 2024), these findings were not generalisable to applied research. Czyż et al. (2024a) did, however, show that age is a significant factor, specifically that contextual interference is more prominent for those who are older (see page 39). Czyż et al. (2024a) also critique some methodological choices and the conclusions drawn from Ammar et al. (2023). Czyż et al. (2024a) points out that their effect size findings align more with the previous work of Brady (1998). Czyż et al. (2024b) conducted another systematic review and meta-analysis, specifically on the effect contextual interference has on retention performance, in motor learning. Again, finding that contextual interference effects are confined to the lab and not generalisable to the field, and that age is an important factor. Czyż et al. (2024b) also repeat their previous critique of Ammar (2023) going as far to say, "the review of Ammar et al. (2023) cannot be considered reliable and valid." (p. 2).

Following these publication (Ammar et al., 2023; 2024; Czyż et al., 2024a; 2024b) both research teams increase the intensity and directness of the debate through their publications. Firstly, Ammar and Schöllhorn (2024) write a commentary on Czyż et al. (2024b) suggesting it was unfairly critical and needed corrections. Specifically, Czyż et al. (2024b) over generalised the usefulness of the contextual interference effect and had missed important points of Ammar et al. (2023), like the focus on sports settings. Ammar and Schöllhorn (2024) also argued that Czyż et al.(2024b) lacks a strong rationale. The research team led by Czyż, wrote a rebuttal this commentary in a publicly available preprint (Czyż & Wójcik, 2024), that has not yet been published. This rebuttal goes through and lists points raised in Ammar & Schöllhorn, (2024) providing more detail for the choices made in Czyż et al.(2024b). This seemingly informed the publication Czyż (2025), a commentary and critique on Ammar et al. (2024). Czyż (2025) formalises and further details points previously made (Czyż et al., 2024a; 2024b; Czyż & Wójcik, 2024) regarding the work of Ammar et al. (2023; 2024). Czyż (2025) specifically highlights issues in database selection, lack of study pre-registration, inconsistent use of definitions for contextual interference, the inclusion of papers that do not directly investigate the contextual interference effect (specifically Memmert, 2006 and Menayo et al., 2010), the lack of consideration for the context the included studies were performed in (sporting, or physical education), and finally issues with analysing only post-test results. This cumulates into the accusation that Ammar et. al. (2023) was misleading to draw more attention and generate more citations. Czyż (2025) does, however, state that Ammar et. al. (2024) was and improvement on Ammar et. al. (2023).

The final publication in this series, at the time of writing, is Ammar et al. (2025) which aims to address this debate by focusing on; the methodology of meta-analysis, the generalisability of contextual interference, while focusing on future directions in the field. Ammar et al. (2025) acts as a rebuttal to Czyż (2025) defending methodological choices used in Ammar et

al. (2024), while reflecting on meta-analytic practices, and providing a breakdown of the key components made so far in a few of the papers in this debate. Ammar et al. (2025) provided four recommendations for future research. Firstly, is a call for well-powered experiments with randomised controlled trials that isolate and compare different motor learning models. Secondly, a call to avoid repeating meta-analyses and systematic reviews that heavily overlap. Thirdly, stressing the need to control for variables such as learner expertise, dominant sensory components of the skill (visual, kinesthetic, proprioceptive), and contextual factors (task specificity, feedback type). All of which can influence the findings of research in contextual interference research. Finally, stressing the interdisciplinary nature of contextual interference and motor learning in general, urging researchers to be more reflective.

It is clear from all the papers discussed briefly above (Ammar et al., 2023; 2024; 2025; Ammar & Schöllhorn 2024; Czyż & Wójcik et al., 2024; Czyż et al., 2024a; 2024b; Czyż, 2025) that in this field there is both consensus and points of disagreement. This series of publications provide clear evidence the contextual interference effect works in lab settings but struggles to be found in field work. This suggests more work needs to be done to understand mediating and moderating factors for the effect (Ammar et al., 2025). This series of papers also repeatedly highlights the lack of clarity and consistency in the contextual interference literature. This can start to be addressed when there is agreement on the definitions and terminology (Ammar et al., 2023; 2024; Czyż, 2025). It is also clear that many of the questions raised about contextual interference will be addressed by well-powered experiments with randomised controlled trials that isolate and compare different motor learning models (Ammar et al., 2025). Much of the disagreement in this series of papers is centred around methodological approaches to meta-analyses. This must be addressed by the larger scientific community to ensure there are clear rationale and methodological procedures to ensure all meta-analyses are reliable, valid, and useful. Much work has been done already in aid of this (Sutton et al., 2001; Israel & Richter,

2011; Cheung & Vijayakumar, 2016; Seidler et al., 2019). An increase in clearer writing, would produce more reliable, valid, and useful research (Table 1 in Ammar et al., 2025, does well to bring clarity to some of the papers in this series). Clearer writing, as well as more collaborative efforts, will increase the efficiency of research in this field by reducing the need for completing commentaries, rebuttals, and heavily overlapping meta-analysis or systematic reviews.

Motor Imagery

Perception is described by Hebb (1968) as the activity that results from sensation. The human mind can manifest perception seemingly without any input from the external world that usually provides us with sensation, (Moran et al., 2012; Markman et al., 2009). Imagery has been defined as a perception-like cognitive process, that acts as a multimodal representation of information within human minds, even in the absence of any external stimulus/sensory input, or physical output (Farah, 1984; Jeannerod, 1994, 2001; Kosslyn, 1987; Kosslyn et al., 2001; Munzert et al., 2009). Imagery is also proposed as a key part of conscious experience (Marks, 1999). Imagery that is specific to movement, known as *motor imagery*, involves generating associated sensations and likely also includes cognitive aspects like the order and timing of a movement sequence (Ladda et al., 2021). Motor imagery is a dynamic mental state, during which the sensations of a given motor movement is rehearsed without overt motor output like physical movement (Di Rienzo et al., 2016; Dickstein & Deutsch, 2007; Moran et al., 2012b; Ladda et al., 2021). Simply put, motor imagery is the "covert simulation of movement" (Holmes, 2007, p. 1). Motor imagery has continuously led to better understanding in fields of psychology, such as cognitive neuroscience (Guillot & Collet, 2010; Hamedi et al., 2016), sport psychology (Simonsmeier et al., 2021; Martin et al., 1999), motor learning (Ruffino et al., 2017), medical education (Sattelmayer, et al., 2016) and rehabilitation science (Caligiore et al.,2017; De Vries & Mulder, 2007) while also building connections between these fields (Moran et al., 2012b).

A term to describe ‘the use of motor imagery’ has been inconsistent in much of the literature over the course of history (Driskell et al., 1994; Dickstein & Deutsch, 2007). It has been referred to as *symbolic rehearsal, imaginary practice, mental rehearsal, mental practice, covert rehearsal,* and *introspective rehearsal/conceptualisation* (Sackett, 1934; Perry, 1939; Rubin-Rabson, 1941; Vandell et al., 1943; Corbin, 1967; Egstrom, 1964). Also of note is the broader term *mental preparation*, which differs from *motor imagery practice*. Instead, *mental preparation* refers to a variety of psychological performance enhancing techniques, for example attention focusing, relaxation, and positive self-talk (Driskell et al., 1994). The term *motor imagery practice* is favoured in more recent years (Ladda et al., 2021) and will be used henceforth to describe the covert rehearsal of a movement skill (Holmes, 2007).

Individual Differences in Imagery

There are clear differences in the effectiveness of individuals' use of imagery (Isaac & Marks, 1994; Mantani et al., 2005). Two key characteristics of imagery ability are vividness and controllability (Callow & Hardy, 2005; Start & Richardson, 1964). Vividness refers to the richness, clarity, and realism of the imagery, and controllability refers to the ability to manipulate the image. Many other aspects of imagery performance have also been proposed and measured in various ways (Suggate, 2024; Suica et al., 2022).

There has been much discussion as to the precise effect aging has on motor imagery performance. A meta-analysis and a systematic review suggesting that motor imagery ability decreases as we age (Fierro-Marrero et al., 2025). This has been observed regardless of whether imagery ability is measured using fMRI, self-reported vividness and controllability, as well as through various mental chronometry tests (Mulder et al., 2007; Malouin et al., 2010; Schott, 2012; Zapparoli et al., 2013; Smits-Engelsman & Wilson, 2013; Saimpont et al., 2013; 2015; Wang et al., 2014a; Kalicinski, 2015).

It has been suggested that males are better at motor imagery when compared to females, (Butler et al., 2006; Hoyek et al., 2009; Schott, 2012). These findings have not been supported in other research (Lutz et al., 2001; Schuster et al., 2011; Campos, 2014; Giacobbi, 2007; Callow & Hardy, 2004). While many of these studies show that vividness is consistent across sex, there have been differences in mental chronometry. With findings suggesting that women overestimate the time taken to imagine a skill (Subirats et al., 2018; Hoyek et al., 2009). There is a suggestion that females self-report a preference for a first person perspective and males prefer a third person perspective, albeit with a very small sample size (Di Tore et al., 2016). More research needs to be done to better understand any potential sex differences in motor imagery.

Assessing Motor Imagery

There are currently thought to be 65 different measures of mental imagery (Suica et al., 2022) Introspective, self-report questionnaires of the vividness and controllability of imagined experiences have been shown to be effective and are commonly used (Baddeley & Andrade, 2000; Eton et al., 1998; Isaac et al., 1986; Richardson, 1977; Roberts et al., 2008). Others have instead proposed that as imagery involves generating, transforming, and maintaining an image in the working memory, measures of imagery ability should aim to measure proficiency in performing these processes (Kosslyn, 1994; Williams & Cumming, 2011). A wide range of mental imagery tasks have been proposed as measures of imagery (see Suggate, 2024 for a review). Suggate, (2024) proposed a mental comparison task to measure imagery ability by asking individuals to compare two mental images to reflect their ability to distinguish between the two. Imagery ability can be quantified on a neurological level to allow for measurable comparisons of vividness between individuals (Dijkstra et al., 2017).

Image inspection has also been suggested as a key skill of imagery, it involves scanning the whole or parts of an image, interpreting any patterns, and extracting information (Kosslyn et al., 2006). Most imagery questionnaires, however, use self-report methods to assess the "ease" of performing these imagery processes (Williams & Cumming, 2011) rather than assessing individuals' ability to do each of these processes. This makes it difficult to compare individuals results as the measure is subjective to individuals perceived imagery ability compared to what they believe is the highest possible score. Individuals may vary in what they believe constitutes a maximum score, which would be based on what they believe any individual could achieve (Williams & Cumming, 2011). While self-report questionnaires have been shown to be useful and reliable (Williams & Cumming, 2011; Roberts et al., 2008), the extent of their validity will always be open to criticism. When assessing and comparing individuals' imagery ability, it is also important to consider modulators of the effectiveness of motor imagery practice such as task characteristics, complexity, expertise, schedule of practice, and individual impairments (Kalicinski et al., 2015; Ladda et al., 2021). Interestingly however, physical motor performance does not seem to predict motor imagery ability (Dey et al., 2012).

Functional Equivalence

Many models have been proposed to explain motor imagery in relation to physical execution (see Hurst & Boe, 2022 for an overview). A relationship between physical and imagined processes was highlighted as early as James (1890) who stated that "sensation and imagination are due to the activity of the same centres of the cortex" (p. 720). Jacobson (1932) developed the Psychoneuromuscular theory which also suggests that imagery duplicates actual motor patterns, with less neuromotor activation. Finke (1979; 1980) proposed a *functional equivalence hypothesis* which highlights the similarity between neural pathways involved in movement imagery and execution. Functional equivalence is supported

by the observed physiological responses during physical execution that correlate with physiological responses during motor imagery, in particular autonomic nervous system and electromyographic activity (Guillot & Collet, 2005; Collet et al., 2011).

This hypothesis is directly supported by the observed overlap in the neural activity observed between imagery and execution, when regarding both the preparation and production of motor movements (Decety, 1996; Jeannerod, 1994; Hardwick et al., 2018). The supplementary motor cortex is activated in motor imagery and motor execution (Hétu et al., 2013; Sepulveda et al., 2016). Weaker activation of the primary motor cortex during motor imagery when compared to motor execution has also been observed (Porro et al., 1996; Schnitzler et al., 1997). This finding has been difficult to replicate (Dechent et al., 2004) which is likely due to different types of activation in the primary motor cortex in imagery when compared to execution. Specifically, a significantly larger negative deflection of a lateralized readiness potential waveform was consistently found during motor execution when compared with motor imagery of the same action (Carrillo et al., 2008). The different types of activation highlight the importance of investigating the degree and nature of the neural overlap between motor imagery and execution (Hurst & Boe, 2022).

Motor Simulation Theory

Functional equivalence has contributed to many contemporary and competing theories of motor imagery such as Jeannerod's (1994; 2001; 2006) *motor simulation theory* (for a review see O'Shea & Moran, 2017). Motor simulation theory regards areas of the brain involved in covert cognitive motor processes (like motor imagery), action intention, and observation. Suggesting that areas involved with motor imagery involve the same mechanisms as actual motor execution, in line with functional equivalence. Motor imagery practice

therefore acts as a covert method of rehearsing neural motor systems, therefore improving subsequent overt motor performance of the imagined task.

Motor simulation theory suggests that motor imagery involves the motor cortex and its associated motor pathways but does not give specifics on the exact process responsible (O'Shea & Moran, 2017; Hurst & Boe, 2022). It also suggests that the differences between motor imagery and motor executions are due to an inhibitory mechanism during motor imagery. This mechanism is said to prevent motor imagery from resulting in actual movement. This is explained either as a mechanism that prevents motor commands from descending past the brainstem or spinal cord, or that motor cortex activation during imagery in reduced below the threshold required to activate the motor neurons in the spinal cord needed for movement (Jeannerod, 2001; Grosprêtre et al., 2016). It is also worth noting that there is subliminal electromyographic activation (muscle activation at a fraction of what is needed for motor execution) during motor imagery that correlates with the imagined task characteristics (Guillot et al., 2007). Previous studies, however, have disputed this (Feltz & Landers, 1983). Lang et al. (1985) named this, subliminal electromyographic activation, as "efferent leakage" and proposed that this could act as an indicator of the vividness of the imagery. This phenomenon could be seen as evidence for an inhibitory mechanism outlined by motor simulation theory (Grosprêtre et al., 2016). The exact nature of this inhibitory mechanism, however, is still unknown (Guillot et al., 2012; O'Shea and Moran, 2017).

Functional Divergence

While the evidence presented above highlights the *functional equivalence* between imagined and executed movements, it is also important to consider how they differ, known as *functional divergent* (Kraeutner et al., 2017). Sackett (1934) for example suggested that the beneficial effects of imagery are due to the familiarisation of the symbolic elements involved

in the skill. Therefore, consciously developing a mental blueprint that could then be used for physical execution.

Functional divergence models highlight processes that are more prevalent in imagery but less so in execution, or vice versa (Hurst & Boe, 2022). The process of inhibiting movement output during imagery, in motor simulation theory, is also used as evidence of functional divergence (Grosprêtre et al., 2016). The exact mechanisms that distinguish motor imagery from execution, however, are still unknown (Hardwick et al., 2018; O'Shea & Moran, 2017). Hurst and Boe (2022) suggest a spectrum of functional equivalence, which considers the degree of neural overlap, is a preferable conceptualisation of this debate. Meta-analysis requires further evidence to fully test the functional equivalence hypotheses (Hardwick et al., 2018).

Motor Cognitive Model

Glover and Baran (2017) use elements of both functional equivalence and divergence to explain the similarities and differences between movement execution and imagery. They use the established distinction between action planning and control (Elliott et al., 2001; Glover, 2004; Meyer et al., 1988; Woodworth, 1899) to distinguish between equivalence and divergence. The processes of imagery and execution are the same during pre-movement action planning. Both modalities are said to access the same stored motor representations. During action control, however, imagery and execution differ, with imagery requiring more cognitive processing. The original paper (Glover & Baran, 2017) shows evidence for this in three experiments comparing predictions from this divergence model to expectations of functional equivalence. The first experiment showed that for low precision tasks, imagery and execution movement times were similar. Another group followed the same procedure with high task precision; however, imagery took significantly longer than execution, suggesting a degree of functional divergence. Task precision was manipulated by making an object that participants

needed to move, more difficult to grasp, or by providing a smaller target in which to place the object. The second experiment added interference into the task, asking participants to count backwards out loud by threes during the imagined or physical task. The difference between imagined and actual movement time increased further with the addition of interference, with imagery again being slower. The final experiment repeated the previous experiment but added complexity by including a computer keyboard and a key pressing task (pressing the "d" key three times). Again, imagined movement time was significantly slower than actual movement, due to the increased complexity of the task, supporting the predictions of the motor cognitive model over functional equivalence.

The motor cognitive model explains that the slower imagined movement time observed is due to increase of cognitive demands. The model suggests this divergence must come after the action planning stage, and instead during the action control stage. During action control motor execution results in movement, and subsequent unconscious external sensory feedback, as outlined by the forward model (Sperry, 1950; Welniarz et al., 2021). According to the motor cognitive model the action control stage for an imagined movement instead involves cognitively and consciously creating a covert multi-sensory image which is monitored and developed in real time. This involves switching attention between creating the image and error processing through comparing the action plan to the image that is being created. This increased use of central executive function means imagery can require more time than execution when increasing both precision and interference of the task. This is because creating a multi-sensory image with high precision and interference requires more cognitive demands relative to the equivalent overt action. Similarly, imagining motor representations with less fidelity requires more elaboration and so also takes longer (Gandrey et al., 2013).

These experimental findings are supported by follow up experiments (Glover et al., 2020; Martel & Glover, 2023). Some propositions of this model, however, have not been supported for example Hardwick et al., (2018) did not support the proposition that ventral stream visual areas may be recruited during motor imagery. A divergent approach, however, does help in explaining differences found in motor imagery practice and physical practice so is important to consider (Kraeutner et al., 2017).

The Application of Motor Imagery Practice

In any context where motor performance can be improved or practiced, motor imagery can be used (Ladda et al., 2021). It is used and proven to produce performance gains in sports (Simonsmeier et al., 2021; Lindsay et al., 2019), rehabilitation (Tong et al., 2017; Suso-Martí et al., 2020), medical practice (Hall, 2002; Wakefield et al., 2020) and in the performing arts (Wright et al., 2014a; Kleber et al., 2007; Meister et al., 2004). More specifically motor imagery practice improves motor sequencing (Gentili et al., 2010), aiming (Kim et al., 2014), motor timing (Pascual-Leone et al., 1995), strength (Lebon et al., 2010), and flexibility of the motor system (Guillot et al., 2010). A literature review conducted by Schuster et al. (2011) suggests that the most successful imagery interventions are individual (one participant), supervised (with an instructor present), and non-directed (no stepwise guidance on how to complete the imagery).

Layered Stimulus Response Training

Lang (1977; 1979) in his Bioinformational Theory proposed that vivid imagery provides us with information about the stimulus characteristics and possible outcomes to imagined situations. Imaging these potential situations can be used to help performers rehearse reactions to real-life situations (Lang et al., 1970; Martin et al., 1999). By using imagery scripts that provided sensory details about a situation and pairing them with descriptions of the

person's emotional and physiological response, Lang et al. (1980) were able to elicit physiological responses (fear or action). This demonstrated that imagery could be used to pair stimuli with responses, to train individuals' reactions to situations. Ahsen (1984) extended this by stating that imagery must include the meaning of the image (e.g., personal pride, goals, and accomplishment), as well as the somatic response, and the image itself. Building on this work Calmels et al., (2004) outlined a method to create imagery interventions that involved five, progressively more detailed, imagined scenarios, showing that adding layers of detail improved vividness. Nordin and Cumming (2005) revealed that professional dancers could also successfully use this layering technique, progressively adding sensory modalities like sound, touch and kinesthetics. Williams et al. (2013) named this technique *layered stimulus response training* in direct reference to Lang's original work (Lang et al., 1970; Lang, 1977; 1979), demonstrating its superior effectiveness, in eliciting performance and vividness gains, by comparing it to standard motor imagery, or visual imagery practice groups. Through this research, a guide has been developed to further the effectiveness of this technique (Cumming et al., 2017). Using layered stimulus response training allows an imagery session to be both non-directed and supervised, which is proposed to be optimal (Schuster et al., 2011).

PETTLEP

At the turn of the century, direction for the application of imagery interventions in sports was said to lack theoretical rigour, prompting Holmes and Collins (2001) to develop the PETTLEP model. The PETTLEP model is an acronym that stands for; Physical, Environment, Task, Timing, Learning, Emotion and Perspective components. Built on the neuroscientific research that developed the functional equivalence hypothesis (Jeannerod, 1995), PETTLEP aims to account for all variables involved in imagining a task. This ensures imagery practice is as close to the experience of physical practice as possible. This model has been shown to

enhance strength performance (Wakefield & Smith, 2011; Wright & Smith, 2009), technical skills in sport (Wakefield & Smith, 2009; Cherappurath et al., 2020), and nursing (Wright et al., 2008).

The *Physical* aspect of the model encourages imagery practice to include as many of the expected physical responses and sensations experienced in actual performance. To improve functional equivalence; imagery practice should include visualising physical elements that will occur during actual performance, like a rapid heart rate or fatigue. A counter to this is the findings that show relaxation may improve individuals' imagery vividness, reduce distractions, and increase subsequent effectiveness of the imagery practice (Miller, 1991; Weinberg et al., 1981). These findings, however, have not been consistently replicated in other studies using pre-imagery relaxation methods (Smith et al., 2007; Gray et al., 1984). Holmes and Collins (2001) use the functional equivalence hypothesis to argue against the notion that pre imagery relaxation is optimal. Wakefield et al., (2013) highlights the importance of including physical afferent information, particularly auditory (sounds) and haptic (tactile), in imagery practice. Studies involving athletes have shown that by performing imagery while holding their equipment and wearing their sports clothing, increases the effectiveness of the practice (Smith et al., 2007; Wright & Smith, 2009, Wang et al., 2014b). This is so effective that using unrelated equipment can cause interference during imagery (Zhang et al., 2018). Also, musicians performing imagery benefit from listening to the piece of music they are performing the imagery practice (Wright et al., 2014a).

Environment refers to the physical surroundings that the individual completes the imagery practice in. The natural responses from the performance environment should be personalised to the individual, considering as many possible, relevant multisensory inputs to emulated physical practice. For example, a footballer looking to imagine taking a penalty in

Wembley stadium, should ideally practice their imagery in a similar climate and in front of a similar sized crowd. As this example suggests, this is often not possible, Holmes and Collins (2001) instead suggested using videos or photographs of the performance environment to prime the imagery experience. For this example, playing simulated crowd noises from previous penalties taken at Wembley stadium. The suggestion that imagery practice effectiveness improves as a result of an increase in similarity between the physical environment of the imagery practice and the environment of the actual performance, has been supported with empirical evidence (Smith et al., 2007; Wright & Smith, 2009).

The *Task* should also be personalised and matched to actual performance when completing imagery practice. Emulating task characteristics in imagery practice aims to increase functional equivalence. To do this all aspects of the task, both the moving (transient), and motionless (intransient) components, need to be imagined. Specifically, the thoughts, feelings and behaviours involved in an individual's actual performance of the task should be replicated during imagery practice (Anuar et al., 2015; Filgueiras, 2017). For example, if an individual has a routine, or repeating thought, during a specific part of performance then this should also be present during imagined practice. Elite and non-elite athletes have shown to focus on different aspects of performance, supporting the need to individualise the task characteristics when prescribing imagery practice (Konttinen et al., 1995). As outlined previously, methods like layered stimulus response training, which involves input from the learner, helps to ensure imagery practice is individualised (Calmels et al., 2004; Lang et al., 1980).

Timing of imaged practice should also aim to match that of physical execution to increase the overlap in neural activation during imagined and physical practice. According to functional equivalence, the same motor representation can be accessed during motor

preparation of imagery and execution. Any temporal information included in a motor pathway can likely be activated during both imagery and execution (Holmes & Collins, 2001). Temporal rhythm during movement is key for performance (Collins et al., 1997) so it should be a focus point for imagery practice (Backley & Stafford, 1995). Vogt (1995) and Moran and MacIntyre (1998) showed that speed and consistency of relative timing were similar in physical and imagined practice conditions for simple motor tasks. It has even been shown that by varying the speed at which the imagery is performed can alter subsequent motor performance, faster imagery can lead to faster performance and slower imagery to slower performance (Louis et al., 2008). As mentioned earlier however, task precision and complexity do influence imagined movement timing (Glover & Baran, 2017). There has still been much support for the benefits of matching the timings of imagined practice to the timings of execution **(**Calmels et al., 2006; Guillot & Collet, 2005). Smith and Holmes (2004) for example, found when imagery was more effective when performed alongside an audio or video recording. Subjects who used a written script reported problems in controlling the timing of their imagery. In imagined movement, knowledge of the amount of force involved in the movement, is required to help ensure imagined practice happens in real time (Decety et al., 1989; Jeannerod, 1997; Holmes & Collins, 2001).

During motor imagery practice the goal is to facilitate *learning* to obtain improvements. As the practiced skill develops the imagined practice will need to develop accordingly to still accurately represent the skill. Motor theories state that as individuals learn motor skills, their performance requires less cognitive control and becomes more autonomous (Fitts & Posner, 1977; Schmidt & Lee, 2019). PETTLEP aims to ensure the imagined practice matches the expected physical performance of the individual, helping to ensure functional equivalence of the imagined practice. Motor imagery practice specifically, induces changes in neural organization that accounts for behavioural modifiability, known as “neural plasticity”, in a

similar manner to physical practice (Debarnot et al., 2014; Ruffino et al., 2017; Pascual-Leone et al., 1995) again supporting the functional equivalence hypothesis. Regularly comparing imagery practice to physical practice will likely help ensure that the imagined and physical skill are in parallel, without one diverging away from the other (Homes & Collins, 2001). It is also important to consider that practising imagery improves imagery proficiency (Cumming & Eaves, 2018) which will likely increase the effectiveness of imagery practice (Ruffino et al., 2017). The *learning* component of the PETTLEP model has, however, received relatively little research attention (Wright et al., 2014a).

Any e*motions* typically experienced during performance should also be replicated during imagery practice. This is largely derived from Lang's (1985) response training, outlined previously (see page 55), which shows that imagery practice can be paired with emotional responses to reap performance gains. This also helps imagery practice to be individualised and personally meaningful. This likely produces similar neural and physiological activity to that produced during physical performance (Homes & Collins, 2001). However, one of the few studies to investigate the benefits of encouraging an emotional focus on imagery interventions did not find any benefits from doing so (Ramsey et al., 2010). It has been suggested however, that this lack of support is due to the absence of a competitive situation in experiments, situations in which emotions are usually most prevalent (Wright et al., 2014b). Arousal levels are a key part of performance and are greatly influenced by our emotions (Hardy & Parfitt, 1991) and so need to be replicated in imagery practice to ensure functional equivalence. Imagery scripts that aim to replicate performance emotions have been shown to lead to greater muscle activity and higher self-rated imagery vividness when compared to scripts without as many emotional elements (Wilson et al., 2010). This element of PETTLEP also disagrees with the findings that pre-imagery relaxation is beneficial for effectiveness of the practice (Miller, 1991; Weinberg et al., 1981) as individuals will not always perform a skill in a relaxed state of

mind, especially in a sporting context. Smith et al. (2007) also found that in sports, a PETTLEP led intervention is more effective than imagery that was completed after relaxation, supporting a functional equivalence approach to developing imagery interventions. More recently, the addition of video observation has shown to exert an effect on the emotions felt by an individual, such as motivation (Birrer & Morgan, 2010).

The *perspective* component details the orientation in which the imagery is viewed. This can be through an internal (first person, through one's own eyes) or external (third person, looking at oneself through someone else's) perspective. This is achieved by using kinaesthetic and/or visual and/or olfaction cues, depending on the task (Smith et al., 2007). Both an internal and external perspective are beneficial for learning (Lu et al., 2020). More specifically an internal perspective encourages functionally equivalent and is therefore more commonly appropriate. However, the use of external visual imagery may enable access to elements of the representation that an internal perspective does not (Holmes & Collins 2001). For example, an external perspective is useful for learning form-based skills allowing the performer to imagine precise positions and movements (Callow et al., 2017; Hardy & Callow, 1999; White, & Hardy, 1995). It is also likely that internal imagery is easier when the skill level of the task is higher (Guillot et al., 2004; Hardy & Callow, 1999). During learning, however, individuals are more likely to use external imagery (Callow et al., 2017; Hardy & Callow, 1999). Kosslyn et al. (2001) suggest that different perspectives can recruit different brain areas, with an internal perspective using sensory-motor system, and an external perspective additionally stimulating areas involved in visuo-spatial transformation. This supports the idea that perspective is an important consideration to ensure functional equivalence in motor imagery practice.

It is important to consider that individuals may switch between perspectives when imaging, something that may be beneficial (Callow et al., 2017; Smith et al., 1998), specifically for more experienced performers (Kaminskiy et al., 2017; Ungerleider & Golding, 1991).

More evidence of participants' unprompted use of perspective switching can be seen in the data analysis of many imagery papers. Where data has had to be removed due to the difficulty of ensuring perspective is consistent (e.g. Glisky et al., 1996; Nodarse, 2025; Roberts et al., 2010). The reason athletes switch imagery perspectives has not been empirically explored (Nodarse, 2025). An explanation could be drawn from the research on the effects of perspective switching during observational learning (Hodges, 2007) as there is an overlap between the areas of the brain involved in imagery, observational learning, and physical execution (Caspers et al., 2010; Filimon et al., 2007). PETTLEP however, outlines the benefits of focusing on specific perspectives to achieve specific goals (Wakefield & Smith, 2012). When using an external perspective, Jeannerod (1994) argues that self-agency is important for the efficacy of MI, encouraging individuals to imagine seeing themselves when using a third person perspective. Holmes and Calmels (2008), however, found that athletes are inclined to imagine other athletes performing the task rather than themselves. Using performers' own successful performance as a model for imagery intervention is likely to increase performance gains when using an external imagery perspective (Lu et al., 2020).

A first-person perspective likely increases self-agency which may determine motor imagery effectiveness (Jeannerod, 1994; Anquetil & Jeannerod, 2007) this combination has long been considered optimal (Collins et al., 1998; Hale, 1982; Lang, 1985). Holmes and Calmels (2008) further this, suggesting that "putting yourself in someone else's shoes" may be beneficial while using a first-person perspective if the other person has superior performance capabilities. This is supported by recent research that demonstrates that using virtual reality to watch yourself perform better than you currently can, is beneficial for motor learning (Frank et al., 2022). Another method of increasing agency during imagery is watching videos of oneself performing at one's best while doing motor imagery (see action observation and motor imagery). Benefits for skill refinement have been demonstrated in a number of recent studies

using this technique but the potential for learning may be limited (Fujiwara et al., 2021; McNeill et al., 2021; Ste-Marie et al, 2011, Scott et al., 2022). On all accounts both perspective and agency need to be carefully considered and better understood (Holmes & Calmels, 2008; Scott et al., 2022).

Successful use of brain computer interfaces is largely dependent on motor imagery ability (Wolpaw et al., 1991; McFarland & Wolpaw, 2018) so research into improving how individuals are able to interact with the interfaces can provide methods to improve imagery practice. For example, the increase in agency, and subsequent improvement in brain computer interface performance, has been well studied (Hougaard et al., 2021; Van de Laar et al., 2013; Burde & Blankertz, 2006). More recently the addition of positive feedback was shown to increase perceived control and therefore brain computer interface performance (Hougaard et al., 2022). This again supports Jeannerod's (1994) view that self-agency is important for the efficacy of MI. This again may explain why using performers' own successful performance for imagery intervention is recommended to gain the best results from a PETTLEP intervention (Lu et al., 2020).

Action Observation Motor Imagery

Action observation had several advantages over motor imagery: for example, the control of agency, perspective, and subject-task angles (Holmes & Calmels, 2008). According to a recent double meta-analysis paper (Chye et al., 2022), the addition of action observation to motor imagery practice (known as AOMI, Vogt et al., 2013) may not provide significant gains in learning movement outcomes. Specifically combining motor imagery and action observation showed improvements in movement outcomes compared to action observation groups and control groups. However, when AOMI is compared to motor imagery only, there are no significant differences (Chye et al., 2022). This was explained by the increased

corticospinal excitability in combined action observation and motor imagery when compared to action observation alone and the control groups. However, an AOMI approach was found not to show any significant increase in corticospinal excitability when compared to using motor imagery alone (Chye et al., 2022). AOMI also requires additional neurocognitive resources to keep the motor imagery synchronized with the observed action (Eaves et al., 2016) potentially restricting its effectiveness in some participants. AOMI's effectiveness compared to motor imagery is still debated; there is still recent evidence that combining motor imagery and action observation improves learning more than one or the other modalities on their own (Binks et al., 2023; Bisio et al., 2017; Eaves et al., 2022).

Functional equivalence is also apparent in observational learning (Blandin & Proteau, 2000). The neural activation during both execution and action observation can also be seen to overlap with the pathways associated with motor imagery, specifically the supplementary motor area, dorsal premotor cortex, supramarginal gyrus and the superior parietal lobe (Grezes & Decety, 2001; Macuga & Frey, 2012). The extent of the neurological and mechanistic overlap between action observation and motor imagery is relatively unknown (Vogt et al., 2013; Hardwick et al., 2018) so they are often treated separately (Kim et al., 2017). Combining, rather than isolating, action observation and motor imagery, however, has been shown to improve imagery ability (Wright et al., 2015), increased relevant neurophysiological activity (Eaves et al., 2016; McNeill et al., 2020), improving self-regulatory processes (such as self-efficacy during specific motor tasks, motivation to engage in practice, self-satisfaction, and reactions to previous performances; Ste-Marie et al., 2012; Wright et al., 2022). All of which lead to improved performance across a range of tasks (Romano-Smith et al., 2018; Smith et al., 2020). Combining action observation with motor imagery has again been shown to be effective in both clinical and sports settings (Caligiore et al., 2017; Moran et al., 2012a). AOMI can be performed simultaneously by imagining oneself performing the skill alongside the model in

the video, or alternatively, switching between imagery then action observation, while still being effective (Romano-Smith et al., 2018).

Volume of Imagery Practice

When discussing practice structure in any context, volume of practice is a key consideration. In the case of motor imagery, volume is important as although there is the advantage of no physical fatigue during imagery (Ladda et al., 2021), there is risk of mental fatigue (Jacquet et al., 2021). To avoid this risk both the duration and frequency of the imagery practice session must be optimised. According to the *cognitive hypothesis*, imagery is more effective in tasks with a high cognitive component, likely due to imagery having on the motor commands, rather than the movement effectors (Heuer, 1989; Sherwood & Lee, 2003). It is also worth noting that even a very small volume of imagery practice, for example a single 45 minute session, can be effective at improving cognitive task performance (Wright & Smith, 2007). These results, however, may not transfer to motor performance. A systematic literature review found studies with successful motor imagery interventions were on average double the length of interventions in studies that found no significant effect (Schuster et al., 2011). Much of the research in this field provides exact durations for imagery interventions (Driskell et al., 1994; Feltz & Landers, 1983; Hinshaw, 1991). However, an optimal volume based on individual differences and task constraints (see challenge point framework, Guadagnoli & Lee, 2004), has not been fully explored (Guillot & Collet, 2008; Toth et al., 2020).

Duration of Imagery Practice Sessions. A recent meta-analysis suggests that there is an inverted U-shaped relationship between the duration and effectiveness of an imagery practice session with around 20 minutes being optimal (Toth et al., 2020). While a linear relationship had previously been proposed (Driskell et al., 1994) the notion that 20 minute sessions are optimal has been supported by empirical evidence (Feltz & Landers, 1983; Driskell

et al., 1994). There has not always been agreement on this (Guillot & Collet, 2008), some have provided evidence that a 10–15-minute session elicits the largest effects on performance (Hinshaw, 1991) while other has suggested the optimal duration to be as low as 10 minutes (Morris et al., 2005). As the optimal duration of an imagery session is largely dependent on the individual's ability to resist mental fatigue (Guillot & Collet, 2008), which will vary slightly due to individual differences, for example sleep deprivation and experience (Van Dongen et al., 2011; Martin et al., 2016) and therefore individualise the optimal duration of imagery practice sessions for each person. Athletes have also shown to have difficulties in maintaining focused attention when every imagined trail is successful, suggesting that session may benefit from limited successive trials (Roure et al., 1999; Guillot et al., 2004).

Frequency of Imagery Practice. The frequency of imagery practice also needs to be considered especially as it can be used much more frequently than physical practice due to imagery usually requiring less equipment, space, movement, and energy. Wakefield and Smith (2009) showed that a PETTLEP imagery practice regime three times per week elicited greater improvements in netball shooting performance, when compared to a practice once or twice a week. The absence of a regime with four or more practice sessions per week makes it difficult to conclude that this is an optimal amount, perhaps more performance gains can be achieved through more imagery practice. It is reasonable to expect that increasing the frequency of imagery practice results in an increase in performance gains (Cumming & Hall, 2002), however, there may be a ceiling to this effect. Wakefield and Smith (2009) discuss the importance of balancing frequency and volume to ensure the time spent practicing imagery is most effective. In the example of Wakefield and Smith (2009) the most positive results came from practicing three times per week (imaging 20 shots per session, 60 shots total), this has been supported in more recent meta-analysis (Paravlic et al., 2018). As they point out, the findings do not show whether practicing 60 shots on one day or 10 shots a day for six days

would have been more beneficial. The action plan reconstruction hypothesis suggests that a higher frequency would be more optimal as the increased period of time between intervals of practice would allow for forgetting, meaning the task must be reimagined more frequently. Page et al. (2016) compared a higher frequency (3x20 minutes daily) to a higher volume (1x60 minutes daily) imagery interventions on stroke patients, aiming to improve upper extremity functionality. Their findings, that higher frequency was more optimal, supporting the action plan reconstruction hypothesis in the context of imagery practice.

Inter-task Processing Effects in Motor Imagery

As with the amount of practice, the structure of the practice is also important predictors of learning (see contextual interference). Gabriele et al. (1989) manipulated the practice structure of four groups, using a combination of imagery and physical practice to elicit the contextual interference effect. Each group completed a variety of imagined and physical movement patterns in a knockdown task. The first group had blocked imagined and physical practice, for example, AaaaAaaaBbbbBbbbCcccCccc (capital letters denote physical trials and lower case letters denote imagined trials, with each letter representing a different skill). The second group undertook blocked physical practice and random imagery practice; AabcAcadBcdaBcba. Another group had random physical practice and blocked imagined practice, BbbbAaaaCcccDddd. The final group had random physical and imagined practice; BacdAbdcDcabCadb. Random imagery practice was shown to result in better retention than blocked imagery practice. In a second experiment, combined random physical and imagery practice were compared with equivalent amounts of random physical practice with rest intervals. This showed that random physical and imagery practice caused as much interference as the random physical practice condition. Interference was derived from the number of acquisition trials required by the groups to achieve the criterion performance level. When

comparing the retention performance across the two studies, random imagery practice was as effective as random physical practice. These findings contradict the belief that the contextual interference effect does not occur in the absence of movement (Carnahan et al., 1990) and instead suggest that by using imagery combined with physical practice elicits similar amounts of interference movement alone. The lack of an imagery only group allowed for criticism that the contextual interference came only from the physical practice. This explains why interference was similar regardless of the inclusion of imagery.

Hall et al. (1995) completed a similar study investigating the effects of retroactive interference while including an imagery only group, something that Gabriele et al. (1989) had not. As previously discussed, retroactive interference has been used as an explanation as to why random practice is superior to blocked practice (Poto, 1988; Davis, 1988, see page 33). They found that both imagined and physical practice both elicited similar retroactive interference effects, suggesting, like Gabriele et al. (1989), that imagery practice is functionally equivalent to physical practice.

The works presented above support the notion that principles of physical practice structure can successfully apply to imagery interventions, while all pointing to a need for more generalisable research. The individual's imagery ability, the cognitive demand of the task, as well as their experience with the task and imagery practice, also need to be considered to reach an optimal practice structure (Broadbent et al., 2017; Del Rey, 1989). The need for more research on imagery practice structure is also apparent as not all findings have supported the equivalence between imagery and physical practice structuring. Overdorf et al. (2004) shows evidence of divergence between imagery and physical practice structuring. They split participants into five groups: (one) blocked imagery practice, blocked physical practice; (two) blocked imagery practice, random physical practice; (three) random imagery practice, blocked

physical practice; (four) random imagery practice, random physical practice; (five) no imagery practice, random physical practice (control condition). Practice of a Bassin Anticipation Timing task was varied by adjusting the speed of the timer to slow, medium, or fast. Blocked practice, in either the imagined or physical conditions, involved repeating the task at the same speed. Random practice involved completing the task at varying speeds. Groups one to four alternated between three imagery practice sequences of nine trials each and three physical practice sequences with 18 trials each. Unlike Gabriele et al. (1989) the imagery practice type (random or blocked) had no significant effect on practice or retention performance, suggesting contextual interference effects can result from physical practice but not imagined practice.

Overdorf et al. (2004) suggest that the lack of significant results may be due to a multitude of factors. Firstly, the Bassin Anticipation Timer task is more of an open skill than the more closed skill used in Gabriele et al. (1989). The anticipation timer task also does not involve much motor skill, simply pressing a button in response to the stimulus. The imagery practice sequence may also not have been sufficiently stimulating, motivating or approximated the physical practice well enough, to produce the contextual interference effect. Participants also had likely no previous experience with the apparatus which may be vital to the effectiveness of imagery practice (Mulder et al., 2004; Olsson & Nyberg, 2010; Gomes et al., 2014). The authors state that this study would benefit replication under more controlled testing conditions and with varied types of open and closed skill tasks.

Inter-task Processing Effects in Observational Learning

Practice structure effects have been tested in observational learning interventions to see if the effects are equivalent to physical practice. Blandin et al. (1994) brought participants into the lab two at a time, one would physically practice the task, the other would observe them practicing the task. The task involved a similar block knock down task to the one used by Shea

and Morgan (1979) with three different movement patterns. After an acquisition phase there was a retention test condition, then another acquisition phase where both individuals would practice physically, then again after 10 minutes and again after 24 hours as a retention test. There were six different groups, in which the practice structure at each of the conditions would be either blocked or random (see table one in Blandin et al., 1994). This allowed for groups of physical and observational learners to do each experimental phase in either a random or blocked structure. They showed the same pattern of results for both the physical and observational groups, showing performance was dependent on the structure of the practice (blocked or random). Specifically showing the presence of the contextual interference in both physical and observation groups. Suggesting equivalence between the cognitive processes involved in physical and observational practice.

Lee and White (1990) had previously shown that the contextual interference did not occur in observational learning in two experiments using a computer game and a timing task. This was despite significant observational learning effects in both experiments. However, Wright et al. (1997) successfully replicated Blandin et al. (1994) using a computer keyboard typing task. These inconsistent findings may be due to the openness of the tasks used, an explanation that has been used to explain the inconsistent findings in the research on the contextual interference in imagery (Overdorf et al., 2004). More recently it is clear that the task plays an important role in the effectiveness of the contextual interference effect (Ammar et al., 2025). The contextual interference effect is dependent on an array of other variables, like the type of task, which are not yet fully understood (Ammar et al., 2025). This likely explains the difficulties in replicating the effect in other modalities like observational learning or motor imagery.

Intra-task Processing Effects in Motor Imagery

Recent research by Lindsay et al. (2023) suggests that movement variability is an important consideration for motor imagery training for rehabilitation and sports. Lindsay et al. (2023), however, does not provide any experimental proof but, using an ecological dynamics perspective, provides a theoretical rationale for including variability in motor imagery interventions. Other more recent research has found no equivalence in variable practice effects in motor imagery (Coelho et al., 2012; Fazeli et al., 2021). These two experiments both used a golf putting task, and single day interventions. Both found that variability in motor imagery practice was not beneficial whereas variability in physical practice was beneficial, calling into question the functional equivalence hypothesis as increasing variability appears to have no effect on imagery practice when it seems to have a positive effect on physical practice. Fazeli et al. (2021) suggests that this functional divergence between physical and imagined practice, in the context of variable practice effects, is due to difference in visual feedback. Specifically, the lack of the knowledge of results during motor imagery. In both physical and observational learning, the action and knowledge of results can be compared to fine-tune future actions (see forward model, Sperry, 1950; Wolpert, 1997, and schema theory, Schmidt, 1975, see page 14). In imagery, where there is no knowledge of the results, this process cannot occur (Wong et al., 2013).

Debarnot et al. (2015) used a simple stimulus response task with a computer keyboard to compare two motor imagery intervention groups, one group who did variable motor imagery and one group who did constant motor imagery. The variable group used different fingers to perform the task to achieve variation. While the groups sizes were reasonably small (15, and 13 participants in each group respectively) they found significant improvement in both groups. Particularly, when repeating the task after one night's sleep, to act as a retention, the variable

imagery group significantly outperformed the constant imagery group. This suggests the presence of the variable practice effects in imagery and therefore supports functional equivalence. This conflicts with Coelho et al. (2012) and Fazeli et al. (2021) demonstrating a clear need for further investigation. The simpler computer task used in Debarnot et al. (2015), compared with the more complex putting task in Coelho et al. (2012) and Fazeli et al. (2021) may be the cause of the differences in findings.

Intra-task Processing Effects in Action Observation

Little research has investigated practice variability effects in non-physical practice. A notable example is from the work of Bird and Rikli (1983) who compared constant and variable practice groups in either physical or observational learning interventions. In which a curvilinear, horizontal positioning task was used. This involved the participant moving their dominant hand to a target (a specific angle) on the horizontal plane. The variable physical group would practice moving to four different targets (40°, 50°, 70°, and 80°) while the variable observation group would watch someone else move to these targets. The constant physical and observation groups would do the same but with only one target. After an acquisition phase all participants were blindfolded and asked to aim for a new target (90°), constituting a transfer performance. The findings indicated that variable practice resulted in superior transfer performance, regardless of the modality of practice. Both physical groups outperformed the observation groups, indicating physical practice is superior to observational learning. These findings do, however, suggest that there is an equivalence in the effects of variability of practice in both observational and physical learning.

Purpose of Experiments

The earlier suggestion, that theories of skill acquisition, developed using physical practice, can also apply to motor imagery, sets precedent for an applied approach to the

functional equivalence and divergence argument. While we do not fully understand the degree of divergence and equivalence between imagined and physical practice, advances in this field have mostly come from extended neuro imaging studies (Hardwick et al., 2018; Ladda et al., 2021). Optimising the practical application of imagery, however, has focused largely on how to best use imagery during a practice session (i.e., PETTLEP model and layered stimulus response training). This provides detailed guidance and many considerations to help create an optimal imagery practice session, but they give little direction about how a session should be structured or how practice should be varied. Specifically, to fit in and around physical practice, other training approaches, or practice of other skills. This presents itself as an opportunity to further optimise imagery practice while also testing functional equivalence.

It is key to distinguish this gap in the research from the existing knowledge on imagery session structuring and variability. For example, much has been done on the optimal amount of imagery per week (Paravlic et al., 2018; Wakefield & Smith, 2009). Only some work, however, has been done specifically on structuring imagery practice, specifically in contextual and retroactive interference effects (Gabriele et al., 1989; Hall et al., 1995). These findings have not been replicated (Overdorf et al., 2004). The work on contextual interference and imagery has also combined imagery and physical practice, leading to questions about where physical practice is required to see the contextual interference effect in imagery. This previous research is useful in a sporting context where imagery and action observation must be used effectively in conjunction with physical training. In some cases, like in rehabilitation and extreme sports, physical movement is not always possible, and imagery or action observation alone is needed.

There is potential to test other well-established approaches to skill acquisition in the context of imagery practice. For example, schema theory does not account for learning without feedback, yet both imagery and observational learning can enhance skill acquisition (Sherwood

& Lee, 2003). Specific approaches that are to be tested in this thesis are, the two components of the contextual interference effect, inter-task processing (blocked and random practice), and intra-task processing (constant and variable practice). These would also provide insight into the ability for functional equivalence, action plan reconstruction, and elaboration hypothesis to predict imagery practice effectiveness. Determining their predictive power within imagery practice would not only test the generalisability of these theories outside physical practice but also provide insight into functional equivalence in an applied practical setting, while aiming to optimise imagery practice.

To test these gaps in the literature the contextual interference effect must be tested in imagery practice, without any physical practice. To address the concerns of Overdorf et al. (2004) regarding the importance of the characteristic of the skill when observing contextual interference effects in imagery, a more open skill than that used in Gabriele et al. (1989) is required. The discrepancies between Blandin et al. (1994), Wright et al. (1997) and Lee and White (1990) regarding the existence of contextual interference in observational learning, also warrants further investigation. There is also discrepancy in the research findings that investigate intra-task processing in motor imagery. Intra-task processing seemingly improves motor imagery practice in simple tasks (Debarnot et al., 2015) but not in more complex sporting tasks (Coelho et al., 2012; Fazeli et al., 2021). Intra-task processing also appears to increase the effectiveness of observational learning (Bird & Rikli, 1983). These experiments, testing contextual interference in non-physical modalities, have also largely single day interventions. A longer intervention period using a more complex task would allow findings to be more generalisable, and may amplify these potentially weak effects (Coelho et al., 2012; Fazeli et al., 2021; Lee & White, 1990; Overdorf et al., 2004)

The aim of the present research is to test the effect of both the inter-task (blocked vs random) and the intra-task (constant vs variable) paradigm, in interventions without physical practice. This can better inform the extent of functional equivalence and divergence when manipulating practice structure and practice variability. The findings can then provide guidance on how to optimise practice structure and variability, in AOMI interventions. This would help to inform future imagery interventions on how to best structure and vary practice. The hypothesis aligns with functional equivalence, whereby increasing contextual interference (either through inter or intra task processing) will increase the effectiveness of action observation and motor imagery practice.

For experiment one the hypothesis is that the random imagery practice group will involve more contextual interference than the blocked imagery practice group. Subsequently the random imagery group will perform better in the retention and transfer task. For experiment two the hypothesis is that the variable imagery practice group will involve more contextual interference than the constant imagery practice group. Subsequently the variable imagery group will perform better in the retention and transfer task. For experiment three the hypothesis is that the contextual interference effect will manifest in both the physical and imagined groups. This would involve the random practice groups having shorter movement times than the blocked imagery practice groups during post-test and transfer. By using reaction time as a measure of cognitive demand, we expect to see higher cognitive demand (slower reaction times) in imagery, when compared to physical practice, as well as greater cognitive demand with higher contextual interference, when compared to lower contextual interference.

Chapter Two

Experiment One: Applying Contextual Interference to a Combined Action Observation and Motor Imagery Intervention to Test Functional Equivalence.

Abstract

Many classical skill acquisition theories are based purely on research involving physical practice. The contextual interference suggests that high contextual interference practice structure (random order of skills) is superior for retention and transfer performance when compared to a low contextual interference practice structure (blocked order of skills). Evidence of the contextual interference effect in non-physical practice has often used simple tasks, small sample sized, included a degree of physical practice, and produced inconsistent results. Participants (N = 64) imagined and observed videos of darts, football, and badminton skills in either a random or blocked practice structure. A third group acted as a control and instead watch interviews with famous darts players for the same duration. Comparing dart throwing performance at pre-test, post-test, and in a transfer condition (using heavier darts) tested for any differences between the practice structures. Preliminary analysis using a three group (Blocked, Random, and Control) three time point (Pre-test, Post-test, Transfer) ANOVA with repeated measures for time, evaluated the effect of practice structure. No group or time main effects were identified, nor interaction between them. These findings are in line with recent meta-analysis and systematic reviews that show the contextual interference effect is only observed in highly controlled lab studies using physical practice. It is also possible that contextual interference relies on mechanisms that are not as active when learning through non-physical modalities, allowing for more informed views on the workings of the contextual interference effect. Future research focus towards a longer intervention protocol, larger sample size, and physical experience with secondary tasks.

Introduction

Imagery that is specific to movement, known as *motor imagery*, is the covert rehearsal of a movement skill (Holmes, 2007). Research has aimed to optimise the use of motor imagery (Schuster et al., 2011; Wakefield et al., 2013; Ladda et al., 2021). For example, motor imagery is paired with action observation to increase or match the intervention's effectiveness when using one or the other in isolation (Eaves et al., 2016; Chye et al., 2022). This involves learning through watching a model and imagining performing the task oneself and is known as action observation motor imagery (AOMI, Vogt et al., 2013). The benefits of interventions using AOMI have been demonstrated in sport performance (Romano-Smith et al., 2018; Smith & Holmes, 2004), neuroscience (Nedelko et al., 2012; Taube et al., 2015) rehabilitation settings (Buccino, 2014; Mulder, 2007), and in reviews and meta-analysis (Chye et al., 2022; Eaves et al 2016). Non-physical interventions are well suited to overcome issues associated with physical practice, such as dystonia, overloading, tension stress, and cases where physical practice is unavailable (Ladda et al., 2021). Non-physical interventions are used in sports (Simonsmeier et al., 2021; Lindsay et al., 2019), rehabilitation (Tong et al., 2017; Suso-Martí et al., 2020), medical practice (Hall, 2002; Wakefield et al., 2020) and in the performing arts (Wright et al., 2014a; Kleber et al., 2007; Meister et al., 2004).

Functional equivalence and functional divergence, describes how similar and how different motor imagery is to physical movement, respectively. The functional equivalence hypothesis suggests that increasing the similarity of imagery practice to its physical counterpart, increases the effectiveness of motor imagery practice (Jeannerod, 1994, 2001). There is a neurological overlap when observing, imagining, or physically performing an action (Eaves et al., 2016; Chye et al., 2022) demonstrating functional equivalence between action observation, motor imagery, and physical practice (Holmes & Calmels, 2008; Holmes et al.,

2006; Williams et al., 2011). The PETTLEP approach (Holmes & Collins, 2001) provides effective practical guidelines for increasing functional equivalence to optimise AOMI interventions (Holmes & Calmels, 2008; Mohammadifard & Rafeiboroujeni, 2024; Romano-Smith, et al., 2019; Smith et al., 2020; Wakefield et al., 2013).

When creating any intervention aimed at developing an individual's motor skills, one must consider how to structure the practice when multiple skills are being learnt. Repetition is needed to facilitate learning (Ebbinghaus, 1885; Pavlov, 1927; Schöllhorn et al., 2022); however, simply repeating a task, before moving onto a different task, is not optimal (Battig, 1966; Jacoby, 1978; Cuddy & Jacoby, 1982; Lee & Weeks, 1987; Weeks et al., 1987). This was highlighted by the contextual interference effect (Battig, 1966) and later expanded on (Battig, 1972; 1979; Shea & Morgan, 1979; Magill & Hall, 1990; Brady, 1998). The effect demonstrates that frequently switching between different tasks during practice resulted in poorer performance during acquisition, but improved retention and transfer performance (i.e., motor learning; Magill & Hall, 1990; Brady, 1998, golf; Porter et al., 2007, basketball shooting; Feghhi, I., Abdoli & Valizadeh, 2011, and football passing; Entezari et al., 2017). Using inter-task processing to elicit the contextual interference effect, is the predominantly discussed form of the contextual interference (Shea & Morgan, 1979; Magill & Hall, 1990; Brady, 1998; Ammar et al., 2023; 2024; 2025; Czyż et al., 2024a; 2024b).

The action plan reconstruction hypothesis (Lee & Magill, 1983; 1985), provides an explanation for the contextual interference effect, specifically the inter-task processing effects. The hypothesis states that randomly switching between tasks facilitates forgetting. Lee & Magill (1983) used a block knockdown task where upon being presented with a stimuli light, participants were asked to knock down small wooden barriers following a given sequence. This task is well established in motor control research (Shea & Morgan, 1979) to test sequences

learning as well as motor coordination of the upper limbs. When a new sequence (B) is presented, the previously practised sequence (A) must be removed from short-term memory to make space for the new sequence (B). When the originally practiced sequence (A) is performed again, later on in random practice, the motor commands must be reconstructed without as much aid from short term memory. Blocked practice, however, causes practice to rely more on short term memory as the same task is repeated, and so can be easily recalled from short-term memory. The more frequent reconstruction, without short term memory, facilitated by random practice, is considered more optimal for learning (Lee & Magill, 1983; 1985; Callan & Schweighofer, 2010). As motor imagery requires the construction of a motor plan (Jeannerod, 1994, 2001; Hurst & Boe, 2022), it has been suggested that the action plan reconstruction hypothesis can also be applied to imagined practice (Gabriele et al., 1989).

Much of the contextual interference research focuses on physical practice. Few have investigated the effect in interventions combining physical practice with other modalities (e.g. action observation Blandin et al., 1994; Lee & White, 1990; Wright et al., 1997, motor imagery Gabriele et al., 1989; Overdorf et al., 2004). The presence of contextual interference in these other modalities has been inconsistent. Blandin et al. (1994) and Lee and White (1990) found evidence of the contextual interference effect in observational learning combined with physical practice. However, in two separate experiments, Wright et al. (1997) failed to replicate these findings. Gabriele et al. (1989) demonstrated the contextual interference effect in a combined physical and imagery intervention. However, Overdorf et al. (2004) failed to replicate these findings when removing physical practice from the intervention and using a different task. Many of these experiments show inconsistent results when using, simple tasks, involve little motor activity, and involve short interventions do not always isolate non-physical from physical practice (Blandin et al., 1994, Lee & White, 1990; Gabriele et al., 1989; Lee & White, 1990; Overdorf et al., 2004; Pauwels et al., 2015; Wright et al., 1997). They also do not isolate

the effects of action observation or imagery, instead they often combine these modalities with physical practice. To date, no experiments have tested the presence of contextual interference in a PETTLEP, or AOMI intervention without physical practice. Doing so would test the presence of contextual interference in non-physical practice intervention, test functional equivalence and help to optimise practice structure in a non-physical practice intervention. While this previous research on contextual interference in non-physical practice, has largely used motor imagery or action observation in isolation, the combination of AOMI has been more popular in recent years (Eaves et al., 2016; Chye et al., 2022) so warrants investigation. Action observation can therefore be seen to help facilitate motor imagery, increasing the functional equivalence, and so facilitating contextual interference in non-physical practice.

There is a need for a well-powered investigation into the presence of contextual interference (specifically inter-task processing effects) in different motor learning contexts and frameworks (Ammar et al., 2025), like non-physical interventions (Overdorf et al., 2004). Thorough investigation requires longer, non-physical interventions that are more in line with current optimisation approaches (like PETTLEP, and AOMI). Combining imagery and action observation has been an effective method of improving darts performance in the absence of physical practice (Romano-Smith et al., 2018). The absence of sensory information in imagery, or the passive act of observation, may not provide enough interference to elicit contextual interference when isolated, combining them may therefore increase functional equivalence and therefore increase contextual interference. Functional equivalence applies to observational learning (Blandin & Proteau, 2000) as well as imagery (Jeannerod, 1994, 2001), so a combined AOMI intervention provides a broad test of the functional equivalence of the contextual interference effect.

More generalisable motor tasks than used in previous experiments are required, while also isolating the contextual interference effects of non-physical practice, from the effects of physical practice. In physical practice, dart throwing performance measured through radial error, has been previously used to demonstrate the advantages of random practice over blocked, however, these findings used a single day intervention with a small sample size (N = 12) and did not reach significance (Van den Tillaar & Aune, 2019). The hypothesis for the current experiment is that the three-day dart throwing imagery intervention involving more contextual interference (through random practice) will result in superior post-test and transfer darts performance when compared to a three-day intervention using less contextual interference (through blocked practice). The secondary tasks (badminton serve and football penalty) used to create the contextual interference effect, will involve completely different movements to isolate the inter-task processing effects, from any intra-task processing. This facilitates a test of the predictions of the action plan reconstruction hypothesis in a non-physical practice intervention. The contextual interference effect, as explained by action plan reconstruction, is hypothesised to occur in the AOMI intervention. The intervention groups are also expected to report higher levels of mental demand than the control group. The random group is also expected to show higher levels of mental demand than the blocked group, due to the increase in contextual interference they experience.

Method

Participants

A total of 64 university students (F = 33, M = 31, M *age* = 20.77, SD = 3.46) volunteered to participate. All participants gave informed consent and stated they were novice darts throwers (defined as an individual who has not thrown a dart on more than five previous occasions and has never played a competitive game of darts, Radlo et al, 2002; Marchant et al., 2009). Other inclusion criteria were that participants passed the PAR-Q+ 2022 (see below) and

had never undertaken any imagery training. Based on a conservative, small to moderate, effect size of η_{p^2} = 0.035 (Gabriele et al., 1989 η_{p^2} = 0.22; Hall et al., 1995 η_{p^2} = 0.25; Overdorf et al., 2004 η_{p^2} = 0.27; Wakefield & Smith, 2009 η_{p^2} = 0.41), a G*Power analysis suggested a sample size of 60 was required to render a three group by three time point mixed model ANOVA, sufficiently powered at an alpha .05 and power of .8 (Lakens, 2022). Ethical approval was granted by the Liverpool Hope University Research Ethics Committee.

Apparatus & Materials

The videos and questionnaires were all completed on a laptop (screen size 32 x 17cm) using PsyToolKit (Stoet, 2010, 2017), except the PAR-Q, for which a paper copy was completed.

PAR-Q+ (Warburton et al., 2019, see Appendix Two)

Participants provided their age and gender that they most closely identified with, before completing the PAR-Q+ 2020. This measure was used to assess the participants' fitness to reduce the risk of any negative health effects that may result from participation in the study. The PAR-Q+ has been widely and successfully used in previous research as a screening tool (Venkataraman et al., 2024; Bredin et al., 2025; Mahbur & Tumijan, 2024; Miller, 2023).

The Edinburgh Handedness Inventory – short form (EHI; Oldfield, 1971, see Appendix Three)

This measure was employed to determine the handedness of the participants. The measure asks participants which hand they use to perform four daily tasks like "brushing teeth", "Using a spoon", "throwing" and "writing". The test has been shown to have a p = .93 on Raykov's composite reliability score (Veale, 2014).

Movement Imagery Questionnaire-Revised (MIQ-R; Hall & Martin, 1997, see Appendix Four)

Participants completed the MIQ-R to assess their ability to effectively use imagery. This measure assessed an individual's ability to perform visual and kinaesthetic imagery of a given physical action that they physically performed before imagining. Following physical execution of the required task (for example, raising and lowering one knee). Participants are required to rate the ease of imagining the action on a 7-point Likert scale ranging from 1 (very hard) to 7 (very easy) for the visual or kinaesthetic reproduction of the task. The actions are then repeated with the alternate form of imagery completed. The MIQ-R has been used in previous imagery studies, as a pre-intervention screening tool (Wright & Smith, 2009; Romano-Smith et al., 2018). During the MIQ-R, the researcher stepped out of the room to allow the participant to complete the questionnaire without the feeling that they were being observed. The two subscales of the MIQ-R have been shown to have test-retest consistency coefficients of .80 for visual and .81 (Monsma et al., 2009). According to the guidance of Smith and Collins (2004), participants scoring less than 14 (the midpoint) on either subscale should be excluded from the study.

NASA-Task Load Index (Hart & Staveland, 1988; Hart, 2006, see Appendix Five)

This measure is a self-report task workload measure during the experiment. The instrument consists of six subscales, each on a scale from one (low) to ten (high). Participants are required to rate the task based on their perception of Mental Demand, Physical Demand, Temporal Demand, Frustration, Effort, and Performance. The test-retest consistency coefficient of the measure is .83 (Hart & Staveland, 1988) and has been used successfully in a wide range of settings (Hart, 2006).

Dartboard and Darts.

A dart throwing task was used to measure performance. This was a full-size concentric circular dartboard (XQ Max Darts, flocked home dartboard, 45.1 cm in diameter with each concentric circle approximately 2.5cm in width). Participants threw from a line 2.37m away

from the wall on which the dartboard was hung. The dartboard was at a height of 1.73m from the bullseye to the floor (international competition standard). Dart throwing accuracy was measured to one decimal place, by hand, using a tape measurement from the darts point of contact, to the centre of the dartboard. Standard darts (weighing 17g) were used for the pre and post-test. To complete an effective transfer task, heavier darts (weighing 30g) were employed for this purpose, and research has demonstrated that using heavier darts is a good option for assessing dart throwing ability (Campos et al., 2019). Transfer tasks are often used in contextual interference research (Czyż et al., 2024a) as the successful reparameterization of movements, act as a thorough hallmark of motor learning (e.g., Schema theory; Schmidt, 1975).

Procedure

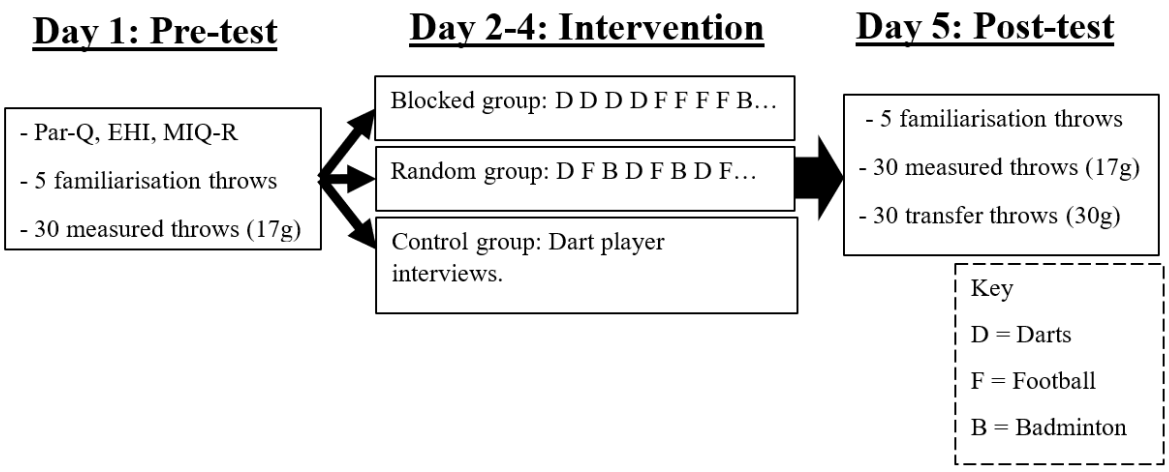
Participants arrived on the first day of testing at pre-allocated individual time slots and performed a pre-intervention test (pre-test) of their dart throwing accuracy. This consisted of a familiarisation task of five practice throws, followed by the pre-test. The pre-test involved completion of 30 assessed throws, performed across six blocks of five with a 30-second pause between each block as a rest period. Participants then completed the NASA-TLX, before being evenly divided into three gender-matched groups (blocked practice, random practice, and a control group) based on their pre-test scores. This involved pseudorandomised allocation of the participants into the three distinct groups depending on their performance compared to the other participants that week. For example, the best performing participant would be allocated to the blocked group, the second best performing participant would be allocated to the random group, and the poorest performer would be allocated to the control group. The order of group allocation changed each week (rotating around which group the best, mid, and worst performer, were allocated into) to ensure there was an equal number of weekly highest performers in each group to reduce the probability of a significant difference at pretest. The same approach was taken if there were only two participants, and if there were more than three participants in a

week then a combination of the two approaches was used. For example, if five participants partook in one week then the first three (that participated on the first day of testing) would be grouped and allocated according to their relative performance. Then the last two participants would be allocated according to their relative performance.

Participants then came back to the same lab to complete a three-day AOMI intervention on the second, third, and fourth day of this five-day study (see figure 1 for a methods flow diagram of the intervention). All testing days were consecutive days in the same week. Participants then returned on day five to complete the post-test, which followed the same protocol as the pre-test, including the completion of the NASA-TLX. Following the post-test, a transfer test consisting of 30 throws with heavier darts was completed. At the end of the transfer test participants were asked whether they thought the intervention improved their darts throwing accuracy on a scale from 1 (very negatively) to 7 (very positively), were thanked, and debriefed.

Figure 1

Methods Flow Diagram



Intervention.

Experimental Imagery Groups

Participants allocated to the random group were introduced to the three imagery tasks, which they then imagined in a random order. These tasks required participants to imagine a darts throw, followed by a football penalty (shooting to the bottom left corner if the participant is right footed), and finally a badminton serve (a backhand serve that goes low over the net and lands just behind the service line). These secondary tasks were chosen as they involve common skills in popular sports and involve different muscle groups and movements and are completed in roughly the same time frame. The imagery intervention was arranged in a pseudorandomised order (never repeating the same task twice, with 100 trials of each task each day), each block taking three-minutes. Every 30-seconds there was a five-second break, and after every three-minute block there was a 20-second rest. This continued, with four groups of three-minute imagery, for the duration of the session. The order of the three tasks changed across the different intervention days, while ensuring the same task was never repeated twice in a row and was counterbalanced between participants. Participants in the blocked practice group spent one third of the session (four repeated blocks, 100 trials) performing darts using imagery, then one third on football and another third on badminton; the order was also counterbalanced across the three days and between participants. The same amount of total imagery training (a 37-minutes per day) was undertaken by both blocked and random groups, only the structure of the practice differs. This was based on research on optimal frequency of imagery practice (Wakefield & Smith, 2009).

Participants completed the AOMI using a first-person video of a non-elite but high level and correct performance of each of the three skills (see fig. 4). These videos were played to participants, and they were asked to simultaneously watch the video while imagining

themselves performing the skills shown. The videos were matched based on participants' gender and handedness (Braaksma et al., 2002; Rohbanfard, & Proteau, 2011). The model in the videos covered their skin during the performance of the three skills, in the darts and badminton videos the model wore blue gloves, this was to minimise any racial bias (Kang et al., 2021). It was also made clear to the participants that they would be physically throwing darts at the end of the study. This was done as observing with the intention to reproduce is more beneficial for motor learning particularly when learning the movement's relative timing structure (Badets et al., 2006).

The AOMI was performed in line with the PETTLEP guidelines (Holmes & Collins, 2001); holding the dart or badminton equipment (Physical), completing the AOMI in the same place as the pre/post-test (Environment), and imagining the specific tasks (Tasks; penalty, serve and dart throw). Participants were instructed to imagine from an internal perspective (Perspective), in real time (Timing), and include any emotions that they experienced in the pre-test (Emotion). After each AOMI session they answered four manipulation check questions: "how easy was it to see the action imagined", "how easy was it to feel the action imagined", "what percentage of the time where you able to imagine the task", as well as asking for details on any feelings or sensations they experienced during the AOMI practice. The AOMI intervention was also supervised and individual (one on one) which is considered optimal (Schuster et al., 2011).

Before the intervention, participants in the random and blocked groups underwent stimulus and response training (Lang, 1977; 1979) for the darts task. Participants stood in a dart throwing position, with their arms down, imagining themselves about to throw a dart, without a dart or any movement, then verbally recalling any aspects they find easy to imagine. The specific aspects participants were asked to recall were "sensations", "thoughts", and

"physical sensations" (Cumming et al., 2017). For example, a participant included details of "a focus on the bull's eye" or "tension in my throwing arm". This was recorded and used to make a personalised dart imagery script for each participant. Over the three training sessions, the individuals' responses from the beginning of each session were discussed and any new propositions were added to create more detailed and personalised imagery scripts.

The individualised scripts developed from the stimulus response training were repeated to participants before every darts block. A standardised imagery script was read before each block of football or badminton AOMI practice. For example, "focus on kicking the ball along the ground to the bottom left corner of the goal" or "imagine yourself performing a backhand serve that goes low over the net and lands just on the opposite side of the service line". The simplicity of these instructions for the badminton and football AOMI, and the personalised nature of the darts imagery script allowed for the intervention to be non-directed, which is considered optimal (Schuster et al., 2011).

Figure 2

A model demonstrating the dart throwing performance measure



Figure 3

A Model Demonstrating the Badminton AOMI Practice Portion of the Intervention



Figure 4

A still image taken from the dart throwing action observation video.



Control group

The control group watched an equivalent time (approximately 35-minutes) of interviews with professional darts players about their personal life and career. The videos contained no dart throwing or technique points and were viewed in the same labs on the same

laptop as the intervention groups. The videos were arranged into three sessions, same as the intervention groups, with each day involving interviews from one darts player (either Phil Taylor, Eric Bristow, or Michael van Gerwen). The order of these interviews was counterbalanced between participants.

Data Analysis

The study was a three group (blocked, random, and control) by three time point (pre-test, post-test, and transfer) mixed model design. Throwing accuracy was calculated by taking the mean radial error of each group at each time point and compared using Repeated Measures ANOVAs. Mauchly's test of homogeneity of variances was used for any ANOVAs with more than two levels (Mauchly, 1940). Sphericity was calculated for all repeated measures ANOVAs (Mauchly, 1940). For instances when Greenhouse-Geisser was above 0.75, the Huynh-Feldt correction was used (Abdi, 2010). Significance was assessed using an alpha of $p < .05$, and effect sizes are indicated using partial eta squared (η_{p^2}). Bayesian statistics are used to supplement and validate the analysis and interpretations; the Bayesian analysis follows the same analytical structure. These parallel analyses are presented after each frequentist output. A uniform prior on the interval (0, 1) was used in all Bayesian analysis, using the default prior settings used in JASP (Heo et al., 2020). All Bayesian analyses are conducted using BF_{01}, all models were ordered by comparing against the null model, this approach was chosen for consistency and clarity across all analyses. According to Jeffreys (1939) a Bayes factor between one and three is considered weak evidence, between 3 and 10 is considered moderate evidence, and greater than ten is considered strong evidence. An error percentage of less than 20% for a Bayes factor is considered acceptable (Van den Bergh et al., 2020). All analyses were completed in JASP 0.18.03.0. All data collection and management procedures used, were approved by Liverpool Hope University's Research Ethics Committee.

Outlier Removal and Manipulation Checks

Two outliers were removed because their radial error deviated by more than two standard deviations from the group mean. Due to a glitch in the online recording eight participants in the control group, one participant in the blocked group and one participant in the random group had some missing NASA-TLX data for at least one day of the intervention. They were removed from analyses using the NASA-TLX data but were included in all other analyses. There were also no significant differences in the four self-reported imagery manipulation checks between the random and blocked groups.

Results

Pre-test ANOVA

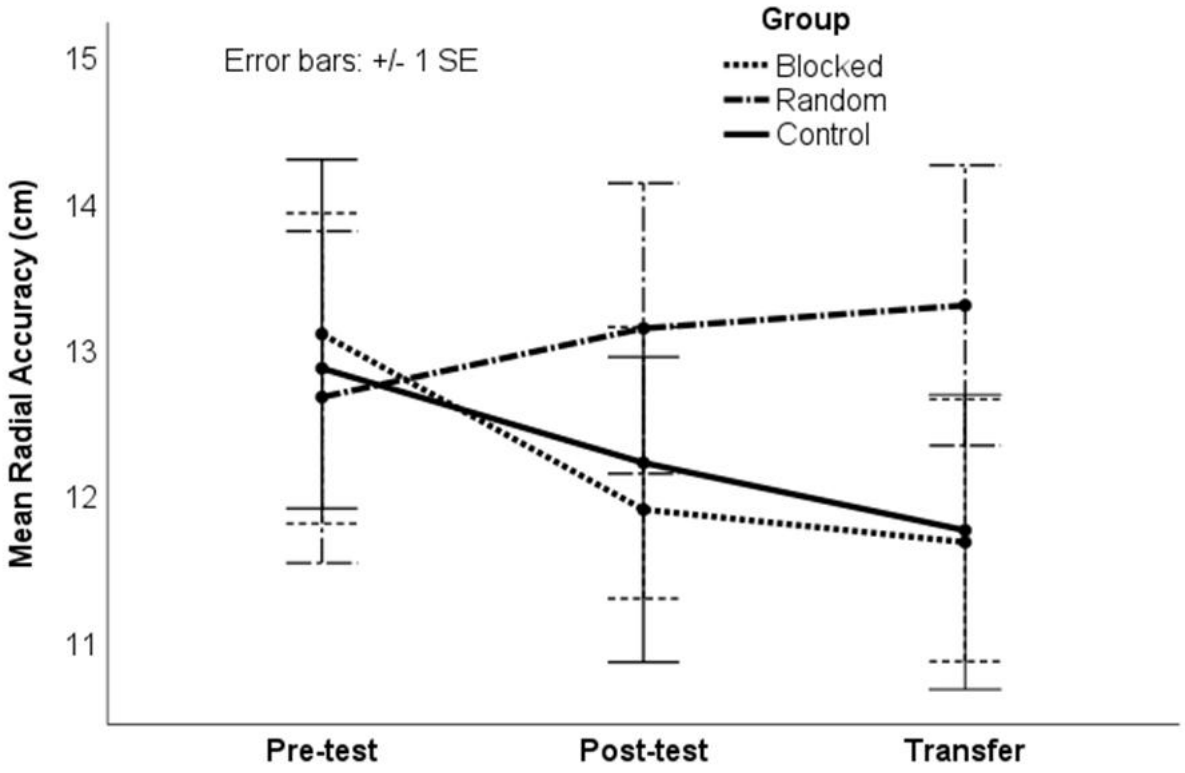
A One-Way three group ANOVA (Blocked, Random, and Control) at pre-test was conducted to check for equivalence and thus comparability between groups. There was no significant difference between groups, $F(2,61) = 0.03$, $p = .966$, $\eta_p^2 < .01$, $BF_{01} = 7.55$, error % = 0.03. Levene's test suggested there was homogeneity of variance, $F(2,61) = 1.43$, $p = .247$.

Mixed-Design ANOVA (Fig. 5)

A three group (Blocked, Random, and Control) by three time point (Pre-test, Post-test, and Transfer) repeated measures ANOVA acted as the omnibus analysis. Neither the main effect for time was not significant, $F(1.72, 105.35) = 2.14$, $p = .130$, $\eta_p^2 = .03$, $BF_{01} = 3.30$, error % = 0.91, nor the main effect for group, $F(2, 61) = 0.21$, $p = .809$, $\eta_p^2 = .01$, $BF_{01} = 2.49$, error % = 3.30. The interaction between time and group was also non-significant, $F(3.45, 105.35) = 2.21$, $p = .083$, $\eta_p^2 = .07$, $BF_{01} = 1.29$, error % = 8.96.

Figure 5

Omnibus Results: A Three Group by Three Time Point Repeated Measures ANOVA

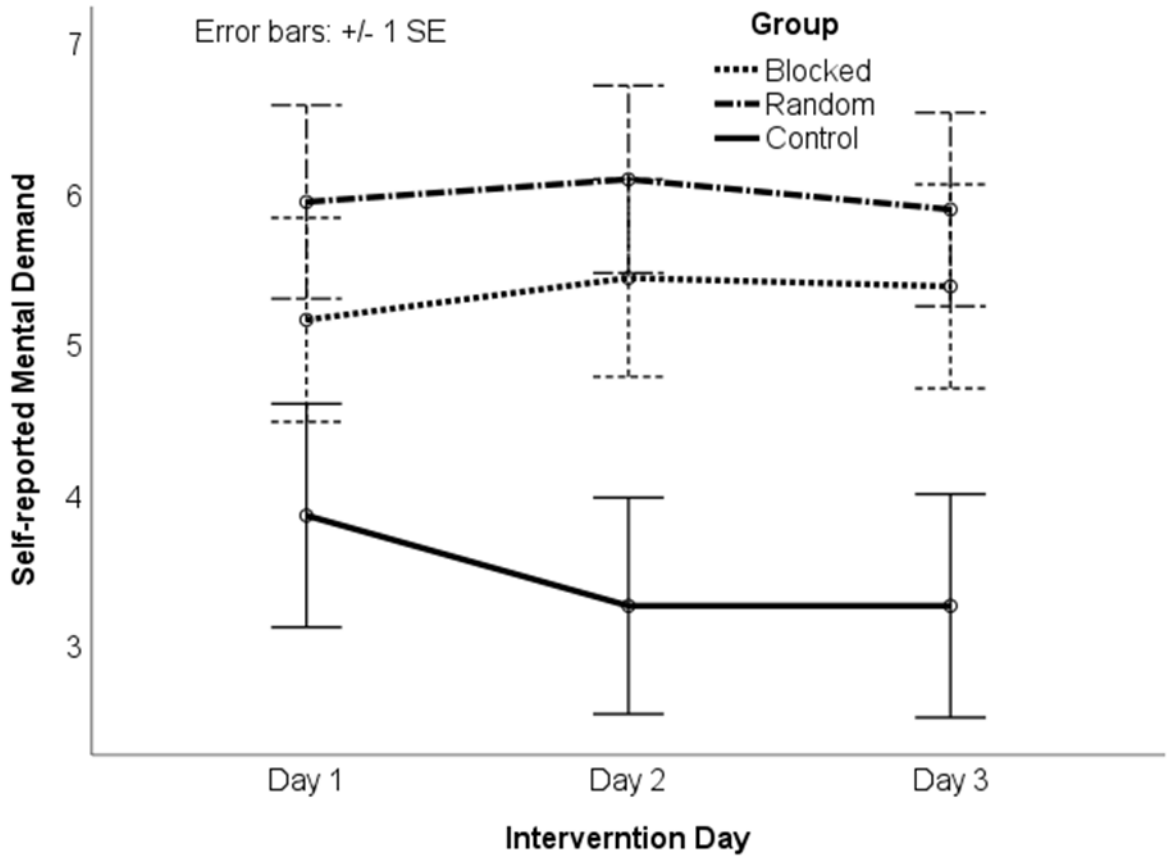


Mental Demand Repeated Measures ANOVAs (Fig. 6)

A three groups (Blocked, Random, and Control) by three time points (intervention day 1, 2, and 3) repeated measures ANOVA was completed, to see variation in self-reported mental demand from the NASA-TLX. Results were non-significant for the main effect for time, $F(2, 100) = .200$, $p = .820$, $\eta_p^2 < .01$, $BF_{01} = 12.39$, error % = 12.24, and the interaction, $F(4,100) = 0.82$, $p = .517$, $\eta_p^2 = .03$, $BF_{01} = 8.78$, error % = 7.15. The main effect for group was significant, $F(2, 50) = 3.93$, $p = .026$, $\eta_p^2 = .14$, $BF_{01} = 0.40$, error % = 7.22. Simple contrasts for groups revealed no significant differences between groups, however, the difference between blocked and control groups was approaching significance $t(50) = -1.99$, $p = .052$.

Figure 6

Self-Reported Mental Demand during the Intervention



Discussion

The hypothesis, which predicted the presence of the contextual interference effect in AOMI practice, was not supported by the present findings. The hypothesis focused on contextual interference from the perspective of inter-task processing, where multiple distinct generalised motor programs are practiced in a random order. This suggests that in AOMI practice the action plan reconstruction hypothesis alone does not predict superior post-test or transfer performance following random practice, when compared with blocked practice. The intervention groups also performed similarly to the control group and showed no main effect

for time, suggesting that the intervention did not meaningfully improve dart throwing performance. There were also significant group differences in self-reported mental demand between groups during the intervention, with the reported mental demand during the intervention groups being higher than the control. This suggests that, as expected, the AOMI intervention was more cognitively demanding than the control videos (Glover & Baran, 2017). However, there were no differences found in mental demand between the two intervention groups. It appears likely that as the intervention involved two irrelevant and interfering secondary tasks, it lacked enough task specific AOMI practice to result in learning. As the participants, who underwent the intervention, failed to show learning effects greater than that of the control group, it was not possible to elicit the contextual interference effect.

This experiment aimed to further the generalisability of the contextual interference in non-physical practice, by using a longer intervention as well as a sports task (Gabriele et al., 1989; Overdorf et al., 2004; Karageorghis, 2016). The superior performance from the control groups, indicated in mixed design ANOVA when compared to the random AOMI groups, could suggest that the contextual interference and/or the AOMI practice had a negative effect on performance. For example, it is likely more difficult to imagine a precise task like a dart throw than a block knockdown (Gabriele et al., 1989) anticipation timing task (Overdorf et al., 2004). Increasing the complexity and precision of an imagined action has been shown to slow motor imagery time suggesting it is more cognitively demanding (Glover & Baran, 2017). This is supported by the significantly higher self-reported mental demand results in the present experiment. This is not to say that motor imagery does not work for precise motor skills (Martzog & Suggate, 2019; Romano-Smith et al., 2018; 2019), especially for those who are experts in the skill (Dahm & Rieger, 2019). However, there may be a reduction in AOMI practice effectiveness when the skill is highly precise and fine, like dart throwing (Glover & Baran, 2017; Ladda et al., 2021). Practice may have also become too cognitively demanding

due to the interference of learning multiple tasks (Shea & Morgan, 1979; Lee & Magill, 1983; 1985; Davids et al., 2008; Broadbent et al., 2017), combined with the cognitive demands of imagining such a precise motor skill (Glover & Baran, 2017). This may result in practice being too demanding for participants to construct and develop action plans in order to produce learning effects (Hebert et al., 1996; Guadagnoli & Lee, 2004; Wulf & Shea, 2002) or see the effects of the action plan reconstruction hypothesis (Lee & Magill, 1983; 1985). The present findings support this as self-reported mental demand for the intervention groups was highest in the random group, and slightly lower in the blocked group, whereas the control group was significantly lower. This suggests that the generalisability of the contextual interference effect in AOMI may be dependent on variables like learners' ability, the task difficulty, and the interaction between the two (cf. challenge point framework, Guadagnoli & Lee, 2004).

The lack of performance improvements that resulted from the intervention is likely to be due to the difficulty of improving dart performance in novices, over a short period of time, without physical practice (Dahm & Rieger, 2019; Romano-Smith et al., 2018; 2019). Novice performers may not be ideal participants when testing learning effects from contextual interference within a dart throwing AOMI intervention. Novices can benefit greatly from imagery combined with physical practice (Brouziyne & Molinaro, 2005) so removing any physical practice would have restricted learning for novices. The feedback information provided from the physical practice can be used to update an action plan (Schmidt, 1975; Lee & Magill, 1983; 1985) that can then be used during motor imagery (Bach et al., 2022; Grush, 2004; Jeannerod, 1994, 2001, 2006). Once the imagined action plan is developed through physical experience, then imagery practice alone may be sufficient to enhance novice performance in these highly precise motor tasks (Ryan & Simons, 1983).

More experienced individuals seem to benefit from random practice than individuals with less experience (Del Rey, 1989). The use of novice performers may therefore have weakened the contextual interference effect. Kim et al. (2014) shows that novices have measurable neurological disadvantages compared to more experienced performers in an imagined self-paced aiming task. Specifically, novices' neural activity is less efficient and less effective at integrating sensorimotor information to automate simultaneous movements during imagery. For example, during dart imagery, simultaneously imagining how to move the arm and when to release the dart. There are relatively low numbers of degrees of freedom in throwing a dart, but high temporal, spatial, and force precision requirements. The high temporal, spatial, and force precision requirements of darts require a high level of fidelity to accurately imagine throwing a dart (Glover & Baran, 2017; Glover et al., 2020; Martel & Glover, 2023). Novices who have had little physical experience of the task, may not have been able to generate motor imagery with enough fidelity to result in measurable learning, when using radial accuracy as a measure of performance (Dahm & Rieger, 2019). The high temporal, spatial, and force precision requirements, may only be learned through many years of physical practice (Dahm & Rieger, 2019). The rehearsal of the sequence of events (Hall, 2002), in association with sensory results to an action (Frank & Schack, 2017), accounts for much of the basic skill of darts, and may have already been learnt by throwing other objects in the past (Schmidt, 1975). Subsequently, the lack of constraints, sensory feedback, and precise requirements of accurate dart throwing and the high cognitive demands of effectively imagining dart throwing, may have had a combined effect. This combination will have made it difficult for novices to develop the action plans required to outperform their pre-test darts performance, using only AOMI (Dahm & Rieger, 2019; Davids et al., 2008; Hebert et al., 1996; Guadagnoli & Lee, 2004; Lee & Magill, 1983; 1985; Wulf & Shea, 2002). With more task

specific practice, participants would have likely been able to improve their dart throwing performance using only AOMI (Romano-Smith et al., 2018; 2019).

The lack of a drop in performance at transfer may have been due to the heavier darts providing more haptic feedback during the throws. Haptic feedback is known to help with motor performance (Sigrist et al., 2013; Frikha et al., 2019) specifically with accuracy performance (Corbett et al., 2016). Some participants verbally reported that they preferred the heavier darts. The same darts were used in this study as were used in Romano-Smith et al. (2018) These darts, however, are lighter that those used than previous dart throwing experiments (Nasu et al., 2014; Chan, 2019; Campos et al., 2019). The darts used in the present experiment are also considered very light (Cornwall, 2025). Future studies could consider using heavier darts than the ones used in these experiments (e.g. 44g darts for transfer and 24g for other test phases) to be more consistent with real world darts performance. Researchers could also consider the use of lighter darts for transfer tests to reduce the sensory feedback of the task. Researchers using darts as their task would also do well to measure the spread of the darts rather than just radial accuracy. For example, using Cartesian coordinates one could better understand changes in dart throwing performance by looking at where the dart throws are clustered to spot biases in the throwing performance.

The lack of physical experience in the secondary tasks (backhand serve and penalty shot) may have reduced the effectiveness of the AOMI practice, making it more difficult, and less likely to result in the contextual interference effect. There is evidence that motor imagery is only effective if the individual has experience physically executing the task before they try to imagine it (Mulder et al., 2004; Olsson & Nyberg, 2010; Kraeutner et al., 2016; Gomes et al., 2014). While it was not feasible to give all participants experience of both secondary tasks, these tasks were selected as they are popular sports and simple skills so participants would

likely still be able to imagine them. Some individuals will have more experience than others in these sporting skills so they may be able to imagine them more effectively. However, as long as the badminton serve and penalty shot imagery resulted in some image generation or caused the imagined darts throw to leave short-term memory, then the prediction of the action plan reconstruction hypothesis would still hold. The participants were also aware that only dart throwing performance was being assessed which may have caused a reduction in engagement in the other tasks. Future research in contextual interference could ensure that performance in all the practiced tasks is measured at pre-test and post-test to circumnavigate this limitation. In this scenario, the predictions of action plan reconstruction suggest that a random structure would improve performance in all the tasks practiced, when compared to a blocked structure. Alternatively, it may be that the mechanisms that create the contextual interference effect rely on a component of physical practice that is absent in AOMI practice. This would explain not only why the present findings show no evidence of learning or the contextual interference, and why previous research that has showed the contextual interference in imagery interventions has involved a degree of physical practice (Gabriele et al., 1989). Imagery in isolation may, for example, require too much cognitive load for novices, prohibiting the mechanisms used in contextual interference.

The present experiment demonstrates an absence of the contextual interference effect after a three day AOMI dart throwing intervention. This supports previous findings that show absence of the contextual interference effect in non-physical practice (Overdorf et al., 2004; Lee &White, 1990) suggesting functional divergence. Another explanation for the findings is that the requirements for the intervention were too demanding for learning to occur (Guadagnoli & Lee, 2004), specifically the use of multiple, distinct unrelated tasks during the intervention (Boutin & Blandin, 2010; Lee & Magill, 1983; 1985; Shea & Morgan, 1979; Cuddy & Jacoby, 1982; Shea & Zimny, 1983), combined with the precise temporal, spatial and

force requirements to produce performance gains from an AOMI intervention (Dahm & Rieger, 2019; Glover & Baran, 2017). This research focused on the predictions of inter-task processing and the action plan reconstruction hypothesis (Lee & Magill, 1983; 1985). Future research could test the predictions of other explanations and aspects of the contextual interference effect. For example, the effects of intra-task processing (also known as variable practice effects) in imagery (Coelho et al., 2012; Fazeli et al., 2021; Lindsay et al., 2023). Interventions using real-world tasks to increase the generalisability of the contextual interference, may require more task relevant practice to elicit the effect (Al-Mustafa, 1989; Ammar et al. 2023; 2024; 2025; Brady, 1998; Czyż et al., 2024a; 2024b). Practitioners looking to optimise practice structure in non-physical interventions should not assume that theories developed using physical practice can be applied in the same way. While theoretically contextual interference should manifest in non-physical practice, practitioners are warned that the effect maybe weakened in non-physical practice.

Chapter Three

Experiment Two: Applying Variable Practice to a Combined Action Observation and Motor Imagery Intervention to Improve Darts Performance.

Abstract

Many classical skill acquisition theories are based purely on research involving physical practice. Schema theory suggests that variable practice (where the parameters of a task are varied during practice) is superior for learning when compared to constant practice. Evidence of variable practice effect in non-physical practice has often used simple tasks, small sample sizes and produced inconsistent results. Participants (N = 63) imagined and observed videos of dart throws in either from a variety of distances (variable practice) or from the same distance (constant practice). A third group acted as a control and instead watch interviews with famous darts players for the same duration. Comparing dart throwing performance at pre-test, post-test, and in a transfer condition (using heavier darts) tested for any differences between the practice structures. Preliminary analysis using a three group (Blocked, Random, and Control) three time point (Pre-test, Post-test, Transfer) ANOVA with repeated measures for time, evaluated the effect of the different practice. No group main effects were identified, nor interaction between them, there was, however, a significant main effect for time in all groups. These findings are in line with previous research that suggest variable practice effects can only be observed in highly controlled lab studies using physical practice. It is also possible that darts is too complex of a skill to show learning effects in novices within a three day non-physical practice intervention. Future research on the functional equivalence of practice effects could take a more mechanistic approach and use a simpler task.

Introduction

The functional equivalence hypothesis suggests that increasing the similarity of imagery practice to its physical counterpart, increases the effectiveness of motor imagery practice (Jeannerod, 1994, 2001). Functional equivalence suggests that theories of motor learning that apply to physical practice, will manifest in a similar way in AOMI (see Experiment One; Badets & Blandin, 2004; Bird & Rikli, 1983; Blandin & Proteau, 2000; Coelho et al., 2012; Debarnot et al., 2015; Fazeli et al., 2021; Gabriele et al., 1989; Overdorf et al., 2004). The opposite of functional equivalence is functional divergence which describes how motor imagery can differ to physical execution (Hurst & Boe, 2022). By increasing functional equivalence PETTLEP has been shown to enhance strength performance (Wakefield & Smith, 2011; Wright & Smith, 2009), technical skills in sport (Wakefield & Smith, 2009; Cherappurath et al., 2020), and nursing (Wright et al., 2008).

It has long been clear that a form repetition can facilitate learning (Ebbinghaus, 1885; Pavlov, 1927; Schöllhorn et al., 2022). Simply repeating the same motor task has been shown to be suboptimal at improving retention or transfer performance (Jacoby, 1978; Cuddy & Jacoby, 1982; Lee & Weeks, 1987; Weeks et al., 1987). The benefit of varying practice is explained by schema theory (Schmidt, 1975). The theory outlines general motor programs as classes of movements that share similar characteristics. A schema is a group of learned rules that controls motor commands that more accurately guide a generalised motor program. Repeated sensory feedback about the relationship of these four aspects is used to update the Schema to make it more accurate and reliable in future. Schmidt proposed that varying these aspects in practice (variable practice) would develop more flexible and reliable schemas when compared to practice that aimed to keep these aspects constant (constant practice). For example, practicing golf putting from various distances would vary the absolute force, and result in superior learning than practicing putts from the same distance.

The advantages of variable over constant practice had been observed previously (Duncan, 1958; Ellis, 1965) and had also been termed intra-task processing effects in the field of contextual interference (Battig, 1966; 1972; 1979; Brady, 1998; Magill & Hall, 1990; Shea & Morgan, 1979). The term variable practice is preferred in more recent years, and the effect has received consistent empirical support (Gerson & Thomas, 1977; Landin et al., 1993; Moxley, 1979; Newell & Shapiro, 1976; Shea & Kohl, 1990; Wrisberg & Ragsdale, 1979; Wulf & Schmidt, 1997; Yao et al., 2009). When practicing different variations of a task, a practice structure using a random order of each variation is optimal and most common (Boutin & Blandin, 2010; Dick et al., 2000; Li & Lima, 2002; Maslovat et al., 2004; Ranganathan & Newell, 2010; Ruano et al., 2022; Reid et al., 2007). The random switching between different tasks invokes a greater degree of inter-task processing (Battig, 1966). However, inter-task processing describes the effect of switching between distinct tasks (see Experiment One) but has often been combined with intra-task processing to increase contextual interference to benefit learning, both experimentally (Dick et al., 2000; Ranganathan & Newell, 2010; Ruano et al., 2022) and theoretically for applied settings (Reid et al., 2007). Functional equivalence would therefore suggest that varying action observations and/or motor imagery would provide the same learning benefits that varying physical practice has.

Little research has investigated practice variability effects in non-physical practice. An early example is Bird and Rikli (1983) who looked at the effect of variable practice in observational learning compared with physical practice. They used a curvilinear, horizontal positioning task (Lafayette Kinesthesiometer) in which participants are asked to place their forearm on a rotating level which restricts their movement to the horizontal plane. participants are then asked to rotate their forearm to a specific angle, acting as a test their movement coordination. The findings indicated that variable practice resulted in superior transfer performance, regardless of the modality of practice, however, the effect was weaker in

observational learning. These findings suggest some equivalence in the effects of variable practice in both observational and physical learning. Debarnot et al. (2015) used a simple stimulus and response task with a computer keyboard to compare two motor imagery intervention groups, one group who did variable motor imagery and one group who did constant motor imagery. The variable group used different fingers to perform the task to achieve variation. While the groups sizes were reasonably small (15 and 13 participants in each group respectively), they found significant improvement in both groups. Particularly, when repeating the task after one night's sleep, to act as a retention, the variable imagery group significantly outperformed the constant imagery group. This suggests the presence of the variable practice effects in imagery and therefore supports functional equivalence. This is in line with an ecological dynamic's perspective of variable practice in imagery, proposed by Lindsay et al. (2023).

Other research has not found variable practice effects in motor imagery interventions (Coelho et al., 2012; Fazeli et al., 2021). These two experiments found that variability in motor imagery practice was not beneficial whereas variability in physical practice was beneficial. Calling into question the functional equivalence hypothesis, as increasing variability appears to have no effect on imagery practice, while having a positive effect on physical practice. Fazeli et al. (2021) suggests that this functional divergence is due to the lack of visual feedback, and knowledge of results during motor imagery. In both physical and observational learning, the knowledge of results can be compared to the actions outcome to fine-tune future actions (Sperry, 1950; Wolpert, 1997; Schmidt, 1975; Badets & Blandin, 2004; Blandin & Proteau, 2000) and is a key mechanism in the variable practice effect (Schmidt, 1977; Wulf & Schmidt, 1997). In imagery, where there is no knowledge of the results, this process cannot occur (Wong et al., 2013; Fazeli et al., 2021). Action observation provides knowledge of results suggesting that an AOMI intervention may produce variable practice effects when imagery alone does not.

This is supported by the consistent findings of variable practice effects in action observation interventions (Bird & Rikli, 1983; Badets & Blandin, 2004; Blandin & Proteau, 2000) but not in motor imagery (Debarnot et al., 2015; Coelho et al., 2012; Fazeli et al., 2021)

Much of the previous literature on variable practice effects in non-physical modalities (observational learning and motor imagery), uses relatively short single day interventions (Coelho et al., 2012; Fazeli et al., 2021), and/or simple laboratory motor tasks (Bird & Rikli, 1983; Debarnot et al., 2015). Motor imagery and action observation practice effects are considered weaker than physical practice effects (Driskell et al., 1994; Feltz & Landers, 1983; Ladda et al., 2021), specifically when eliciting variable practice effects (Coelho et al., 2012; Fazeli et al., 2021). This suggests it will require greater time and more optimised intervention to elicit greater learning through variable practice, when compared with constant practice, in interventions where physical practice is absent. The present study aims to test the benefits of variable practice, over constant practice, in a longer intervention that does not involve any physical practice, using a real-world sporting task. Previous research has also used motor imagery or action observation in isolation (Bird & Rikli, 1983; Coelho et al., 2012; Debarnot et al., 2015; Fazeli et al., 2021), however the combination of the two (AOMI), has yet to be investigated in the field of contextual interference, despite being a popular choice of non-physical intervention. The combination of imagery and action observation also aims to maximise the potential for learning in the absence of physical practice (Romano-Smith et al., 2018). The absence of sensory information in imagery or action observation in isolation may not provide enough interference to elicit contextual interference, combining them may therefore strengthen the effectiveness of the interference. Experiment one failed to show learning effects in dart when using AOMI, however the inclusion of the two secondary tasks meant that only a third of the intervention was dedicated to task relevant practice. An increase in the task relevant imagery practice used in experiment one may encourage the manifestation

of contextual interference or variable practice effects. Functional equivalence applies to observational learning (Blandin & Proteau, 2000), so to test if variable practice manifests in non-physical practice, as functional equivalence predicts, a combined AOMI intervention provides a more complete approach when compared to investigating action observation or motor imagery in isolation.

Providing empirically supported suggestions for optimising AOMI practice variability, requires a well powered test of variable practice in an AOMI intervention. The AOMI intervention must be in line with current optimisation approaches (like PETTLEP), while also isolating the effects of AOMI from physical practice. A longer intervention that uses a task other than golf putting is also required to make the variable practice effect in non-physical interventions, more generalisable (Coelho et al., 2012; Fazeli et al., 2021). In physical practice, dart throwing performance measured through radial error, has been previously used to demonstrate practice structure effects, however, these findings were using a single day intervention with a small sample size (N = 12) and did not reach significance (Van den Tillaar & Aune, 2019). Experiment One did not find the learning effects when aiming to elicit contextual interference, through inter-task processing, in a multiple day AOMI darts intervention. To elicit inter-task processing unrelated secondary tasks were used (badminton serving and a football penalty shot), reducing the time spent on dart throwing AOMI. The current experiment will use a similar set up, but investigate variable practice effects, known in the contextual interference literature as intra-task processing effects (Battig, 1966) of dart throwing. Investigating variable practice of a single task (intra-task processing), instead of inter-task processing, removes the need for secondary tasks, providing the opportunity to increase the amount of task relevant practice. More task relevant practice increases learning and the potential of finding learning effects. The absence of physical practice aims to provide insight as to whether the mechanisms of theories of skill acquisition require physical practice.

The hypothesis for the current experiment is that variable practice will result in superior post-test and transfer darts performance when compared to constant practice. This effect is hypothesised to occur even when physical practice is replaced with an AOMI intervention. The intervention groups are also expected to report higher levels of mental demand when compared to the control group. The variable group is also expected to show higher levels of mental demand than the constant group, due to the increase in intra-task processing and schema development they experience.

Method

Participants

A total of 63 university students volunteered to participate (F = 26, M = 37, M *age* = 23.87, SD = 10.21). All participants gave informed consent and stated that they had never undertaken any imagery training and were novice dart throwers. A novice dart thrower was defined as an individual who has not thrown darts on more than five previous occasions and have never played a competitive game of darts (Radlo et al, 2002; Marchant et al., 2009). Participants also had to complete the PAR-Q+ 2022 (see Appendix Two). Based on a conservative, small to moderate, effect size of η_{p^2} = 0.035 (Experiment One η_{p^2} = 0.035, Ranganathan & Newell, 2010 η_{p^2} = 0.10; Prado et al., 2017 η_{p^2} = 0.29; Gabriele et al., 1989 η_{p^2} = 0.22; Hall et al., 1995 η_{p^2} = 0.25; Overdorf et al., 2004 η_{p^2} = 0.27; Wakefield & Smith, 2009 η_{p^2} = 0.41; Ruano et al., 2022 moderate effect size), a G*Power analysis suggested a sample size of 60 was required to render a three group by three time point mixed model ANOVA, sufficiently powered for a three group design, at an alpha level .05 and power of .8 (Lakens, 2022). Ethical approval was granted by the Liverpool Hope University Research Ethics Committee.

Apparatus & Materials

The videos and questionnaires were all completed on a laptop (screen size 32 x 17cm) using PsyToolKit (Stoet, 2010, 2017), except the PAR-Q where a paper copy was completed.

PAR-Q+ (Warburton et al., 2019, see Appendix Two)

Participants provided their age and gender they most closely identify with before completing the PAR-Q+ 2020. This measure was used to assess the participants' fitness in order to reduce the risk of any negative health effects that may result from participation in the study. The PAR-Q+ has been widely and successfully used in previous research as a screening tool (Venkataraman et al., 2024; Bredin et al., 2025; Miller, 2023).

The Edinburgh Handedness Inventory – short form (EHI; Oldfield, 1971, see Appendix Three)

This measure was employed to determine the handedness of the participants. The measure asks participants which hand they use to perform four daily tasks like "brushing teeth", "Using a spoon", "throwing" and "writing". The test has been shown to have a $p = .93$ on Raykov's composite reliability score (Veale, 2014).

Movement Imagery Questionnaire-Revised (MIQ-R; Hall & Martin, 1997, see Appendix Four)

Participants completed the MIQ-R to assess their ability to effectively use imagery. This measure assessed an individual's ability to perform visual and kinaesthetic imagery of a given physical action that they physically performed before imagining. Following physical execution of the required task (for example, raising and lowering of one knee). Participants are required to rate the ease of imagining the action on a 7-point Likert scale ranging from 1 (very hard) to 7 (very easy) for the visual or kinaesthetic reproduction of the task. The actions are then repeated with the alternate form of imagery completed. The MIQ-R has been used in previous imagery studies, as a pre-intervention screening tool (Wright & Smith, 2009; Romano-Smith et al., 2018). During the MIQ-R, the researcher stepped out of the room to allow the participant

to complete the questionnaire without the feeling that they were being observed. The two subscales of the MIQ-R have shown to have test-retest consistency coefficients of .80 for visual and .81 (Monsma et al., 2009). According to the guidance of Smith and Collins (2004), participants scoring less than 14 (the mid-point) on either subscale should be excluded from the study.

NASA-Task Load Index (Hart & Staveland, 1988; Hart, 2006, see Appendix Five)

This measure is a self-report task workload measure through the experiment. The instrument consists of six subscales, each on a scale from one (low) to ten (high). Participants are required to rate the task based on their perception of Mental Demand, Physical Demand, Temporal Demand, Frustration, Effort, and Performance. The test-retest consistency coefficient of the measure is .83 (Hart & Staveland, 1988) and has been used successfully in a wide range of settings (Hart, 2006).

Dartboard and Darts.

A dart throwing task was used to measure performance. This was a full size concentric circular dartboard (XQ Max Darts, flocked home dartboard, 45.1 cm in diameter with each concentric circle approximately 2.5cm in width). Participants threw from a line 2.37m away from the wall on which the dartboard was hung. The dartboard was at a height of 1.73m from the bullseye to the floor (international competition standard). Dart throwing accuracy was measured to one decimal place, by hand, using a tape measurement from the darts point of contact, to the centre of the dartboard. Standard darts (weighing 17g) were used for the pre and post-test. In order to complete an effective transfer task, heavier darts (weighing 30g) were employed for this purpose, and research has demonstrated that using heavier darts is a good option for assessing dart throwing ability (Campos et al., 2019).

Procedure

Upon arriving on day one, participants completed the MIQ-R, EHI, and PAR-Q+ before completing a task familiarisation involving five throws from each of the following distances (in this order): 1.37m, 1.87m, 2.37 m (competition distance), 2.87m, 3.37m. Although little research has been done on varying dart throwing distances, pilot testing, and previous research (Edwards et al., 2007) suggest this is a reasonable spread of distances (See Appendix Six for pilot test data). This was followed by a pre-test performance measure of 30 throws from a distance of 2.37m (competition distance) where the experimenter took the radial accuracy measurements after each five throws, acting as a rest period. The NASA TLX task difficulty questionnaire was administered upon completion of pre-test performance. Participants were then divided into the three experimental groups: constant practice, variable practice, and control. This involved pseudorandomised allocation of the participants into the three distinct groups depending on their performance compared to the other participants that week. For example, the best performing participant would be allocated to the constant group, the second best performing participant would be allocated to the variable group, and the poorest performer would be allocated to the control group. The order of group allocation changed each week, rotating around which group the best, mid, and worst performer, were allocated into, to ensure there was an equal number of weekly highest performers in each group to reduce the probability of a significant difference at pretest. The same approach was taken if there were only two participants, and if there were more than three participants in a week then a combination of the two approaches was used. For example, if five participants partook in one week then the first three (that participated on the first day of testing) would be grouped and allocated according to their relative performance. Then the last two participants would be allocated according to their relative performance.

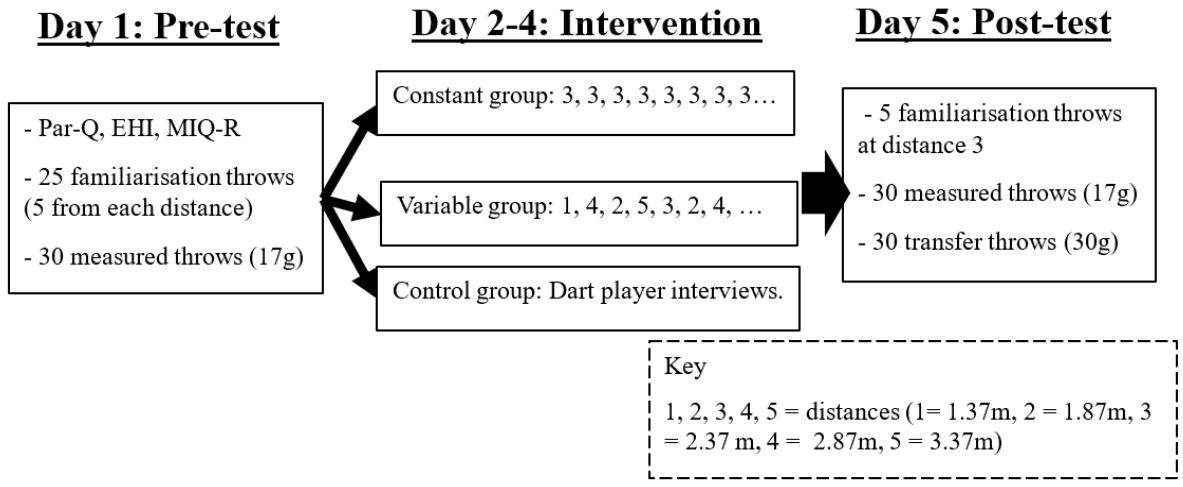
The day after the pre-test participants then came back to the same lab to complete a three-day supervised AOMI intervention on the second, third, and fourth day of this five day

study (see page 113 for details of the intervention). After each AOMI session participants completed the NASA TLX questionnaire and answered four manipulation check questions: "how easy was it to see the action imagined", "how easy was it to feel the action imagined", “what percentage of the time were you able to imagine the task”, as well as asking for details on any feelings or sensations they experienced during the AOMI (Romano-Smith et al., 2018). The control group watched interviews with famous dart players for the same duration of time as the intervention groups.

On day five, all participants completed a post-test, involving 30 throws from a distance of 2.37m. This was followed by a novel transfer test of 30 shots with darts that were double the mass. Following this the NASA TLX was completed, and participants were asked how effective they thought the intervention was at improving their darts throwing performance, thanked and debriefed.

Figure 7

Methods Flow Diagram



Intervention.

Experimental Groups

Participants allocated to the variable group were asked to imagine dart throwing from five distances. The different distances were arranged in a pseudorandomised order, whilst ensuring the same distance was never repeated twice, and there was an equal number of trials for each distance for each day. The constant group would instead imagine throwing from the same distance as the pre and post-test. The same amount of total AOMI training (35-minutes per day) was undertaken by both constant and variable groups, only the variability of the practice differed, the structure of the rest and practice was identical. This was based on research on optimal frequency of imagery practice (Wakefield & Smith, 2009).

The constant group completed ten blocks of approximately two-minutes of AOMI practice, all from the 2.37m distance. Between each block was a 30-second rest. Each block consisted of five sub-blocks; each sub-block contained five throws. There was a three-second break between each sub-block. The variable group practiced all the distances in a random order (using the same rest intervals as the constant group) maximising interference (Li & Lima, 2002; Maslovat et al., 2004; Ranganathan & Newell, 2010; Boutin & Blandin, 2010; Ruano et al., 2022). The same distance is not repeated twice in a row, and not in a sequential order. The order was randomised, and each participant completed the same number of distances in each of the 10 blocks, each block lasting approximately 2.5-minutes. Each block consisted of five sub-blocks, one for each of five distances in a random order. Each distance was shown using five throws, meaning each block contained 25 throws and all five distances in a random order. Participants switched distance every five throws, which constituted a sub-block. After every block was completed, participants were asked to verbally recall the distance and block they were practicing to the researcher to ensure the participants were engaging with the video.

During the AOMI intervention, participants passively held a dart to increase the effectiveness of the imagery (Smith et al., 2007; Wang et al., 2014b).

Participants completed the intervention using a first-person video of a non-elite, but high level performance of the dart throws at each distance. These videos were played to participants, and they were asked to simultaneously watch the video while imagining themselves throwing the darts from the distance shown. Videos were matched based on their gender and left/right handedness (Braaksma et al., 2002; Rohbanfard & Proteau, 2011). Handedness was assessed by the Edinburgh Handedness Inventory. The model in the video covered their skin and wore blue gloves to minimise any racial bias (Kang et al., 2021). It was also made clear to the participants that they would be physically throwing darts at the end of the study. This was done as observing with the intention to reproduce is more beneficial for motor learning particularly when learning the movement's relative timing structure (Badets et al., 2006).

The AOMI was performed in line with the PETTLEP guidelines (Holmes & Collins, 2001); holding the dart or badminton equipment (Physical), completing the AOMI in the same place as the pre/post-test (Environment), and imaging the specific tasks (Tasks; penalty, serve and dart throw). Participants were instructed to imagine from an internal perspective (Perspective), in real time (Timing), and include any emotions that they experienced in the pre-test (Emotion). After each AOMI session they answered four manipulation check questions: "how easy was it to see the action imagined", "how easy was it to feel the action imagined", "what percentage of the time where you able to imagine the task", as well as asking for details on any feelings or sensations they experienced during the AOMI practice. The intervention was also supervised and individual (one on one) which is considered superior to non-supervised, and/or group imagery interventions (Schuster et al., 2011).

Before performing any AOMI, participants in the variable and constant groups underwent stimulus and response training (Lang, 1977; 1979). Participants stood in a dart throwing position, with their arms down, imagining themselves about to throw a dart, without a dart or any movement, then verbally recalling any aspects they find easy to imagine. The specific aspects participants were asked to recall were "sensations", "thoughts", and "physical sensations" (Cumming et al., 2017). For example, a participant would recall "a focus on the bull's eye or tension in my throwing arm". This was recorded and used to make a personalised dart imagery script for each participant. Before each block participants in both AOMI groups were read their imagery script. Over the three training sessions, the individuals' responses from the beginning of each session were discussed and any new propositions were added to create more detailed and personalised imagery scripts.

Control group

The control group watched an equivalent time (approximately 35-minutes) of interviews with professional darts players about their personal life and career. The videos contained no dart throwing or technique points and were viewed in the same labs on the same laptop as the intervention groups. The videos were arranged into three sessions, same as the intervention groups, with each day involving interviews from one darts player (either Phil Taylor, Eric Bristow, or Michael van Gerwen). The order of these interviews was counterbalanced between participants.

Data Analysis

The study had a three group (constant, variable, and control) by three time points (pre-test, post-test, and transfer) mixed model design. Throwing accuracy was calculated by taking the mean radial error of each group at each time point and compared using ANOVAs. Mauchly's test of homogeneity of variances was used for any ANOVAs with more than two levels

(Mauchly, 1940). Sphericity was calculated for all repeated measures ANOVAs (Mauchly, 1940). For instances when Greenhouse-Geisser was above 0.75, the Huynh-Feldt correction was used (Abdi, 2010). Significance was assessed using an alpha of $p < .05$, and effect sizes are indicated using partial eta squared (η_p^2). Bayesian statistics are used to supplement and validate the analysis and interpretations; the Bayesian analysis follows the same analytical structure. These parallel analyses are presented after each frequentist output. A uniform prior on the interval (0, 1) was used in all Bayesian analysis, using the default prior settings used in JASP (Heo et al., 2020). All Bayesian analyses are conducted using BF_{01}, all models were then ordered by comparing against the null model, this approach was chosen for consistency and clarity across all analyses. According to Jeffreys (1939) a Bayes factor between 1 and 3 is considered weak evidence, between 3 and 10 is considered moderate evidence, and greater than ten is considered strong evidence. An error percentage of less than 20% for a Bayes factor is considered acceptable (Van den Bergh et al., 2020). All analyses were completed in JASP 0.18.03.0. All data collection and management procedures used, were approved by Liverpool Hope University's Research Ethics Committee.

Outlier removal and Manipulation Checks

Three outliers were removed because their radial error deviated by more than two standard deviations from the group mean. There were also no significant differences in the four self-reported imagery manipulation checks between the variable and constant groups.

Results

Pre-test ANOVA

A One-way three group ANOVA (Blocked, Random, and Control) at pre-test was conducted to check for equivalence and thus comparability between groups. This showed that

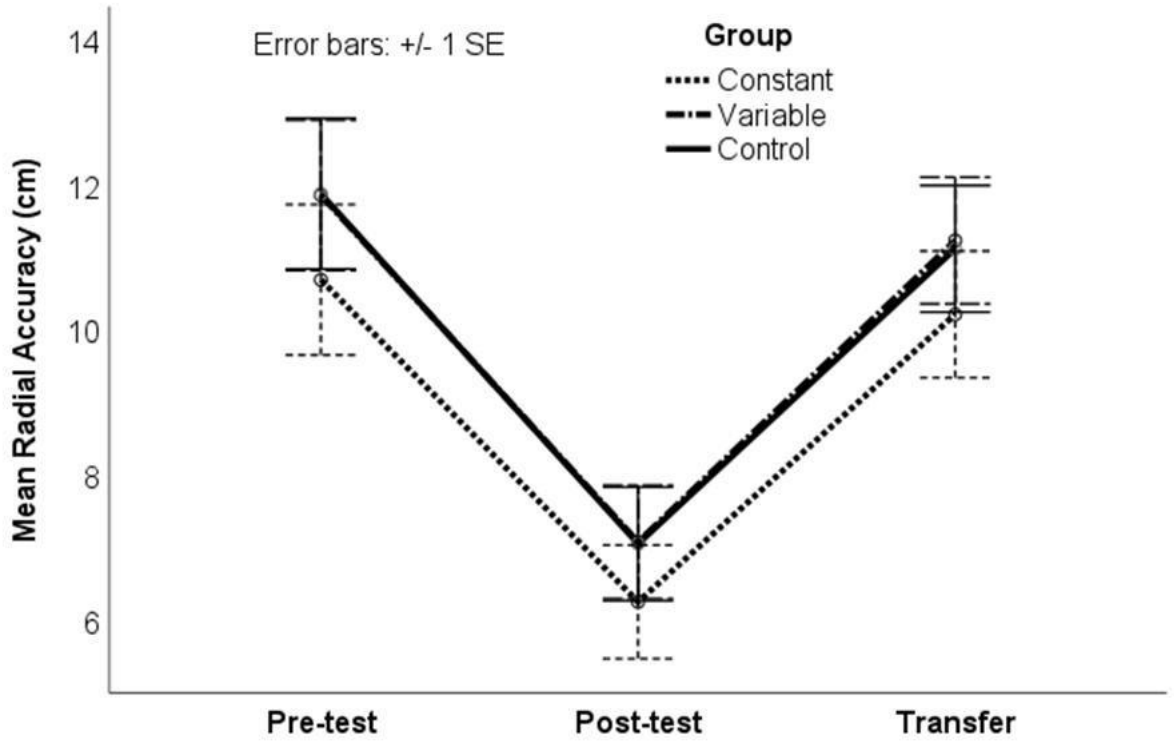
there were no significant differences between groups at pre-test, $F(2,60) = 19.32$, $p = .654$, $\eta_p^2 = .01$, $BF_{01} = 5.59$, error % = 0.01. Levene's test suggested there was homogeneity of variance ($F(2,60) = 0.02$, $p = .982$).

Repeated Measures ANOVAs

A three group (Constant, Variable and Control) by three time points (Pre-test, Post-test, and Transfer) repeated measures ANOVA acted as the omnibus analysis (fig. 8). The main effect for time was significant $F(1.77, 106.01) = 10.41$, $p < .001$, $\eta_p^2 = .15$, $BF_{01} < 0.01$, error % = 0.71, showing a significant change from pre-test to post-test, then a return to pre-test level performance during transfer (see fig. 8). Both the main effect for group $F(19.96, 44.13) = 0.45$, $p = .638$, $\eta_p^2 = .01$, $BF_{01} = 2.60$, error % = 3.14, and the interaction between time and group, $F(3.53, 106.01) = 0.11$, $p = .968$, $\eta_p^2 < .01$, $BF_{01} = 23.35$, error % = 9.64, was non-significant.

Figure 8

Omnibus Results: Three Group by Three Time Point Repeated Measures ANOVA



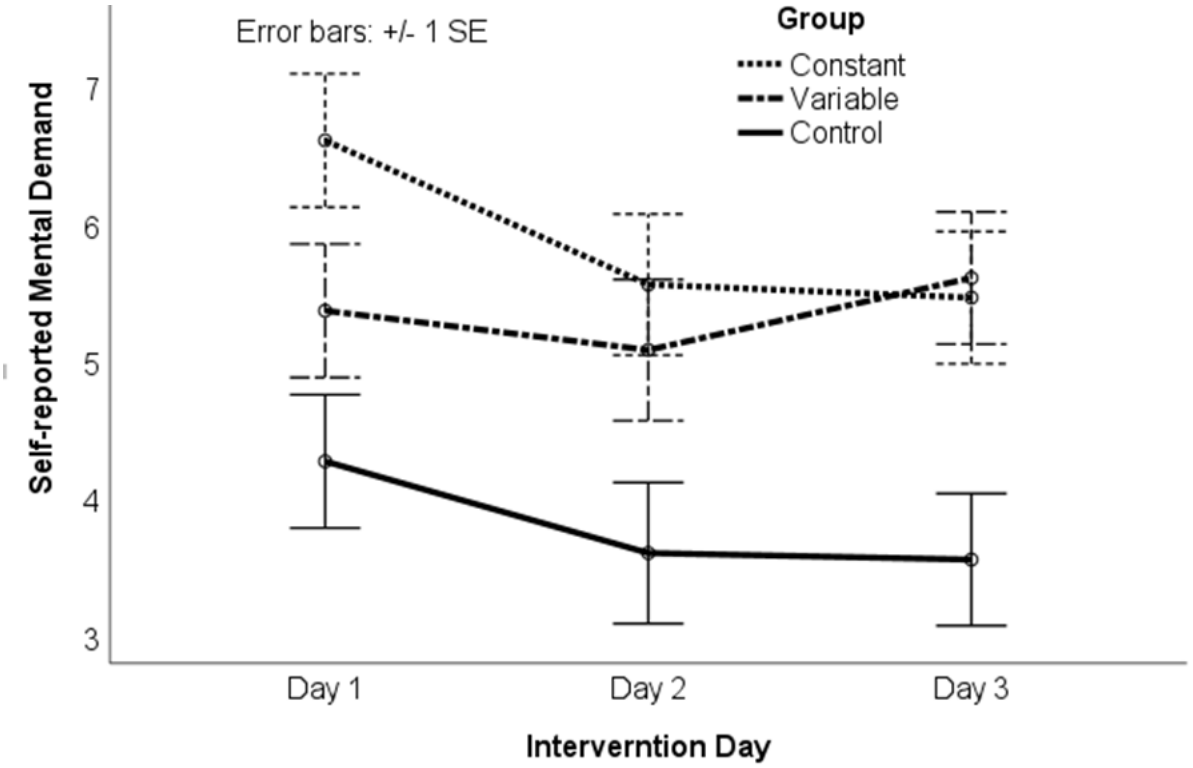
Mental Demand Repeated Measure ANOVAs

Another three groups (Constant, Variable, and Control) by three time points (intervention day 1, 2, and 3) repeated measures ANOVA was conducted, to see variations in self-reported mental demand (Fig. 9). Results were significant for the main effect for time, F(1.67, 100.01) = 3.87, p = .031, η_p^2 = .06, BF_{01} = 0.69, error % = 1.10, and group F(2,60) = 6.45, p = .003, η_p^2 = .18, BF_{01} = 0.07, error % = 1.16. The interaction was non-significant, F(3.33, 100.01) = 1.31, p = .275, η_p^2 = .04, BF_{01} = 4.56, error % = 4.99. Simple contrasts revealed there was a significant difference when comparing the control group to the constant group, t(60) = -3.45, p = .001. This also showed no significant difference between the constant and variable group, t (60) = -

0.88, p = .384. There was also a significant difference between day two and day one $t(120)$ = -2.62, p = .010, and day three and day one, $t(120)$ = -2.12, p = .036, these show that mental demand decreased as the experiment progressed.

Figure 9

Self-Reported Mental Demand During the Intervention



Discussion

The hypothesis, which predicted the presence of variable practice effects in motor imagery practice, was not supported by the findings of this experiment. The intervention groups performed similarly to the control group, despite a significant main effect for time, suggesting that the AOMI intervention was not effective. The hypothesis that mental demand in the AOMI groups would be higher during the interventions, when compared to the control, was supported. This suggests that the AOMI intervention was more cognitively demanding than the control videos (Glover & Baran, 2017; Glover et al., 2020; Martel & Glover, 2023; Lee & Magill,

1983, 1985; Davids et al., 2008; Broadbent et al., 2017). There was also a higher mental demand in the constant group on day one when compared to the variable group. This goes against the idea that more variable practice increases cognitive load (Lelis-Torres et al., 2017; Kashani et al., 2020). This could, however, be explained as the repetitive nature of the constant imagery practice, over the three days, was less engaging and so required more mental demand to maintain focus. Despite these differences, between the intervention groups and the control regarding mental demand, as well as evidence of learning in all groups, the lack of difference in performance between the groups show no evidence of variable practice effects.

The intervention used here required imagining precise and subtle differences in the forces required to throw darts from the different distances, as well as simulating the subsequent knowledge of results. Previous research, using shorter less optimised imagery interventions, also varied distance to compare constant and variable practice in golf putting (Coelho et al., 2012; Fazeli et al., 2021). These findings also found no difference between variable and constant motor imagery interventions for novice performers. The difficulty in imagining the subtle variation in forces as well as the subsequent outcomes, during variable practice, may have been too cognitively demanding for the learners (Glover & Baran, 2017). The brief physical familiarisation of each distance may have also resulted in a higher cognitive demand (Brouziyne & Molinaro, 2005; Mulder et al., 2004; Olsson & Nyberg, 2010; Kraeutner et al., 2017; Gomes et al., 2014). The variable practice may have lacked distinctiveness when imagining the different distances and therefore was likely not sufficient to elicit variable practice effects. Distinguishing between different variations of a task is the mechanism that causes variable practice to be superior to constant practice (Battig, 1966; Cuddy & Jacoby, 1982; Fisher, 1981; Schmidt, 1975; Shea & Morgan, 1979; Shea & Zimny, 1983; Winograd, 1981). As the variable AOMI practice likely lacked distinctiveness between the variations of the task, the variable practice will likely have had similar effects as constant practice. This

explains the similar results that both constant and variable practice have on a complex fine motor task in the present and previous findings using non-physical interventions (Coelho et al., 2012; Fazeli et al., 2021). This suggests that the variable practice effects are weakened by removing physical practice (Coelho et al., 2012; Fazeli et al., 2021), despite the strong theoretical argument supporting the benefits of variability in motor imagery for rehabilitation (Lindsay et al., 2023).

As the intervention group failed to outperform the control group it may be that AOMI was unsuccessful and that the similar performance gains seen in all groups are a result of the familiarisation to the experiment set up and the physical experience at pre-test. This is support by the findings that effective AOMI depends upon high levels of sensorimotor coupling between the action observation and the motor imagery. To achieve effective AOMI practice, a high level of experience is required (Clayton et al., 2020; Eaves et al., 2022). AOMI can there for be argued to be suboptimal for lower-skilled participants (Kraeutner et al., 2018) like the participants in the present study. The ineffectiveness of AOMI interventions on novice participants is supported by the explanation of cognitive overload and the high self-reported mental effort in the intervention groups.

The optimal level of variability during practice is known to vary depending on the interaction environment, task, and individual (Harrison & Stergiou, 2015; Stergiou et al., 2006; Ruano et al., 2022; Cardis et al., 2018; Hossner et al., 2016). These mediating variables can explain the difficulties in replicating variable practice effects in motor imagery, specifically in more complex tasks (Coelho et al., 2012; Fazeli et al., 2021). The use of a combination of both variable practice (intra-task processing) and of inter-task processing, in physical practice, is optimal for learning (Li & Lima, 2002; Maslovat et al., 2004; Ranganathan & Newell, 2010; Boutin & Blandin, 2010; Ruano et al., 2022). In the present experiment, inter-task processing was isolated so only one task was used (dart throwing). The lack of inter-task processing may

have reduced the effectiveness of the variable practice (Boutin & Blandin, 2010; Ranganathan & Newell, 2010). Novices also benefit less from variable practice (García-Herrero et al., 2022), instead benefiting from constant practice followed by variable practice (Ruano et al., 2022). Better optimisation of these influencing variables, for example using more experienced participants, would likely increase the benefits of practice variability during motor imagery.

Motor imagery also has associated variables that modulate its effectiveness, specifically in improving sports performance (Slimani et al., 2016). We accounted for two well established variables that affect motor imagery effectiveness; imagery ability (Callow & Hardy, 2005; Isaac & Marks, 1994; Mantani et al., 2005; Paivio & Clark, 1991) and age (Fierro-Marrero et al., 2025). However, adding imagery ability or age as a covariate in our analysis did not significantly change any of the results (see Appendix Nine). There are, however, other variables that modulate the effectiveness of motor imagery, such as task characteristics, complexity, expertise, schedule of practice, and individual impairments (Kalicinski et al., 2015; Ladda et al., 2021).

Although action observation can facilitate learning without physical practice (Zihlman, 2006), combining observational and physical practice is optimal for learning (Shea et al., 2000). The absence of physical practice, in the present experiment, likely weakened the effectiveness of the action observation component of the AOMI intervention. Observational learning is also less effective within the age range used in this study (Ashford et al., 2007), as well as when using less experienced individuals (Vickers, 2007), potentially further weakening any variable practice effects. Regarding other mediating factors for observational learning, the similarity hypothesis suggests matching the model and learner as closely as possible. The present experiment matched dominant handedness (Braaksma et al., 2002; Rohbanfard & Proteau, 2011a) and used a glove to hide race (Kang et al., 2021). Also matching the model to individuals' perceived ability (Schunk, 1987, 1991, 1998), gender (Braaksma et al., 2002), may

have increased the effectiveness of the observational component of the intervention. The model used in this experiment performed at a high level (hitting within 6cm of the bullseye) which is predominantly considered optimal (Al-Abood et al., 2001; Bird & Heyes 2005; Heyes & Foster 2002; Hodges et al., 2003; Lee et al., 1994; Martens et al., 1976; McCullagh et al., 1989). More recently, Rohbanfard and Proteau (2011b) have suggested that models with a range of abilities are best for learners. This could be a different method of adding variability in the present experiment and is recommended for future research.

The significant performance gains for novices in this experiment, but not in previous non-physical dart throwing interventions (Experiment One, Dahm & Rieger, 2019), are likely due to the increase of darts specific AOMI practice in this experiment. The present intervention also contains more task relevant practice than much of the previous work in the field of practice effect in non-physical interventions, as well as being the only intervention that is performed over multiple days (Bird & Rikli, 1983; Coelho et al., 2012; Dahm & Rieger, 2019; Debarnot et al., 2015; Fazeli et al., 2021). The absence of a physical practice group makes it difficult to ascertain whether dart throwing performance can be improved in an intervention of this length, regardless of the modality of the intervention. This means we cannot determine if the modality, or the duration of the intervention cause the absence of significant learning effects when compared to the control. While research has compared the effectiveness of motor imagery with physical practice (Driskell et al., 1994; Feltz & Landers, 1983; Ladda et al., 2021) but has yet to definitively compare the effectiveness of AOMI to physical practice.

The similarity in learning effects between the intervention and the control groups, suggests that the intervention was not sufficient to overcome the extraneous effects on performance. For example, the physical experience participants endured by completing the familiarisation and pre-test in the present experiment. There were an additional 20 physical familiarisation trials than in Experiment One. This could explain the significant performance

gains seen in all groups in the present experiment and the absences in previous experiments with less physical experience of the task (Experiment One; Dahm & Rieger, 2019). The groups also performed similarly during the transfer task. Like in Experiment One, these findings in this experiment show the transfer task eliciting similar performance to pre-test. This allows us to be more certain of transfer effects when using different weights of darts, as there was a large and significant decrease in performance from post-test to transfer.

The demonstration of variable practice effects in other non-physical interventions that use simpler tasks (Debarnot et al., 2015; Bird & Rikli, 1983) supports the idea that the effects are weaker and therefore less generalisable to sports tasks (Coelho et al., 2012; Fazeli et al., 2021). These weak effects, of practice effects in non-physical interventions of sporting tasks, also explain the null findings of Experiment One. The lack of a physical practice group as a comparison makes it difficult to know for certain if these weak effects are due to the task, or the modality of practice, or a combination. Experiments looking for the functional equivalence of practice effects, should consider having parallel physical and non-physical groups to compare the effectiveness of modality as well as difference practice effects. Eliciting these weak effects likely requires large sample sizes and long interventions to demonstrate significant findings when using real world sports tasks (Coelho et al., 2012; Fazeli et al., 2021). Experiments using short duration interventions and simpler tasks can achieve significant findings (Bird & Rikli, 1983; Badets & Blandin, 2004; Blandin & Proteau, 2000). The present findings support the concerns regarding the generalisability of variable practice effects in non-physical interventions (Coelho et al., 2012; Fazeli et al., 2021).

To conclude, this study demonstrates an absence of variable practice effects in an AOMI dart throwing intervention. This supports previous research that functional divergence in the variable practice effect within shorter, non-physical interventions for sports tasks (Coelho et al., 2012; Fazeli et al., 2021). The absence of performance results may also be due

to the high level of challenge, due to the precise temporal, spatial, and force requirements of darts (Dahm & Rieger, 2019). These precise requirements increase the cognitive requirements of dart throwing motor imagery (Glover & Baran, 2017), making practice too demanding for participants to demonstrate performance gains (Hebert et al., 1996; Wulf & Shea, 2002; Guadagnoli & Lee, 2004). While observational learning and motor imagery have both shown to facilitate variable practice effects in previous research, this was only when using comparatively simpler motor tasks. It is likely the effects are too weak to demonstrate performance gains in darts, and therefore too weak to show differences between the variable and constant practice group in the present intervention. This does not, however, mean that variable and constant practice had different cognitive effects on the participants. Future research could use a more mechanistic approach that observes cognitive indicators of variable practice effects in AOMI practice, alongside performance measures. The use of a more controlled and simple motor task may also allow for measurable performance differences in different practice effects in AOMI interventions, considering the effects are likely weakened in non-physical practice (Bird & Rikli, 1983; Debarnot et al., 2015). Practitioners looking to optimise practice structure in non-physical interventions should not assume that theories developed using physical practice can be applied in the same way. While theoretically there are advantages to varying non-physical practice, the findings of previous research and the present findings highlight the lack of generalisability of these theoretical implications in more complex skills. Answering the question of whether the intra-task processing is weakened in non-physical practice, or if this processing is non-existent, requires findings from even longer interventions than the ones presented here. Practitioners should also consider the task difficulty and skill level of the learner when making decisions about varying non-physical practice (Hebert et al., 1996; Wulf & Shea, 2002; Guadagnoli & Lee, 2004), research should also address these variables in non-physical practice.

Chapter Four

Experiment Three: The Effects of Contextual Interference on Performance and Processing in Motor Imagery Compared to Physical Practice.

Abstract

Functional equivalence theory states that motor imagery shares the same internal representation as physical execution. As a result, it is possible to learn novel skills through imagery practice. However, there have been comparatively few studies to examine whether imagery and physical practice are equally sensitive to changes in practice structure. Physical practice can be enhanced following random compared to blocked practice, which is referred to as the contextual interference effect. It is unclear whether the same effect exists in motor imagery. Participants (N = 114) completed a series of rapid typed sequences on a home computer, in a pre-test, between-subject intervention, and post-test design. For the intervention, participants were randomly allocated to one of four groups involving imagery or physical practice that assumed either a random or blocked structure. Results indicated a significantly improved (shorter) movement time for the random compared to blocked structure, but only when it was featured in physical practice, and not imagery practice. These findings suggest that the contextual interference effect does not extend to imagery practice and thus reflects a level of functional divergence. More work is needed to optimise practice structuring in motor imagery interventions. Future studies could manipulate practice in other ways to establish the degree of functional equivalence and divergence between motor imagery and physical practice.

Introduction

Simply repeating the same task over and over, is not always optimal for retention or transfer performance (Battig, 1966; 1972; 1972; 1979; Cuddy & Jacoby, 1982; Jacoby, 1978; Lee & Weeks, 1987; Weeks et al., 1987). This was first shown by Battig (1966) then expanded on (Battig, 1972; 1972; 1979; Shea & Morgan, 1979; for reviews see Ammar et al., 2023; Brady, 1998; Czyż et al., 2024a; 2024b; Magill & Hall, 1990), demonstrating that when learning multiple distinct tasks, a less repetitive practice structure can hinder acquisition performance but improve retention and transfer performance, this is known as the contextual interference effect (Battig, 1966; 1979; Shea & Morgan, 1979). In lab based research, random practice has been repeatedly shown to result in slower acquisition but superior retention and transfer performance, when compared to blocked practice (Magill & Hall, 1990; Brady, 1998; Ammar et al., 2023; 2024; 2025; Czyż et al., 2024a; 2024b).

The majority explanations for the contextual interference effect revolve around the idea that there is increased cognitive processing during random practice when compared to blocked practice (Broadbent et al., 2017). Originally this was said to be a product of the more frequent comparisons between the different tasks during random practice, when compared to blocked. This was known as inter-task processing (Battig, 1966) and developed into the elaboration hypothesis Shea & Morgan, 1979). The increase in cognitive processing in random practice, relative to blocked practice, is also suggested to occur from less reliance on short-term memory (Lee & Magill, 1983; 1985), an increase in the frequency of overcoming constraints during practice (Davids et al., 2008), and an increase in error processing, due to the poorer acquisition performance during random practice (Broadbent et al., 2017).

Functional equivalence and functional divergence, describe how similar and how different motor imagery is to physical movement, respectively (Hurst & Boe, 2022). This

spectrum can be applied to motor imagery practice, which is the covert rehearsal of a movement skill (Holmes, 2007). The motor cognitive model (Glover & Baran, 2017; Glover et al., 2020; Martel & Glover, 2023) explains that the degree of functional divergence can be measured using the temporal differences between motor imagery and physical execution. Motor imagery becomes slower than physical execution when the task is more complex, requires more precision, or involves an interfering secondary task. The motor cognitive model suggests that as these task variables increase, the cognitive processing required for motor imagery also increases, which slows the motor imagery down relative to physical execution. As the motor cognitive model only makes predictions about motor imagery, this experiment will remove the action observation component that was present in the previous two experiments. This also addresses concerns from the previous two experiments that AOMI is suboptimal for novice learners (Kraeutner et al., 2018) and potentially too cognitively demanding when also applying contextual interference.

Controlled lab studies investigating whether the contextual interference effect occurs in imagery (Gabriele et al., 1989; Overdorf et al., 2004) and observational learning (Blandin et al., 1994; Lee & Write, 1990; Wright et al., 1997) has produced inconsistent results. Gabriele et al. (1989) demonstrated the contextual interference effect in a block knock down task that combined physical and imagery intervention. However, Overdorf et al. (2004) failed to replicate these findings when removing physical practice and using a Bassin Anticipation Timing Task. Research that applies contextual interference to observational learning interventions has also shown functional equivalence when using block knock down (Blandin et al., 1994) and computer typing (Wright et al., 1997) tasks. However, in computer gaming tasks and timing tasks, the contextual interference was not facilitated in observational learning, suggesting functional divergence (Lee & White, 1990). In Experiment One the contextual interference effect, through inter-task processing, was not elicited when using a

dart throwing task and a three day intervention that combined action observation and motor imagery. In Experiment Two the effects of intra-task processing (variable practice effects), did not manifest when using a similar three day dart throwing intervention. These findings collectively suggest that practice effects (specifically inter and intra task processing effects) are weakened by the removal of physical practice and when a more complex task is used to measure learning effects. The contextual interference effect can be strengthened in physical practice by combining inter and intra-task processing to maximise interference. Maximising interference by using both inter and intra-task processing, involves practicing similar, but distinct tasks in a random order (Boutin & Blandin, 2010; Dick et al., 2000; Li & Lima, 2002; Maslovat et al., 2004; Ranganathan & Newell, 2010; Ruano et al., 2022; Reid et al., 2007). This approach was successfully used by Gabriele et al. (1989), who used different movement sequences during the same block knock down task, to demonstrate contextual interference in a motor imagery and physical practice intervention.

Research on functional equivalence has primarily looked at neurological evidence (Hardwick et al., 2018). Creating the contextual interference effect in physical practice, while comparing it to an identical imagery intervention, facilitates an applied approach to testing the functional equivalence hypothesis (Overdorf et al., 2004). This could also help optimise practice structuring in imagery interventions. The inconsistent findings previously discussed (Gabriele et al., 1989; Overdorf et al., 2004; Blandin et al., 1994; Lee & White, 1990; Wright et al., 1997, see also experiment one) suggests that the contextual interference effect may be weakened when physical practice is replaced by other modalities. The effect is also weakened when the task is more complex or involves less motor learning (Lee & White, 1990; Overdorf et al., 2004). To assess the degree that the effect is weakened, by the removal of physical practice, a direct comparison of the contextual interference effect in physical and non-physical practice is needed (Overdorf et al., 2004). A large sample is required to observe the

seemingly weak practice structure effects in non-physical interventions (Coelho et al., 2012; Fazeli et al., 2021; Overdorf et al., 2004). A simple and controlled motor task is also required as the contextual interference effect lacks generalisability for more complex tasks (Ammar et al., 2023; 2024; 2025; Czyż et al., 2024a; 2024b; Pauwels et al., 2015).

A task that can be performed physically and through imagery is required to test functional equivalence. Movement time and reaction time measures can be used to observe the increasing cognitive demands, which result from increasing contextual interference (Battig, 1966; Broadbent et al., 2017; Davids et al., 2008; Getchell & Shewokis, 2023; Lee & Magill, 1983; 1985; Shea & Zimny, 1983; Thomas et al., 2021). This can help demonstrate contextual interference effects on cognition, even if learning effects are weakened physical practice is removed. In the present case a task where movement time performance can be compared between an imagery and physical group. This also allows for comparison between the cognitive requirements when the task is imagined or physically performed. If movement time is slower during imagery compared to physical execution it suggests that there is more cognitive requirements in imagery when compared to physical practice (Glover & Baran, 2017). Reaction time can also be an indicator of cognitive load, with a longer reaction time indicates an increase in cognitive load (Henry & Rogers, 1960; Christina et al., 1982; Klapp, 1980). Reaction time during early acquisition has shown to be slower during random practice when compared to blocked, however, during retention, reaction time is faster after random practice (Lee & Magill, 1983). Slower reaction time is also an indicator of an increase in error processing (Koehn et al., 2008) which occurs during acquisition when practice involves higher levels of contextual interference (Broadbent et al., 2017; Kim et al., 2015; Lee & Magill, 1983; 1985). This would suggest that during the intervention, the random practice groups would have longer reaction times when compared to the blocked practice groups.

As imagery is suggested to be more cognitively demanding than physical execution (Glover & Baran, 2017), there should also be an increase in reaction and movement time in imagery practice when compared to the physical practice regardless of practice structure. The motor cognitive model also predicts slower reaction and imagined movement times during randomly structured imagery practice, when compared to a blocked structured imagery practice. This is due to the increase in cognitive demands that result from the contextual interference. According to the functional equivalence hypothesis, there should be slower reaction and movement times during randomly structured acquisition when compared to a blocked structured acquisition, regardless of the modality of practice. However, combining functional equivalence (Finke, 1979; 1980; Jeannerod, 1994), the motor cognitive model (Glover & Baran, 2017) and explanations for the contextual interference effect (Broadbent et al., 2017; Davids et al., 2008; Kim et al., 2015; Lee & Magill, 1983; 1985) suggests that a blocked structured acquisition would produce more similar reaction and movement times regardless of modality. However, a randomly structured acquisition, where there is more interference, would result in longer reaction and movement times in imagined practice when compared to physical practice.

Much of the literature on contextual interference has used sequence learning tasks (Gabriele et al., 1989; Shea & Morgan, 1979) and a typing sequence task has been successfully used to demonstrate the benefits of variable practice (involving intra-task processing, Battig, 1966) in imagery (Debarnot et al., 2015). The hypothesis for the current experiment is that higher contextual interference (through increased inter-task processing) will result in superior post-test and transfer motor performance when compared to interventions with lower contextual interference. According to functional equivalence, the contextual interference effect should occur regardless of modality, however, it may be less pronounced in imagery. Motor imagery practice should produce longer reaction times when

compared to physical practice as it is more cognitively demanding. Despite this, random practice should produce longer reaction times than blocked practice in each of the two modalities, indicating an increase in cognitive demand.

Method

Participants

A total of 117 participants (F = 53, M = 61, M *age* = 32.31, SD = 16.79) completed the study. All participants had to average more than 3.5 on two item version of the MIQ-R, completed informed consent, and state they had never undertaken any imagery training. Based on other contextual interference and imagery research, a conservative, medium effect size of η_{p^2} = 0.09 was used (Debarnot et al., 2015 η_{p^2} = 0.13; Takeo et al., 2021 η_{p^2} = 0.16; Allami et al., 2008 no effect size reported but used groups of 25 participants), a G*Power analysis suggests a sample size of 112 is required to render a fixed effects, one-way ANOVA sufficiently powered a four group design at an alpha 0.05 and power of 0.8 (Lakens, 2022). Ethical approval was granted by the Liverpool Hope University Research Ethics Committee.

Apparatus & Materials

The Edinburgh Handedness Inventory – short form (EHI; Oldfield, 1971, see Appendix Three)

This measure was employed to determine the handedness of the participants. The measure asks participants which hand they use to perform four daily tasks like “brushing teeth”, “Using a spoon”, “throwing” and “writing”. The test has been shown to have a *p* = .93 on Raykov’s composite reliability score (Veale, 2014).

Two items of the MIQ-R (Hall & Martin, 1997 see Appendix Four)

Two item versions, from the MIQ-R were used to assess if individuals were able to perform visual and/or kinaesthetic imagery of a given physical action. Participants rated the

ease of imagining the action on a 7-point Likert scale ranging from 1 (very hard) to 7 (very easy). Focusing on how easy it was to *see* (visual imagery) or *feel* (kinesthetic) an imagined action. The MIQ-R has been used in previous imagery studies as a pre-intervention screening tool for imagery ability (Wright & Smith, 2009; Romano-Smith et al., 2018), the two items version used here attempts to provide a simple, seated, test to screen out individuals with aphantasia (Blomkvist & Marks, 2023). The eight item version of the MIQ-R, known as the MIQ-RS, has shown a correlation coefficient of .82 for the visual subscale and .80 for kinesthetic (Gregg et al., 2010).

NASA-Task Load Index (Hart & Staveland, 1988; Hart, 2006, see Appendix Five)

This measure is a self-report task workload measure through the experiment. The instrument consists of six subscales, each on a scale from one (low) to ten (high). Participants are required to rate the task based on their perception of Mental Demand, Physical Demand, Temporal Demand, Frustration, Effort, and Performance. The test-retest consistency coefficient of the measure is .83 (Hart & Staveland, 1988) and has been used successfully in a wide range of settings (Hart, 2006).

Task

The online experiment was created using PsyToolKit (Stoet, 2010; Stoet, 2017) so could be accessed by participants on their home computer. The resolution was set to 1000 by 800 pixels, and the framing was set to 1000 by 800 so the experiment display was standardised, so it would appear the same regardless of the computer the participants used. A black screen was presented with a letter sequence (e.g. mirmr) written in green text in the centre of the screen. Either side of the text was an image of an enter key to remind participants to press enter before and after they physically type or imagine typing the letter sequences. After 3 seconds the screen would turn black and then participants would be able to

press enter on their physical computer keyboards, type the letter sequence out, and then press enter again. This constituted one trial and then would then repeat.

During the familiarisation they were given feedback on whether they had completed the task correctly or incorrectly. During the imagery intervention if they pressed any key other than enter, they were reminded to not press any keys other than enter and to only imagine pressing the keys.

Reaction time was measured from the moment the screen turned black to the moment participants first pressed enter. Movement time was measured from the first time enter was pressed to the second enter press. The keys that the participants pressed were also recorded as well as whether their input was correct or incorrect acting as a measure of accuracy.

Procedure

Participants would email the experimenter expressing interest in participating in the study. The Experimenter would send them an email with information about the study and a link to participate. After clicking the link the participant information was shown, only allowing participants to continue if they had a physical computer keyboard plugged in, and asked to complete the study in a distraction free environment. After consenting to the participant, they were encouraged not to participate if they had a history of repetitive strain injuries and asked to wear any glasses or contacts if needed. Their personal information, dominant handedness, and imagery ability. After being encouraged to take a break to prevent the need during the rest of the study, they were given an overview of the sequence typing task portion of the experiment. A sequence typing task was chosen as it has been used in contextual interference and motor imagery research previously (Debarnot et al., 2015). Observational learning in a sequence task has also shown to be functionally equivalent to physical practice (Boutin et al., 2010).

Participants were asked to complete all typing tasks with the index finger on their dominant hand and given instructions on how to complete the typing task and what keys were going to be used in the experiment. This then led into three trials where participants were guided through with reminders of what to do in red text. They then did nine unguided trials, all using the two non-test sequences (mirmr, cimri), and all with feedback telling them if they completed the task correctly or not. They were then given the NASA-TLX s which succeeded each of all the following sections of the typing task; pre-test (10 trials, test sequence: cmric), intervention (60 trials), post-test (10 trials, identical to pre-test), and transfer (10 trials, test sequence: nexneu). During the intervention participants were split into four groups: blocked physical, random physical, blocked imagery, and random imagery. The blocked groups completed 20 repeated trials of each sequence, with a counterbalanced order of blocks. The random order differed between participants but contained no repetition of more than two of the same sequences. Both practice structures contained the same number each sequence. The physical group were asked to complete the trials physically as they had done in pre-test. The imagined groups were instructed to physically press the enter key at the start of the trial, imagine typing the letter sequence shown, then physically press enter again when they had completed the imagery.

After all the typing tasks had been completed participants were asked “When completing the imagery intervention, what percentage of the trials did you actually imagine doing? Remember answers are anonymous so please be as honest as possible”. They were asked to respond on a scale between 0% and 100% in increments of 10%. Finally, they were thanked for their time and asked to email the experimenter if they had any questions or queries.

Data Analysis

The study had four groups (blocked physical, random physical, blocked imagery, and random imagery) with three test time points (pre-test, post-test, and transfer) as well as an acquisition phase (intervention). Accuracy was measured as a percentage of correct trials out of the total trials. Three outliers were removed using z scores of more than two standard deviations away from the mean for both movement and reaction time. Mauchly's test of homogeneity of variances was used for any ANOVAs with more than two levels (Mauchly, 1940). Sphericity was calculated for all repeated measures ANOVAs (Mauchly, 1940). For instances when Greenhouse-Geisser was above 0.75, the Huynd-Felt correction was used (Abdi, 2010). Significance was assessed using an alpha of $p < .05$, and effect sizes are indicated using partial eta squared (η_p^2). Bayesian statistics are used to supplement and validate the analysis and interpretations; the Bayesian analysis follows the same analytical structure. These parallel analyses are presented after each frequentist output. A standard prior of 0.2 was used in all Bayesian analysis (Burton et al., 1998; Dienes & McLatchie, 2018), using the default prior settings used in JASP (Heo et al., 2020). All Bayesian analyses are conducted using BF_{01}, all models were then ordered by comparing against the null model, this approach was chosen for consistency and clarity across all analyses. According to Jeffreys (1939) a Bayes factor between 1 and 3 is considered weak evidence, between 3 and 10 is considered moderate evidence, and greater than 10 is considered strong evidence. An error percentage of less than 20% for a Bayes factor is considered acceptable (Van den Bergh et al., 2020). All analyses were completed in JASP 0.18.03.0. All data collection and management procedures used, were approved by Liverpool Hope University's Research Ethics Committee.

Outlier removal and Manipulation Checks

Thirteen outliers were removed because their movement time deviated by more than two standard deviations from the group mean in at least one of the test phases. All participants in the imagery group scored higher than an average of three on the two item MIQ-R, indicating they could all perform motor imagery. There were also no significant differences in the two item MIQ-R between the groups.

Results

Self-reported Imagery percentage

A one-way ANOVA was conducted between the two imagery groups (block image, and random image) to compare the self-reported percentage of imagery that was performed during the intervention. This was to check for equivalence and comparability between groups. There was no significant difference between the two groups $F(1, 53) = 2.59$, $p = .383$, $\eta_{p^2} = .01$, $BF_{01} = 2.67$, error % = 0.01. Levene's test suggested there was homogeneity of variance, $F (1, 53) = 0.05$, $p = .828$.

Movement Time

Pre-test ANOVAs

A one-way ANOVA was conducted for movement time at pre-test between the four groups (block physical, block imagery, random physical, and random imagery) to check for equivalence and comparability between groups. There were no significant differences $F(3, 110) = 0.45$, $p = .718$, $\eta_{p^2} = .01$, $BF_{01} = 12.75$, error % < 0.01. Levene's test suggested there was homogeneity of variance, $F (3, 110) = 0.49$, $p = .693$.

Repeated Measures ANOVAs

A three time point (pre-test, post-test, and transfer) repeated measures ANOVA between the two modalities was conducted for movement time data. The main effect for time was significant; F(1.86, 208.52) = 169.63, $p < .001$, $\eta_p^2 = .55$, $BF_{01} < 0.01$, error % = 0.73 showing participants had quicker movement time in post-test and slowest in transfer.. Both the main effect for modality; F(1, 112) = 0.92, $p = .339$, $\eta_p^2 = .01$, $BF_{01} = 2.40$, error % = 0.53, and the interaction between time and group F(1.86, 208.52) = 2.52, $p = .087$, $\eta_p^2 = .02$, $BF_{01} = 1.88$, error % = 7.93, was non-significant.

The same three time point repeated measures ANOVA was conducted for the two practice structures. The effect for time was significant F(1.88, 210.15) = 139.20, $p < .001$, $\eta_p^2 = .55$, $BF_{01} < 0.01$, error % = 0.65, showing participants had quicker movement time in post-test and slowest in transfer. The interaction was also significant F(1.88, 210.15) = 3.90, $p = .024$, $\eta_p^2 = .03$, $BF_{01} = 0.55$, error % = 8.11. The main effect for practice structure F(1, 112) = 0.58, $p = .448$, $\eta_p^2 = .01$, $BF_{01} = 2.78$, error % = 0.69, was non-significant.

Factorial Repeated Measures ANOVA Post-hoc

A factorial, three time point (pre-test, post-test, and transfer) RM ANOVA was conducted has a post-hoc to include both practice structure and modality as the between subject factors. The main effect for time F(1.86, 204.25) = 142.00, $p < .001$, $\eta_p^2 = .53$, $BF_{01} < 0.01$, error % = 0.68, and the interaction between time and practice structure F(1.86, 204.25) = 3.83, $p = .026$, $\eta_p^2 = .03$, $BF_{01} = 0.57$, error % = 14.52, were significant, showing that performance improved from pre-test to post test at different amount depending on the practice structure used. The other two interactions were not significant; time and modality F(1.86, 204.25) = 2.63, $p = .079$, $\eta_p^2 = .02$, $BF_{01} = 1.82$, error % = 10.00, and the time, practice structure and modality interaction F(1.86, 204.25) = 2.66, $p = .077$, $\eta_p^2 = z.02$, $BF_{01} = 1.29$, error % = 17.44. The between subject main effects, modality F(1, 110) = 0.34, $p = .339$, $\eta_p^2 = .01$, $BF_{01} = 1.74$, error

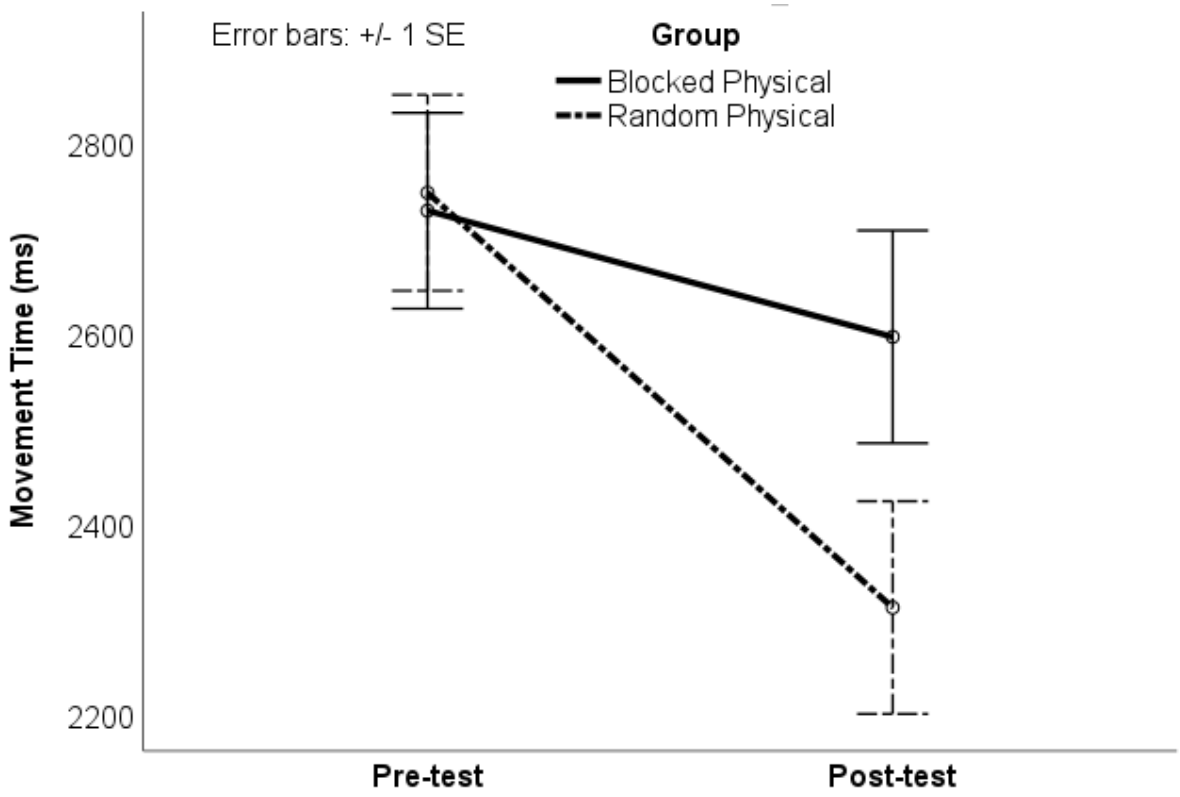
% = 4.85, and practice structure F(1, 110) = 0.59, p = .445, η_p^2 = .01, BF_{01} = 1.98, error % = 4.86, as well as their interaction, F(1, 110) = 0.29, p = .589, η_p^2 < .01, BF_{01} = 2.48, error % = 4.05 was also non-significant.

Between Physical Groups Post-hoc (Fig. 10)

Following this significant interaction between (time and practice structure) in the repeated measures ANOVA across the three time points. A post hoc repeated measures ANOVA between pre-test and post-test was conducted just for the physical groups (blocked physical and random physical). This was to assess for the presence of the contextual interference effect in the physical practice conditions, by comparing the two practice structures, without the imagery group data or the transfer condition. The main effect for time was significant, showing performance improved over time F(1, 56) = 39.21, p < .001, η_p^2 = .41, BF_{01}< 0.01, error % = 0.99, as was the interaction, suggesting the amount of improvement over time was superior in the random group, F(1, 56) = 11.16, p = .001, η_p^2 = .16, BF_{01} = 0.05, error % = 4.46. This suggesting that the contextual interference effect manifested in the intervention. The main effect for practice structure was not significant F(1, 56) = 0.84, p = .364, η_p^2 = .02, BF_{01} = 1.92, error % = 0.49. A final post hoc test was conducted using a one way ANOVA on post-test between the two physical practice groups, to see if there was a difference in movement time between groups at post-test. This was non-significant F(1, 56) = 3.24, p = .077, η_p^2 = .06, BF_{01} = 0.99, error % = 0.01. Levene's test suggested there was homogeneity of variance, F (1, 56) = 0.05, p = .821.

Figure 10

A Comparison of Movement Time Between the Blocked and Random Physical Groups from Pre to Post-Test.



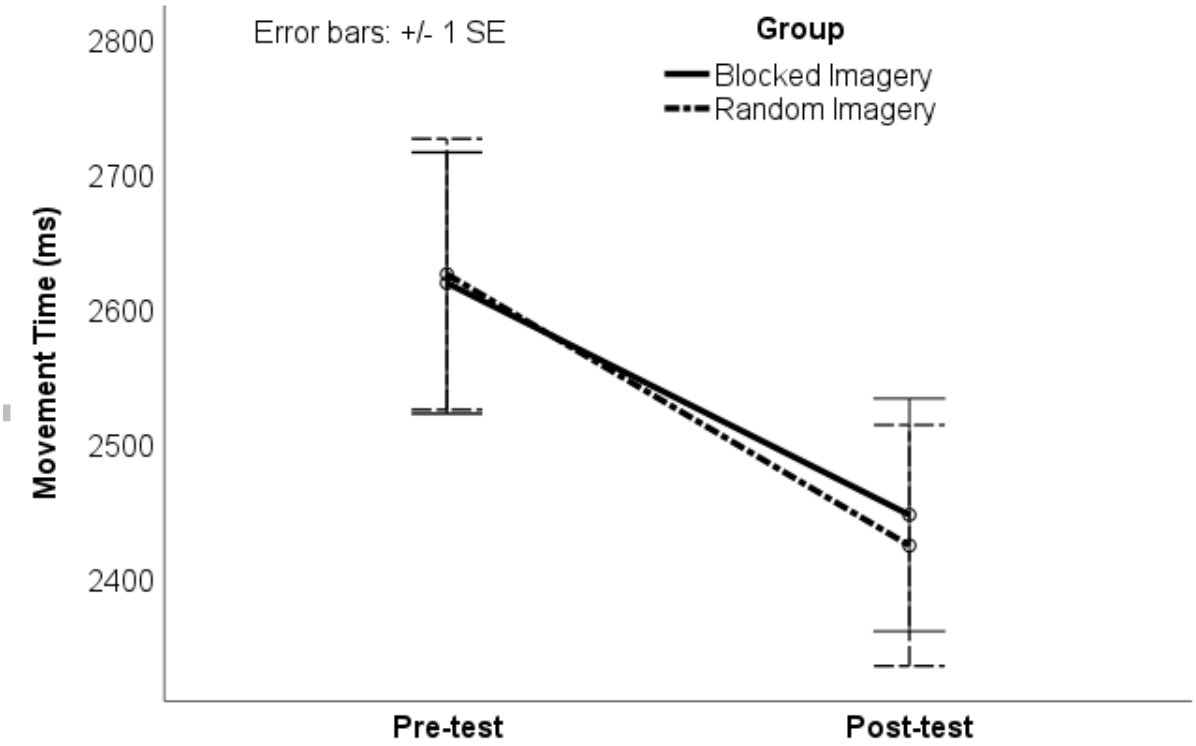
Between Imagery Groups Post-hoc (Fig. 11)

Another post hoc repeated measures ANOVA between pre-test and post-test was conducted just for the imagery groups (blocked imagery and random imagery). This was to test for the presence of the contextual interference effect in the physical practice conditions, by comparing the two practice structures, without the physical group data or the transfer condition. The main effect for time $F(1, 54) = 31.17$, $p < .001$, $\eta_p^2 = .37$, $BF_{01} < 0.01$, error % = 0.83, was significant showing both groups improved over time. The main effect for practice structure $F(1, 54) < 0.01$, $p = .950$, $\eta_p^2 < .01$, $BF_{01} = 2.19$, error % = 2.42, and interaction $F(1, 54) = 0.19$, $p = .663$, $\eta_p^2 < .01$, $BF_{01} = 3.50$, error % = 4.84, was not significant, suggesting

that the practice structures used did not impact the degree of improvement and therefore the contextual interference effect was not present.

Figure 11

A Comparison of Movement Time Between the Blocked and Random Imagery Groups from Pre to Post-Test



Intervention ANOVAs

A one-way ANOVA was conducted for movement time during the intervention, between the two practice modalities. There were no significant differences $F(1, 112) = 0.10$, $p = .750$, $\eta_p^2 < .01$, $BF_{01} = 4.80$, error % = 0.03. Levene's test suggested there was homogeneity of variance, $F(1, 112) = 1.01$, $p = .317$. The same analysis was conducted to compare the two practice structures, showing no significant difference $F(1, 108.33) = 0.31$, $p = .577$, $\eta_p^2 < .01$, $BF_{01} = 4.37$, error % = 0.03. Levene's test suggested there was no homogeneity of variance, $F(1, 112) = 4.53$, $p = .036$.

Reaction Time

Pre-test ANOVAs

A one-way ANOVA was conducted for reaction time at pre-test between the four groups (block physical, block imagery, random physical, and random imagery) to check for equivalence and comparability between groups. There were no significant differences $F(3, 110) = 0.82$, $p = .486$, $\eta_p^2 = .02$, $BF_{01} = 8.41$, error % < 0.01. Levene's test suggested there was homogeneity of variance, $F(3, 110) = 0.26$, $p = .853$.

Repeated Measures ANOVAs

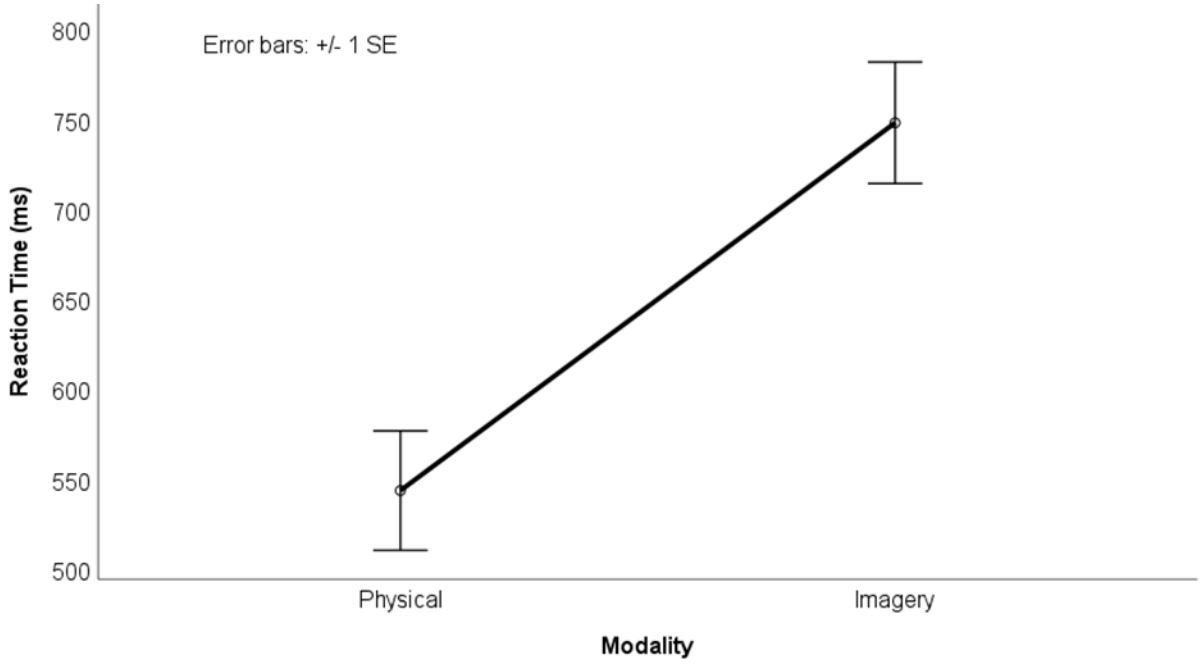
A three time point (Pre-test, Post-test, and Transfer) repeated measures ANOVA between the two modalities was conducted for reaction time data. The main effect for time was significant, showing reaction time decreased during the post-test but then increased during the transfer test; $F(1.80, 202.5) = 32.44$, $p < .001$, $\eta_p^2 = .23$, $BF_{01} < 0.01$, error % = 0.66. Both the main effect for modality; $F(1, 112) = 0.95$, $p = .332$, $\eta_p^2 = .01$, $BF_{01} = 2.73$, error % = 0.65, and the interaction between time and group $F(1.81, 202.55) = 1.27$, $p = .280$, $\eta_p^2 = .01$, $BF_{01} = 5.72$, error % = 1.39, was non-significant. The same three time point repeated measures ANOVA was conducted for the two practice structures. The effect for time was significant, again showing reaction time decreased during the post-test but then increased during the transfer test $F(1.80, 201.83) = 32.45$, $p < .001$, $\eta_p^2 = .23$, $BF_{01} < 0.01$, error % = 0.66. Both the main effect for practice structure $F(1, 112) < 0.01$, $p = .966$, $\eta_p^2 < .01$, $BF_{01} = 4.07$, error % = 0.55, and the interaction $F(1.80, 201.83) = 0.42$, $p = .634$, $\eta_p^2 < .01$, $BF_{01} = 11.89$, error % = 2.63, was non-significant.

Intervention ANOVAs (Fig. 12)

A one-way ANOVA was conducted for reaction time during the intervention, between the two practice modalities. There was a significant difference between groups with the imagery groups having longer reaction times than the physical groups, $F(1,87.26) = 18.30$, $p < .001$, $\eta_p^2 = .14$, $BF_{01} < 0.01$, error % < 0.01. Levene's test suggested there was no homogeneity of variance, $F(1,112) = 6.90$, $p = .010$. The same analysis was conducted to compare the two practice structures, showing no significant difference $F(1,112) = 0.08$, $p = .772$, $\eta_p^2 < .01$, $BF_{01} = 4.84$, error % = 0.03. Levene's test suggested there was homogeneity of variance, $F(1,112) = 0.28$, $p = .601$.

Figure 12

The Difference in Reaction Time During the Intervention Phase Between the Two Modalities



Between Groups Intervention Post Hoc

Following this significant difference between practice structures during the intervention for the reaction time data, a post hoc one way ANOVA between the two practice structures for the intervention was conducted just for the physical groups. This was to assess the effect of practice structure during the intervention in the physical practice groups. There was no

significant main effect for practice structure on reaction time F(1,56) = 0.17, p = .168, η_p^2 < .01, BF_{01} = 3.50, error % = 0.01. The same analysis was then repeated for the imagery groups (blocked imagery and random imagery) to see the effect of practice structure during the intervention in the imagery practice groups. There was no significant main effect for practice structure on reaction time F(1,54) = 0.48, p = .491, η_p^2 = .01, BF_{01} = 3.03, error % = 0.01.

Accuracy Percentage

Pre-test ANOVAs

A one-way ANOVA was conducted for accuracy percentage at pre-test between the four groups (block physical, block imagery, random physical, and random imagery) to check for equivalence and comparability between groups. There were no significant differences F(3, 110) = 1.01, p = .390, η_p^2 = .03, BF_{01} = 6.86, error % < 0.01. Levene's test suggested there was homogeneity of variance, F (3,110) = 0.22, p = .884.

Repeated Measures ANOVAs

A three time point (Pre-test, Post-test, and Transfer) repeated measures ANOVA between the two modalities was conducted for the accuracy percentage data. The main effect for time F(2, 224) = 2.36, p = .097, η_p^2 = .02, BF_{01} = 16.69, error % = 1.07, modality F(1, 112) = 1.25, p = .267, η_p^2 = .01, BF_{01} = 3.63, error % = 0.88, and the interaction between time and group F(2, 224) = 0.03, p = .970, η_p^2 < .01, BF_{01} = 16.69, error % = 5.44, was non-significant.

The same three time point repeated measures ANOVA was conducted for the two practice structures. The main effect for practice structure F(1, 112) = 4.73, p = .032, η_p^2 = .04, BF_{01} = 0.78, error % = 1.48, was significant, showing accuracy improved during the post-test but was poorer during the transfer task. The effect for time F(2, 224) = 2.34, p = .098, η_p^2 =

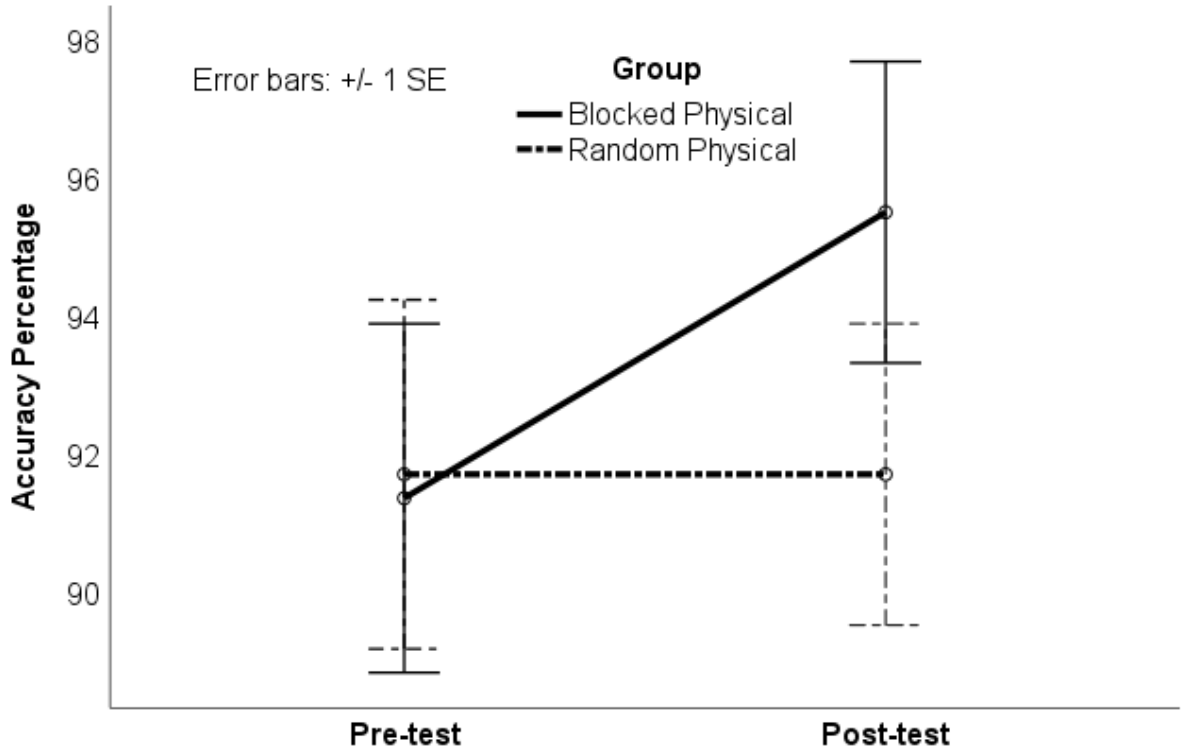
.02, BF_{01} = 3.40, error % = 0.70, and the interaction F(2, 224) = 0.67, p = .512, η_p^2 = .01, BF_{01} = 9.14, error % = 5.05, was non-significant.

Between Physical Groups Post-test Post-hoc (Fig.13)

Following this significant main effect for practice structure in the repeated measures ANOVA across the three time points using the accuracy data. A post hoc repeated measures ANOVA between pre-test and post-test was conducted just for the physical groups (blocked physical and random physical). This was to assess the differences in accuracy in the physical practice conditions, across the two practice structures, without the imagery group data or the transfer condition. The main effect for time F(1, 56) = 1.15, p = .020, η_p^2 = .02, BF_{01}= 3.04, error % = 1.84, and the interaction F(1, 56) = 1.15, p = .020, η_p^2 = .02, BF_{01}= 2.24, error % = 3.56, was significant. Here the frequentist results were identical due to the mean post-test scores being identical, suggesting in the physical groups there was no difference between groups. The main effect for practice structure confirmed this and was not significant F(1, 56) = 0.40, p = .529, η_p^2 = .07, BF_{01}= 3.24, error % = 0.88.

Figure 13

A Comparison of Accuracy (Percentage of Correct Scores) Between the Blocked and Random Physical Groups from Pre to Post-Test



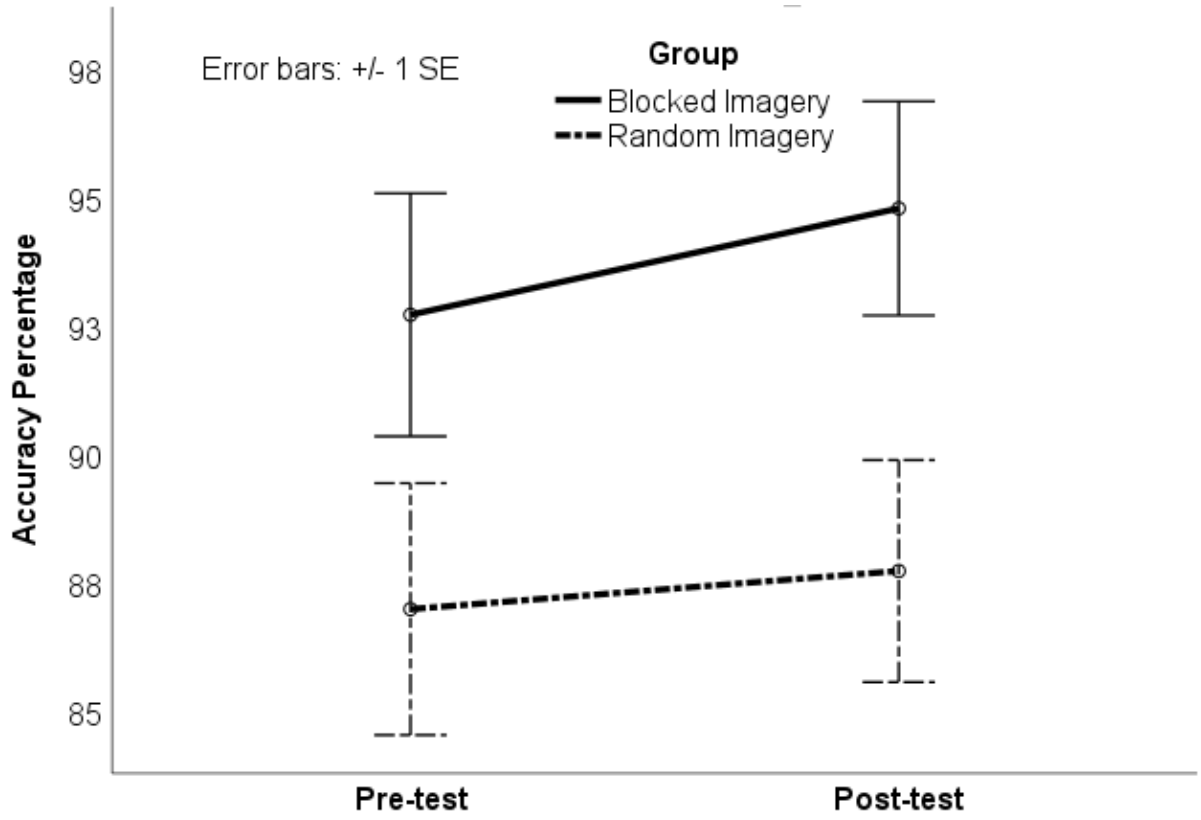
Between Imagery Groups Post-test Post-hoc (Fig. 14)

Another post hoc repeated measures ANOVA between pre-test and post-test was conducted just for the imagery groups (blocked imagery and random imagery). This was again to assess the differences in accuracy in the physical practice conditions, across the two practice structures, without the physical group data or the transfer condition. The main effect for practice structure was significant, as the blocked group improved to a greater degree than the random group $F(1, 54) = 8.79$, $p = .004$, $\eta_p^2 = .14$, $BF_{01} = 0.27$, error % = 0.81. The main effect for time was not significant $F(1, 54) = 0.35$, $p = .557$, $\eta_p^2 = .01$, $BF_{01} = 4.15$, error % = 1.14, as was the interaction $F(1, 54) = 0.09$, $p = .781$, $\eta_p^2 < .01$, $BF_{01} = 2.97$, error % = 15.53. A post hoc test was conducted using a one-way ANOVA on post-test between the two imagery

practice groups, to see if there was a difference in accuracy between groups at post-test. This was significant F(1, 54) = 5.53, p = .022, η_p^2 = .02, BF_{01} = 0.39, error % = 0.01, with the blocked imagery group outperforming the random imagery group. Levene's test suggested there was homogeneity of variance, F (1, 54) = 2.24, p = .077. It is of note that there was a near significance difference for accuracy between these two groups (blocked imagery and random imagery) at pre-test F(1, 54) = 2.83, p = .098, η_p^2 = .05, BF_{01} = 1.16, error % = 0.01. Levene's test suggested there was homogeneity of variance, F (1, 54) = 0.67, p = .417.

Figure 14

A Comparison of Accuracy (Percentage of Correct Scores) Between the Blocked and Random Imagery Groups from Pre to Post-Test



Discussion

The hypothesis of functional equivalence in practice structure effects, between motor imagery and physical practice, was not supported by the findings of this experiment. Instead, the results imply that there is a level of functional divergence as the contextual interference was elicited in the physical practice groups but not the imagery groups. When the movement time data of the two modality groups were separately analysed, the physical practice groups showed a significant interaction between time and practice structure, clearly demonstrating the contextual interference effect. Specifically, the random physical group shows significantly faster movement times from pre to post-test when compared to the blocked physical group. Importantly, however, the imagery groups showed no interaction between time and practice structure, and therefore no evidence of the contextual interference effect. The presence of the contextual interference effect in the physical group and not in the imagery groups demonstrates functional divergence in practice structure effects. The movement time post-hoc ANOVAs at post-test show no significant difference between the two physical groups or the two imagery groups. This supports the importance of analysing the changes in performance from pre-test to post through repeated measures (Ammar et al., 2024; 2025), rather than just at a single time point (Czyż et al., 2024a; 2024b), when investigating the contextual interference effect. Interestingly it appears that both imagery groups had faster movement times than the blocked physical group, but slower than the random physical group at post-test, but this lacks significance. The lack of a main effect for group or an interaction when comparing modality suggests that physical and imagined practice had similar effects on movement time which supports a previous findings (Driskell et al., 1994; Gentili et al., 2010; Ladda et al., 2021) and a degree of functional equivalence (Calmels et al., 2006; Carrillo et al., 2008; Finke, 1979; 1980; Jeannerod, 1994; Hardwick et al., 2018). When this lack of significance between modalities is paired with the significant

interaction when comparing the two practice structures, it shows again that the practice structure caused differences between groups, from pre to post test, rather than modality.

The significant main effect for time for the ANOVA comparing reaction time in either the two modalities or practice structures suggests that the intervention affected participants cognitive processing. This finding of significantly slower reaction time in the imagery group compared to the physical group supports the second hypothesis, indicating that the motor imagery intervention was more cognitively demanding (Henry & Rogers, 1960; Christina et al., 1982; Glover & Baran, 2017; Glover et al., 2020; Klapp, 1980; Martel & Glover, 2023). The post hoc results showed that this significant difference occurred regardless of practice structure, showing that the third hypothesis was not supported, practice structure did not significantly affect reaction time. The lack of significant difference between the two practice structures in either modality may be a result of the simplicity of the task. It may also be a product of the weak effect that practice structure has on cognition when measured through reaction time when compared to the movement time (Lee & Magill, 1983). It is possible to directly assess the influence of error processing on reaction time in the physical group, by seeing if an error or the previous trial increased reaction time on the subsequent trial (Broadbent et al., 2017). This approach cannot be done during imagery practice as it is impossible to show an error during an imagery trial in this study. Future neurological research may be able to demonstrate differences in cognitive processing during random imagery compared to blocked imagery practice, which may be suggestive or more error processing during high levels of contextual interference.

Many have shown that increasing contextual interference is more cognitively demanding, (Lee & Magill, 1983, 1985; Davids et al., 2008; Broadbent et al., 2017). However, the present findings found no significant differences in reaction time (our measure

of cognitive demand Henry & Rogers, 1960; Christina et al., 1982; Klapp, 1980) between the two practice structures used. Large differences in reaction time were observed between the two modalities. This suggests that the cognitive demand required for imagery can be much greater than that of physical practice, shortly prior to motor execution. In the present experiment this large difference in cognitive demand between the two modalities may have washed out the differences in cognitive demand between the two practice structures. This demonstrates some level of functional divergence and shows a possible explanation for the lack of consistency in findings from previous research into contextual interference and imagery (Gabriele et al., 1989; Overdorf et al., 2004). The reaction time findings also clearly show that modality has a greater effect on cognition than practice structure.

The accuracy data showed no significant differences between modality, however, there were significant differences between practice structures. Post hoc analysis showed the blocked physical practice appears to improve accuracy more than the random physical group. This appears to counter the expectations of contextual interference, where higher contextual interference improves overall motor performance in retention and transfer tests (Ammar et al., 2023; 2024; 2025; Czyż et al., 2024a; 2024b). However, the present study found no between group differences at transfer, and the post-test was arguable too soon after the intervention to constitute a retention. It may be that participants in the blocked group still had the test sequence in short term memory and so were able to more accurately retrieve it (Lee & Magill, 1983; 1985). The imagery practice groups showed no significant differences in accuracy performance. This paired with the significant accuracy improvement of the blocked physical group when compared to the random physical group again supports functional divergence in practice structure effects. Previous research in observational learning and the contextual interference effect has failed to show group differences in accuracy (Lee & White, 1990). It is also worth noting that much of the research on contextual interference in

nonphysical interventions, has used movement time to demonstrate the advantages of random practice over blocked (Blandin et al., 1994; Gabriele et al., 1989; Wright et al., 1997). Understanding the interaction between contextual interference, non-physical interventions, and various performance measures (e.g. movement time, accuracy, speed-accuracy trade off, efficiency of movement) may allow for better understanding of these inconsistent findings.

The findings of this research support the absence of the contextual interference in imagery (Overdorf et al., 2004), and observational learning (Lee & White, 1990). This shows that previously shown contextual interference effects, when using combined physical and imagery practice, were likely a result of the physical practice effect (Gabriele et al., 1989). Will the findings here address imagery practice, more research is needed to address the conflicting evidence of the contextual interference effect in observation learning (Blandin et al., 1994; Wright et al., 1997; Lee & White, 1990). The present research manipulated inter-task processing to elicit the contextual interference effect (Battig, 1966). Debarnot et al. (2015) and Bird and Rikli (1983) manipulated intra-task processing (also known as variable practice effects) to demonstrate the contextual interference effect within motor imagery and action observation, respectively. This compared variable and constant practice to demonstrate the advantages of varying practice (Schmidt, 1975) in nonphysical practice. This suggests that presence of the contextual interference in non-physical practice is dependent on the similarity of the motor programs that are practiced. The effect seems to appear in non-physical practice when the tasks are more similar (intra-task processing effects) but not when the motor programs practiced are more distinct like in the present study (inter-task processing effects). This reflects the task similarity debate which has been raised when discussing the contextual interference effect in physical practice (Lee et al., 1992). Battig (1979) observed that intra-task processing elicited more interference than inter-task processing, however, Magill and Hall (1992) suggested the opposite effect. While much discussion has been had

regarding the task similarity debate in physical practice (Sekiya et al., 1994; Wulf & Lee, 1993), the consensus in more recent years seems to be that using a combination of both intra-task and inter-task creates the most interference and is optimal for learning (Boutin & Blandin, 2010; Li & Lima, 2002; Maslovat et al., 2004; Ranganathan & Newell, 2010; Ruano et al., 2022; Sherwood, 1996). The task similarity debate has yet to be applied to non-physical practice and may help optimise future interventions.

It is clear many variables influence the contextual interference effect, for example, age (Shapiro & Schmidt, 1982; Pollock & Lee, 1997; Graser et al., 2019; Ammar et al., 2024), experience (Gentile, 1972; Del Rey, 1989; Magill & Hall, 1990), gender (Del Rey, 1983b), experience (Del Rey, 1989), and cognitive style (Jelsma & Van Merrienboer, 1989). These mediating variables may be key to understanding the clear lack of generalisability of the contextual interference effect (Ammar et al., 2023; 2024; 2025, Czyż et al., 2024a; 2024b). Successfully applying the contextual interference to motor imagery may require better control of these variables. The present finding of the contextual interference effect in the physical group and not in imagery does suggest that the effect is at least weaker in imagery. This supports previous findings that the contextual interference effect (both inter and intra-task processing effects) is weaker in non-physical interventions (Bird & Rikli, 1983; Coelho et al., 2012; Fazeli et al., 2021). This could be explained by the weaker learning effect of imagery when compared to physical practice (Driskell et al., 1994; Feltz & Landers, 1983; Ladda et al., 2021). However, in the simple sequence task used in the present study, the imagery groups improved to a similar degree to the physical groups, suggesting that the differences between imagery and physical practice only present when the task requires more precision, complexity, and involves dual task processing (Glover & Baran, 2017; Glover et al., 2020; Martel & Glover, 2023).

The absence of a control group means we do not know the extent that the physical experience of the task, during pre-test, improved movement time at post-test, without an imagery intervention. The simplicity of the task likely means that learning effects can occur from relatively little experience, like the pre-test phase. We cannot therefore be sure that performance changes occurred solely from the interventions. However, the contextual interference effect, demonstrated in the physical groups, provides evidence that learning effects resulted from the intervention, and that differences in learning effects were due to the manipulation of practice structure. The absence of a control group also allowed for a greater sample size and therefore more statistical power to compare physical and imagined practice.

The findings of this experiment show that imagery and physical practice have similar effects on movement time performance when practice structure is not accounted for, supporting a degree of functional equivalence. The contextual interference was observed in the physical practice groups but not in the motor imagery groups. This suggests some level of functional divergence in practice structure effects, specifically when comparing physical practice interventions to motor imagery. Imagery practice also appears to be more cognitively demanding than physical practice, when measured through reaction time, in line with the motor-cognitive model (Glover & Baran, 2017; Glover et al., 2020; Martel & Glover, 2023). The difference in reaction time between high and low contextual interference conditions was non-significant, suggesting no differences in cognitive demand. While the mechanisms of the functional divergence in practice structure effects are unclear, the present evidence implies this is due to the increase in cognitive demands during imagery. These findings also support the importance of both functional equivalence and divergence when applying motor imagery (Hurst & Boe, 2022). More research is needed before practical recommendations can be given regarding the optimal practice structure of motor imagery. The findings presented here show that practitioners should exercise caution when applying skill acquisition theories motor

imagery interventions, until there is evidence of the theories functional equivalence. Theoretically there does appear to be a strong rational for applying contextual interference to motor imagery interventions, however these findings show that the effect is either weakened or non-existent in motor imagery. To provide more guidance to practitioners, longer interventions with various types of skills should be examined in the context of contextual interference and motor imagery.

Chapter 5 General Discussion

Summary of findings

The aim of this thesis is to investigate the presence of contextual interference, through either inter and intra task processing, in non-physical practice. This not only provides evidence for optimal structuring and varying of non-physical practice but also investigates the degree of functional equivalence and divergence between non-physical and physical practice. The hypothesis favoured functional equivalence, predicting that contextual interference would affect performance similarly regardless of the modality of practice. The findings instead consistently point to a degree of functional divergence when applying motor learning theories regarding practice structure and variability.

Experiment one tested the presence of the contextual interference effect, specifically inter-task processing effect, in a three day AOMI dart throwing intervention. This acts as an applied approach to test the functional equivalence hypothesis. The tasks (badminton serve, football penalty, and dart throwing) involved distinctly different general motor programs to specifically test the predictions of the action plan reconstruction explanation of the contextual interference effect (Lee & Magill, 1983; 1985). While the contextual interference effect suggests random practice is superior to blocked practice for retention, the post test results showed no differences between the three groups (blocked, random, and control). This did not provide support for the functional equivalence, or the action plan reconstruction hypothesis, instead suggesting functional divergence. The intervention did not improve dart performance, likely due to the lack of task relevant practice, combined with the high challenge of the practice and task for the novice participants (Guadagnoli & Lee, 2004; Pauwels et al., 2015).

Experiment two used a similar three day AOMI intervention on dart throwing performance to test the function equivalence of intra-task processing effects. This involved comparing a control group to a variable AOMI practice group, where the distance was varied during the intervention, and a constant AOMI practice group, where the same distance was

used throughout the intervention. The predictions of schema theory (Schmidt, 1975) and research in physical practice (Gerson & Thomas, 1977; Moxley, 1979; Newell & Shapiro, 1976; Wrisberg & Ragsdale, 1979; Shea & Kohl, 1990; Landin et al., 1993; Wulf & Schmidt, 1997; Yao et al., 2009) show that variable practice is superior to constant practice in retention performance (also known as intra-task processing effects). While Functional equivalence would imply this relationship would be the same in imagery, the lack of significant difference between the variable and constant groups at post-test suggests functional divergence rather than functional equivalence. The significant improvement over time in the intervention groups in experiment two and not in experiment one is likely due to the increase in task relevant practice in experiment two. The intervention groups in both experiments failed to outperform the control groups performance, suggesting the intervention did not significantly improve dart throwing performance, regardless of practice structure or variability. The lack of intervention effectiveness is likely due to the demanded intervention being too challenging for the novice performers to observe performance changes. During the intervention in both experiment one and two there were, however, significant differences in mental demand between all the intervention groups and the control groups. While there were no differences found in self-reported mental demand between the two imagery groups in either experiment, practice involving higher levels of inter and/or intra-task processing would be expected to require greater cognitive demands. A direct measure of cognitive demand could therefore act as an indicator of the contextual interference effect. As the contextual interference and variable practice effect is likely weakened by the removal of physical practice, a direct measure of cognitive demand may help identify the mechanistic effect of contextual interference and variable practice.

Experiment three added parallel physical groups to compare against imagery groups in an online sequence learning typing task. Action observation was removed from this

intervention to isolate the predictions of the motor cognitive model (Glover & Braran 2017) and due to the difficulty of doing simultaneous action observation and motor imagery in an online PsyToolKit study. For movement time, the physical groups demonstrate the contextual interference effect. Specifically, random physical practice produced significantly better motor learning effects when compared to blocked physical practice. In the imagery groups however, there was no significant difference between the random or blocked groups. This indicates that the contextual interference is not present in imagery practice, suggesting functional divergence. Measuring reaction time as well as movement time allowed us to observe differences in cognition during the intervention and post-test. Higher levels of contextual interference are more cognitively demanding, when compared to lower levels of contextual interference (Broadbent et al., 2017; Kim et al., 2015; Lee & Magill, 1983; 1985). This suggests that reaction time would be longer when the intervention involved higher contextual interference, when compared to lower physical practice (Henry & Rogers, 1960; Christina et al., 1982; Klapp, 1980). Imagery is also more cognitively demanding, when compared to physical practice (Glover & Baran, 2017; Glover et al., 2020; Martel & Glover, 2023). Reaction time was then expected to be slower during imagery practice, when compared to physical practice. The reaction time was higher in the imagery groups, when compared to physical groups, regardless of practice structure. There was no difference in reaction time between the two practice structures used regardless of the modality of the intervention. This suggests that modality was responsible for differences in reaction time and not practice structure. This demonstrates functional divergence and suggests that the increase in contextual interference did not result in an increase in cognitive processing.

The findings of experiment one, two, and three collectively support the suggestion that contextual interference does not occur in the absence of movement (Carnahan et al., 1990). This aligns with previous research on the contextual interference effect in a motor imagery

intervention (Overdorf et al., 2004) while going against the original literature on the topic (Gabriele et al., 1989). It appears that the contextual interference effect is weakened by the removal of physical practice (Coelho et al., 2012; Fazeli et al., 2021; Lee & White, 1990; Overdorf et al., 2004). The findings of all three experiments support the notion that the contextual interference effect is weaker than originally thought (Ammar et al., 2023; 2024; 2025; Czyż et al., 2024a; 2024b), particularly when practice involves non-physical modalities.

Inter and Intra-task Processing in Motor Imagery and AOMI

Experiment one and two used a combined motor imagery and action observation intervention to investigate inter and intra-task processing, respectively. The intervention groups failed to outperform the control groups meaning that no inter and intra-task processing was observed. As previously discussed this is likely due to the high cognitive demands of the AOMI intervention and task in combination with the use of novice experiment three used only a motor imagery intervention (Glover & Baran, 2017; Glover et al., 2020; Kraeutner et al., 2018; Martel & Glover, 2023). Experiment three focused on understanding the underlying cognitive processes that occur during contextual interference by comparing physical and non-physical practice. To understand these cognitive processes the motor cognitive model was used, however as this model only applies to imagery the action observation portion of the intervention had to be removed. The lack of a physical practice group in experiment one and two, as well as the absence of a control group and change of task in experiment three make it difficult to comparing the findings of the experiments. Experiment three, however, demonstrated not only clear learning effects in all groups but also the contextual interference was not present in the imagery group while being present in the physical practice group. This supports the explanation in experiment one and two the combination of AOMI and the darts task was too challenging for novice learners to learn. This also provides an explanation as to why there were no significant differences between the intervention groups in experiment one

and two. In experiment three, the clear difference in reaction time, and therefore cognitive processing, between physical and non-physical practice provides an indication as to why there maybe functional divergence when applying inter and intra-task processing. Finally, the present study supports the suggestion that AOMI upon high levels of sensorimotor coupling, which requires high level of experience is required (Clayton et al., 2020) to access the additive benefits of AOMI (Eaves et al., 2022), particularly for novices (Bar & DeSouza, 2016; Binks et al., 2025; Kraeutner et al., 2018) . There is also considerable evidence that motor imagery is only effective if the individual has experience physically executing the task before they try to imagine it (Mulder et al., 2004; Olsson & Nyberg, 2010; Kraeutner et al., 2016; Gomes et al., 2014).

The similarity between tasks used to elicit the contextual interference effect is an important consideration when eliciting the contextual interference effect. Some have suggested that if vastly different general motor programs are used, increasing inter-task processing, the contextual interference effect may be weaker or non-existent (Boutin & Blandin, 2010; Albaret & Thon, 1998; Jarus & Gutman, 2001;_Wulf & Shea, 2002). Some results have instead indicated that intra-task processing does not produce the contextual interference effect (Lee et al., 1992) and that inter-task processing produces more interference (Magill & Hall, 1992). The consensus in more recent years seems to be that using inter and intra-task processing together creates the most interference and is optimal for learning (Boutin & Blandin, 2010; Li & Lima, 2002; Maslovat et al., 2004; Ranganathan & Newell, 2010; Ruano et al., 2022). Experiment one aimed to isolate inter-task processing effects to test the action plan hypothesis. The intervention groups performed similarly to the control group, making it difficult to make conclusions regarding the presence or absence of the contextual interference as the intervention appeared to be unsuccessful. One can argue that the intervention resulted in too much interference as there were multiple distinct tasks that had to be learnt (Magill & Hall 1990;

Quinn & Sherwood, 1983). One could also argue that the tasks were too dissimilar to facilitate the benefits of contextual interference (Boutin & Blandin, 2010). Either way, optimising the level of similarity between the tasks, during the contextual interference, is key to increasing the beneficial effects of interference on learning (Boutin & Blandin, 2010; Li & Lima, 2002; Maslovat et al., 2004; Ranganathan & Newell, 2010; Ruano et al., 2022; Sherwood, 1996). Optimising the parameters of the contextual interference effect may increase the strength of the effect (Ammar et al., 2023; 2024; 2025; Czyż et al., 2024a; 2024b) to the point it can be observed within imagery interventions.

According to Schema theory the different sequences in experiment three constituted as different general motor programs because they involved different sequences of events. However, the other invariant features (relative timing, and relative forces) as well as many other aspects of the schemas (the effector used, initial conditions, relative force, relative timing, response specifications, sensory consequences) were similar (Schmidt, 1975). Experiment two aimed to isolate intra-task processing (also known as variable practice effects) by keeping the invariant features of the motor programs the same. Instead, only the parameters of the schema would vary, isolating the intra-task processing effects. The findings from experiment one and two showed no differences when manipulating either inter or intra-task processing. It is possible that combining inter and intra-task processing would increase contextual interference, making it easier to see different learning effects (Boutin & Blandin, 2010; Li & Lima, 2002; Maslovat et al., 2004; Ranganathan & Newell, 2010; Ruano et al., 2022). Especially in non-physical practice, where the effects are likely weakened (Bird & Rikli, 1983; Coelho et al., 2012; Fazeli et al., 2021) when compared to physical practice (Driskell et al., 1994; Feltz & Landers, 1983; Ladda et al., 2021).

The task used in experiment three required learners to create distinct representations of each sequence, favouring the elaboration hypothesis (Battig, 1966; Shea & Morgan, 1979;

Cuddy & Jacoby, 1982; Shea & Zimny, 1983). The functional divergence observed in experiment three may be a result of individuals in the imagery groups being unable to create motor programs that were distinct enough to produce the contextual interference effect. This lack of distinction between the different sequences, likely explains the observed slower reaction times in imagery, when compared to physical practice. This increase in reaction time indicates an increase in cognitive processing in the imagery group. It is likely more cognitively demanding to create distinct motor programs through imagery, when compared to physical practice (Driskell et al., 1994; Feltz & Landers, 1983; Ladda et al., 2021). This is in line with the predictions of both the motor cognitive model (Glover & Baran, 2017; Glover et al., 2020; Martel & Glover, 2023) and schema theory (Schmidt, 1975). Participants were, however, able to generate motor programs through imagery that were sufficient to improve their motor performance to a similar degree to the physical practice groups, demonstrating some functional equivalence (Finke, 1979; Jeannerod, 1994, 2001; Ladda et al., 2021). This suggests that if participants are more able to produce more vivid imagery, then functional equivalence would increase (Finke, 1979; Jeannerod, 1994, 2001; Mateo et al., 2018), and the contextual interference effect would be more apparent. This is to say that individuals, capable of highly vivid imagery, would be more likely to elicit the contextual interference effect. The lack of experience the novice participants had with the novel tasks used in experiment two and three, likely meant few were able to vividly imagine the task to a point where elaboration or variable practice effects could occur. Future research could investigate the effect task experience, and imagery ability has when eliciting contextual interference within motor imagery. This approach that accounts the complexity task relative to the learner (Guadagnoli & Lee, 2004) may help to address the inconsistencies in task similarity debate in physical practice (Boutin & Blandin, 2010; Lee et al., 1992; Magill & Hall, 1992; Sekiya et al., 1994; 1996), as well as within motor imagery.

Functional Equivalence and Divergence in the Contextual Interference Effect

Experiment one, two and three aimed to test the predictions of functional equivalence of the contextual interference effect, a longer, more optimised intervention as well as a more complex and generalisable task, than the previously inconclusive research (Gabriele et al., 1989; Overdorf et al., 2004). Experiments one and two, however, had no physical comparison, to increase the sample size of the imagery groups, so we cannot compare the two modalities to physical practice to assess functional equivalence. We assume that the predictions of the inter (experiment one) and intra-task (experiment two) processing effects would have manifested if this intervention was physically done, instead of AOMI. However, we cannot say for certain that if the experiments were conducted using physical practice, instead of AOMI, that the results would have been different. Functional equivalence would suggest the same results would have occurred regardless of the modality of practice. The purpose of experiment three was to address functional equivalence more directly by comparing imagery and physical practice, when applying the contextual interference effects. This tests functional equivalence using a more applied method, extending the large amount of neurological research on functional equivalence (Hardwick et al., 2018). The presented evidence instead supports functional divergence, by demonstrating the contextual interference within physical practice and not in imagery practice. Another finding that supports functional divergence is the slower reaction time in the imagery groups when compared to the physical groups. An interaction in accuracy data between the two practice structures was also only present in the physical practice groups, and not the imagery groups.

A useful conceptualisation of functional equivalence and divergence is the spectrum model (Hurst & Boe, 2022). This spectrum approach considers the degree of neural overlap depending on the context of the imagery practice. For example, task, expertise, and individual differences affect the level of equivalence or divergence. This spectrum model shows us that

more evidence is required to test functional equivalence and explain the mechanisms that distinguish motor imagery from execution (Hardwick et al., 2018; O'Shea & Moran, 2017; Hurst & Boe, 2022). While there are many models that explain both the equivalent and divergent nature of motor imagery and physical practice, more work is needed to integrate these theories (Hurst & Boe, 2022). Specifically, a multimodal imagery approach (Lacey & Lawson, 2013), a greater focus on research on other, non-motoric forms of imagery (Pearson et al., 2015), as well as an understanding of the role of memory, is needed to better understand the spectrum of equivalence and divergence (Hurst & Boe, 2022). Experiment one and two addressed this by using a PETTLEP and action observation, constituting a multimodal approach. Another popular way of achieving a better understanding is through integration of imagery with our current theories of motor systems (Grush, 2004; Moulton & Kosslyn, 2009; Bardouille & Boe, 2019; Hurst & Boe, 2022), and theories of motor learning (Gabriele et al., 1989; Hall et al., 1995; Overdorf et al., 2004; Coelho et al., 2012; Debarnot et al., 2015; Fazeli et al., 2021). This can be achieved by replacing physical practice with another modality, to try and replicate experiments that have established theories of motor learning like the contextual interference effect (Bird & Rikli, 1983; Lee & White, 1990; Blandin et al., 1994; Wright et al., 1997; Gabriele et al., 1989; Hall et al., 1995; Overdorf et al., 2004; Coelho et al., 2012; Debarnot et al., 2015; Fazeli et al., 2021). This integrating approach was used in the present research, to integrate contextual interference into an AOMI intervention, to better understand functional equivalence and divergence.

Dart throwing involves highly precise temporal, spatial, and force requirements (Dahm & Rieger, 2019), which are learnt by comparing motor executions to sensory feedback (Adams, 1971; Schmidt, 1975; Sperry, 1950; Proteau, 1992; Welniarz et al., 2021). This feedback loop between motor executions and sensory feedback can be facilitated by action observation and motor imagery (Jeannerod, 1994, 2001; Kosslyn, 1987; O'Shea & Moran, 2017). The action

observation of dart throwing used in this study may not have provided the sufficient sensory feedback needed to create vivid enough images to develop significantly more accurate motor programs. Imagery alone has no sensory feedback (Farah, 1984; Jeannerod, 1994, 2001; Kosslyn, 1987; Kosslyn et al., 2001; Munzert et al., 2009), relying on the imaginer to simulate sensory feedback (Holmes, 2007; Jeannerod, 1994), which was likely too challenging for the novice participants (Dahm & Rieger, 2019). This potentially insufficient sensory feedback, in the interventions of all three experiments, may have reduced the functional equivalence of practice, resulting in the functional divergence observed. In a computer aiming task, Owen et al. (2024) showed that when sensory feedback is removed, motor imagery is as effective as physical practice at eliciting online corrections. This could be used to argue that, despite the lack of fidelity in the action observation, motor imagery alone would be expected to perform similarly to physical practice in the darts task. The presence of action observation in experiment one or two prevents a direct comparison with the findings of Owen et al. (2024) who had no action observation. More research is needed to determine whether the simulated feedback in imagery is sufficient to produce learning effects in darts (Dahm & Rieger, 2019). Much of the existing action observation research neglects fine motor tasks (Ashford et al., 2006), instead using simpler grasping tasks (Castiello et al., 2002; Gianelli et al., 2008; Hardwick & Edwards, 2011) and knot tying tasks (Roshal 1949, 1961). The effect of action observation has not been tested in darts. The extent that action observation, motor imagery, or AOMI can provide the required sensory feedback needed for novices to learn a task, likely dictates the level of functional equivalence or divergence of the practice (Hurst & Boe, 2022; Ladda et al., 2021).

The use of novice participants and the high task difficulty likely reduced the learning effects of imagery (Glover & Baran, 2017; Glover et al., 2020; Hebert et al., 1996; Martel & Glover, 2023; Wulf & Shea, 2002). Novices may not be able to effectively imagine darts with enough fidelity to learn effectively (Dahm & Rieger, 2019). Imagining motor representations

with less fidelity requires more elaboration which results in slower, less functionally equivalent, imagery (Gandrey et al., 2013; Glover & Baran, 2017). Even when accounting for imagery ability (using the MIQR) there was no evidence of superior learning in the imagery groups when compared to the control. Combined with the compelling evidence of the effectiveness of imagery (Driskell et al., 1994; Hardwick et al., 2018; Ladda et al., 2021), this leads to the conclusion that motor imagery interventions of this length are not conducive with darts performance gains. Longer interventions using AOMI have been effective at improving darts performance (Romano-Smith et al., 2018; 2019). Using other measures like the spread of the darts and the kinematics of the throwing arm are more sensitive than performance measures in darts (Dahm & Rieger, 2019; Romano-Smith et al., 2019). These more subtle, non-performance measures, could also be more sensitive to the weak effects of the contextual interference effect in dart throwing imagery interventions.

Further Optimising Contextual Interference in Motor Imagery and AOMI

The generalisability of the contextual interference effect has been called into question repeatedly (Al-Mustafa, 1989; Ammar et al., 2023; 2024; 2025; Brady, 1998). Many other interacting variables are shown to amplify or reduce the effect (Ammar et al., 2023; 2024; 2025; Czyż et al., 2024a; 2024b). For example, according to Pollock & Lee (1997), the age range predominantly used in the present study can be used to successfully demonstrate contextual interference effects. However, for young children there was no difference between random and blocked practice (Pollock & Lee, 1997). As age is one of the main mediating variables of the effect (Ammar et al., 2023; 2024; 2025; Czyż et al., 2024a; 2024b) we accounted for age as a co-variate. This, however, did not change the results of any of the experiments. The intertrial duration is also an important consideration of the contextual interference effect. If this is too short then it does not facilitate between trial forgetting which is key for contextual interference (Lee & Magill, 1983, 1985). In experiment one and two, our

intertrial period between throws, around five seconds, was chosen to match the speed that novices throw darts at in our pilot tests, increasing functional equivalence. This is relatively short, which could have arguably reduced the effectiveness of the contextual interference effect (Kim et al., 2015). However, between each sub-block of five throws there was a longer period of rest, approximately ten seconds, and between blocks there would be periods of 18 seconds of rest. More research needs to be done to understand the mechanisms of varying the inter-trial duration and before a specific intertrial duration is known to be optimal (Kim et al., 2015). More research on the many mediating variables of the contextual interference effect also needs to be done to optimise practice structure. Particularly in field research (Czyż et al., 2024a; 2024b), for example in sports where more complex tasks, and varying skill levels are involved (Ammar et al., 2023; 2024; 2025). This optimisation may lead to stronger practice structuring effects in non-physical practice.

In experiment one and two the control group showed improvement over time. This improvement could be explained by the familiarisation of the lab environment, physical experience during familiarisation and pre-test, as well as an increase in motivation and positive afferent from watching the videos (previously discussed see page 166). The intervention groups, however, experienced task relevant practice with contextual interference. It then appears that both forms of contextual interference may have negatively interfered with their pre-test physical practice. The blocked group appears to trend towards improvement although this is not a significant improvement. The random group appears to show no signs of improvement and even trends towards poorer performance. This would suggest that more contextual interference negatively impacted performance. While these are non-significant inferential findings it is important to consider the possibility that the interference, from learning multiple tasks during an intervention, can negatively affect performance. The negative effect on acquisition can be explained due to increasing cognitive processing demands from practice

structures that increase contextual interference (Shea & Morgan, 1979; Lee & Magill, 1983; 1985; Pollock & Lee, 1997; Davids et al., 2008; Broadbent et al., 2017), specifically through inter-task processing (Magill & Hall, 1992). This may result in practice being too demanding for novices to produce learning effects (Hebert et al., 1996; Guadagnoli & Lee, 2004; Wulf & Shea, 2002). Importantly, however, the constant practice group in experiment two, contained no contextual interference but was still unable to outperform the control group. This instead suggests that the lack of learning effects in both experiment one and two is due to the non-physical practice being too cognitively challenging for novices learning a complex skill such as darts (Glover & Baran, 2017; Glover et al., 2020; Guadagnoli & Lee, 2004; Martel & Glover, 2023; Pauwels et al., 2015).

An issue with the contextual interference effect is that it is possible to provide a rationale that favours either random or blocked practice. If blocked out performs random, it can be argued that the performance measure was earlier in the acquisition phase where blocked is superior to random. The negative effect of a random structure could result from the practice involving too much interference, which at first can be overwhelming for novices' skill (Gentile, 1972; Magill & Hall, 1990; Wulf & Shea, 2002; Guadagnoli & Lee, 2004). This explains why more experienced individuals seem to benefit more from random practice than individuals with less experience (Del Rey, 1989). With more complex skills the learning curve of blocked and random practice likely varies (Guadagnoli & Lee, 2004), hence why the effect is difficult to replicate in field research with more complex tasks (Ammar et al., 2023; 2024; 2025, Czyż et al., 2024a; 2024b). When random outperforms blocked practice, it suggests that the interference was beneficial as it was more cognitively demanding than blocked (Lee & Magill, 1983; 1985; Davids et al., 2008; Broadbent et al., 2017). This may be the effect that random and blocked practice have in simple controlled lab tasks (Ammar et al., 2023; 2024; 2025, Czyż et al., 2024a; 2024b; Pauwels et al., 2015).

Future research could focus on an approach of using an optimal level of interference depending on the learner and task, to more effectively apply contextual interference to field settings. For inter-task processing (random vs blocked practice), the presence of the superior random practice effect in simple lab experiments can be explained by an optimal challenge point framework (Pauwels et al., 2015). For a novel simple motor task, initially a blocked structure provides a more optimal challenge point. However, after ceiling effects are reached, the random structure group will catch up and reach the same ceiling level of performance (Shea & Morgan, 1979). As the random group overcomes more challenges during, they can perform better during the more challenging retention and transfer performance. An optimal challenge approach has been demonstrated in the practice variability research (known as intra-task processing in the contextual interference literature), aiming to understand how to optimally vary practice (Stergiou et al., 2006; Harrison & Stergiou, 2015; Ruano et al., 2022).

Further Optimising Motor Imagery and AOMI to Elicit Practice Effects

Imagining a high fidelity, task like dart throwing, is known to increase cognitive demands (Dahm & Rieger, 2019; Glover & Baran, 2017; Glover et al., 2020; Martel & Glover, 2023) as is contextual interference (Broadbent et al., 2017; Davids et al., 2008; Lee & Magill, 1983, 1985). This high cognitive demand may have been too challenging for these novice imagers to learn effectively (Dahm & Rieger, 2019; Guadagnoli & Lee, 2004). Broadbent et al. (2017) suggests that an increase of cognitive demand makes it more difficult to observe the contextual interference effect. It therefore likely requires highly skilled imagers to see the contextual interference effect in imagery for a high fidelity skill like darts. The findings that novices benefit less from contextual interference has, however, been proven difficult to replicate (Del Rey et al. 1982a; 1982b; 1983a; 1983b; 1987). Novices can also still benefit from higher contextual interference when learning more complex tasks (Ollis et al., 2005). A better understanding of the effect of the performer's ability to imagine the task relative to the imagined

task difficulty (see challenge point framework Guadagnoli & Lee, 2004) is required for the optimal application of contextual interference.

Novices who are still in the cognitive stage of learning (Fitts & Posner, 1967) can be negatively affected if their motor learning is more explicit or conscious, for example through excessive verbal instructions (Maxwell et al., 2000). In the case of experiments one and two the repeated imagery scripts could have also functioned as excessive verbalisation which negatively affects motor performance (Maxwell et al., 2000), in novices (Chauvel et al., 2013). Imagery itself may be susceptible to becoming more explicit as it is seen as a fundamental part of the conscious experience (Marks, 1999). Imagery has also been shown to require more cognitive processing when task complexity increases (Glover & Baran, 2017; Glover et al., 2020; Martel & Glover, 2023). Jeannerod (1994) describes motor imagery from the first person perspective to be more explicit. Our use of first person action observation videos may have encouraged learning to be more explicit. These factors could have combined in experiment one and two, causing novices practice to become explicit. This would lead to more conscious processing which can negatively affect subsequent physical performance in complex skills, known as reinvestment (Masters, 1992; Bright & Freedman, 1998; Maxwell et al., 2000; Masters & Maxwell, 2008; Garnaas & Tillaar, 2024). Reinvestment theory, however, relies on the presence of pressure during performance. While no pressure manipulation was used, there is arguably inherent pressure in conducting tests in a laboratory with a post-test after a three day intervention. This is to say that in this study participants may have felt a pressure to show improvements, however, no measure of performance pressure was gathered, only time pressure. Reinvestment theory is also usually applied to well learnt skills; one could argue that the act of throwing (or the generalised motor program) was already well learnt and automatic in most of the participants. The high cognitive demand (Glover & Baran, 2017; Glover et al., 2020; Martel & Glover, 2023), combined with the use of repeated imagery scripts (Maxwell et

al., 2000), may have caused participants to regress further back to more cognitive stage of learning (Fitts & Posner, 1967) resulting in inferior performance. As predicted by reinvestment theory (Masters, 1992).

Research is needed to optimise imagery scripts, the current recommendation suggests the verbal imagery scripts done is optimal (Lang et al., 1970; Lang, 1977; 1979; Williams et al., 2013; Cumming et al., 2017). This suggests developing an imagery script based on the reflections the imaginer has about their imagery practice. The present study did this reflection at the start and of each session, after the participant was asked to imagine throwing a dart. This reflection was then used to develop an imagery script to read to the participants at the start of each block. The start of each session would use the layers recommended by Cumming et al. (2017), namely "sensations", "thoughts", and "physical sensations". The process of reflection could have been done more frequently; however, no empirical evidence has been developed to provide a recommended frequency for layered stimulus response training. Experiment one and two for example could have discussed the imagery the participant had done after each block, rather than only at the start. This would increase engagement with the imagery, potentially helping generate new elements to imagine. Increasing the imagery scripts may constitute excessive verbal instructions, which can have a negative effect on learning (Maxwell et al., 2000). This demonstrates the possibility of further optimising the use of imagery script.

Experiment one could have optimised the participants ability to image the secondary tasks (backhand serve and the penalty shot) by providing them with some physical experience before imagining those tasks (Gomes et al., 2014; Kraeutner et al., 2016; Mulder et al., 2004; Olsson & Nyberg, 2010). Participants will have had varying levels of experience with these sporting skills, and varying imagery ability, so would be able to imagine them more vividly. Without the prior physical experience, some participants may not have generated vivid enough

motor imagery to create the comparisons between movement plans that some explanations of the contextual interference effect rely on (Battig, 1966; Shea & Zimny, 1983). However, if the badminton serves and penalty shot imagery resulted in the generation of any motor imagery, then this should constitute an alternate task, regardless of the level of vividness. Even motor imagery of the secondary tasks that lacked vividness, would then have interfered with the imagery of the darts task. The action plan reconstruction hypothesis (Lee & Magill, 1983; 1985), blocked practice explanation (Poto, 1988), and constraints led explanation would therefore still predict the presence of contextual interference in our intervention, regardless of the vividness of the secondary tasks. The inclusion of action observation will have also increased the effectiveness of the motor imagery (Caligiore et al., 2017; Moran et al., 2012a), providing participants with enough information to form motor programs (Castiello et al., 2002; Gianelli et al., 2008; Hardwick & Edwards, 2011; Ste-Marie et al., 2012). The use of relatively simple and popular sports for the secondary tasks will have also made it easy for novice participants to perform motor imagery. Many participants also self-reported efferent leakage during the football and badminton. For example, “I could feel the muscles (same as the ones used in demonstration) being activated and could physically feel those parts of my body wanting to do that action/preparing for that action the more I thought about it”. Participants also reported feelings and sensations associated with badminton and football. For example, " I could feel the weight of the football on the inside of my foot. I could feel the movement of the badminton serve and clearly see myself performing the action.”. These suggest that for many the intervention was sufficient to facilitate motor imagery for darts and football despite the lack of physical familiarisation.

It is possible that the familiarisation with the laboratory environment, and the experience of physically performing at pre-test, contributed to the improved performance in the control groups. It is also possible the interview videos in the control groups were perceived

as more motivating and engaging than the intervention. The charismatic, motivational, and comedic nature of the interviews, may have created a more enjoyable experience, and a positive association with being in the lab. This may have increased positive affect and motivation which could help improve performance (Lemos et al., 2017; Kaefer & Chiviacowsky, 2021). In comparison the AOMI intervention was more repetitive, requiring more effort and mental demand while being much less interesting and engaging. This may have created a negative association with the laboratory environment in some participants, negatively affecting performance (Lemos et al., 2017; Kaefer & Chiviacowsky, 2021). When participants in the intervention groups were asked how they felt during the imagery some reported finding it "difficult" and feeling "fatigue" and "boredom".

Task Generalisability

The level of challenge a task elicits during learning is an important consideration in motor learning research (Boutin & Blandin, 2010; Albaret & Thon, 1998; Jarus & Gutman, 2001; Guadagnoli & Lee, 2004; Wulf & Shea, 2002). In experiment one and two a real world sports task was chosen to increase generalisability of the findings. Previous research has used more controlled and simple lab tasks and found mixed results (Gabriele et al., 1989; Overdorf et al., 2004). Gabriele et al. (1989), for example, used a block knockdown task which involves learning a sequence of movements, found evidence of the contextual interference effect in motor imagery combined with physical practice. The sequence learning task used in experiment three also demonstrated the contextual interference effect in the physical practice groups, suggesting that sequence learning task lend themselves to the contextual interference effect. As the contextual interference effect was not observed in the imagery group in experiment three this also supports the earlier suggestion that contextual interference manifested in Gabriele et al. (1989) because of the physical practice being combined with imagery. Imagery, when isolated, does not appear to facilitate contextual interference. Overdorf et al. (2004) used a

Bassin Anticipation timer task which involves pressing a button which does not involve learning a motor skill but is instead a measure of coincidence timing (Shea et al., 1981). While the Bassin Anticipation timer task has been paired with a motor response in other experiments it has not been clearly established as a good task to facilitate the contextual interference effect (Goode, 1986; Magill & Hall, 1990), let alone in imagery. This lead Overdorf et al. (2004) to suggest the use of other more generalisable tasks. Real world tasks have also failed to show intra-task processing effects in imagery (Coelho et al., 2012; Fazeli et al., 2021) but have been shown in similar experiments using physical practice (Chua et al., 2019). The intra task processing effects have been demonstrated by Debarnot et al. (2015) in simple keyboard sequence learning task like the task used in experiment three. Debarnot et al. (2015) however used a retention test, one day after the acquisition to demonstrate these effects, likely explaining why the results were not replicated in experiment three. It therefore appears that the contextual interference effect in imagery lacks generalisability to more complex tasks and requires the benefits of sleep consolidation to show effects in relatively simple sequence learning tasks.

The darts task used was potentially too challenging to see significant learning differences when comparing the intervention groups to the control in experiment one and two (Dahm & Rieger, 2019; Pauwels et al., 2015). This was despite the three day intervention and using the optimal imagery practice (Cherappurath et al., 2020; Chye et al., 2022; Holmes & Collins, 2001; Ladda et al., 2021; Romano-Smith et al., 2018; Schuster et al., 2011; Wakefield & Smith, 2009). Our understanding of the level of challenge involved in the intervention, can be inferred from the self-reported mental demand data. The high levels of mental demand imply the challenge may have been too high in the intervention task. Previous research using shorter imagery interventions in dart throwing, also show no performance changes, particularly in novices (Dahm & Rieger, 2019) suggesting that improving performance in darts through motor imagery is too challenging for novices. However, over a long enough time, dart performance

can improve from an AOMI intervention (Romano-Smith et al., 2018; 2019). The increase in task specific practice in experiment two explains the presence of learning effect, when compared to experiment one. Performance in experiment two was, however, no different from the control, suggesting that imagery has a limited ability to improve dart throwing performance in novices (Dahm & Rieger, 2019).

The task used in experiment three showed significant performance differences between the two physical groups over time but was more simple and less generalisable than the dart throwing task in experiment one and two. The lack of difference in the two imagery groups and the significant differences between the two physical groups, in experiment three, allows for direct comparison between the two modalities. Demonstrating the task was conducive to the contextual interference effect, but only in physical practice. This task also allows us to capture other performance measures, namely reaction time and accuracy. The slower reaction times in the imagery groups when compared to the physical groups also support functional divergence. The significant interaction in accuracy data for the two physical groups, and not in the two imagery groups also support functional divergence. However, the near significant difference between the two imagery groups at pre-test, calls into question the equivalence and comparability of the accuracy data. This reduces confidence in any findings or conclusions from the results of the accuracy data for the two imagery groups at any of the subsequent time points. The simplicity of the task also reduces the generalisability of the findings. However, experiment three does support the null findings from experiment one and two, where a more complex and generalisable task was used.

Limitations and Future Directions

In both experiment one and two, the heavier dart used at transfer, seemed to result in throwing performance like that of pre-test. In experiment one this made it difficult to see if

there were any transfer effects as performance was so consistent across the three time points. With the results of experiment two and the benefit of hindsight it is clear that transfer task did have a significant effect on performance. This is confirmed by the significant change from post-test to transfer in experiment two. While the same darts were used in this study as were used in Romano-Smith et al. (2018; 2019; 2022), they are lighter than those used in previous experiments (Nasu et al., 2014; Chan, 2019; Campos et al., 2019). The darts used in the present experiment are also considered very light in professional and amateur darts (Cornwall, 2025). Future studies could consider using heavier darts than the ones used here (e.g. 44g darts for transfer and 24g for other test phases). It is possible that the use of lighter darts for transfer tests could reduce the sensory feedback of the task. Specifically, the haptic feedback which is an important consideration in motor learning (Sigrist et al., 2013; Frikha et al., 2019).

It is possible that the familiarisation with the laboratory environment, and the experience of physically performing at pre-test, contributed to the improved performance in the control groups. It is also possible the interview videos in the control groups were perceived as more motivating and engaging than the intervention. The charismatic, motivational, and comedic nature of the interviews, may have created a more enjoyable experience, and a positive association with being in the lab. This may have increased positive affect and motivation which could help improve performance (Lemos et al., 2017; Kaefer & Chiviacowsky, 2021). A different control condition would mitigate these risks, for example a copy writing task where participants copy a text about darts by hand. In comparison to the control group interview videos, the AOMI intervention was more repetitive, requiring more effort and mental demand while being much less interesting and engaging. This may have created a negative association with the laboratory environment in some participants who underwent the intervention, negatively affecting performance (Lemos et al., 2017; Kaefer & Chiviacowsky, 2021). When participants in the intervention groups were asked how they felt during the imagery some

reported finding it “difficult” and feeling “fatigue” and “boredom”. Research using lengthy non-physical interventions must ensure the interventions are engaging and avoid the risks of mental fatigue (Jacquet et al., 2021). This is especially necessary when the practice is challenging (see page 53), repetitive, like the blocked, or constant practice groups in experiment one and two, respectively.

It is difficult to clearly observe the contextual interference effect without repeated acquisition performance measures to directly observe changes in learning over time (Shea & Morgan, 1979). This cannot be done easily in motor imagery as it requires repeated physical performance tests. This dramatically increases the amount of physical experience a motor imagery intervention group would experience. Failing to properly isolate the effect solely in motor imagery. It is also possible to directly assess the influence of error processing in the physical practice, by seeing if an error or the previous trial increased reaction time on the subsequent trial (Broadbent et al., 2017). This approach, again, cannot be done during imagery practice as it is impossible to show an error during an imagery trial in this study. Future neurological research may be able to demonstrate differences in cognitive processing during random imagery compared to blocked imagery practice, which may be suggestive or more error processing during high levels of contextual interference. The present findings of functional divergence in the present studies, when using an applied approach, provide a clear direction for future neurological research to try and understand the mechanisms of this divergence. Indirect performance measures, like the reaction time have, in recent years, successfully advanced the field of contextual interference (Broadbent et al., 2017), imagery (Glover & Baran, 2017; Glover et al., 2020; Martel & Glover, 2023), and the combination of the two (see experiment three). Future research using indirect performance measures, in this way, provides a more holistic view of the learning effects these motor learning principles have, which can unveil the mechanisms that cause these effects.

Summary of Conclusions

The lack of inter and intra task processing effects, in non-physical practice, suggest that these effects are not present in non-physical practice or that are weakened by the removal of physical practice. This provides direction for future research in optimally structuring and varying non-physical practice. Specifically, a direction that is focused on functional divergence rather than equivalence. The findings of this thesis reject the original hypothesis that favoured functional equivalence, predicting that contextual interference would affect performance similarly regardless of the modality of practice. The findings instead consistently point to a degree of functional divergence when applying these motor learning theories regarding practice structure and variability.

In experiment one and two our attempts to demonstrate the contextual interference effect in a darts throwing imagery intervention was unsuccessful. It is suggested that the task was too challenging (Dahm & Rieger, 2019; Guadagnoli & Lee, 2004; Pauwels et al., 2015), which is supported by the higher self-reported effort and mental demand in the intervention groups when compared to the control. The improvement in the control group in both experiments is explained by the physical practice during the pre-test and familiarisation, the increase in familiarity of the lab environment, and the motivating effect the control videos may have had. In experiment one the control group appeared to improve more than the random intervention group, also this did not produce a significant interaction. While this is unusual, it can be explained by the negative effect of the high information processing demands on motor learning (Hebert et al., 1996; Wulf & Shea, 2002; Guadagnoli & Lee, 2004). In experiment two there were clear learning effects, likely due to the threefold increase of task relevant practice. The apparent absence of transfer effects in experiment one is explained by the change of performance from post-test to transfer in experiment two. Our transfer task elicited

performance like that of pre-test in both experiments. Future directions for dart throwing research are discussed, particularly regarding the weight of the dart, eliciting transfer, as well as the use of darts in AOMI research. The use of darts as the task aimed to make the findings more generalisable than previous motor learning research in contextual interference and imagery. While this was unsuccessful, the findings of experiment three suggests that the contextual interference is not present in imagery. This supports the findings of Overdorf et al. (2004) and counters the findings of Gabriele et al. (1989)

The present findings support the increasing view that contextual interference is potentially weak and potentially a laboratory artifact (Al-Mustafa, 1989; Brady, 1998; Ammar et al., 2024) specifically in the context of AOMI interventions. More work is needed to understand various mediating variables that influence the contextual interference effect. An optimal challenge point framework approach to contextual interference is suggested for future researchers aiming to optimise practice structures, particularly in imagery. This will simultaneously test theories of contextual interference, and imagery. For example, the error processing explanation would suggest that contextual interference cannot be present in imagery as there is not sufficient error feedback. The lack of kinesthetic feedback in observational learning would also explain the absence of the contextual interference effect according to the error processing explanation. Some explanations of contextual interference, however, would translate to motor imagery (elaboration, action plan, blocked practice).

The findings, particularly in experiment three, support functional divergence over functional equivalence, in the context of practice structure. This supports the spectrum approach when discussing the overlap of neural activity in physical and imagined practice (Hurst & Boe, 2022). Of the many models that explain motor imagery the present findings align most with the motor cognitive model (Glover & Baran, 2017), which explains the

functional divergence and high effort and mental demand we observed. More work is still needed, however, to better understand this model (Owen et al., 2024). These findings also support an applied research approach when testing the functional equivalence hypothesis as neurological research shows support for functional equivalence (Hardwick et al., 2018). Applied research has shown mixed results, sometimes favouring functional divergence (Gabriele et al., 1989; Hall et al., 1995; Overdorf et al., 2004; Coelho et al., 2012; Debarnot et al., 2015; Fazeli et al., 2021). The same approach of applying theories of motor learning, like contextual interference, can be applied to observational learning where there have also been issues with consistency (Bird & Rikli, 1983; Lee & White, 1990; Blandin et al., 1994; Wright et al., 1997). Research also needs to be conducted to address the concerns raised about the explicit nature of imagery scripts in motor imagery research, which may have also affected our results. Our understanding of contextual interference in non-physical modalities of practice is incomplete; this means we cannot provide practitioners with specific advice on optimal practice structuring and variation in AOMI and interventions solely using motor imagery. Theoretically, the advantages of inter and intra-task processing are clear in non-physical practice. This research, however, highlights that theories of motor learning, developed using experiments with physical practice, cannot simply be applied to motor imagery interventions. There is a level of divergence between motor imagery and physical practice. It is demonstrated here using the diverging effects of practice structure and variation on motor learning in two different modalities.

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Appendix

Appendix One

In a stroop task (Stroop, 1935) participants are shown words of colours printed in ink that either matches (congruent) or contradicts (incongruent) the word's meaning. For example, an incongruent trial would have the word GREEN printed in red ink. A congruent trail would have the word GREEN printed in green ink. Typically, participants take longer and are more prone to errors during incongruent trials.

Appendix Two

2021 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	**YES**	**NO**
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** _____	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

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FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you currently have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

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6. **Do you have any Mental Health Problems or Learning Difficulties?** This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome

If the above condition(s) is/are present, answer questions 6a-6b If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

7. **Do you have a Respiratory Disease?** *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. **Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. **Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. **Do you have any other medical condition not listed above or do you have two or more medical conditions?**

If you have other medical conditions, answer questions 10a-10c If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: _____

_____

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

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If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact

www.eparmedx.com
Email: eparmedx@gmail.com

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Appendix Three

Edinburgh Handedness Inventory - Short Form

Please indicate your preferences in the use of hands in the following activities or objects:

	Always right	Usually right	Both equally	Usually left	Always left
Writing					
Throwing					
Toothbrush					
Spoon					

Scoring:

For each item: Always right = 100; Usually right = 50; Both equally = 0; Usually left = -50; Always left = -100

To calculate the Laterality Quotient add the scores for the four items in the scale and divide this by four:

Writing score	
Throwing score	
Toothbrush score	
Spoon score	
Total	
Total ÷ 4 (Laterality Quotient)	

Classification:	Laterality Quotient score:
Left handers	-100 to -61
Mixed handers	-60 to 60
Right handers	61 to 100

Appendix Four

The following is text is the instructions for the MIQ-R, followed by the rating scales, the eight items. At the end of Appendix Four there is the two item version of the MIQ-RS used in experiment three.

MIQ-R Instructions

This questionnaire concerns two ways of mentally performing movements which are used by some people more than others and are more applicable to some types of movements than others. The first is attempting to form a visual image or picture of a movement in your mind. The second is attempting to feel what performing a movement is like without actually doing the movement. You are requested to do both of these mental tasks for a variety of movements in this questionnaire and then rate how easy/difficult you found the tasks to be. The ratings that you give are not designed to assess the goodness or badness of the way you perform these mental tasks. They are attempts to discover the capacity individuals show for performing these tasks for different movements. There are no right or wrong ratings or some ratings that are better than others.

Each of the following statements describes a particular action or movement. Read each statement carefully and then actually perform the movement as described. Only perform the movement at a single time. Return to the starting position for the movement just as if you were going to perform the action a second time. Then depending on which of the following you are asked to do, either (1) form as clear and vivid visual image as possible of the movement just performed, or (2) attempt to feel yourself making the movement just performed without actually doing it.

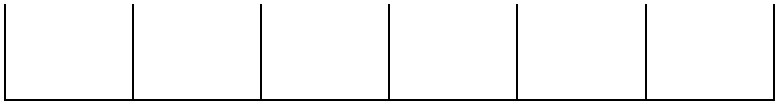
After you have completed the mental tasks required, rate the ease/difficulty with which you were able to do the task. Take you rating from the following scale. Be as accurate as

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

Ratings Scales.

Visual Imagery Scale.

7 6 5 4 3 2 1



Key:

7 = Very easy to see

6 = Easy to see

5 = Somewhat easy to see

4 = Neutral (not easy or hard)

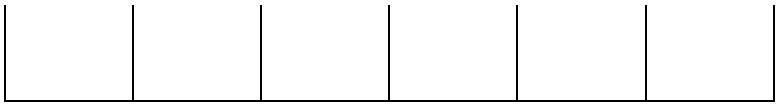
3 = Somewhat hard to see

2 = Hard to see

1 = Very hard to see

Kinaesthetic Imagery Scale.

7 6 5 4 3 2 1



Key:

7 = Very easy to feel

6 = Easy to feel

5 = Somewhat easy to feel

4 = Neutral (not easy or hard)

3 = Somewhat hard to feel

2 = Hard to feel

1 = Very hard to feel

1. Starting Position: Stand with your feet and legs together and your arms by your sides.

   Action: Raise your right knee as high as possible so that you are standing on your left leg with your right leg flexed (bent) at the knee. Now lower your right leg so that you are again standing on two feet. Perform these actions slowly.

   Mental Task: Assume the starting position. Attempt to feel yourself making the movement just performed without actually

doing it. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: _____

2. Starting Position: Stand with your feet slightly apart and your hands at your sides.

Action: Bend down low and then jump straight up in the air as high as possible with both arms extending above your head. Land with your feet apart and lower your arms to your sides.

Mental Task: Assume the starting position. Attempt to see yourself making the movement just performed with as clear and vivid a visual image as possible. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: _____

3. Starting Position: Extend the arm of your non-dominant hand straight out to your side so that it is parallel with the ground, palm down.

Action: Move your arm forward until it is directly in front of your body (still parallel to the ground). Keep your arm extended during the movement and make the movement slowly.

Mental Task: Assume the starting position. Attempt to feel yourself making the movement just performed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: _____

4. Starting Position: Stand with your feet slightly apart and your arms fully extended above your head.

Action: Slowly bend forward at the waist and try to touch your toes with your fingertips (or if possible, touch the floor

with your fingertips or hands). Now return to the starting position, standing erect with your arms extended above your head.

Mental Task: Assume the starting position. Attempt to see yourself making the movement just performed with as clear and vivid a visual image as possible. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: _____

5. Starting Position: Stand with your feet slightly apart and your hands at your sides.

Action: Bend down low and then jump straight up in the air as high as possible with both arms extended above your head. Land with your feet apart and lower your arms to your sides.

Mental Task: Assume the starting position. Attempt to feel yourself making the movement just performed without actually

doing it. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: _____

6. Starting Position: Stand with your feet and legs together and your arms by your sides.

Action: Raise your right knee as high as possible so that you are standing on your left leg with your right leg flexed (bent) at the knee. Now lower your right leg so that you are again standing on two feet. Perform these actions slowly.

Mental Task: Assume the starting position. Attempt to see yourself making the movement just performed with as clear and vivid a visual image as possible. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: _____

7. Starting Position: Stand with your feet slightly apart and your arms fully extended above your head.

Action: Slowly bend forward at the waist and try to touch your toes with your fingertips (or if possible, touch the floor with your fingertips or hands). Now return to the starting position, standing erect with your arms extended above your head.

Mental Task: Assume the starting position. Attempt to feel yourself making the movement just performed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: _____

8. Starting Position: Extend the arm of your non-dominant hand straight out to your side so that it is parallel with the ground, palm down.

Action:	Move your arm forward until it is directly in front of your body (still parallel to the ground). Keep your arm extended during the movement and make the movement slowly.
Mental Task:	Assume the starting position. Attempt to see yourself making the movement just performed with as clear and vivid a visual image as possible. Now rate the ease/difficulty with which you were able to do this mental task.
Rating:	_____

The following is the two item version from MIQ-RS (Gregg et al., 2010)

While sitting, put your hand in your lap. Pretend you see a drinking glass on a table directly in front of you. Action Reach forward, grasp the glass and lift it slightly off the table with your dominant hand. Now place it back on the table and return your hand to your lap. Mental task: Assume the starting position. Attempt to feel yourself making the movement just performed without actually doing it. Now rate the ease/difficulty of seeing and feeling the action you just imagined during the mental task.

- How easy was it for you to feel he imagined action.

- How easy was it for you to see the imagined action.

Appendix Five

MENTAL DEMAND

1	2	3	4	5	6	7	8	9	10
Low									High

TIME PRESSURE

1	2	3	4	5	6	7	8	9	10
Low									High

PERFORMANCE

1	2	3	4	5	6	7	8	9	10
good									poor

EFFORT

1	2	3	4	5	6	7	8	9	10
Low									High

FRUSTRATION LEVEL

1	2	3	4	5	6	7	8	9	10
Low									High

Appendix Six

The following data is five participants radial error in cm, for 10 throws at each of the five distances. This was done to make sure there was a difference in performance across the distances and that the difficulty was not too great or small.

Throws from 1.75m

Participant 1	6.4	4.8	11.7	13.9	12	6.3	10.6	8.3	3.6	5
Participant 2	1.5	4.6	1	2	3	1.8	1.8	2.7	3.2	4.4
Participant 3	8.3	10	4.6	3.9	12.1	0.3	6.4	6.6	13.5	8.6
Participant 4	2.6	1.9	11	13.1	1.4	3.8	2.3	5	10.9	15
Participant 5	7.2	9.6	13	13.1	10	11.7	5.6	5.5	7	3.5

Throws from 2.25m

Participant 1	9	14.4	26.6	19.4	17	9.9	5.8	18.8	18.9	16.1
Participant 2	0.3	0.7	8.7	7.9	7.2	3.5	2.9	5.1	7.8	5.4
Participant 3	10.9	4.2	7.9	12.6	9.1	14.3	15.1	1.3	8	11.1
Participant 4	3.5	7.4	9.9	9.4	3.6	8.5	7.8	7.8	5.5	7.4
Participant 5	5.9	3.8	8	20.9	4.1	2.7	4.1	3.4	13.9	10.4

Throws from 2.75m

Participant 1	10	4.4	19.3	28.2	27.2	9.2	8.6	4.2	8.2	7.8
Participant 2	3	3.9	9.5	8	7.8	0.8	3.7	10.6	3.9	0.8
Participant 3	6.5	4.9	10	10.5	10.1	6.9	29.4	7.8	16.1	14.3
Participant 4	12.6	4.9	5.3	6	8	3.3	3.6	3	8	6.8
Participant 5	6	17	10.6	8.3	14.7	5.1	2.3	5.8	7	12.6

Throws from 3.25

Participant 1	9	28.2	10.4	57.8	47.4	5.1	15	18.6	19.2	34.5
Participant 2	5.8	3.8	5	6.9	18.5	3.4	10.6	5.9	8.1	10.3
Participant 3	3.5	3.4	10.7	23.1	30.5	9.2	4	10.1	21.2	19.4
Participant 4	3.5	8.7	11.2	16.4	19.6	3	11.4	3.8	14.6	42.6
Participant 5	8.4	5.6	18.4	15	19.4	7.5	15.7	29	7.9	17.5

Throws from 3.75

Participant 1	12.5	10.8	35.5	35.2	87.6	15	18.6	35.8	60	83.8
Participant 2	9.7	6.1	12	13.2	22.2	2.6	5.1	12.1	13.4	16.1
Participant 3	18.3	13.1	13	21.4	33	4.7	8.4	20.2	16.2	17.3
Participant 4	1.7	8.9	9.6	28	40.8	0.4	12.5	16.6	24.4	30
Participant 5	11.2	18.5	13.4	34.5	28.2	7.5	7.5	28.8	29.5	29.8