A Nonlinear Pedagogy Approach to Mental Imagery for Skill Acquisition

Riki Steven Lindsay

Masters of Sport and Exercise (Auckland University of Technology)

College of Sport and Exercise Science

Institute for Health and Sport

This thesis is submitted in fulfilment of the requirements for admission to the degree of Doctor of Philosophy

Of

Victoria University

April 2022

Abstract

Previous research has found mental imagery (MI) to be an effective tool for enhancing performance and skill learning across a range of contexts from sport to music and dance. The beneficial effects of MI are often contextualised through the functional equivalence hypothesis, which proposes that MI and physical practice (PP) activate similar neural mechanisms. Therefore, MI research has often emphasised replicating critical aspects of PP in MI to maximise functional equivalence. Despite this, the MI research literature has rarely investigated the application of key skill acquisition principles commonly utilised in PP to MI. One approach to skill acquisition strongly influencing our current understanding of how to develop skill is nonlinear pedagogy (NLP). NLP draws on key principles of ecological dynamics, proposing that skill development is nonlinear, and emerges as the result of dynamic learner-environment interactions. Captured this way, implementation of NLP design principles such as constraint manipulation, representative design, information-movement coupling, and movement variability are proposed to facilitate the development of adaptable, individualised movement solutions. Given the emphasis on creating MI practice conditions that mimic PP, using a NLP informed approach in MI may help facilitate the effective development of adaptable, individualised skills that can deal with changing performance contexts.

The inclusion of non-sport related skills (e.g., finger tapping) and other psychological techniques in previous MI reviews made it difficult to ascertain how MI directly attributes to skill development in sport. Therefore, *Study 1* attempted to address this gap in the literature through a meta-analytic review of MI, focusing on sport-specific-motor skills. From the 36 studies reviewed, it was found that MI has a significant positive effect on the development of sport-specific-motor skills ($g = 0.476$). Further analysis revealed MI combined with PP to be

most effective (*g* = 0.579). Skill complexity, MI delivery type (i.e., MI combined or independent of PP), and performance measures were found to moderate the efficacy of MI interventions. A key finding that has helped to further understanding about the impact of MI interventions was the identification of skill complexity as moderating MI effectiveness. Results indicated that MI interventions practicing simple skills are significantly more effective relative to more demanding, complex movements. However, MI research investigating complex sport-specific-motor skills was lacking (5/58 analysed effect sizes). The need for further MI research on complex sport-specific-motor skills formed the rationale for selecting the power clean (PC) – a complex Olympic weightlifting skill – in *Study 4* of this thesis.

An ecological dynamics perspective of skill acquisition in PP was presented in *Study 2*, highlighting the importance of adaptability in skill development and the relevance of such a perspective to MI was discussed. The applicability of NLP design principles to MI interventions was presented alongside practical examples of how these principles could be integrated alongside existing MI guidelines. Key considerations included the incorporation of movement variability through task constraint manipulation, inclusion of critical aspects of performance environment (e.g., defensive pressure and other team members), and the use of movement outcome focused instructions. This study provided the theoretical foundation to further examine the application of NLP to MI interventions.

Based on the review of NLP research in Chapter 2, the influence of a NLP approach for skills that emphasise movement form for performance (e.g., Olympic weightlifting) was identified as an area for further investigation. Specifically, preliminary case study evidence was identified using a constraints-based approach (key methodological influence on NLP) to the PC (e.g., Verhoeff et al., 2018) which presented promising results for the use of ecological dynamics informed approaches (i.e., NLP). Therefore, the effectiveness of NLP relative to linear pedagogy (LP) practice was investigated in *Study 3.* This study involved beginner learners to engage in either NLP or LP practice of the PC over a 4-week intervention. Contrary to predictions, exploratory behaviour (i.e., presence of movement variability) was not significantly different between NLP and LP conditions. However, equivalent improvements between conditions in performance accuracy (i.e., F×D; forward barbell displacement) were observed. This suggested that pedagogical approach may not be a precondition for adopting a particular technique, and inherent individual and task constraints may require learners to self-organise behaviour to develop an individual task solution. Importantly, deviation from an instructed technical model does not appear to lead to less efficient performance. Such a finding has important implications for a practitioner's overall learning philosophy. Even in activities considered to rely upon a specific movement form (i.e., PC), practitioners might want to distinguish between techniques that are effective and movement patterns that look correct. That is, the effectiveness of the movement for producing specific outcomes may be more a more important consideration than reproducing the ideal 'aesthetic' or movement style (i.e., what the movement looks like).

Study 4 aimed to investigate the influence of a NLP approach to MI in relation to a LP practice approach to MI with beginners learning the PC. The same design was implemented as *Study 3* (i.e., practice sessions, instructions, reps, and 3-D motion capture and horizontal barbell displacement). Like *Study 3*, no significant differences were observed in exploratory behaviour and equivalent improvements in performance accuracy (R×D; rearward barbell displacement) for both conditions. Consistent with the *Study 3,* these findings suggest that establishing a movement pattern that achieves overall performance goals (e.g., reduced forward or backward barbell displacement) is more important than replicating a prescribed technique that looks correct. Considered with the results of *Study 3* these results suggest an equivalence in training-related improvements, highlighting that it may be possible to reproduce similar behavioural adaptations observed (to a lesser magnitude) when using NLP or LP approaches in MI.

In summary, the aim of this thesis was to enhance our understanding of applying a NLP approach to MI intervention design. Therefore, this thesis did not aim to investigate whether NLP was ‘better’, but rather to provide preliminary findings and hopefully stimulate further discussion about incorporating established skill acquisition principles from PP into MI. It is not definitive whether NLP provides further benefits to skill development over and above LP practice, however, the overall improvement in performance outcomes in *Studies 3* and *4* suggest it is a legitimate consideration for future interventions. The lack of significant differences between LP and NLP conditions suggests that despite being prescribed a specific movement form, learners may search for more individually appropriate techniques, and importantly, these deviations are not necessarily detrimental to overall performance.

Student Declaration

"I, Riki Steven Lindsay declare that the PhD thesis entitled *"A Nonlinear Pedagogy Approach to Mental Imagery for Skill Acquisition"* is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

"I have conducted my research in alignment with the Australian Code for Responsible Conduct of Research and Victoria University's Higher Degree by Research Policy and Procedures"

"All research procedures reported in the thesis were approved by the Victoria University Human Research Ethics Committee (HRE18-225 and HRE19-090)"

Signature: [redacted] **Date**: 8/04/2022

Riki Steven Lindsay

List of Publications

Peer Reviewed Journal Publications

Chapter 3: **Lindsay, R.,** Larkin, P., Kittel, A., Spittle, M. (2021). Mental imagery training programs for developing sport-specific motor skills: a systematic review and meta-analysis. *Physical Education and Sport Pedagogy*, https://doi.org/10.1080/17408989.2021.1991297

Chapter 4: **Lindsay, R.,** Chow, J-Y., Larkin, P., Spittle, M. (in review). Applying principles of nonlinear pedagogy to mental imagery interventions for skill acquisition. *Journal of Sport Psychology in Action.*

Chapter 5: **Lindsay, R.,** Komar, J., Chow, J-Y., Larkin, P., Spittle, M. (2022). Is prescription of specific movement form necessary for optimal development? A nonlinear pedagogy approach. *Research Quarterly for Exercise and Sport,* https://doi.org/10.1080/02701367.2022.2054925

Chapter 6: **Lindsay, R.,** Komar, J., Chow, J-Y., Larkin, P., Spittle, M. (in review). Characterising exploratory behaviour during mental imagery practice: a nonlinear pedagogy approach. *PLOS ONE.*

Conference Presentations

Lindsay, R., Spittle, M., & Larkin, P. (2019) The effect of mental imagery on skill performance in sport: A systematic review. Poster Presentation at Sports Medicine Australia, Sunshine Coast, Australia, 2019.

Acknowledgements

This thesis, though it is assigned to me, was built on countless hours of support and sacrifice from the many people involved in my life. I would like to extend my gratitude to these people in this section. Firstly, I would like to thank God, from whom all blessings flow. It is by His grace that I was able to start and complete this PhD.

To my supervisors, **Professor Michael Spittle** and **Dr. Paul Larkin**. You have both supported me immensely throughout this process, and your advice and encouragement has been invaluable to me.

Michael, your investment not only in my PhD but also in my career pursuits has not gone unnoticed. Throughout this process you have pushed me outside my comfort zone, developing skills and knowledge that will serve me well in the future. Without your support for my work, I would not be where I am today.

Paul, thank you for your constant input throughout this project, your advice and support in bringing fresh perspectives to different issues that arose was critical to the successful completion of this PhD. It has been privilege to work with you.

Associate Professor Jia Yi Chow, thank you for your continued input since beginning this journey. Your support for me in the early stages and throughout my PhD has been invaluable. Your expertise and support of my work has been vital for me. The development of ideas from our discussions consistently challenged my thinking, giving rise to new understanding, which was invaluable for me throughout my studies.

Assistant Professor John Komar, thank you for your constant assistance and support in trouble shooting the many challenges that arose during the data analysis and interpretation process. I really appreciate all the effort you have put into this project.

To all the participants that took part in my research, without your willingness and commitment, this PhD would not have been possible.

Thank you to the Biomechanics team at Victoria University, specifically, **Shannon Barnes, Azadeh Kian**, and **Rhett Stephens**. Your countless hours of support and assistance throughout the data collection and analysis of this thesis was huge, I cannot thank you all enough for your help.

I would like to specially thank my **Laneway church family**. I began this journey with you all and you have been right there with me through all the ups and downs, your support and encouragement were more than I could have ever asked for, thank you.

Thanks to my friends and colleagues, for sacrificing your time and expertise throughout this thesis: **Aden Kittel, Kechi Anyadike-Danes, Anthony Mak, Stefan and Abi Chenoweth.** You have all supported and encouraged me in your own individual ways, making this journey just a little bit easier.

Mum, Dad, Sarah, and **Sam.** Thank you for your continued support in whatever I choose to pursue. You all mean so much to me and I look forward to being able to celebrate together soon.

Wayne and **Clare.** You have been a real source of strength throughout this journey. I cannot thank you enough for supporting and encouraging me to pursue this PhD. I remember vividly receiving the email of my acceptance to VU with you both and now this journey has finally finished. I look forward to celebrating with you very soon.

Lastly, but most importantly, to my incredible wife **Gabrielle Lindsay**, thank you a million times. I cannot describe how much your support and encouragement has carried me through this PhD. On the many occasions that I wanted to give up you continued to encourage me to keep going that little bit more. This thesis is yours as much as it is mine.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction and overview of the thesis

1.1. Introduction

Mental imagery (MI) has frequently been identified as the most implemented technique in psychological skills training (Morris et al., 2005), proving beneficial across a range of contexts from sport (Simonsmeier et al., 2021) to surgical techniques (Goble et al., 2021). Furthermore, MI has been shown to be a versatile tool for improving several different outcomes including skill acquisition, controlling emotions (e.g., pre-game anxiety), implementing tactical strategies, mastering difficult situations, and goal achievement (Martin et al., 1999; Nordin & Cumming, 2008). The present thesis will focus on MI practice for skill acquisition. Although physical practice (PP) is viewed as the 'gold' standard for skill acquisition, substantial evidence supports the use of MI to enhance skill development and performance (Driskell et al., 1994; Lindsay et al., 2021; Simonsmeier et al., 2021). In the literature, MI is referred to by many terms, including *mental practice, motor imagery training,* or *imagery.* To avoid confusion, the term mental imagery (MI) will be used within this thesis. MI has been defined in a number of different ways. From the field of cognitive psychology, Richardson's (1969) classic definition has been utilised most frequently, proposing that MI comprises of "1) all those quasi-sensory and quasi-perceptual experiences of which 2) we are self-consciously aware and which 3) exist for us in the absence of those stimulus conditions that are known to produce their genuine sensory or perceptual counterparts, and which 4) may be expected to have different consequences from their sensory or perceptual counterparts" (pp. 2 -3). However, a key criticism of this definition is that it does not clearly separate MI from similar cognitive processes such as dreaming and daydreaming (Morris et al., 2005). Subsequently, the importance of volitional control of images in the mind of the individual has been highlighted as key to distinguishing MI from states such as dreaming (Morris et al., 2005). Further, when applying Richardson's (1969) definition with a sporting context, there is little acknowledgement of the dynamic images that are often an integral feature of sporting movements. To address these issues, Morris et al. (2005) draw from the definition of Richardson and other notable MI conceptualisations (e.g., Suinn, 1976; Vealey and Greenleaf, 1998; 2001) to present a complete definition of sport MI. It is proposed that MI "… in the context of sport, may be considered as the creation and re-creation of an experience generated from memorial information, involving quasi-perceptual, and quasi-affective characteristics, that is under the volitional control of the imager, and which may occur in the absence of the real stimulus antecedents normally associated with the actual experience" (Morris et al., 2005, p. 19). Such a definition contextualises MI within sport and acknowledges the volitional control of the individual, separating it from other cognitive activities (e.g., daydreaming), and the multi-sensory nature of MI. In addition, the experiential component of MI is emphasised, indicating that MI is not restricted only to static objects, but includes dynamic situations. Based on the holistic approach to defining MI, the present thesis with utilise the MI definition proposed by Morris et al. (2005). This is consistent with the literature, in which Morris's definition has become the most common approach to describing what MI is.

Anecdotally, elite performers have been reported to mentally recreate their performance to prepare for an event. For example, 14-time Olympic gold medallist Michael Phelps explains, "I can visualise how I want the perfect race to go. I can see the start, the strokes, the walls, the turns, the finish, the strategy, all of it" (Phelps, 2008, p. 8). Supplementing these claims, a considerable amount of experimental evidence supports MI training for skill development and performance across a range of disciplines such as music (Schuster et al., 2011), sport (Driskell et al., 1994; Simonsmeier et al., 2021), dance (Cumming & Williams, 2013), and surgery (Goble et al., 2021). There is considerable evidence for skill development of MI in sport and movement contexts, for example a review by Simonsmeier et al. (2021) found MI training to significantly improve skill learning and performance (*d* = 0.416). Despite evidence supporting the use of MI for performance and skill development in sport, several elements of MI interventions require further investigation. For example, previous meta-analytic reviews have frequently included studies that combine other psychological techniques such as self-talk and relaxation, making it difficult to ascertain the direct effects of MI (Toth et al., 2020). Further, reviews have often analysed the effects of MI with movement tasks, including studies not wholly relevant within a sporting context (e.g., drawing) (Driskell et al., 1994; Toth et al., 2020). Such reviews provide a solid foundation to support the efficacy of MI training for motor skill performance and development. However, further research should address these limitations to strengthen previous results and clarify the effects of MI on sport-specific skills.

The benefits of MI have often been interpreted through motor simulation theory (MST; (Jeannerod, 1994, 2006), suggesting that MI shares similar neurophysiological structures and mental representation systems as physically executed actions (Frank & Schack, 2017; Moran & O'Shea, 2019). Based on these similarities, MI and PP are considered to be functionally equivalent, described as the functional equivalence hypothesis (Jeannerod, 1994). The functional equivalence hypothesis provides a neurophysiological explanation of why MI can effectively enhance behavioural outcomes without a physical stimulus (McNeill et al., 2020). In support this hypothesis, neuroimaging research has demonstrated the overlap in brain areas between MI and PP (Burianová et al., 2013). For example, in a meta-analytic review by Hétu et al. (2013), MI was found to activate the brain's premotor and parietal cortices and frontoparietal regions, similar to activation patterns displayed during motor actions. The activation of these brain areas through MI training has been attributed to the beneficial impact of MI on performance and skill development (Moran & O'Shea, 2019).

Further, MI has been shown to activate motor-related brain areas and share similar training-related changes to neural structures as observed in PP (Debarnot et al., 2014). Leung et al. (2013) observed that MI training of a strength-based task (e.g., bicep curl) led to similar increases in corticospinal excitability as physical training.

The proposed functional equivalence between MI and PP has shaped current MI guidelines (Wakefield & Smith, 2012). For example, Holmes and Collins (2001) propose the PETTLEP model which emphasises the need for MI training to include the following key elements to replicate PP as closely as possible: P (Physical) – MI should include as much of the physical experience as possible, such as holding a relevant implement, E (Environment) – ideally MI should be performed in the same physical environment as actual performance, T (Task) – the content of MI should match the skill level of the individual, T (Timing) – the pace of MI practice should imitate the same movement speed as physical performance, L (Learning) – MI content should be adapted alongside the skill level of the individual, E (Emotion) – details regarding the emotions experienced during performance should be included in MI content, and P (Perspective) – to replicate physical performance, MI should aim to adopt a first person view of the movement being practiced (Wakefield & Smith, 2012). Similarly, Bio-informational theory focuses on producing similar physiological responses to those experienced in PP (Lang, 1979). Such frameworks have provided excellent guidelines for practitioners and have been shown to effectively design MI interventions for enhanced skill development and performance (Wakefield et al., 2013; Williams et al., 2013).

Presently, MI interventions often approach skill development as a linear process in which expertise is acquired from task repetition. The aim is to reduce variability through repetitive practice to create accurate and consistent actions (McNeill et al., 2020). Captured this way, practitioners impose a pre-determined movement model that is viewed as ‘optimal’ and learning is characterised as a process of transferring the ‘optimal’ movement to the learner until they can accurately replicate the prescribed model (Schmidt et al., 2018). This approach is highlighted in MI interventions by implementing instructions that expert performers, coaches or researchers often generate to provide a technical description of what is considered an ‘optimal’ technique (Cooley et al., 2013). In essence, this approach is prescriptive and repetitive, which places the coach/practitioner at the centre, with great importance on specialist technical knowledge. Essentially, a coaches’ role is to provide direct instruction to tell the learner exactly how to perform the movement, and the learners’ job is to comply with these instructions and repeat the movement over and over again until the desired movement pattern is achieved (Renshaw & Chow, 2019). The aim is to provide the learner with a criterion model of the movement they must try to attain through repetition. At the core of this approach is the idea that a ‘perfect’ movement exists (Button et al., 2020). Such an approach to skill acquisition is not in and of itself negative, however, alternative approaches have been proposed that deserve consideration, such as nonlinear pedagogy (NLP; Chow et al., 2019).

NLP is an approach to skill acquisition founded upon an ecological dynamics rationale and utilises a constraints-based methodology that views learning as a nonlinear process (Chow et al., 2019). According to a NLP perspective, skilled behaviour emerges from interactions between the individual and dynamic performance environment (Chow, 2013; Chow et al., 2019). In contrast to linear approaches to skill acquisition - where movement variability is viewed as noise that needs to be reduced through repetition and corrective feedback - NLP posits that movement variability plays an essential role in skill development (Button et al., 2020; Komar et al., 2019). Movement variability can be leveraged during learning to encourage learners to explore individualised movement patterns that more appropriately match individual constraints, capacities, and skills (Chow et al., 2019). NLP is a skill acquisition framework that provides principles on appropriately incorporating variability into practice to facilitate learners in developing individualised movement solutions to harness the capability to adapt movement patterns when performing within dynamic performance contexts (Button et al., 2020). The capacity to adapt is a crucial attribute of expert performers as it means movement patterns are highly flexible to satisfy environmental demands while also maintaining performance (Barris et al., 2014).

Given that PP and MI are proposed to share similar motor processes, the investigation of skill acquisition frameworks, such as NLP, is an important focus for future MI research. To date, few studies have examined the application of such frameworks to MI and how they may be considered alongside pre-existing guidelines (e.g., PETTLEP or bio-informational theory).

1.2. Aims of Thesis

1.2.1. General Aims

This thesis aimed to enhance our understanding of applying a NLP approach to MI intervention design. Therefore, this thesis did not aim to investigate whether NLP was a 'better' approach but rather to provide preliminary findings and hopefully stimulate further discussion about incorporating established skill acquisition principles from PP into MI. Further, this thesis aimed to provide preliminary recommendations on how NLP principles of practice design can be applied to MI training to facilitate the development of individualised, adaptable skilled behaviour.

1.2.2. Specific Aims

- Conduct a meta-analytic review of the MI literature to clarify the overall efficacy of MI interventions for improving sport-specific skills by excluding studies that implement MI for a single session, non-sport-related skills, and combined with other psychological techniques

- Discuss and provide practical recommendations for how principles of NLP can be incorporated into MI interventions for skill acquisition.
- Examine the impact of NLP practice (physical training, not MI) on exploratory behaviour and performance relative to traditional, prescriptive type practice for beginners learning a movement form-based skill, an Olympic weightlifting derivative known as the power clean (PC).
- Investigate the application of NLP practice design principles in MI training and its influence on exploratory behaviour and performance for beginners learning a movement form-based skill, the PC.

1.3. Chapter organisation

The topic of this thesis is introduced in **Chapter 1** to provide an overall rationale for the research conducted and outlining the general and specific aims and the organisation of chapters for the thesis.

The relevant theoretical underpinnings and benefits of MI for skill development in sport are reviewed in **Chapter 2**. The second portion of the review focuses on NLP and its ecological dynamics origins to establish the theoretical underpinnings of this thesis. Further, empirical research is reviewed to examine the implications of NLP for skill acquisition in sport.

The first of four studies that comprise this thesis is presented in **Chapter 3**. Several components of MI interventions have been identified from the general review of MI literature that require further examination to build upon previous meta-analytic reviews and clarify the efficacy of MI for sports-specific skills. Study 1 is a meta-analysis and systematic review of MI programs for sport-specific motor skills. To address the limitations of previous reviews, the specific aims of Study 1 are:

I. Clarify the overall effect of MI training programs by excluding studies from the analysis that implement MI for a single practice session, use a non-sport-related skill (e.g., drawing or finger tapping task), or combine MI with techniques such as self-talk or relaxation.

II. Identify variables that may moderate the effects of MI on the performance of sport-specific motor skills.

Chapter 3 (Lindsay et al., 2021) was published in *Physical Education and Sport Pedagogy* and is presented in pre-publication format.

Study 2 is presented in **Chapter 4***,* which focuses on how NLP principles of practice design could be incorporated into MI for skill acquisition. Little is known about how to apply NLP to MI. Therefore, the findings observed in Study 2 aim to provide a theoretical rationale for Study 3 and 4 that culminates in practical recommendations for how NLP can be applied to MI practice design alongside pre-existing guidelines (e.g., PETTLEP). The proposed recommendations outline each fundamental NLP principle and how it should be practically applied in MI. The aim is to provide an evidence-based approach to incorporating key elements of NLP into MI practice to facilitate the development of adaptable, individualised skills.

Several studies have successfully implemented NLP for skill acquisition (Brocken et al., 2020; Buszard et al., 2016; Lee et al., 2014). However, much of the research has been conducted on open, game-like motor skills. It could be argued that movement form is not necessarily the most critical factor for the performance of such skills (Spittle, 2021). The impact of NLP on learning self-paced skills that focus on movement form for performance is yet to be investigated. Therefore, prior to applying the recommendations of *Study 2* into an MI intervention, **Chapter 5** presents Study 3, which focuses on a NLP approach to developing a self-paced movement form-based skill, the PC. The aim of Study 3 is to establish a preliminary understanding of the influence of NLP practice relative to traditional linear type practice with beginners when learning a movement form-based skill (PC). Findings from Study 3 aim to further understanding about the application of NLP for movement-form based skills in beginners in PP forming the foundation for how it can be utilised for the design and delivery of MI interventions.

Chapter 6 presents Study 4, which explores the practical application of a NLP approach to MI relative to traditional, prescriptive practice with beginners learning the PC. Drawing on the practical recommendations of Study 2 and the empirical findings of Study 3, this final study of the thesis aims to observe the learning behaviours demonstrated when using a NLP approach to MI.

A general discussion and overall summary of Studies 1, 2, 3, and 4 are presented in **Chapter 7**. Practical applications and directions for future research that have emerged from this research are also discussed.

Chapter 2:Literature Review

2.1. Mental imagery

The ability to simulate actions and other physical sensations in the mind is one of the most incredible capacities of the human brain. This ability to retrieve, recall, and engage in mental simulation, has commonly been studied under the broad heading of mental imagery (MI). MI is one of the most well utilised and researched psychological tools in sport psychology (Morris et al., 2005). More formally, MI is defined as "…the creation and re-creation of an experience generated from memorial information, involving quasi-perceptual, and quasi-affective characteristics, that is under the volitional control of the imager, and which may occur in the absence of the real stimulus antecedents normally associated with the actual experience" (Morris et al., 2005, p. 19). In the literature, MI is referred to under many names, such as mental practice and motor imagery, and can often confuse terminology. The use of such as wide range of terms may be explained by the fact that imagery can be used for a range of purposes. The Applied Model of Imagery Use in Sport (AMIUS) – which will be discussed in more detail later in the chapter (pp. 24) - proposed that different types of imagery can be used to serve specific functions, including skill development (cognitive specific imagery), arousal management (motivation general-arousal imagery), and implementing tactical game strategies (cognitive general imagery), such as motivational, cognitive, and skill development (Nordin & Cumming, 2008). As previously stated in Chapter 1, this thesis applies Morris et al's. (2005) definition of MI, to avoid confusion in terms and the purpose of imagery. Such a definition generally outlines what MI is, but does not delineate the specific purpose of MI (e.g., motivation, skill development). Since the present thesis is focussed on skill development, Morris et al's (2005) definition will be utilised, but specifically refer to the mental rehearsal of movement for the purpose of skill development (Moran & O'Shea, 2019; Morris et al., 2005).

Elite athletes have been reported to utilise MI to prepare for competition intuitively. Murphy (1994) stated that from a sample of athletes at the US Olympic Training Centre, 90% reported using MI regularly. Further, anecdotal reports reveal similar insights. For example, Formula One driver Jensen Button explained that "I'll sit down on a Swiss ball with a steering wheel in my hands and close my eyes. I'll drive around the circuit, practising every gear shift", prior to each race (Jackson, 2014). Supplementing these informal accounts of MI use, numerous studies show MI is an effective adjunct to physical practice (PP) in a range of fields such as surgery, music, dance, and sport (Cumming & Williams, 2013; Goble et al., 2021; Simonsmeier et al., 2021). MI further demonstrates its effectiveness and versatility, proving to be a viable technique for improving skill performance in a range of individuals from healthy sporting populations (Lindsay et al., 2021) and clinical groups (Mateo et al., 2015). There is strong empirical evidence in a sporting context to support MI use for skill acquisition, with several studies showing reliable increases in performance outcomes from MI use (Frank et al., 2013; Kim et al., 2017; Pain et al., 2011; Smith et al., 2008). The following section will review current evidence for the benefits of MI for motor skill performance and development.

2.1.1. Benefits of mental imagery for skill acquisition in sport

Empirical research indicates that MI provides substantial benefit for performance and skill development in applied settings such as sport (Simonsmeier et al., 2021), dance (Schuster et al., 2011), and even medical settings like nursing (Wakefield et al., 2020) and surgical skills (Goble et al., 2021). Regarding MI in sport, the literature has consistently reported a moderate effect on performance and skill development (Driskell et al., 1994; Toth et al., 2020). For example, Toth et al. (2020) reported in a meta-analytic review that MI training had a moderate effect on cognitive and general motor skills ($d = 419$). Similarly, Simonsmeier et al. (2021) reported a moderate effect size of $d = 0.431$ for MI interventions in sport. These findings highlight how MI can be applied effectively to a diverse range of motor skills. However, a few limitations have been identified in previous reviews that could be addressed to add to our understanding of how MI can be effectively applied for skill development in sport. Firstly, previous reviews on MI have often included studies from different settings, such as finger tapping tasks, drawing, and tactical manoeuvres in basketball (Guillot et al., 2009). Secondly, calculation of overall effect sizes often included studies that combine other psychological techniques (e.g., relaxation or self-talk) with MI interventions. Subsequently, the directly attributable influence of MI for developing skills specific to a sporting context have been difficult to ascertain. Finally, the impact of MI on skills of differing complexities requires a more nuanced examination. Previous reviews have indeed investigated the effect of MI based on skill type; however, this has often included broad categories (e.g., motor and cognitive skills) that do not entirely account for the complexity of skills that may exist within each of these broad categories. Empirical research is consistent with this idea, indicating that the beneficial effects of MI may vary across skill classifications based on task complexity. For example, Coelho et al. (2007) found that MI practice of dynamic, reactive skills (tennis serve return) was less effective relative to using MI for self-paced, closed type skills (tennis serve).

Chapter 3 of the current thesis presents a meta-analytic review of MI training programs (Lindsay et al., 2021) that attempts to address the previously mentioned limitations and clarify the overall effect of MI interventions and factors that moderate the performance and development of sport-specific motor skills. Briefly, results were consistent with previous reviews, indicating that MI interventions have a significant and moderate effect on the performance and development of sport-specific motor skills (*g* = 0.476). Further, MI combined with PP had a significant and larger effect (*g* = 0.579) on performance outcomes than MI implemented on its own (*g* = 0.298). These findings align with previous intervention studies that suggest MI is most beneficial as an adjunct to PP. For example, Smith et al. (2008) revealed that golf bunker shot accuracy improved significantly more for MI combined with PP relative to MI alone. In addition, MI combined with PP improved performance to a greater degree than PP alone. These findings suggest that MI combined with PP could be a helpful technique in situations where physical training may be reduced (e.g., in-season sports training) or training may be not possible from injury (Pastora-Bernal et al., 2021). Consistent with this notion, Lebon et al. (2012) observed significant increases in EMG activation of the quadriceps when rehabilitating from an anterior cruciate ligament tear using MI training combined with physiotherapy relative to the control group. Again, these findings suggest MI to be a highly versatile tool. A more in-depth analysis of the efficacy of MI training programs for sport-specific skills is presented in Chapter 3 of the current thesis by way of meta-analysis and systematic review.

2.1.2. Early psychophysiological explanations for mental imagery

The psychoneuromuscular theory (Jacobson, 1932) originated mainly from the ideomotor principle, suggesting that weak muscular activity occurs during mental simulation of movement imagery of physical action (Moran et al., 2012). Captured this way, there is an overlap between muscular activation elicited during imagined and actual movement that is suggested to be attributable to the effectiveness of MI practice. Findings from psychophysiological research have suggested that feedback generated from lower magnitude muscle activity, like that of physical movement, is responsible for the effectiveness of MI practice (Guillot et al., 2007; Jacobson, 1932; Lebon et al., 2010). However, further studies have exhibited mixed results, supporting the psychoneuromuscular hypothesis. For example, (Guillot et al., 2007) found similar muscular activity between MI and physical training, showing that electromyography (EMG) activity – nine upper arm muscles - during a bicep curl mirrored that of the physical training. Furthermore, these results indicated that the simulated movements during MI were more than just activating similar muscles, but graded muscular responses were also reported (i.e., when participants imagined lifting a heavier weight there was an increase in EMG activity). This latter finding is critical, as it partially addresses one common issue in MI research, known as the validation problem. The validation problem is whether MI is successfully recreating actual physical experience, or put another way, whether MI and physical movement are functionally equivalent (Wakefield et al., 2013). Support for the psychoneuromuscular model, however, is inconsistent. For example, the results from (Guillot et al., 2007) confirmed this hypothesis, whereas Gentili et al. (2006) found conflicting results, with participants not recording any significant muscular activity during MI. One possible explanation for these inconsistent findings could be that participants were not adequately imagining the specified task the entire time or at all. One method implemented to mitigate this issue is the use of a MI script, described as a detailed explanation of the imagined movement to guide individuals through the task. The use of an MI script in the study conducted by Guillot et al. (2007) could explain the conflicting results compared to Gentili et al. (2006). Furthermore, Guillot et al. (2007) implemented a manipulation check following MI, asking participants to describe what was being imagined. These findings highlight the importance of providing a detailed description of the specified task to be imagined ensuring (at least attempt to) that the individual is using MI and contains images of the specific task being practiced.

2.1.3. Cognitive-based models of mental imagery

Several explanations have been proposed by cognitive psychologists for the MI process, including Dual-Code theory, Bio-informational theory, and Triple-Code theory.

These theories were not originally developed for sport-based contexts but were later adapted and applied in sport settings. For example, bio-informational theory (Lang, 1979) and triple code theory (Ahsen, 1984), have been applied successfully in sport contexts due to the consideration of both visual and kinaesthetic features of the imagined skill or task. Due to the relevance of these theories to skill development in sport, the following section will primarily focus of bio-informational and triple code theories of MI.

From a cognitive psychology perspective, simulation states like MI are often contextualised through an information-processing paradigm of the human mind (Goldstein, 2014). Such a paradigm draws comparisons between the brain and its cognitive processes (e.g., MI) to that of a computer, in which the brain perceives sensory input from the physical environment, this information is stored and processed, producing a specific behavioural output (Goldstein, 2014; Munzert et al., 2009). Crucial to the cognitive perspective of MI is understanding how learners store and retrieve relevant skill or task information for producing MI. Providing insight to this process Paivio (1975) proposed Dual-code theory, which suggests that mental images are stored as both verbal and visual memory codes that are later retrieved to produce MI. According to Paivio (1975), the effectiveness of MI is attributed to the notion that encoded mental images represent two independent memory codes (visual or word codes) that facilitate retrieval of relevant memories. For example, if cricket bat is encoded in memory as both a word and image, both means can be used to access the memory of the cricket bat. A limitation of dual code theory is that it may be confined to explaining association-based learning. Further, from a dual-coding perspective the role of physiological sensations in MI is largely ignored, leading to a heavy emphasis on visual MI and potentially reducing its applicability in sport-based contexts.

Another cognitive-based theory of early MI can be found in bio-informational theory (Lang, 1979). Bio-informational theory is a cognitive hypothesis that differs from other cognitive theories where the psychophysiology of imagery is considered (Lang, 1979). Lang developed this theory to investigate phobias and anxiety disorders by incorporating psychophysiology and information-processing models. Like psychoneuromuscular theory, bio-informational theory leverages the psychophysiological connection between MI and physical movement. Proposing that for imagery to be most effective, image content should contain information that enhances the psychophysiological connection, eliciting imagery that is representative of the specified task and meaningful to the individual not just in the visual sense but also induces physiological responses (Lang, 1979).

Utilising an information-processing model, at the centre of bio-informational theory is the interaction of three units of information, termed propositions: stimulus propositions – referring to information about the environment a movement is executed (e.g., “feeling” the hard court under foot before hitting a forehand in tennis), response propositions – describe a learner's actual response to a particular situation (e.g., tensing my forearms when hitting a forward defensive shot in cricket), and meaning propositions – relating to the level of importance the learner attaches to the skill being practiced (e.g., feeling calm when taking a penalty kick because you can hear your coach encouraging you). Lang proposed that these propositions represent units of information that have been extracted and interpreted from perceptual experiences and are stored in long term memory (LTM), forming a roadmap that needs to be activated to generate MI. Captured this way, MI is a network of propositions that are uniquely arranged in the brain that can unlock mental representations of a skill stored in LTM. Subsequently, this theory presents a cause-and-effect model for MI, indicating that when the appropriate propositional network is accessed, this will result in a specific physiological response known as “efferent leakage”. Though proposed as a theory, bio-informational theory has frequently been utilised as more of an applied model for the design of MI instructions, known as scripts, in sport contexts (Williams et al., 2013). Therefore, bio-informational theory will be discussed in more detail in the scripts and applied models section (pp. 20)

Finally, a cognitive based MI model aiming to explain how MI affects behaviour is proposed in triple-code theory (Ahsen, 1984). According to triple-code theory, three components are key to explaining the MI-performance relationship: (1) the image – conceptualised as the internal representation of a given skill or task comprising of all the critical aspects making up physical sensation; (2) psychophysiological response – like bio-informational theory, triple-code theory proposes that MI elicits a physiological response; and (3) image meaning – each learner will bring unique past experiences and capacities that mean the MI experience will be completely different between learners (Morris et al., 2005; Nordin & Cumming, 2008). Research by Kornspan et al. (2004) supports triple code-theory, with results showing that learners' pre-existing beliefs and experiences were key factors in shaping meaningful MI practice experiences, contributing to beneficial performance outcomes. However, the application of triple-code theory in sport is fairly limited with further research necessary to provide a clearer indication of this theory in relation to skill development and performance in sport.

The cognitive-based theories discussed in this section are important in understanding how MI may facilitate improved skill development in sport, however, with the exception of bio-informational theory, these theories have not been well researched in sporting contexts. Other potential explanations for MI have been proposed from a neurophysiological perspective, indicating that the beneficial effects of MI are based on shared neural mechanisms with PP referred to as functional equivalence. The following section will review and discuss the research regarding the neurophysiological explanation of MI.

2.1.4. Neurophysiological mechanisms underlying mental imagery

Motor simulation theory (MST; see Implementation of mental imagery: scripts and applied models, pp. 20) attempts to explain the underlying neurophysiological mechanisms involved in MI (Jeannerod, 1994, 2006). According to MST, MI involves an internal simulation of physical action (Moran & O'Shea, 2020) that activates similar neurophysiological processes and mental representation systems as those utilised during physical action (Frank & Schack, 2017; Jeannerod, 2006). Therefore, based on shared neural and motor processes, MI and action are proposed to be functionally equivalent, referred to as the functional equivalence hypothesis (Moran & O'Shea, 2020).

The functional equivalence hypothesis finds support in several neuroimaging and behavioural studies. Hétu et al. (2013) showed that some motor-related regions of the brain utilised during movement execution were activated during MI, such as the premotor cortex, parietal cortex, and frontoparietal regions (basal ganglia, putamen, and pallidum). It was noted that the basal ganglia, putamen, and pallidum seem to be of particular importance for MI based on the involvement of these areas in motor program selection in motor execution (Hétu et al., 2013). In partial support of these findings, Hardwick et al. (2018) identified consistently shared activation of premotor and parietal networks. However, following conjunction and volume comparison analysis, the shared brain networks between MI and physical action was reduced by half, indicating that MI may share fewer brain regions than identified in previous research (Hétu et al., 2013).

Further studies show that MI can also induce changes in function plasticity similar to physical action (Debarnot et al., 2014). For example, Lafleur et al. (2002) reported functional organisation in the orbito cortices, the rostral portion of the anterior cingulate, and striatum following learning of a sequential foot movement task. In a follow-up study, similar results were observed following MI practice of the same task, with increased cerebral blood flow in the right medial orbitofrontal cortex reported (Jackson et al., 2003). Therefore, it is proposed that the repeated activation of motor-related brain regions plays a role in improved performance and skill learning from MI practice (Moran & O'Shea, 2020).

Although there is strong evidence to indicate neural similarities between MI and motor action, this raises the question of whether these shared mechanisms facilitate the development and acquisition of motor skills. Empirical research indicates that although MI may produce motor commands that are not large enough to enact motor execution, MI may be capable of eliciting training-related adaptations to neural structures utilised in action execution (Grosprêtre et al., 2018; Grosprêtre et al., 2019; Leung et al., 2013). For example, Leung et al. (2013) explored the effects of interventions involving either MI or physical training of a bicep curl on corticospinal excitability following 3-weeks of training. They found that both conditions significantly increased strength (one repetition maximum), with the physical training condition showing a more significant increase than MI training. However, both conditions significantly increased corticospinal excitability to the same degree. These findings indicate that MI and physical action activate similar brain regions and may share training related adaptations to neural structures (Debarnot et al., 2014). A limitation of these findings is that they are largely restricted to simple movement tasks (e.g., foot movement or bicep curl tasks) with the neurophysiological mechanisms involved in more complex skills being relatively unknown. This represents a significant challenge for the neurophysiological research paradigm as much of the equipment used (e.g., functional magnetic resonance imaging) to measure brain and central neural structure activity means that learners have severely restricted movement, limiting the type of skills that can be investigated.

Based on these findings, it is evident that MI could be an effective tool for activating motor-related brain regions and eliciting training-related adaptations involved in skill acquisition. The notion of functional equivalence goes further than considering shared neural and physiological similarities but suggests that if MI and physical action share similar processes, MI interventions should aim to incorporate critical aspects of physical action into MI sessions.

2.1.5. Implementation of mental imagery: scripts and applied models

2.1.5.1. Mental imagery scripts

MI interventions typically provide instructions to learners on what to imagine during practice using what is referred to as a *script*, which provides the imagery content and when learning or practicing a skill guides the learner through the movement by providing specific details of how the action should be performed (Moran & O'Shea, 2019). Established frameworks such as bio-informational theory and PETTLEP (see 2.1.4.3 and 2.1.4.4 for more detail) are often utilised to inform script design. Overall, MI scripts are often designed around a specific technical model. In a systematic review of guided MI interventions, Cooley et al. (2013) found that scripts were primarily informed by four key sources of information: physical task, research, experience, and participants. Regarding physical task, the source of details for the imagined skill or situation was primarily provided by researchers, expert coaches, or elite athletes. This suggests that the basis for MI instructions tend to be optimal technical models as detailed by expert performers. The inclusion of expert descriptions of the imagined task or skill appears to be an effective performance and skill development approach. For example, Ramsey et al. (2010) constructed MI scripts on a penalty kick in soccer based on researcher and expert player descriptions. Results showed that the MI interventions' performance scores were significantly higher than the stretching-only control condition. Though the use of expert skill descriptions has been shown to produce beneficial performance outcomes, skill acquisition research has recently highlighted the importance of behavioural flexibility or adaptability in skilled performers (Ranganathan et al., 2020; Renshaw et al., 2019). A critical capacity of elite-level performers is the ability to adapt to dynamic environmental conditions while maintaining performance (Renshaw et al., 2019). Consistent with this notion, research in elite level weightlifters showed that athletes utilised various techniques - some considered suboptimal - to successfully achieve performance outcomes (Akkuş, 2012). These findings suggest that the focus of skill development may not necessarily be the acquisition of a specific movement form that is aesthetically correct based on an expert model. This has important practical implications for the design of MI scripts, as it highlights the need to distinguish between movement techniques that look correct and movement patterns that are effective in achieving successful performance, as they are often not synonymous. This issue is discussed in more depth in Chapter 4, where an alternative approach to skill acquisition is presented and how it may be applied to MI interventions.

2.1.5.2. Motor Simulation Theory (MST)

MST proposes that MI and physical action are functionally equivalent, whereby MI shares similar neural pathways as the planning and execution processes of action (Jeannerod, 1994) and draws on a shared mental representation system (Frank & Schack, 2017; Moran & O'Shea, 2020). MST proposes that motor skills are executed as the result of two main stages of processing:1) a planning stage where a mental representation of the movement is present, comprising of critical details relating to action execution (e.g., relevant motor program, movement plan, and potential movement outcomes), and 2) actual movement execution. The initial covert stage of motor execution MI is proposed to be an integral process in the planning stages of motor execution. Therefore, MI operates by accessing the same motor systems and mechanisms that drive motor execution. However, instead of executing the actual movement, the motor system enters a simulation state, inhibiting actual movement

(Jeannerod, 2004). Regarding skill acquisition, MST proposes that skill development and improved performance are attained through repeated simulated action of the shared neural and mental representation systems utilised during physical action (Moran & O'Shea, 2020).

2.1.5.3. Bio informational theory

As mentioned earlier, bio-information theory builds on the predictions of psychoneuromuscular theory by considering MI content and how it can predict and influence physiological responses. Hecker and Kaczor (1988) provided early support for bio-informational theory in a sporting context observing that MI containing only response propositions led to more significant heart rate increases than stimulus-only MI. Consistent with these findings, Bakker et al. (1996) also found that response laden scripts produced significantly higher muscular responses on a bicep curl task than stimulus-only scripts. Overall, the consensus is that MI containing response propositions will elicit greater effects. Later research using a bio-informational approach has highlighted the importance of implementing an individualised approach to MI, considering personal meaning attributed to specific skills (Moran et al., 2012). Lang (1979) proposed that if MI content is more meaningful to the individual, there will be a greater match between propositional information in LTM, the imagined situation, and higher physiological responses. Subsequently, as the context of response and meaning propositions coded in LTM differs between individuals, this requires MI content to contain individualised response propositions to elicit effective MI (Cuthbert et al., 1991). In support of using individualised content, Wilson et al. (2010) found that participant-generated scripts (i.e., meaningful response propositions) produced more significant physiological responses relative to researcher dictated MI scripts. Wilson et al. (2010) noted that participant-generated scripts were more meaningful and enabled complete access to individual movement representations in LTM, therefore, eliciting a stronger muscular response. A limitation of early bio-informational research was that it did not adequately consider how MI may need to be adjusted to account for more or less complex skills (Morris et al., 2005). Nordin and Cumming (2005) found that professional dancers intuitively build up images when engaging in MI, starting with a simple image slowly adding more detail as MI ability improves. This observation led to recent research using stimulus and response propositions in layers to gradually build up images from simple to complex in stages, known as layered stimulus response training (LSRT; Cumming et al., 2017). For example, Williams et al. (2013) found that participants practicing a golf putting task under LSRT showed significant improvements in MI ability and putting performance compared with other MI types (e.g., motor and visual imagery). Overall, research utilising bio-informational theory has highlighted the importance of designing MI practice that presents representative detail of a skill to allow for more complete access of movement information held in memory, leading to stronger physiological responses. In addition, MI scripts should aim to implement propositional information that is meaningful to the individual to optimise the efficacy of MI practice.

2.1.5.4. PETTLEP

A more recent MI model is PETTLEP (Holmes & Collins, 2001; Wakefield & Smith, 2012). The purpose of the model was to present an applied tool for practitioners that improves the quality of MI and its influence on performance, recommending that seven key elements should be considered when designing MI interventions (Carson & Collins, 2017). Of the seven PETTLEP elements, ‘P’ refers to physical, meaning how the individual physically responds within a specific situation. ‘E’ stands for environment – the environment where the physical skill is executed should match where MI is practiced. ‘T’ stands for task. ‘T’ stands for timing – the timing of the actual task and MI should aim to be similar. ‘L’ refers to learning – imagery content (i.e., scripts) should be tailored to the individual's skill level and updated in line with skill development. ‘E’ relates to emotion – emotions experienced during performance should be incorporated into MI practice. Finally, ‘P’ refers to perspective – imagery should attempt to recreate physical performance, with MI recommended from an internal or first-person perspective (Wakefield & Smith, 2012).

A considerable number of studies attest to the beneficial impact of PETTLEP for the development of sport-based skills (Smith & Holmes, 2004; Smith et al., 2001; Smith et al., 2007; Smith et al., 2008; Wakefield & Smith, 2009), strength tasks (Wright & Smith, 2009), and even nursing skills (Wakefield et al., 2020). For example, Smith et al. (2007) found that PETTLEP-based MI improved field hockey penalty flicks significantly more than MI with generic content. Further, combining PETTLEP with PP appears to additively influence performance, producing similar performance outcomes as PP alone. For example, Smith et al. (2008) compared the effect of three interventions involving (i) MI + PP, (ii) MI alone, and (iii) PP alone for a golf bunker shot with international and county level participants. Following a 6-week intervention period, all three conditions improved shot accuracy. However, the MI + PP intervention improved significantly relative to the MI alone and PP alone groups. These findings suggest that PETTLEP intervention can effectively enhance the performance and development of sport-based skills.

The benefits of PETTLEP are primarily attributed to the focus on designing MI interventions that replicate as many elements of the physical movement as possible, which forms the central tenant of the model. Subsequently, PETTLEP was initially proposed as a functional equivalence model (Holmes & Collins, 2001). However, recently the application of the term functional equivalence has been reviewed. In a review of PETTLEP, Wakefield et al. (2013) explain that functional equivalence may not appropriately capture the original intentions of the model. Instead, it is proposed that the beneficial effects of PETTLEP should be attributed to *behavioural matching*. Although research supports the functional equivalence hypothesis (Debarnot et al., 2014; Hétu et al., 2013), there is difficulty in quantifying whether

PETTLEP can produce more or less functional equivalence then relating this to performance (Wakefield et al., 2013). Wakefield et al. (2013) explain, “there is as yet no agreed independent measure of the ‘amount’ of functional equivalence that exists between movement imagery and motor production/motor behaviour” (p. 116). Subsequently, proponents of PETTLEP have recommended using the term *behavioural matching,* referring to similarities at an experiential level rather than shared neurophysiological mechanisms. Taken this way, the incorporation of PETTLEP elements enhances the experiential/behavioural compatibility between physical movement and MI as opposed to the activation of equivalent psychological processes (Wakefield et al., 2013).

2.1.5.5. Applied Model of Imagery Use In Sport (AMIUS)

Drawing on the work of Paivio (1985), which examined the cognitive and motivational functions of MI for performance, Martin et al. (1999) developed the Applied Model of Imagery Use in Sport (AMIUS). AMIUS divides MI into five types based on the purpose it serves the learner; (1) motivational specific (MS) – refers to MI of a specific goal or behaviour that is directed to the achievement of a specific goal (e.g., hitting a particular section of the dartboard); (2) Motivational General-Mastery (MGM) – MI that focuses on how the learner navigates stressful situations (e.g., having confidence when approaching a lift in weightlifting); (3) Motivational General-Arousal (MG-A) – focuses on arousal management (e.g., reducing anxiety while approaching a jump in diving); (4) Cognitive-Specific (CS) – MI directed toward skill development (e.g., putting in golf), and (5) Cognitive General (CG) – focuses explicitly on strategies implemented in competition (e.g., tactical manoeuvres during a basketball game). Central to the AMIUS model is the idea that MI practice can be designed to produce a specific purpose or function (Martin et al., 1999). However, research indicates that these proposed MI types do not necessarily ensure a specific performance outcome (Nordin & Cumming, 2008). For example, Nordin and Cumming

(2008) observed that athletes would engage in multiple MI types to serve a particular function. Results showed that athletes perceived MS, MG-M, and MG-A types to be equivalent for improving motivation. In addition, the perception of the purpose of each MI type varied across individuals. These findings suggest that theoretical MI functions may not be constrained to producing specific outcomes, with individual perception playing an important role in the purpose MI serves.

2.1.5.6. Revised Applied Model of Deliberate Imagery Use

The Revised Applied Model of Deliberate Imagery Use (RAMDIU) comprises nine components that relate to the application of MI in sport, dance, exercise, and rehabilitation. RAMDIU aims to provide guidelines for practitioners to appropriately align imagery type and specific situations (Cumming & Williams, 2013). Figure 2.1 displays key components of the RAMDIU model; *where, how, who, why, what, meaning, imagery ability,* and *outcome.* According to the model, an essential task for practitioners is to understand that individual and situational factors can impact the overall outcome of training and impact the overall efficacy of MI (Quinton, Cumming, Allsop, et al., 2018).

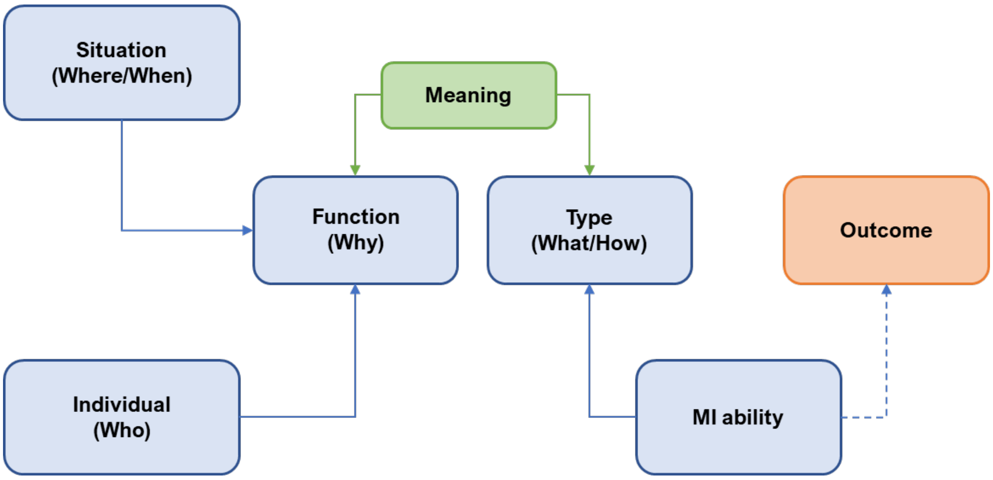


Figure 2.1. Revised applied model of deliberate imagery use adapted from (Quinton, Cumming, Allsop, et al., 2018).

Recent studies do indicate support for some of the models' predictions (Quinton, Cumming, Allsop, et al., 2018; Quinton, Cumming, & Williams, 2018). Quinton, Cumming, Allsop, et al. (2018) explored whether MI content and individual characteristics (skill level: novice and experts) influences measures of performance, anxiety, and confidence in golfers. They found that experts perceived MI practice missing a target significantly unhelpful relative to novices regardless of the missing distance (20cm or 40cm). In addition, participants who used MI that focused on missing by 40cm, performance significantly declined, and cognitive and somatic anxiety measures were higher relative to missing the target by 20cm. These results indicate that individual factors such as skill level may impact perceived MI meaning and deserve consideration when developing MI interventions.

2.1.6. Conclusion

The critical message that has consistently been emphasised throughout the literature is that practitioners must carefully consider and incorporate critical aspects of PP for MI to be most effective. Existing MI guidelines facilitate intervention design by providing recommendations on what details should be included. These details include things like the physical properties of the environment (PETTLEP), content relating to physiological responses (bio-informational theory), the perceived outcome of practice (AMIUS), and individual and situational factors (RAMDIU). Despite recognition that MI interventions need to replicate PP, little research has examined skill acquisition approaches implemented in PP and how they could potentially inform MI intervention design. The following sections aim to review approaches to skill acquisition in sport, proving a theoretical foundation for how key principles from skill acquisition may be applied to MI interventions.

2.2. Skill acquisition in sport

2.2.1. Linear approach to skill acquisition and implications

Traditionally, cognitive-based models have commonly been proposed to describe motor learning and control, suggesting that motor actions result from a hierarchical process, whereby movement commands are formulated and sent from higher control centres (i.e., brain) to lower levels of control (i.e., muscles) (Magill & Anderson, 2021 Schmidt & Lee, 2019). Central to cognitive based models is the notion that movements are stored in memory as central commands that are sent out to execute a given skill, forming the basis of the motor program theory of motor learning and control (Magill & Anderson, 2021). According to motor program theory, skills are stored in long term memory as movement plans that comprise of all the necessary information for the muscles to execute a given skill (Schmidt & Lee, 2019). The idea that skills are stored as motor programs is key to understanding traditional, linear type approaches to skill development. Drawing on motor program theory, traditional approaches to the development of skilled behaviour have been described as a process of acquiring and developing an internal model (i.e., motor program) of what a specific skill should look like based on external instruction (i.e., coach), leading to changes in internal states that underpin permanent changes in the movement abilities of the learner (Araujo & Davids, 2011; Magill & Anderson, 2021; Schmidt et al., 2018). Defined this way , practice is typically designed to include; (1) skill demonstration, representing the 'ideal' technique; (2) delivery of instructions that explicitly outline correct skill execution; (3) repetitive practice, typically in environments isolated from performance context; (4) practitioner feedback by way of error correction; (5) repetition of skill following feedback; (6) performing a skill under competitive conditions (Lee et al., 2014; Magill & Anderson, 2021; Schmidt & Lee, 2019) . From this perspective, skill development focuses on replicating a specific technique presented via prescriptive and repetitive practice, aimed at correcting movement errors, and directing learners toward developing a predetermined technical model (Renshaw & Chow, 2019; Schmidt & Lee, 2019; Schmidt et al., 2018).

Lee et al. (2014) have attempted to draw together traditional motor learning perspectives under the term *linear pedagogy,* described as involving "instructions that are prescriptive, repetitive, and drill-like with a strong focus on 'criterion model' technique…" (p. 2). The focus on repetitive practice to attain a criterion model is consistent with motor program theory, which emphasises the role of a central motor program, with practice therefore being structured in a way that aims to strengthen motor programs that can be accessed and applied by learners when needed (Magill & Anderson, 2021; Schmidt & Lee, 2019; Schmidt, 1975) Previous research shows that a linear pedagogy approach can effectively develop complex motor skills in novice level learners (Haug et al., 2015). Rucci and Tomporowski (2010) found that explicit coach driven feedback (i.e., error correction-based feedback) significantly improved technical performance of the hang power clean (weightlifting skill) relative to implicit self-directed video feedback. Advantages of such an approach include opportunities for repetitious practice of skills that allow the learner to progress faster and more smoothly through the development process, which may provide a sense of subjective mastery of the skill (Abraham & Collins, 2011; Baker & Young, 2014).

Contemporary skill acquisition approaches have challenged the role of explicit, coach-led instruction as the most effective approach for developing skills. For example, Lee et al. (2014) found that under a linear pedagogy approach, learners successfully acquired a 'correct' tennis serving shot, measured against a criterion performance model. In addition, learners who practiced under a nonlinear pedagogy (NLP) (i.e., exploratory type learning approach, including the manipulation of task constraints) demonstrated more significant movement variability over the 4-week intervention but improved performance accuracy to the same level as the linear pedagogy condition. These findings challenge the assumption that skilled behaviour is more effectively developed through isolated, low variability practice environments. Instead, alternative approaches to skill acquisition (i.e., NLP) are equally viable for successful skill development and may more appropriately accommodate individual movement differences and prepare learners for dynamic performance contexts (Button et al., 2020; Chow, 2013). Research indicates that repetitive, isolated forms of practice in low variability environments can effectively improve skill performance (Haug et al., 2015; Rucci & Tomporowski, 2010; Silverman et al., 1992). This, however, may come at the expense of reduced transfer to competitive performance environments (Pinder et al., 2011; Renshaw & Chow, 2019). Practice in high variance environments has been shown to improve transfer to competitive performance contexts (Douvis, 2005; Memmert, 2006; Oppici et al., 2018a, 2018b; Seifert et al., 2015). When designing practice environments to develop skills and improve performance, simulating critical aspects of the performance context is a key consideration for practitioners (Button et al., 2020). Subsequently, an essential task for practitioners is to understand how to incorporate critical environmental and task information encountered in specific performance contexts, including variability, to create practice environments that represent what will be experienced in competition (Chow et al., 2019; Pinder et al., 2011). An alternative approach to skill acquisition that provides a practical framework for the design of representative, individualised learning environments is NLP. The following section will explore NLP and its implications for skill acquisition.

2.2.2. Ecological dynamics approach to skill development

Traditional views of skill development have focused on acquiring and enhancing internal representations (i.e., motor programs) of a skill that led to stable and enduring changes in movement abilities (Magill & Anderson, 2021; Schmidt & Lee, 2019). There is an assumption that skills are developed much like a computer processes information, in which motor programs and representations lead to specific behavioural outputs (Schmidt & Lee, 2019). Captured this way, skilled behaviour is viewed as an entity that can be acquired and improved through regular and repetitive practice of a central, generalised representation of a specific skill (Renshaw & Chow, 2019). Therefore, the practice of motor skills is focused on developing strong motor programs that define a general pattern of movement to be applied across a range of situations (Schmidt, 1975; Spittle, 2021).

Alternatively, an ecological dynamics perspective proposes that motor skills are not developed from a central, generalised motor program. Instead, skilled behaviour emerges from continuous interactions between the learner and practice/performance environment (Button et al., 2020; Renshaw et al., 2015), where learners develop the capacity to adapt movements to changing environments while still maintaining performance (Renshaw & Chow, 2019). Therefore, the focus of practice shifts from attaining a specific technique to facilitating learners in searching for individually appropriate movement solutions that align with individual constraints (e.g., physiological make-up, previous experience) (Button et al., 2020). Considered in this way, the term *skill adaption* has been proposed as an alternative to skill acquisition, defined as "enhancing one's functionality in a performance environment which can be continually improved" (Renshaw et al., 2019). Consistent with this view, Ranganathan et al. (2020) explain that behavioural flexibility is a key attribute of skilled performance. Similar to skill adaption, behavioural flexibility is the capability to "not only produce a movement pattern reliably and efficiently achieve a given task outcome but also possess the ability to change that movement pattern to fit a new context" (Ranganathan et al., 2020, p. 1). From this perspective, skill acquisition is a process of searching, compiling, and stabilising flexible or adaptable behaviours (Komar et al., 2019). In support of this idea, Akkuş (2012) showed that seven elite female weightlifters displayed individually unique movements to achieve the same overall task solution (i.e., winning world championship). These results indicate that skilled behaviour involves developing adaptable/flexible, stable, and highly individualised movements capable of achieving successful task solutions (Renshaw et al., 2019).

2.2.3. Nonlinear pedagogy

Grounded in key principles of ecological dynamics, and drawing upon a constraints-based approach, a NLP approach to skill acquisition posits that learning occurs in a nonlinear fashion, whereby humans are viewed as nonlinear dynamical systems (Chow, 2013; Chow et al., 2019). NLP draws on the pioneering work of James Gibson (1979), the founder of ecological psychology, which established important principles to inform practice design. These principles include: (1) information plays a regulatory role in movement and movement influences the perception of information (i.e., information-movement coupling); (2) practice should provide opportunities for action that are present in competitive environments to represent the demands of performance accurately; and (3) manipulation of task constraints can facilitate attuning to key invitations for action available in the perceptual-motor landscape (Button et al., 2020; Chow et al., 2019).

Drawing on ecological dynamics, NLP aims to provides a practical framework to guide practitioners in designing practice environments that simulate important elements of the performance context to improve skill development and performance To appropriately apply NLP it is important to consider the following key design principles that underpin the approach: (1) manipulation of constraints – practice should be designed to encourage the exploration of the movement landscape affordances, leading to the development of functional movement solutions; (2) representative design – task design should aim to preserve action-fidelity, with practice replicating the performance environment to provide the learner with key perceptual information to appropriately adjust their movements; (3) learning design should support the strengthening of the perception-action coupling; (4) learning design should be developed to encourage the development of individualised movement solutions by accounting for functional variability and how it can aid in exploratory learning; (5) attentional focus – instructions should be developed to focus on movement outcomes (external focus), rather than specific body positions (internal focus), as this facilitates self-organising processes (Correia et al., 2019; Renshaw et al., 2015). Chapter 4 provides a comprehensive explanation of these key concepts that form the theoretical underpinnings for NLP and its potential application to MI interventions.

2.2.4. Empirical support for nonlinear pedagogy

A number of studies indicate that practice that implements principles of NLP can successfully develop and enhance performance across a range of skills such as tennis (Buszard et al., 2016), field hockey (Timmerman et al., 2019), soccer (Chow, Davids, Button, & Koh, 2008; Chow, Davids, Button, & Rein, 2008), and diving (Barris et al., 2014). Fitzpatrick et al. (2018) explored the impact of manipulating task rules and size of the playing area (i.e., task constraints) on technical shot proficiency in junior tennis players. They found that backhand shots were more proficient after practice under task constraints than controls. Further, when assessed during an actual game, learners who practiced under task constraints hit a more significant percentage of winning backhand shots, indicating that performance improvements gained during practice were transferred into a competitive environment.

There is a clear representation of open, game-like motor skills in the NLP literature. It could be argued that a specific movement form is not a critical aspect of successful performance when performing these open, game-like motor skills (Spittle, 2021). For example, when attempting to score a goal in soccer, achievement of overall outcome (scoring a goal) is the primary determinant of success, rather than executing a ‘textbook’ style kick (Breed & Spittle, 2020). Given that these skills are often executed in dynamic environments, the ability to adapt movements and quickly make decisions is of primary importance (Spittle, 2021). Viewed in this way, it is not surprising that NLP has demonstrated beneficial effects for open, game-like skills. It advocates for practice design that facilitates the development of important determinants of successful performance for such skills, including the capacity to adapt and formulate individualised movement solutions.

An important point highlighted in NLP studies is the role movement variability, referred to as exploration, plays in skill development. Previously, movement variability has been viewed as ‘noise’ that needs to be contained or wholly removed from a learner’s skill executions (Pacheco et al., 2017). However, NLP research has challenged this view of movement variability in practice. Lee et al. (2014) observed that learners who practiced under task constraints (e.g., modified rules, scaled equipment) displayed a higher number of movement patterns (i.e., movement variability), yet, produced equivalent improvements in performance relative to learners who focused on replicating an ‘optimal’ technique. These findings indicate that many movement patterns are capable of achieving improved performance.

Although NLP can facilitate exploration in open and game-like skills, the impact of NLP for self-paced, movement form-based skills on performance is relatively unknown. Movement form-based skills are reliant on the way a movement looks for success (e.g., diving and gymnastics) (Spittle, 2021). Whereas, in some sports like soccer, movement outcomes (e.g., completing a pass to team member) are more important than movement form (Breed & Spittle, 2020). For movement form-based skills the focus is on reproducing a specific style of movement pattern as this is key to successful outcomes, and in some cases adhering to a specific movement form are the rules of the sport (Breed & Spittle, 2020). For example, in competitive diving, athletes are graded on their ability to produce a predetermined style of movement, which influences the results that can be achieved in competition (Barris et al., 2014). However, when considering skills this way there is a temptation to classify them in a binary fashion. That is, either movement form-based or outcome focused, when in some movements, a specific form is required to achieve the outcome. For example, in Olympic weightlifting to complete a clean and jerk, the rules state the bar must be lifted from the ground in one movement onto the shoulders, into a squat position, and then pushed over head with the arms fully extended with no bend in the elbows (Everett, 2012). Therefore, the success of lifting the barbell (outcome) is reliant on a specific movement form. A key characteristic of the clean and jerk, and similar movements, that differentiates it from movement outcome focussed skills, is that they are self-paced and occur in stable environments (Everett, 2012; Spittle, 2021). In such skills, the movement is initiated by the individual, rather than external pressure (e.g., defenders), and is executed in a relatively stable environment (Spittle, 2021). For example, the clean and jerk is performed on a standard sized platform, using a standardised barbell and weights, with a set number of attempts for every competition (Everett, 2012). By contrast, open, movement outcome focussed skills, such as passing in soccer, can be executed in a variety of dynamic situations that change as a game progresses. It should be noted that this is not to say that self-paced, movement form based skills are not performed in a completely stable environment (e.g., different competition venues), but rather, environmental stability should be considered as a continuum when applied to different movements (Spittle, 2021).

There is some evidence to suggest that principles of NLP can be successfully applied to self-paced, movement form-based skills. For example, Barris et al. (2014) found elite-level divers practicing under variable take-off conditions (i.e., task constraint) demonstrated a significant increase in completed dives and improved performance scores. However, this study was conducted on an elite sample with an established movement form. Therefore, such findings may not apply to less skilled individuals. Case study findings in three novice weightlifters suggest manipulating constraints can facilitate exploration of individualised movement patterns and improve overall performance in the power clean (Verhoeff et al., 2018). These findings indicate a NLP may be a viable pedagogical approach for movement form-based skills; however, further research is needed to corroborate these claims.

2.3. Conclusions

MI is a well-established technique for enhancing skill development and performance. Despite robust evidence to support MI interventions for skill development, several limitations were identified when assessing the overall effectiveness of MI in sport, namely the calculation of effect sizes in meta-analytic reviews that included studies combining psychological techniques and/or non-sport related skills. Therefore, the directly attributable influence of MI on the development of sport-specific skills is not evident. Such observations form the rationale for Study 1, which comprises a meta-analysis and systematic review.

Established evidence-based MI models exist to guide practitioners on what details should be incorporated and how they could be applied to facilitate successful MI interventions. Many of these models emphasise incorporating critical aspects of PP to improve MI intervention efficacy. This emphasis is primarily based on the concept of functional equivalence, which proposes that MI and physical action share similar neural mechanisms (Jeannerod, 2006). Subsequently, some MI models advocate for the inclusion of details such as (1) performing MI in the performance environment and holding a sport-specific implement during MI practice (PETTLEP), (2) inclusion of imagery content that elicits physiological responses related to the imagined skill (bio-informational theory). Further models (i.e., RAMDIU) highlight the importance of considering individual (i.e., skill level) and situational factors. The application of these models has demonstrated positive effects for performance and development across a broad range of skills in several settings from sport (Smith et al., 2007; Williams et al., 2013) through to surgical techniques (Raison et al., 2018). However, the instructions designed using these models, referred to as scripts, tend to focus content on an ideal technical model, commonly informed by researchers, elite coaches, and athletes (Cooley et al., 2013). An alternative ecological dynamics perspective of skilled behaviour suggests focussing on reproducing a specific technical model is not the only viable method for successfully developing motor skills. From this perspective, skilled behaviour is not about acquiring a specific movement form. Instead, it is about developing behavioural flexibility or adaptability, the capacity to adapt movement patterns to dynamically changing environmental conditions while maintaining performance (Button et al., 2020; Ranganathan et al., 2020). Captured this way, practice design shifts from aiming to help learners acquire a prescribed technique to facilitating learners' exploration for individualised movement solutions that satisfy individual, task, and environmental constraints present in the perceptual-motor landscape (Button et al., 2020). This way of conceptualising skill development has important implications for MI intervention design. It suggests that practitioners may want to consider designing instructions focusing less on whether a movement looks correct and more on achieving successful performance outcomes.

NLP presents a skill acquisition framework that could be considered for MI interventions to practically apply ecological dynamics principles. NLP research has highlighted the functional role movement variability may serve during skill acquisition, enabling learners to explore alternative movements and attune to opportunities for action that match individual capacities (Barris et al., 2014; Lee et al., 2014). Observational findings indicate the individualised approach proposed by NLP may be an essential consideration for developing skilled behaviour. For example, research in elite level weightlifters showed athletes utilised highly individualised movements - some commonly considered suboptimal - to achieve performance outcomes (Akkuş, 2012) successfully. Research utilising a NLP approach has primarily focused on open, game-like skills (e.g., tennis return serve).

Therefore, the influence of a NLP approach for self-paced, movement-form focused skills (e.g., weightlifting) is relatively unknown. Study 3 of this thesis aimed to address this gap in the literature by investigating the influence of NLP practice for learning the power clean (Olympic weightlifting skill).

Given the importance of designing MI interventions that incorporate critical elements of PP environments, investigating the application of skill acquisition approaches is important to better understand how to successfully design and deliver MI. However, there is an evident dearth of research examining the influence of alternative approaches to skill acquisition on MI interventions. Therefore, Study 2 presents a review of key NLP practice design principles to provide a theoretical foundation for applying these principles to MI interventions. Utilising the same methods and building on findings of Study 3, Study 4 aims to practically apply the principles of NLP outlined in Study 2 into a MI training intervention. This intervention aimed to explore the impact of an MI intervention designed using principles of NLP MI practice for beginners learning a weightlifting derivative known as the power clean. The overall purpose of these studies was not to present a 'better' approach to MI, but instead to enhance our understanding of MI for skill acquisition and stimulate areas for future research.

Chapter 3:Mental imagery training programs for developing sport-specific motor skills: a systematic review and meta-analysis

Background

Review of existing systematic and meta-analytic reviews in Chapter 2 revealed the directly attributable effects of MI interventions on the development of sport-specific-motor-skills required further investigation. The inclusion of studies in previous reviews examining non-sport related skills (e.g., finger tapping tasks) and combined MI with other psychological techniques (e.g., relaxation) in overall effect size calculations make it difficult to ascertain the true impact of MI interventions for sport. Therefore, this systematic and meta-analysis of the MI literature was undertaken to address these limitations and assess the overall effectiveness of MI interventions on the development of sport specific-motor-skills. In addition, this review aimed to examine intervention variables that may moderate the beneficial effects of MI, including practice type, skill level, skill complexity, performance measures, intervention duration, practice context, and MI session frequency. By examining the influence of key intervention variables this review aimed to identify important practical considerations for designing and delivering effective MI practice to inform *Study 4* of this thesis.

This chapter is presented in pre-publication format of a recent publication titled:

Lindsay, R., Larkin, P., Kittel, A., Spittle, M. (2021). Mental imagery training programs for developing sport-specific motor skills: a systematic review and meta-analysis. *Physical Education and Sport Pedagogy*, https://doi: 10.1080/17408989.2021.1991297

3.1. Abstract

Background: Physical practice is the cornerstone of acquiring and developing movement skills in physical education and sport. However, research has suggested that psychological tools, such as mental imagery (MI), could effectively supplement a learner's physical practice schedule. MI is the mental simulation of a movement or situation in the absence of an overt physical output. Previous reviews have established the efficacy of MI for improving motor skills in sport. Further investigation, however, will help strengthen previous findings by focusing exclusively on studies that apply MI programs for the development of sport-specific motor skills.

Purpose: The purpose of this paper is to examine the overall effectiveness of MI programs for developing sport-specific motor skills and investigate program principles that may moderate the efficacy of MI programs, such as practice type, skill level, skill complexity, performance measures, duration, practice setting, and session frequency. By examining key program variables for MI, this review seeks to provide practical recommendations for physical educators and sports coaches on how they might effectively design and deliver a MI program to develop sport-specific motor skills.

Method: The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. To provide practical recommendations for physical educators and sports coaches for effective MI programs, the following moderator variables were examined using subgroup analysis: (1) skill complexity, (2) skill level, (3) program duration, (4) session frequency, (5) MI practice type, and (6) practice context. The PEDro scale was used to assess study quality. The presence of publication bias was evaluated using the Trim and Fill method to calculate an adjusted and unbiased overall effect.

Results: The systematic review included 36 studies (n = 1449). A random-effects meta-analysis of standardised mean differences yielded an initial 135 individual effect sizes. A composite approach accounted for statistical dependence between effects and yielded 58 individual effects for further analysis. Analysis indicated that MI has a significant effect on performance (g = 0.476). Further analysis revealed significant effects on performance outcomes for MI combined with physical practice and MI alone (g = 0.579 and 0.298, respectively). Subgroup analyses revealed these beneficial effects be moderated by skill complexity, elements of skill performance, and MI delivery type.

Conclusions and recommendations: These results presented in our meta-analysis highlight the overall benefit of MI practice for developing sport-specific motor skills. However, there is a paucity of research on the effects of MI on complex skills and in physical education and sport coaching contexts. Although most studies presented in this review were conducted in controlled research settings, there are clear parallels between the skills practiced in these studies and those implemented in physical education and sport coaching. The efficacy of MI alone presents a potentially beneficial tool when physical practice is not possible or when physical training needs reduction (e.g., in-season sports competition). Therefore, it is encouraged that physical educators and sports coaches collaborate with sport psychology practitioners to investigate the efficacy of the several MI program variables presented in this review.

Keywords: imagery; physical education, pedagogy; motor learning; skill acquisition.

3.2. Introduction

The development of skilled action has often been attributed to long hours of physical practice, requiring high levels of effort and attention. One of the primary objectives of physical education programs and sport is to develop and acquire motor skills (Hall & Fishburne, 2010). This highlights an important link between the underpinning mechanisms involved in motor learning and how physical educators and sports coaches promote motor skill development. One practice technique that has been successfully implemented by sports psychologists to promote motor learning is mental imagery (MI; Driskell et al., 1994; Toth et al., 2020; Simonsmeier et al., 2021). MI is the mental simulation of a movement or situation without overt physical output (Morris et al., 2005). Given the importance of skill acquisition and development for physical educators and sports coaches, MI represents a valuable tool that could be utilised to enhance the development of sport-specific motor skills in physical education and sport.

The potential value of MI in physical education and sport is patently clear. Consider a 15 – year - old preparing for the upcoming representative basketball season. The coach would likely reduce pre-season practice volume to accommodate the inclusion of competitive games. This coach is presented with the challenge of balancing skill maintenance with the increased physiological demands of the competitive season. In such circumstances, MI offers physical educators and sports coaches a unique opportunity to reduce the physiological stress of extra training and maintain or improve motor skill performance by integrating 'offline' practice that can be used with physical practice schedules. There is limited research on MI directly in real-world physical education and sport contexts, so the review of studies will need to rely on training of sport-specific motor skills in a range of settings (e.g., controlled research settings). Despite the logical benefits of integrating MI into physical practice schedules, several elements of MI programs could benefit from further investigation, extending upon previous findings on the use of MI for the development of sport-specific motor skills. Firstly, previous meta-analytic reviews examined the efficacy of MI by combining a diverse range of tasks, from drawing to shooting in netball under defensive pressure (Wakefield et al., 2009), analysis focussed on sport-specific motor skills alone would help further understand the potential effectiveness of MI when applied to movements relevant to physical education and sports coaching. Secondly, studies using other techniques such as relaxation or self-talk have been included in overall effect size calculations, again clouding the directly attributable effects of MI for sport-specific motor skill development (Driskell et al., 1994; Toth et al., 2020). Thirdly, skill complexity requires closer examination. Although previous reviews (Driskell et al., 1994; Toth et al., 2020; Simonsmeier et al., 2021) have analysed the efficacy of MI by task type (e.g., internal vs. external and cognitive vs. motor skill), further investigation into the difficulty of these skills would provide more information around the differential effects of MI based on task complexity and whether MI delivery needs to be adjusted. Lastly, further examination of the learning effects of MI practice is needed. Previous reviews (Driskell et al., 1994; Toth et al., 2020; Simonsmeier et al., 2021) provide sound recommendations on the amount of MI practice necessary for improved skill performance, however, analysis that excludes single-session studies would help further strengthen previous findings. Therefore, a fruitful line of inquiry may be to exclude single session studies and focus on MI practice delivered over repeated sessions. This aligns with the physical practice literature, where the assessment of skill performance is delivered over repeated teaching or coaching sessions, which is more representative of real-world practice environments (Spittle, 2021).

A crucial element required to successfully participate in sport is the ability to execute sport-specific motor skills, defined as specialised movement skills specific to a particular game or sport (Spittle, 2021). Breed and Spittle (2020) explain that sport-specific motor skills are more highly developed versions of fundamental movement skills applied explicitly to a specific sport. For example, this may involve kicking a rugby ball to another player to advance the ball down the pitch. In addition, sport-specific skills are often delivered as specific modules to begin teaching learners to apply skill in sport specific settings (Spittle, 2021). Given their importance to sport and physical education, examining the relationship between MI and sport-specific skills with further build understanding about the applicability of MI as a potential practice tool in sports coaching and physical education contexts. The positive effects of MI on motor skills have been established (Driskell et al., 1994; Toth et al., 2020; Simonsmeier et al., 2021). For example, Simonsmeier et al. (2021) conducted a meta-analytic review that indicated MI programs are linked with beneficial increases in motor learning and performance in general with a moderate effect size (d = 0.416). However, previous reviews have combined skills under broad categories that often differ significantly in complexity (e.g., golf-putting vs. tennis serve) and executed in non-sports related settings (e.g., drawing and finger-tapping tasks) (Driskell et al., 1994; Toth et al., 2020; Simonsmeier et al., 2021). Furthermore, details such as the skills practiced (i.e., skill complexity and elements of skills developed) have seldom been reported. To build upon the work of previous MI reviews, it is essential to understand whether complexity influences the efficacy of MI. It is well established in the physical practice and skill acquisition literature that as skill complexity increases (e.g., passing standing still vs. passing while running), there is an increased technical and mental demand (Farrow & Robertson, 2017). Wulf and Shea (2002) explain that simple skills require smaller amounts of practice, lower attention, memory, and processing demands to reach satisfactory levels of performance. This is in contrast with more complex skills, which require more practice and have higher demands on processing capacity. Despite the apparent consensus in previous reviews around the contribution of skill type (i.e., cognitive or sport-based categorisation), further work is needed to investigate the impact of skill complexity on the efficacy of MI interventions given that many sport-specific skills learnt in physical education and sport may be of higher complexity.

A further area that requires in-depth examination is the impact of MI on specific elements of sport-specific motor skill performance (Driskell et al., 1994; Toth et al., 2020). Performance outcome measures aim to examine the performance result and often use frequency, consistency, distance to the target, or speed to complete a task. Conversely, performance process measures are concerned with the movement process that led to a specific performance outcome, focussing on the movement pattern or the quality of the skill being performed. Movement technique is typically measured using motion analysis to assess kinematic and kinetic variables (e.g., joint angles, force, and velocity output) or muscle activation measures (e.g., electromyography). Skill quality is assessed using subjective observational measures (e.g., checklist, rating scale, rubric) (Spittle, 2021). Delineating and analysing different elements of skill performance will help to clarify whether MI has differential effects on specific aspects of sport-specific motor skills such as movement technique (i.e., process measures) or results of performance (i.e., outcome measures). These findings highlight the influence various task types have on the efficacy of MI interventions. However, the efficacy of MI between skills of varying difficulty (e.g., soccer penalty kick vs. netball shot under defensive pressure) and different performance elements requires further investigation.

Previous meta-analytic reviews have proposed several factors that moderate the effectiveness of MI on performance (Driskell et al., 1994; Feltz & Landers, 1983; Simonsmeier et al., 2021; Toth et al., 2020), such as skill type, the skill level of the participant, practice duration, the delivery mode of MI used (i.e., combined with physical practice [PP] or alone) and session frequency (Kremer et al., 2009). The delivery mode of MI has consistently been identified as a critical factor in understanding how effective MI practice is for motor learning and performance. For example, Simonsmeier et al. (2021) found that MI combined with PP was more effective than PP alone for improving motor learning and performance in sport. These findings indicate that MI may have an additive effect on PP and provide an alternative means of practice that does not require further physiological stress to the athlete. The influence of mode of delivery requires further clarity concerning how it impacts sports-specific skills. Clarifying the impact of MI combined with PP on sport-specific motor skills may provide physical educators and sports coaches with alternative practice option to be utilised when skill performance needs to be maintained and PP decreases (e.g., tapering of physical practice during competitive season).

A further consideration raised from MI research has been the influence of the amount of practice and how this contributes to overall performance outcomes of physical and cognitive tasks (Driskell et al., 1994). In a recent meta-analytic replication and extension of Driskell's (1994) review, Toth et al. (2020) emphasised the importance of duration, with MI showing more substantial effects for internally cued, externally cued, and cognitive-based tasks when implemented for 1 – 6 weeks, rather than interventions that were more than 6 weeks. These findings are invaluable for extending the body of research on MI and understanding its learning and performance benefits.

Previous meta-analyses provide a foundation to understand the influence MI has on skill learning and performance. However, several limitations need to be addressed to strengthen previous findings on effectively implementing MI for sport-specific motor skills. Primarily, this review seeks present evidence to support the potential use of MI in physical education and sport coaching contexts to acquire and develop sport-specific motor skills. There is limited research on MI in real-world physical education or sport coaching settings. However, there is a large body of research on developing sport-specific motor skills in controlled research settings. Therefore, this review seeks to synthesise information about the overall effectiveness of MI programs for developing sport-specific motor skills by excluding studies using; (1) single practice sessions, (2) non-sport-related skills, and (3) MI combined with other psychological techniques. From these findings, this review aims to identify variables that moderate the MI-skill performance relationship to provide practical recommendations that can inform future MI research in physical education and sport coaching settings. Therefore, the following hypotheses were formulated:

1. We predicted that MI would have a significant, positive effect on overall performance of sport-specific motor skills, as measured by outcome and process measures (Driskell et al., 1994; Feltz & Landers, 1983; Simonsmeier et al., 2021; Toth et al., 2020).

2. Previous research indicates that the effect of MI may decrease as skill complexity increases (e.g., open versus closed skills; Coelho et al., 2007). Therefore, it was hypothesised that skill complexity, as measured by Gentile's (2000) two-dimensional system, would moderate the effectiveness of MI practice on skill performance, with effect sizes being significantly larger for simple skills compared with complex skills.

3. It was hypothesised that performer skill level would be a significant moderator of the effect MI has on performance of sport-specific skills, with effect sizes being significantly larger for skilled performers than novices (Driskell et al., 1994).

4. We hypothesised that MI + PP would improve performance outcomes of sport-specific motor skills significantly more compared with PP and MI alone (Driskell et al., 1994; Feltz & Landers, 1983; Toth et al., 2020). It was further predicted that MI alone would significantly enhance the performance of sport-specific motor skills compared with no practice control groups.

5. In the early stages of learning, considerable improvements are often observed, and the rate of improvement decreases as practice progresses (Newell & Rosenbloom, 1981).

Therefore, we predicted that MI would enhance performance across each intervention length, however, the magnitude of effect would be significantly larger for interventions 3 days – 1 week compared with longer interventions.

3.3. Method

3.3.1. Search strategy

The review conformed to the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) guidelines (Moher et al., 2009). An article search was conducted using SPORTDiscus, PubMed, Medline, PsychInfo, and SCOPUS (Figure 1).

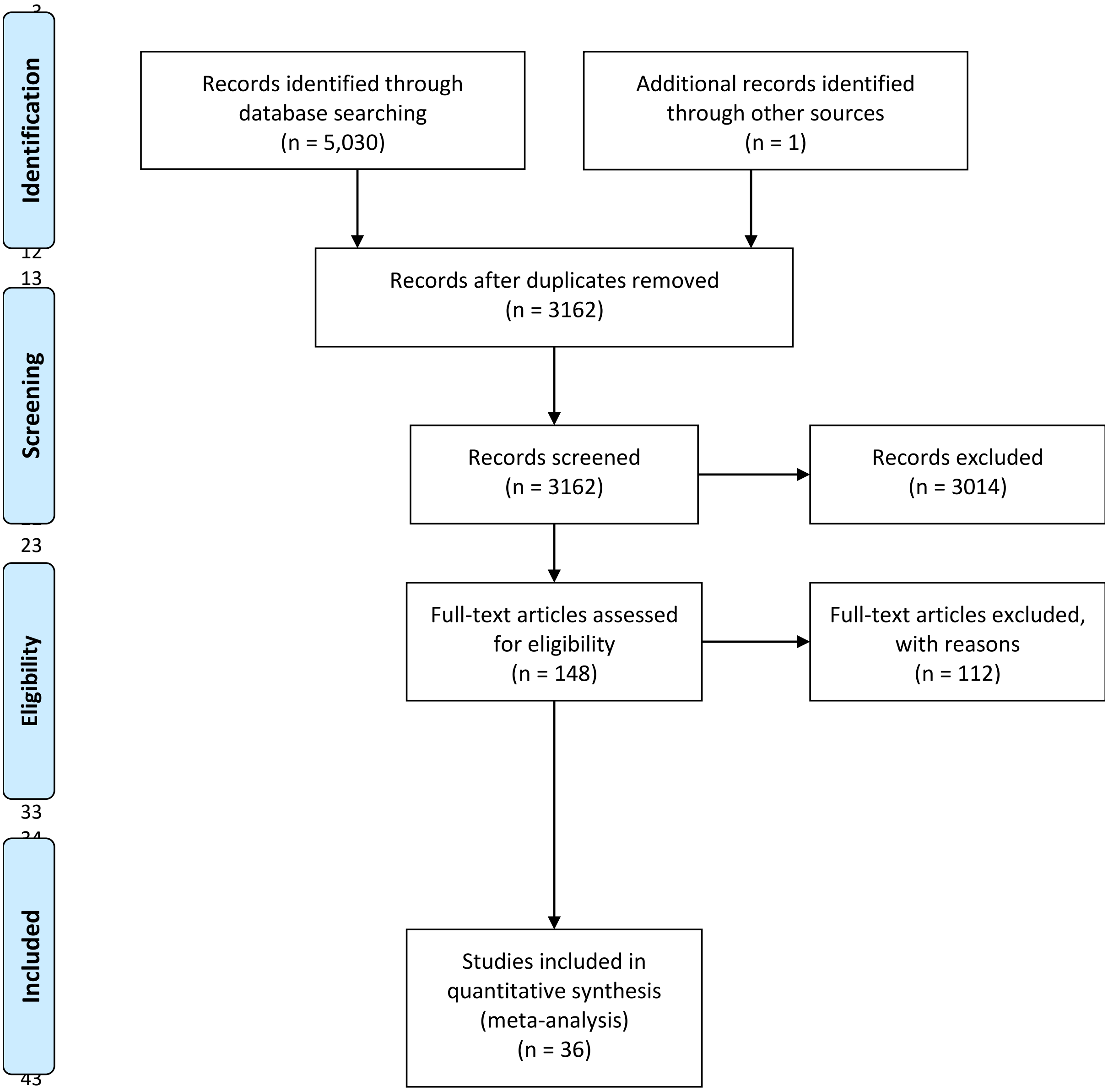


Figure 3.1. Preferred reporting items for systematic reviews and meta-analysis (PRISMA) flowchart.

3.3.2. Inclusion/exclusion criteria

Peer-reviewed studies were included in the review based on the following criteria: (1) aimed to improve a sport-specific motor skill (e.g., athletes' performance), (2) full text available in English, (3) intervention involved MI of sport-specific motor skills, and (4) participants included healthy volunteers, students, professionals, or athletes from any discipline. Studies were excluded based on the following: (1) special or clinical populations were used, (2) single session interventions, (3) mean age of participants was less than 13 years old, to reduce developmental and maturational effects on imagery ability (Cooley et al., 2013), (4) MI was used in conjunction with other mental skills training (e.g., action observation, relaxation).

3.3.3. Quality assessment

Depending on the design, included studies were assessed for methodological quality using the physiotherapy evidence database (PEDro) scale (Maher et al., 2003). The PEDro was devised to assess the quality of randomised control trials (RCT) and comprises 11 criteria that are answered either 'Yes' or 'No'. If a criterion cannot be ascertained from a direct reading of the article, the criterion must be scored as a 'No'. Following suggestions from Cashin et al. (2020) Cashin (2020), scores were interpreted as follows: < 4 were considered 'poor', 4 – 5 'fair', 6 – 8' good, and 9 – 11 'excellent'. It is important to note that PEDro scores should not be used to determine the validity of each study's findings (Cashin et al., 2020).

3.3.4. Data extraction

The following variables from included studies were extracted: (1) descriptive data, including sample size and skill level of participants; (2) characteristics of the MI intervention, including intervention groups, session frequency, session duration, length of intervention, and practice setting; (3) performance measure(s) used; and (4) the main findings related to performance measures. Participants were novices if they were described to have no or limited experience with the task being performed. Skilled participants were defined as competing in their chosen sport at a national level or higher. These extracted variables were used to conduct subgroup group analyses to determine the influence on moderating the effectiveness of MI programs. Included studies did include other outcomes (e.g., motivation, anxiety, MI ability). However, this review aimed to investigate the impact of MI practice on sport-specific motor skill performance (e.g., accuracy and consistency). Therefore, performance measures were extracted and categorised as either performance outcome or process measures for further analysis.

3.3.5. Classification of skill complexity

The influence of skill complexity on the efficacy of MI was assessed using Gentile's (2000) two-dimensional system to classify skills to explore the influence of skill complexity on the efficacy of MI programs (Figure 2). Gentile (2000) proposes a two-dimensional system that divides skills into 16 categories, creating a taxonomy in terms of motor skills. It is important to note that Gentile's original intention for designing this system was to aid physical therapists in assessing motor skills in patients. Gentile's taxonomy categorises skill based on two dimensions: the environment in which a skill is executed and the action requirements. Environment refers to whether the conditions that regulate the execution of skill are stationary or in motion and is there any variability between trials. Action requirements identify whether a skill involves changes in body position or body transport and any object manipulation (Gentile, 2000).

3.3.6. Statistical analyses

A random-effects meta-analysis of standardised mean differences (SMD), expressed as Hedges' g where possible, was conducted using Comprehensive Meta-analysis software (CMA; Biostat Inc., Englewood, NJ, USA). Furthermore, we identified outliers following specific outlier diagnostics for meta-analysis proposed by Viechtbauer and Cheung (2010).

After examining studentised deleted residuals, Cook's distances, DFFITS values, three effects sizes across two studies were removed (Afrouzeh et al., 2013; Smith et al., 2001). Random effects were analysed in three main ways: 1) overall Hedges' g was calculated for MI on program outcomes, MI + PP compared with PP and MI alone compared with PP and no practice conditions, 2) overall Hedges' g was calculated for program variables (program duration, session frequency, practice setting, and MI practice type) and skill variables (skill level, skill complexity), and 3) skill complexity was used as a categorical variable for subgroup analyses on each aspect of MI program design and skill variables. The rationale for using skill complexity as a categorical variable for each subgroup was to examine the influence of skill difficulty has on MI program variables. The effectiveness of MI was assessed by calculating pre-post within-group changes. Between-group differences have been calculated where possible to indicate changes between MI, PP, and no practice control.

3.3.6.1. Calculation of Hedge's g

Hedges' g and 95% confidence intervals (CI) were calculated using sample size (n), the correlation between conditions/within conditions, and mean ± standard deviation. Correlation values were not available in all studies reviewed; therefore, a conservative 0.5 correlation was assumed for all studies (Follmann et al., 1992). Hedges' g was interpreted as follows: trivial < 0.2; small 0.2 – 0.6; moderate 0.6 – 1.2; large 1.2 – 2.0; and very large > 2.0 (Cohen, 1988). Each included study provided Hedges' g for the effects of MI; therefore, they were statistically dependent. We addressed this issue using a composite approach as detailed by Borenstein et al. (2009). This approach utilises CMA software to compute a composite score for each study using the mean of study outcomes. This approach provides a more conservative estimate of the overall effect by calculating a variance that accounts for the correlation among different study outcomes (Borenstein et al., 2009). A significance level of p < .05 was considered for all analyses. To evaluate whether the observed effect of MI on sport-specific motor skills was the result of publication bias, Duval and Tweedie's Trim and Fill method was used to calculate an adjusted and unbiased overall effect (Duval & Tweedie, 2000).

3.3.6.2. Subgroup analysis and investigation of heterogeneity

In accordance with section 9.5 and 9.6 of the Cochrane Handbook for Systematic Reviews of Interventions, statistical heterogeneity was assessed using the Q and I2 statistics to show the dispersion of true effects, expressed as Hedges' g, between predefined subgroups (Higgins et al., 2021). The I2 statistic was interpreted as follows: 0% – 40% was considered ‘might not be important’, 30% – 60% ‘may represent moderate heterogeneity’, 50 – 90% ‘may represent substantial heterogeneity’, and 75 – 100% ‘considerable heterogeneity’ (Higgins et al., 2021). To further understand the sources of heterogeneity for the observed effects of MI on performance, moderator analysis was conducted using subgroup analysis for categorical variables including skill complexity, skill level, intervention duration, frequency of MI sessions, performance measure used, practice context, and MI delivery (i.e., MI + PP, PP, MI alone, and control).

The skill complexity moderator variable was classified using Gentiles' (2000) two-dimensional system. Each skill was coded into the following levels: 1 – 4 (stationary regulatory conditions, limited intertrial variability, body stability, and object manipulation), 5 – 8 (stationary regulatory conditions, increased intertrial variability, greater stability demands, and increased object manipulation), 9 – 12 (in-motion regulatory conditions, limited intertrial variability, body stability, and object manipulation), and 13 – 16 (in-motion regulatory conditions, greater stability demands, and increased object manipulation). The intervention duration moderator refers to the overall length of the MI intervention and was based on the explicitly stated number of days or weeks for each included study. For each of the included studies, intervention lengths were divided into the following levels: 3 days – 1 week, 1 – 3 weeks, 4 – 6 weeks, and > 6 weeks. The session frequency moderator, pertaining to the number of weekly MI sessions, was characterised by the following levels: 2 – 3, 4 – 5, 6 +.

The skill level moderator was categorised as either novice or skilled based on the sample information stated in the included studies. Participants were coded as not reported when skill level was not stated. The performance measure moderator was classified as either outcome or process measure, forming two levels for analysis. Outcome measures were classified according to accuracy, frequency, consistency, distance to the target, and reaction-based measurements. Conversely, process measures were characterised as kinematic, kinetic, and subjective observational measures. The practice setting moderator was characterised according to the intervention context (i.e., sports coaching, physical education, and controlled research). The setting was categorised as controlled research when participants were recruited for an intervention conducted by the investigators with limited or no involvement from sports coaches in the design and implementation of practice. Sports coaching was characterised as interventions where MI practice was designed in consultation with coaches and implemented in conjunction with, or entirely by relevant sports coaches. Finally, physical education context was categorised as MI practice conducted as part of a physical education unit or lessons and delivered in conjunction with trained physical educators. The MI delivery moderator was classified according to the type of practice implemented within the included studies. Conditions were categorised as either MI + PP, MI alone, PP alone, and no practice control. To compare the mean effects of different levels of each subgroup, we conducted Z - tests following Borenstein et al. (2009). Specific calculations can be found in Appendix I.

Additionally, meta-regression was performed on study quality (i.e., PEDro scores). Each included study was scored 1 – 11, which was subsequently used as a continuous variable in the meta-regression. Study quality scores were meta-regressed using a random-effects meta-regression model (method of moments) using CMA software (Biostat Inc., Englewood, NJ, USA) following recommendations by Borenstein et al. (2009).

3.4. Results

3.4.1. Study selection

The initial search yielded 5,030 results, of which 35 studies met the inclusion criteria. Searches through the reference lists resulted in one additional paper; therefore, the total number of studies included is 36. The study search and selection process are presented in Figure 1

3.4.2. Characteristics of included studies

The total number of participants across all included studies was 1,449 with an average sample size of 36.2 ± 18.5 (range: 10 – 92). A total of 23 intervention groups included participants at a novice level (n = 1059), and a further 13 groups included skilled performers (n = 390). From the accepted studies, 14 sports were examined. Golf was the most frequent sport investigated (n = 10), the remaining studies examined basketball (n = 7), tennis (n = 3), soccer (n = 3), darts (n = 3), hockey (n = 2), volleyball (n = 1), karateka (n = 1), figure skating (n = 1), acrobatic gymnastics (n = 1), high jump (n = 1), trampoline (n = 1), netball (n = 1), and table tennis (n = 1).

Of the 36 studies, only 10 were conducted in actual physical education (n = 1) and sport coaching settings (n = 9) controlled research settings. A total of 24 studies implemented MI practice in controlled research settings. The remaining two studies did not provide adequate information to determine practice context and were classified as 'Not reported'. From the included studies, performance outcome measures were the most frequently measured (84%). with the remaining studies using performance process measures (16%). These measures are summarised in Table 1.

All 36 investigations stated independent and dependent variables, and 23 included a control group. The length of MI programs was reported for 36 studies with an average of 4.4 ± 3.9 (range: 0.4 – 18) weeks. Average MI sessions per week were reported for 36 studies with an average of 2.8 ± 1.5 (range: 1 – 7). Of the accepted studies, MI session duration was not consistently reported using one metric. A total of 23 studies reported using minutes with an average of 8.8 ± 4.8 (range: 2 – 16). A further 12 studies reported MI duration using trials imagined with a mean of 25.8 ± 18.8 (range: 6 – 60); one study did not report MI duration. Table 1 summarises the studies analysed.

Studies were categorised using Gentile's (2000) two-dimensional classification system. Skills placed in category two were most common (n = 19), the remaining MI groups implemented skills placed in category four (n = 12), 7 (n = 2), 8 (n = 3), 15 (n = 3), and 16 (n = 5). Figure 2 summarises studies organised by skill complexity.

3.4.3. Quality of included studies

From the accepted studies, 36 were assessed using the PEDro scale with scores ranging from 3/11 to 8/11. The overall quality of the included studies was 'good' with a mean score of 6 (SD = 1.11). Quality assessment scores and descriptors for individual studies can be found in Table 1. One study was a single-case study design; therefore, the PEDro scale was not appropriate. This study was not included in the final meta-analysis. A regression analysis on study quality revealed a coefficient value of 0.136, SE = 0.126, 95% CI [-0.111, 0.384], meaning that for one unit increase in PEDro scores, the effect size increases by 0.136. This relationship, however, failed to reach significance (p = .281), indicating that study quality was not a significant predictor of MI effects of sport-specific motor skills.

Table 1. Overview of studies investigated for effects of mental imagery programs on sport-specific motor skills

Study	Sport (skill)	Setting	Sample	Groups	PEDro scale (score/quality)	Program			Performance measures
						Duration (weeks)	MI session frequency (per week)	MI trials/minutes (per week)	
Brouziyne and Molinaro (2005)	Golf (Approach shot)	Controlled research	Novice (*n* = 23)	1 MI + PP; 1 PP; 1 control	6/11; 'good'	1	5	13 minutes	Shot accuracy
Frank et al. (2014)	Golf (Putting)	Controlled research	Novice (*n* = 52)	1 MI; 1 MI + PP; 1 PP; 1 control	7/11; 'good'	0.7	3	60 trials	Putting accuracy; putting consistency
Frank et al. (2016)	Golf (Putting)	Controlled research	Novice (*n* = 45)	1 MI + PP; 1 PP; 1 control	7/11; 'good'	0.4	3	30 trials	Putting accuracy; putting consistency
Kim et al. (2017)	Golf (Putting)	Controlled research	Novice (*n* = 40)	1 MI; 1 AO; 1 PP; 1 control	7/11; 'good'	0.4	3	60 trials	Putting accuracy
Kim et al. (2011)	Golf (Putting)	Controlled research	Novice (*n* = 60)	1 MI; 1 AO; 1 PP; 1 MI + PP; 1 AO + PP; 1 control	7/11; 'good'	0.4	3	10 minutes	Putting accuracy; putting consistency
Kornspan et al. (2004)	Golf (Putting)	Controlled research	Novice (*n* = 40)	1 MI + PP; 1 Positive self-talk + PP; 1 PP; 1 control	6/11; 'good'	0.7	4	2 minutes	Successful putts
Smith and Holmes (2004)	Golf (Putting)	Controlled research	Skilled (*n* = 40)	2 MI + PP (Written script & audio); 1 AO; 1 control	8/11; 'good'	6	2	15 trials	Putts holed, performance score
Smith et al. (2008)	Golf (Bunker shot)	Controlled research	Skilled (*n* = 32)	1 PETTLEP MI; 1 PETTLEP MI+PP; 1 PP; 1 control	7/11; 'good'	6	2	5 minutes	Shot performance score

Table 1. (Continued)

Williams et al. (2013)	Golf (Putting)	Controlled research	Novice (*n* = 24)	3 MI (Bio-informational; visual, motor imagery)	7/11; ‘good’	0.6	4	15 minutes	Putts holed; distance from hole
Woolfolk et al. (1985)	Golf (Putting)	Controlled research	Novice (*n* = 30)	2 MI+PP (Positive; negative); 1 PP	5/11; ‘fair’	1.8	6	10 trials	Successful putts
Fazel et al. (2018)	Basketball (Free-throw)	Controlled research	Novice (*n* = 49)	3 MI (Routine, progressive; retrogressive); 1 control	6/11; ‘good’	4	3	5-10 minutes	Shots scored
Gaggioli et al. (2013)	Basketball (Lay-up)	Controlled research	Novice (*n* = 60)	1 MI + PP; PP	5/11; ‘fair’	4	3	10 minutes	Subjective rating:
Grouios et al. (1997)	Basketball (Free-throw)	Controlled research	Skilled (*n* = 36)	1 MI; 1 PP; 1 control	5/11; ‘fair’	1	7	30 trials	Number of shots scored
Guillot et al. (2009)	Basketball (Tactical gameplay)	Sport coaching	Skilled (*n* = 10)	1 MI + PP; 1 PP	4/11; ‘fair’	6	2.4	11 minutes	Subjective player and coach rating
Lamirand and Rainey (1994)	Basketball (Free-throw)	NR	Intermediate (*n* = 18)	1 MI+PP; 1 Relaxation + PP	3/11; ‘poor’	2	2	5 minutes	Shots scored
Post et al. (2010)	Basketball (Free-throw)	Sport coaching	Skilled (*n* = 16)	1 MI+PP; 1 PP	NA	18 games	1	15 minutes	Frequency of missed/made shots
Ziegler (1987)	Basketball (Free-throw)	Sport coaching	Novice (*n* = 92)	2 MI (Passive or active); 1 MI+PP; 1 PP; 1 control	6/11; ‘good’	3	3	20 trials	Number of successful shots
Dana and Gozalzadeh (2017)	Tennis (Serve; Forehand; Backhand)	Sport coaching	Novice (*n* = 36)	2 MI + PP (Internal and external); 1 PP	5/11; ‘fair’	6	3	15 minutes	Serve, forehand and backhand performance error

Table 1. (Continued)

Study	Sport	Setting	Sample	Groups	PEDro scale (score/quality)	Program			Performance measures
						Program duration (weeks)	Frequency (per week)	Duration (trials/minute)	
Guillot et al. (2012)	Tennis (Serve)	Sport coaching	Novice (*n* = 22)	2 MI + PP (Regular and placebo racket); 1 control	6/11; 'good'	6	2	15 trials	Ball velocity; COV for velocity; successful serves; subjective coach score; COV for coach score
Robin et al. (2007)	Tennis (Serve return)	Controlled research	Skilled (*n* = 30)	2 MI+PP (Good and poor imager); 1 control	6/11; 'good'	10	1.5	6 minutes	Amplitude (long and short), direction (left and right), number of invalid returns
Björkstrand and Jern (2013)	Soccer (Penalty shot)	Sport coaching	Novice (*n* = 41)	1 MI; 1 PP	4/11; 'fair'	1	5	10 trials	Shots scored
Blair et al. (1993)	Soccer (Passing)	Physical education and Sports coaching	Novice (*n* = 20); Skilled (*n* = 20)	2 MI (novice and skilled); 2 control (novice and skilled)	5/11; 'fair'	6	2	15 minutes	Passing accuracy
Ramsey et al. (2010)	Soccer (Penalty shot)	Controlled research	Skilled (*n* = 52)	2 MI+PP (Skill and emotion based); 1 control	7/11; 'good'	6	4	5 minutes	Shot accuracy
Romano Smith et al. (2019)	Darts (Dart throw)	Controlled research	Novice (*n* = 50)	1 MI; 1 AO+PP, 1 simultaneous AO+MI; 1 alternate AO+MI; 1 control	7/11; 'good'	6	3	4 minutes 12 seconds	Dart score, EMG of select upper body muscles movement time, follow-through time, angular velocity

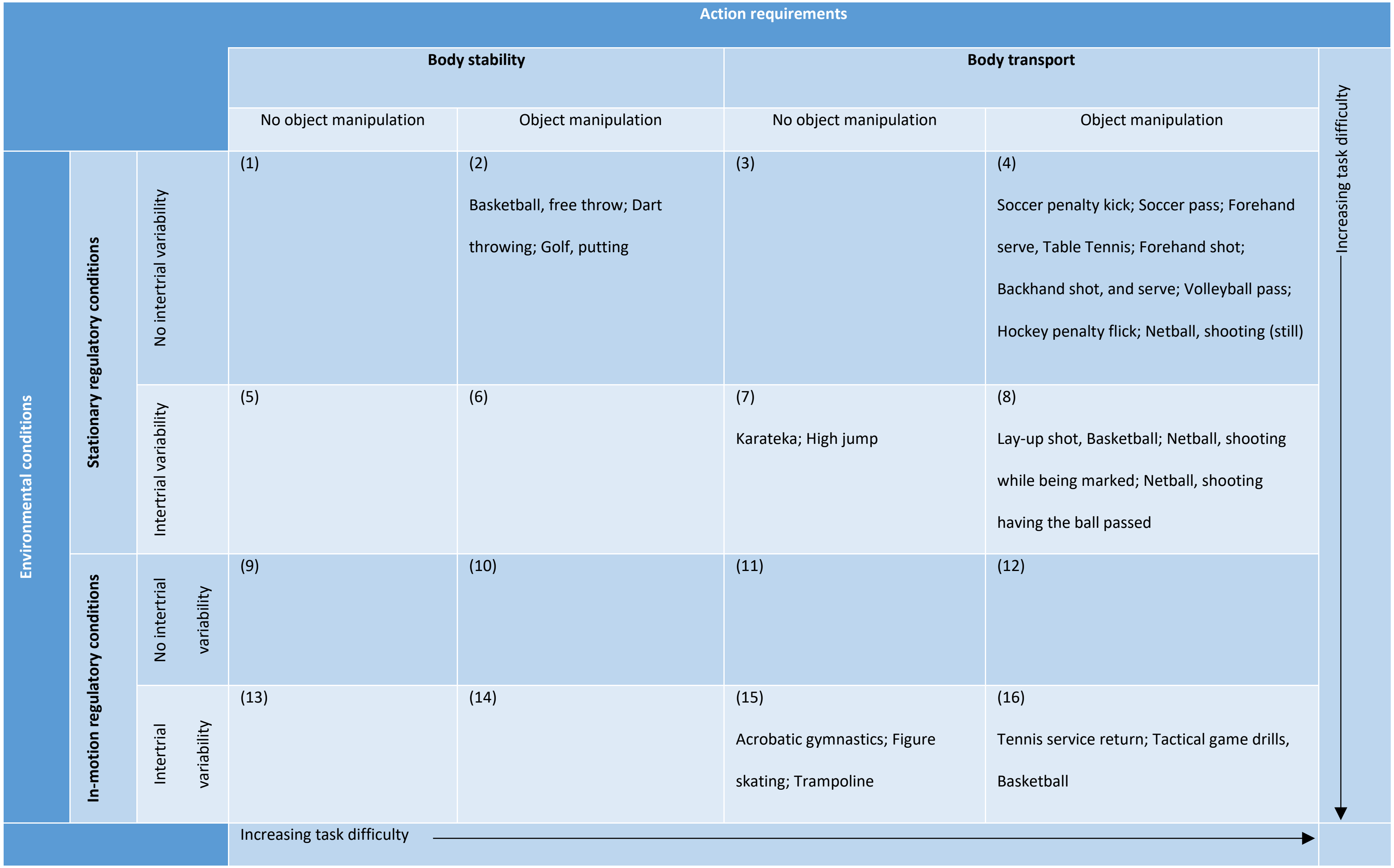
Table 1. (continued)

Romano-Smith et al. (2018)	Darts (Dart throw)	Controlled research	Novice (n=50)	1 MI; 1 AO+PP, 1 simultaneous AO+MI; 1 alternate AO+MI; 1 control	7/11; ‘good’	6	3	4 minutes 12 seconds	Throwing score
Weber and Doppelmayr (2016)	Darts (Dart throw)	Controlled research	Novice (*n* = 43)	1 MI+PP; 1 control	6/11; ‘good’	2.1	3.5	50 trials	Throwing score
Smith et al. (2001)	Field hockey (Penalty flick)	Controlled research	Novice (*n* = 27)	2 MI+PP (Bio-information; stimulus and response) 1 control	8/11; ‘good’	7	3	20 trials	Shot score
Smith et al. (2007)	Field hockey (Penalty flick)	Controlled research	Skilled (*n* = 48)	3 MI+PP (PETTLEP sport specific, clothing & traditional); 1 control	7/11; ‘good’	6	7	5 minutes	Shot score
Afrouzeh et al. (2013)	Volleyball (Passing)	Controlled research	Novice (*n* = 36)	2 MI + PP (PETTLEP & traditional); 1 PP	6/11; good’	7	3	15 minutes	Passing accuracy
Fontani et al. (2007)	Karate (Hand strike)	NR	Skilled (*n* = 30)	1 MI; 1 PP; 1 control	6/11; ‘good’	4.3	7	16 minutes	Reaction time; EMG activation of abdominals and trapezius
Caliari (2008)	Table tennis (Forehand shot)	Controlled research	Novice (*n* = 85)	2 MI + PP; 2 PP (Focus on racket or ball)	7/11; ‘good’	6	1	6 trials	Shot accuracy
Isaac (1992)	Trampoline (Straddle jump; half twist to front drop; front somersault)	Sport coaching	Novice (*n* = 39); Skilled (*n* = 39)	1 MI + PP; 1 PP	7/11; ‘good’	18	NA	5 minutes	Nationally accredited judges score
Marshall and Gibson (2017)	Gymnastics (Acrobatic routine)	Sport coaching	Skilled (*n* = 19)	1 MI+PP; 1 PP	6/11; ‘good’	4	2	15 minutes	FIG qualified judge score

Table 1. (continued)

(Olsson et al., 2008)	Athletics (High jump)	Sport coaching	Skilled (*n* = 19)	1 MI+PP; 1 PP	7/11; ‘good’	6	2	6 minutes	Jump height; take off angle; bar clearance; false jumps
(Rodgers et al., 1991)	Figure skating (set skating routines)	Sport coaching	Skilled (*n* = 40)	1 MI+PP; 1 PP; 1 Control	6/11; ‘good’	16	2	15 minutes	Number of CFSA routine elements completed, CFSA score, subjective coach score
Wakefield and Smith (2009)	Netball (Shooting)	Controlled research	Novice (*n* = 32)	3 MI+PP (PETTLEP; 1, 2, 3 times per week); 1 control	6/11; ‘good’	4	1-3	20 trials	Points scored; shots scored

Note. MI = mental imagery; PP = physical practice; AO = action observation; COV = coefficient of variation; EMG = electromyography; NA = not applicable; NR = not reported; IGF = International Gymnastics Federation; CFSA = Canadian Figure Skating Association.



			Action requirements				
			Body stability		Body transport		
			No object manipulation	Object manipulation	No object manipulation	Object manipulation	Increasing task difficulty
Environmental conditions	Stationary regulatory conditions	No intertrial variability	(1)	(2) Basketball, free throw; Dart throwing; Golf, putting	(3)	(4) Soccer penalty kick; Soccer pass; Forehand serve, Table Tennis; Forehand shot; Backhand shot, and serve; Volleyball pass; Hockey penalty flick; Netball, shooting (still)	
		Intertrial variability	(5)	(6)	(7) Karateka; High jump	(8) Lay-up shot, Basketball; Netball, shooting while being marked; Netball, shooting having the ball passed	
	In-motion regulatory conditions	No intertrial variability	(9)	(10)	(11)	(12)	
		Intertrial variability	(13)	(14)	(15) Acrobatic gymnastics; Figure skating; Trampoline	(16) Tennis service return; Tactical game drills, Basketball	
			Increasing task difficulty				

Figure 3.2. Two-dimensional skill classification taxonomy (Adapted from Gentile, 2000). Number in top left-hand corner denotes the classification of complexity

3.4.4. Overall effect of MI

The random effects included in the model comprised of overall effect size, expressed as Hedges' g, calculated for the following conditions: MI + PP, PP, MI alone, and no practice controls. Hedges' g for each study were statistically dependent. A total of 135 individual effects were extracted from the included studies. A composite approach was implemented to account for statistical dependence to provide an overall conservative effect for each study (see section 2.7). Subsequently, a total of 58 individual effects were used for analysis from the following conditions: MI + PP, MI alone, PP, and control. Tables 2 and 3 provide an overview of overall results for subgroups and comparisons conducted between subgroups. The overall analysis revealed a significant moderate effect ($g = 0.754$; 95% CI = 0.557, 0.951; $p < .001$) for MI on skill outcomes. Duval and Tweedie's trim-and-fill analysis revealed publication bias might be present. With the trim-and-fill correction applied, the overall effect of MI was adjusted to be small and significant ($g = 0.476$, $p < .001$). A forest plot of individual effects and the overall effects of MI, MI + PP, and MI alone is presented in Figure 3.

The statistical heterogeneity of MI effects on performance was significant ($Q = 100.650$, $p < .001$) and was indicative of substantial heterogeneity ($I2 = 66.2\%$). These findings suggest that the variability within the included studies could be due to other moderating factors instead of sampling error. Therefore, subgroup analysis and meta-regression were performed on predefined MI program variables to identify potential sources of heterogeneity.

3.4.5. Mental imagery delivery type

Subgroup analysis for the moderator variable MI delivery type revealed a significant impact on skill performance following practice using MI + PP ($g = 0.868$; 95% CI = 0.603, 1.133; p < .001), PP (g = 0.877; 95% CI = 0.575, 1.179; p< .001) and MI alone (g = 0.612; 95% CI = 0.317, 0.907; p < .001). With Duval and Tweedie's trim-and-fill correction applied the overall effect of MI + PP was adjusted and becoming small and significant (g = 0.579, p < .001) and MI alone still showed a small significant effect (g = 0.298, p < .001) on performance outcomes. Z - tests revealed MI + PP had a significant impact on performance outcomes compared with control groups (z = 3.935; 95% CI = 0.376, .095; p < .001). MI alone compared with control groups revealed a significant between-group difference (z = 2.413; 95% CI = 0.089, 0.862; p < .001), which was not the case when compared with PP (Table 3).

3.4.6. Skill level

For the moderator variable skill level subgroup analysis revealed that MI programs significantly improve performance across both novice and skilled participants (Novice; g = 0.912; 95% CI = 0.600, 1.222; p < .001) (Skilled; g = 0.567; 95% CI = 0.329, 0.805; p < .001). Between-group variability was significantly heterogeneous (Q = 7.815, p = .002), indicating that effect sizes may be different between groups (Table 3). However, z - tests revealed that MI with novices was not significantly more effective than skilled performers (z = 1.721; 95% CI = -0.047, 0.736; p = .085).

3.4.7. Skill complexity

Using Gentile's (2000) two-dimensional framework, analysis of the moderator variable skill complexity showed that MI significantly improves performance of sport-specific motor skills classified between one to eight (1 – 4; g = 0.883; 95% CI = 0.660, 1.107; p < .001) (5 – 8; g = 0.585; 95% CI = 0.180, 0.990; p < .05), which was not the case for more complex skills (13 – 16; g = 0.212; 95% CI = -0.081, 0.505; p = .156). The variability between sub-groups was heterogeneous (Q = 12.80, p < .001) indicating that effect sizes significantly differed. Subgroup analysis revealed that MI has a significant impact on skills classified between 1 – 4 and 13 – 16 (z = 3.57; 95% CI = 0.302, 1.040; p < .001).

3.4.8. Program duration

For the moderator variable "program duration" subgroup analysis showed that MI has a significant positive effect on sport-specific motor skills for programs 3 days – 1 week (g = 0.909; 95% CI = 0.249 1.568; p < .05), 1–3 weeks (g = 0.823; 95% CI = 0.547, 1.099; p < .05), and 4 – 6 (g = 0.817; 95% CI = 0.556, 1.077; p < .05). Between-group, variability was not significantly heterogeneous (Q = 4.584, p = .205), suggesting that effect sizes did not vary between groups and z - tests revealed no significant differences between MI programs of different lengths (Table 3).

3.4.9. Session Frequency

Weekly session frequencies of once per week were only identified in one study and subsequently contributed only one combined effect size and, therefore, was removed from further analysis. Subsequent subgroup analysis revealed that MI practice had a significant impact on skill performance when implemented for 2 – 3 (g = 0.840; 95% CI = 0.579, 1.101; p < .001), 4 - 5 (g = 0.697; 95% CI = 0.274, 1.119; p < .001), and 6 + (g = 0.660; 95% CI = 0.199, 1.121; p < .001) sessions per week. Between-group, variability was not significantly heterogeneous (Q = 0.606, p = .739), suggesting no differences between effect sizes. Z - tests revealed no significant differences between MI programs with different frequencies. These results indicate a robust effect of MI programs of different weekly session frequencies.

3.4.10. Elements of skill performance

Subgroup analysis of the moderator variable performance measures revealed that MI had a significant positive effect for performance outcome measures (g = 0.822; 95% CI = 0.608, 1.036; p < .001) but not for process measures (g = 0.158; 95% CI = -0.083, 0.399; p =

.198). Analysis of between-group variability showed significant heterogeneity (Q = 12.800, p < .001), indicating that effect sizes varied between subgroups. Z - tests revealed that MI practice had a significantly larger effect on performance outcomes than process measures (z = 4.039; 95% CI = 0.341, 0.985; p < .001).

3.4.11. Practice setting

Studies were categorised into four setting levels; controlled research, sports coaching, physical education, and not reported. The physical education sub-group contributed no effects and the Not reported category only contributed one study and could not be included in further analyses. Results indicated that MI had a significant positive effect for controlled research setting (g = 0.820; 95% CI = 0.623, 1.017; p < .001) and sport coaching (g = 0.669; 95% CI = 0.087, 1.250; p = .024). Between-group variability was not significantly heterogeneous (Q = 4.533; 95% CI = -0.464, 0.766; p = .630), indicating no significant differences between effects. Z - tests confirmed that there were no significant differences between controlled research and sports coaching subgroups.

Table 2. Effects for included studies with 95% confidence intervals and sub-groups comprising each program variable

Sub-group	*j*	*k*	*g*	95% CI		d*f*	*Q*	*z*	*p*
				LL	*UL*				
MI overall	20	35	0.754	0.557	0.951	34	100.650	7.493	< .001
Practice type									
MI + PP	13	21	0.868	0.603	1.133	20	59.289	6.417	< .001
MI alone	10	14	0.612	0.317	0.907	13	36.531	4.069	< .001
PP	10	10	0.877	0.575	1.179	9	19.144	5.691	< .001
Control	13	13	0.136	-0.142	0.397	12	31.230	1.070	.285
Skill level									
Novice	10	18	0.911	0.600	1.222	17	59.238	5.734	< .001
Skilled	9	16	0.567	0.329	0.805	15	32.30	4.664	< .001
Skill complexity									
1 – 4	16	30	0.883	0.660	1.107	29	86.551	7.741	< .001
5 – 8	2	4	0.585	0.180	0.990	3	3.985	2.832	.005
13 – 16	3	4	0.212	-0.081	0.505	3	3.224	1.418	.156
Performance measures									
Performance outcome	17	32	0.822	0.608	1.036	31	92.842	7.541	< .001
Performance process	5	6	0.158	-0.083	0.399	5	4.548	1.287	.198

Table 2 (Continued)

Program Duration									
3 days – 1 week	4	7	0.909	0.249	1.568	6	30.304	2.701	.007
1 – 3 weeks	2	4	0.823	0.547	1.099	3	1.0355	5.840	< .001
4 – 6 weeks	10	19	0.817	0.556	1.077	18	43.857	6.150	< .001
> 6 weeks	4	5	0.322	-0.106	0.750	4	11.120	1.474	.140
Session Frequency (per week)									
2 – 3	13	24	0.840	0.579	1.101	23	75.467	6.311	<.001
4 – 5	5	8	0.697	0.274	1.119	7	21.340	3.233	< .001
6 +	2	4	0.660	0.199	1.121	3	6.561	2.807	< .001
Practice Setting									
Controlled research	24	27	0.820	0.623	1.017	26	56.650	8.140	< .001
Sport coaching	9	7	0.669	0.087	1.250	6	31.187	2.54	.024

Note. *j* = number of studies; *k* = number of effect sizes; *g* = Hedges' g; CI = confidence interval; *LL* = lower limit; *UL* = upper limit; d*f* = degrees of freedom. *Q* statistic and degrees of freedom were used to test for heterogeneity of effect size variance. *Z*-scores and associated *p*-values indicate whether effects were significantly different from 0.

Table 3. Difference in Hedges' g for included studies with 95% confidence intervals and sub-groups comprising each moderator variable. Q statistic was used to test for heterogeneity of effect size variance. Z - scores and associated p-values indicate whether effects were significantly different from 0.

Sub-group	Difference	95% CI		*Q*	*z*	*p*
		LL	*UL*			
Practice type						
MI + PP - PP	-0.009	-0.410	0.392	23.11	-0.044	.964
MI + PP - MI	0.255	-0.141	0.651	23.11	1.262	.206
MI + PP - Control	0.731	0.367	1.095	23.11	3.935	< .001
PP - MI	0.265	-0.157	0.686	23.11	1.228	.215
MI - Control	0.476	0.089	0.862	23.11	2.413	< .001
Skill level						
Novice - Skilled	0.344	-0.047	0.736	7.82	1.721	.085
Program Duration						
3 days – 1 week - 1-3 weeks	0.086	-0.628	0.800	4.584	0.236	.813
3 days – 1 week – 4 – 6 weeks	0.092	-0.616	0.801	4.584	0.255	.798
3 days–1 weeks - >6 weeks	0.587	-0.199	1.372	4.584	1.463	.143
1 – 3 weeks – 4 - 6 weeks	0.006	-0.373	0.385	4.584	0.031	.974
1 – 3 weeks - >6 weeks	0.501	0.008	1.010	4.584	1.927	.054
4 – 6 weeks - > 6 weeks	0.495	-0.006	0.995	4.584	1.935	.052

Table 3. (Continued)

Skill complexity						
1 – 4 – 5 – 8	0.298	-0.164	0.760	12.800	1.263	.206
1 – 4 – 13 – 16	0.672	0.302	1.040	12.800	3.57	< .001
5 – 8 – 13 – 16	0.373	-0.126	0.873	12.800	1.463	.143
Performance Measures						
Outcome - process	0.664	0.341	0.985	16.32	4.039	< .001
Session Frequency						
2 – 3 – 4 – 5	0.143	-1.015	1.300	0.61	0.242	.809
2 – 3 - 6 +	0.179	-1.010	1.369	0.61	0.296	.767
4 – 5 - 6 +	0.037	-1.279	1.353	0.61	0.055	.956
Practice setting						
Controlled - Sport coaching	0.151	-0.464	0.766	4.533	0.482	.630

Note. CI = confidence interval; *LL* = lower limit; *UL* = upper limit; d*f* = degrees of freedom. *Q* statistic and degrees of freedom were used to test for heterogeneity of effect size variance. *Z*-scores and associated *p*-values indicate whether effects were significantly different from 0.

3.5. Discussion

The present review aimed to investigate the overall effectiveness of MI practice programs on the performance of sport-specific motor skills. Following this, moderator variables were examined to identify potential sources of heterogeneity in the effect of MI on the performance of sport-specific motor skills. As predicted, MI had an overall significant, positive effect ($g = 0.476$) on the performance of sport-specific motor skills, as measured by outcome and process measures. This finding is consistent with previous meta-analyses on MI focusing on performance outcomes for general motor and cognitive skills and overall sports performance, which found effect sizes of $d = 0.527$ (Driskell et al., 1994), $d = 0.419$ (Toth et al., 2020), and $d = 0.431$ (Simonsmeier et al., 2021).

Our findings also identified moderator variables that impact the effect of MI on the performance of sport-specific skills, such as MI delivery type, skill complexity, and type of performance measure. When considering MI delivery type, as hypothesised, MI alone was more effective than no practice controls. This finding has important implications for training periods where PP needs to be decreased, or training load needs to be monitored (e.g., tapering in training). MI alone would provide an alternative type of practice without the added physiological load of PP. This point is particularly poignant for populations regularly utilising high training volumes (e.g., elite athletes).

Contrary to our hypothesis, however, MI + PP was not found to be significantly better than PP alone. These findings are inconsistent with previous research reviews of imagery in general (Simonsmeier et al., 2021) which indicate MI + PP to be superior to PP. A possible explanation for these disparate findings may be that an inadequate volume of MI practice being programmed to produce beneficial effects over and above PP. Moran and O'Shea (2019) suggest that practitioners aim to have the learner practice the skill once for every 10

MI trials. In the present review, 23 of the included studies programmed MI practice in minutes instead of the actual number of MI trials completed, making it challenging to complete the actual practice volume. If MI is equivalent to PP, MI programs need to delineate a specific number of trials being completed to quantify the ratio of practice compared with PP (Holmes & Collins, 2001).

Regarding the skill complexity moderator, as predicted, the magnitude of effects was significantly higher for simple skills (1 – 4) compared with more complex skills (13 – 16). A potential explanation for these findings is the potential interaction between skill complexity and skill level. Contrary to previous reviews (e.g., Driskell et al., 1994), novice performers displayed larger improvements than skilled performers, although differences between groups did not reach significance. This finding may be explained by the uneven distribution of effects within the different levels of skill complexity. Studies included in the review with novice performers (n = 22), except for one study, examined simple skills (1 – 4), whereas 47% of studies with skilled performers involved complex skills (5 – 8 and 13 – 16). These findings are consistent with the power law of practice (Newell & Rosenbloom, 1981) in which quick improvements in performance characterise the early stages of learning a skill and smaller performance gains as practice progresses as the learner's level of performance is much higher and would also make sense that rapid improvements occur initially in learning a skill that is lower in complexity (Spittle, 2021). Therefore, a reduced magnitude of change using MI would be expected for complex skills practiced by skilled learners due to smaller available performance increases (Spittle, 2021).

The findings highlight that for optimal effectiveness, the skill level of the learner and the complexity of the skill should be matched. This idea is consistent with the learning element of the PETTLEP model, which explains that MI practice should consider the skill level of the learner and skill, and adapt MI content accordingly (Wakefield & Smith, 2012).

Wakefield and Smith (2012) suggest that MI content should be regularly updated to reflect skill development, with more complex skills matching technical developments. By examining skill complexity, we have extended previous meta-analytic research by going beyond broadly applied skill types (e.g., cognitive or motor skills) through the utilisation of Gentiles' (2000) two-dimensional skill classification framework to define and analyse the complexity of skills being practiced. However, it should be noted; there is a dearth of research investigating the use of MI to improve complex skills, with only five out of 58 individual effect sizes from studies using skills classified as being high in complexity (13–16) according to Gentile's (2000) classification framework. Further research is needed on the differential impact of MI and the development of complex skills. As MI practice of complex skills may have implications on how program design variables (e.g., practice duration, intervention duration) moderate the effectiveness of MI for skill performance.

Analysis of practice context revealed that MI practice positively affected skill performance when implemented in controlled research and sport coaching setting. However, these findings should be interpreted with caution. Of the 36 studies, only 10 were conducted in actual physical education (n = 1) and sport contexts (n = 9), with most studies (n = 24) implementing MI in a controlled setting with the intervention run by the investigators. This meant that a review of MI in physical education and sport coaching contexts was significantly limited. A key concept from the skill acquisition literature is representative learning design, which explains that tasks should aim to incorporate as much contextual information into practice as possible (Correia et al., 2019). Findings from the present review highlight a dearth of research investigating the use of MI in naturalistic, real-world contexts such as physical education and sport coaching. Further research is needed in these contexts, as this may have implications on how program variables moderate the effectiveness of MI when applied in dynamic, real-world settings (Spittle, 2021).

Elements of skill performance were found to be a significant moderator of the effectiveness of MI practice, with outcome focussed measures improving to a greater degree than process measures. An explanation for these findings might be that studies using process measures investigated more complex skills than those using outcome measures. When analysing process measures, 60% of the extracted data was on moderate to highly complex skills (5 – 8 and 13 – 16) compared with 9% of studies using outcome measures. Focus of attention is another potential explanation for these results. Previous research in PP has consistently shown that an external focus of attention (i.e., attention focussed on the movement outcome) is more effective than an internal focus (i.e., instructions that focus on specific movement elements) (Wulf & Prinz, 2001). Such effects have been reported when using an external focus of attention with MI for tennis serve accuracy (Guillot et al., 2013). Studies that focused on improving outcome measures may have directed learners to adopt a more external focus of attention, potentially influencing the effectiveness of MI practice.

In partial support for our hypothesis, MI programs of 3 days – 1 week and up to 6 weeks were all found to significantly improve sport-specific motor skills, with the magnitude of effect decreasing as program length increased. However, there were no significant differences between other durations. These findings on MI align with previous meta-analytic reviews, which suggest that programs between 1 – 6 weeks are most effective (Toth et al., 2020). Similarly, MI session frequency improved performance significantly, and the magnitude of effect decreased as weekly sessions increased. Although program duration and session frequency appear not to moderate the effect of MI on sport-specific motor skills, these findings demonstrate that MI is a robust practice method that is effective across various intervention lengths and weekly sessions.

3.5.1. Considerations for physical educators and sports coaches

Results from the present review have highlighted a significant gap in the literature on MI in actual physical education and sport coaching contexts. Although most of the research presented in this review was conducted in controlled research settings, there are clear parallels between the skills practiced in these studies and those implemented in physical education and sport coaching. Therefore, it is encouraged that physical educators and sports coaches collaborate with sport psychology practitioners to investigate the efficacy of the several MI factors presented in this review. Figure 4 summarises considerations for developing and implementing an MI practice program in physical education and sport coaching settings. These variables should be considered when designing an MI program aiming to develop sport-specific motor skills.

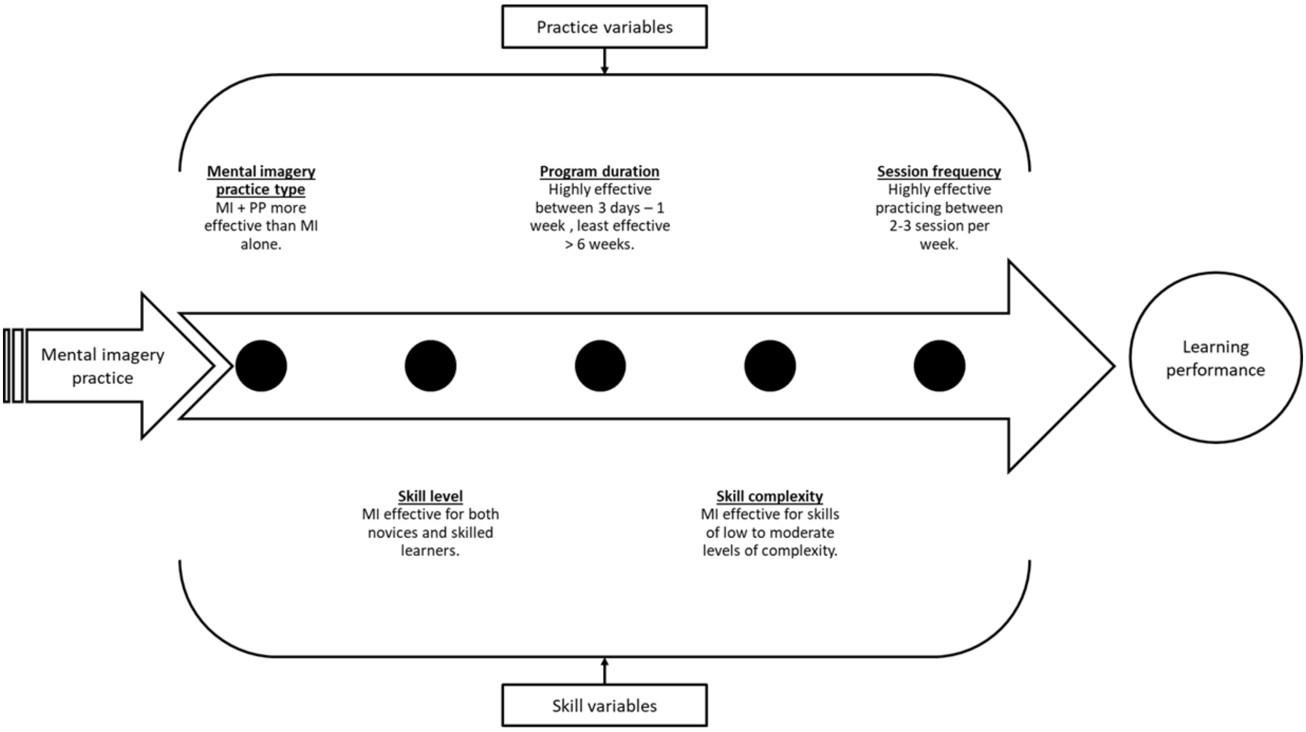


Figure 3.3. Considerations for MI practice programs for the development of sport-specific motor skills

3.5.2. Limitations

While the current review provides an overview of the effectiveness of MI for developing sport-specific motor skills, the results should be considered concerning several limitations. Limitations of the research are the evident lack of studies conducted in sports coaching and physical education contexts, with most studies conducted in controlled research settings. Furthermore, a considerably low number of studies have examined skilled performers, complex skills (13–16), and performance process measures. This could explain the inconsistency observed with previous reviews, with skilled performers significantly better when using MI. In contrast, the present analysis revealed similar effects for novice and skilled performers. The present review aimed to examine several key variables as determined by previous reviews. However, it is possible that other factors that were not assessed could also explain and contribute to the observed effectiveness of MI programs. Therefore, caution is advised when interpreting the results of the present review.

3.5.3. Conclusions

The present review highlights that MI programs have a significant positive effect on developing sport-specific motor skills. Variables such as MI delivery, skill complexity, skill level, duration, and session frequency were found to be important factors for the development of sport-specific motor skills. Results indicate a spectrum of effectiveness for MI practice type, with MI + PP producing more significant performance improvements than MI alone. Overall, skill complexity and elements of skill performance were found to be moderators of performance outcomes of sport-specific motor skills. Analyses revealed that MI programs are more successful with less complex skills and outcome-based measures. The summary of MI research in our meta-analysis highlights a paucity of research on the effects of MI on complex skills and in physical education and sport coaching contexts. Further research is needed to understand better how MI impacts more complex skills and the development of sport-specific motor skills in physical education and sport coaching. We conclude that MI is an effective tool for developing sport-specific motor skills, both when combined with PP and when implemented independently.

Chapter 4:Applying principles of nonlinear pedagogy to mental imagery interventions for skill acquisition

Background

Previous research indicates that MI and physically executed actions share the same neurophysiological mechanisms and draw on a similar mental representation system involved in generating physical movements (Moran & O'Shea, 2020). These shared mechanisms are often referred to when explaining how MI effectively produces similar training related adaptations as physical practice (e.g., improved motor performance). Subsequently, a key focus of MI program design has centred around replicating the same training conditions produced when physically practicing a particular skill. The present chapter focuses on how skill acquisition approaches utilised in physical practice, such as nonlinear pedagogy (NLP), may be adapted and replicated in MI training for the purpose of skill development. Given the emphasis on creating MI interventions that replicate PP, the application of key NLP practice design principles could be a viable approach for facilitating the development of adaptable, individualised skills that support learner to cope with dynamic performance contexts. Therefore, an outline of an ecological dynamics perspective of skill acquisition in PP is presented. Following this key NLP practice design principles are discussed. Finally, NLP principles are presented alongside practical examples of how these principles could be integrated alongside existing MI guidelines. The overall purpose of this chapter is to provide a theoretical foundation to inform the practical application of NLP to MI presented in Chapter 6 of this thesis.

This Chapter is presented in pre-publication format of an article currently under review titled:

Lindsay, R., Chow, J-Y., Larkin, P., Spittle, M. (in review). Applying principles of nonlinear pedagogy to mental imagery interventions for skill acquisition. *Journal of Sport Psychology in Action.*

4.1. Abstract

Research findings indicate that mental imagery (MI) effectively enhances skill development and performance. A frequently proposed explanation for the beneficial effects of MI is the activation of shared neural mechanisms and the capability to produce similar training-related adaptations to physical practice. Subsequently, existing MI guidelines emphasise that MI should aim to replicate critical aspects of physical practice as closely as possible. Therefore, this article aims to provide practical recommendations for sports psychologists on applying a contemporary skill acquisition framework; Nonlinear Pedagogy (NLP), to facilitate MI practice design that replicates essential principles of physical practice. Accordingly, this article presents an ecological dynamics perspective on developing skilled behaviour to bring attention to different focus points for practitioners when developing skills with MI. The overall purpose is to introduce fundamental NLP design principles and present specific examples for sports psychologists on how these principles may be applied for MI interventions.

Keywords: mental imagery, Nonlinear Pedagogy, representative design, constraints, skill acquisition

4.2. Introduction

Mental imagery (MI) in applied sport psychology is defined as a cognitive simulation of perceptual and movement information in the absence of a physical stimulus (Morris et al., 2005). A number of studies attest to the efficacy of MI (Lindsay et al., 2021; Simonsmeier et al., 2021) for developing a range of motor skills, particularly when combined with physical practice. The proposed benefits of MI are often contextualised through motor simulation theory (MST), indicating that MI and physical practice share similar neural structures and are, therefore, functionally equivalent (Moran & O'Shea, 2020).

For the development of motor skills, MI interventions often adhere to a paradigm that purports the motor learning process to be linear, in which skilled behaviour is developed from task repetition, where over many iterations there is a reduction of variability in repeated movements (Lindsay et al., 2021). From this perspective, coaches or practitioners possess a pre-existing representation of an ideal or optimal mental model of what skilled action is and learning is then a process of transferring this model to the learner (Renshaw & Chow, 2019). In MI, this perspective is highlighted by the use of technical descriptions provided by skilled athletes, coaches, or researchers that are often considered to provide an optimal model of performance for learners to replicate (Cooley et al., 2013). Conversely, from a Nonlinear Pedagogy (NLP) perspective, the learning process is neither linear nor easy to quantify (Chow et al., 2022). Grounded in an ecological dynamics rationale and drawing on a constraints-based methodology, a NLP approach to skill acquisition views humans as nonlinear, dynamical systems, emphasising that skill acquisition occurs in dynamic contexts and movement patterns emerge from continuous interactions between the learner and environment (Chow et al., 2022). A key principle of NLP is that movement variability plays a functional role in the skill acquisition process. Movement variability increases exploratory behaviour and can facilitate learners to develop individualised performance solutions that match specific individual constraints, skills and experiences (Chow et al., 2022). NLP provides a skill learning framework that infuses variability into practice to encourage learners to explore individualised movement solutions to foster the capability to successfully adapt behaviour in the face of dynamically changing conditions (Renshaw & Chow, 2019). The ability to adapt in this sense is a key attribute of elite level athletes and enables performance to be maintained across varied competitive environments (Ranganathan et al., 2020). Given that physical practice and MI processes are related, the investigation of an NLP approach for skill acquisition in MI appears a worthwhile endeavour. A key attribute of skilled behaviour is adaptability, the capacity to adjust movement patterns to altered conditions while maintaining performance (Renshaw & Chow, 2019). Key design principles of NLP provide practical guidelines on how practitioners could help learners develop attributes such as adaptability using MI. For example, rather than providing a specific movement form, MI content could incorporate details of nets that differ in height across tennis practice (e.g., task constraint) and tell leaners to try and hit the ball toward a target. This would require learners to adapt movements continuously to the different net heights to achieve performance outcomes. Further, instead of having learners use MI to hit to a target, details could describe an actual opponent and the noise of a crowd. Such details would capture the NLP design principle of representativeness, an important consideration for practitioners when assessing whether practice environments actually represent the demands of competitive performance (Chow et al., 2022). These are just some examples of how NLP could be relevant to MI interventions. Yet, to date, limited research has discussed the practical considerations of MI within the context of NLP and how it could potentially enhance the learning effects of MI for the learner. Therefore, the purpose of this article is to introduce sport psychologists to key practice design principles of NLP, and outline considerations relating to the application of these principles to the design of MI interventions.

4.2.1. Benefits of mental imagery for skill acquisition

There has been a considerable amount of research attesting to the efficacy of MI for improving skill performance and acquisition in a range of settings such as sport, music, dance, and even surgical skills (Simonsmeier et al., 2021). In a recent meta-analytic review by Simonsmeier et al. (2021) MI programs in sport were found to have a moderate positive effect on motor learning and performance ($d = 0.416$). Similarly, Lindsay et al. (2021) revealed consistent findings in a review focusing exclusively on sport-specific skills (i.e., motor skills that are explicitly applied to a specific sport; Breed and Spittle, 2020), with MI having a significant moderate effect on skill performance ($g = 0.476$). Such research has highlighted the versatility and efficacy of MI practice for a diverse range of motor skills from open, reactive motor skills executed in dynamic environments, such as netball shooting under defensive pressure, and tactical game drills in basketball through to closed, self-paced motor skills, including golf putting and gymnastics (Lindsay et al., 2021; Toth et al., 2020). For example, Smith et al. (2008) compared the effect of physical practice alone against two MI interventions involving (i) MI alone, and (ii) MI combined with physical practice for golf bunker shot. Following a six-week intervention period, the MI combined with physical practice condition was found to produce significant improvements in shot accuracy ($d = 2.10$), relative to the physical practice alone condition ($d = 1.37$). Interestingly, the MI alone condition demonstrated a significant increase in accuracy ($d = 0.80$), indicating that MI alone is still effective, yet, appears inferior to physical practice combined with MI.

Further research indicates that the efficacy of MI interventions may vary across different skill classifications. Lindsay et al. (2021) found the benefits of MI to be moderated by skill complexity with the magnitude of effects being significantly greater for less demanding skills like golf putting ($g = 0.585$) compared with more complex skills, such as figure skating or acrobatic gymnastics (*g* = 0.212). Taken together, these findings indicate that MI interventions can effectively facilitate improvements in skill performance in sport-based tasks, but efficacy may vary across different skill classifications.

4.2.2. Neurophysiological mechanisms underlying mental imagery

Motor simulation theory (MST) is often proposed to explain the underlying mechanisms responsible for MI. This theory posits that MI and physically executed actions share the same neurophysiological mechanisms and draw on a similar mental representation system involved in generating physical movements (Moran & O'Shea, 2020). Therefore, MI and physical action are functionally equivalent due to shared neural mechanisms utilised during motor execution. This is referred to as the *functional equivalence* (FE) hypothesis (Chow et al., 2022). Consistent with this hypothesis, Hétu et al. (2013) reported that MI appears to rely on similar motor related regions of the brain as motor execution including the premotor cortex (IFG, SMA), parietal cortex (IPL, SMG, SPL), and fronto-parietal regions (basal ganglia, putamen and pallidum). Specifically, fronto-parietal regions, such as the basal ganglia, putamen and pallidum appear particularly important for MI as these areas have been associated with the selection of motor programs during physically executed actions (Hétu et al., 2013). Subsequently, repeated activation of these regions of the brain through MI practice is proposed to be responsible for the observed improvements in skill performance and learning (Moran & O'Shea, 2020).

According to MST, MI is proposed to be involved in an early covert stage of motor execution that simulate action details such as the overall movement goal, motor program, and the predicted outcome of the physical action (Moran & O'Shea, 2020) Captured this way, MI improve performance and learning by preparing the performer for action through simulating and refining the processes involved in skill execution (Moran & O'Shea, 2020). For example, Leung et al. (2013) showed that following a three-week training period, MI training alone and physical training of a bicep-curl exercise produced equivalent increases in corticospinal excitability, which indicates that MI engages covert movement execution processes. Further, these findings demonstrate that MI and physical execution do not just share similar neural structures, but also indicate the MI is capable of producing similar training-related adaptations in central neural structures to those generated in physical training.

4.2.3. Implementation of mental imagery training

When implementing MI interventions in applied contexts, established techniques exist to guide practitioners in developing and delivering successful MI intervention. Currently, MI interventions are typically delivered using an MI *script* to guide the learner through the imagined action (Cooley et al., 2013). A commonly utilised approach to script development in sport is the PETTLEP model, which features prominently in applied research due to its focus on practical considerations for MI practice. Drawing on the functional equivalence hypothesis, the PETTLEP model is centred around designing practice that replicates, as closely as possible, the physical elements of the movement being practiced, focusing on maximising the equivalence between imagined and actual behaviours (Wakefield et al., 2013). Subsequently the PETTLEP model is proposed to provide practitioners with a set of parameters to guide the use of MI in a practical setting with the aim of making programs more functionally equivalent with physical practice. The model uses an evidence based seven-point checklist that includes: physical, environmental, task, timing, learning, emotional, and perspective aspects of imagery. The real strength of the model is that it provides a robust method or process to implement MI with the goal of improving performance, which was the specific intention of why this model was designed. Though the PETTLEP framework has consistently demonstrated positive effects in a range of motor skills (Wakefield et al., 2013), a potential limitation is the isolated drill-like approach to MI practice. For example, in a study by Wakefield and Smith (2009) exploring the impact of PETTLEP MI on netball shooting accuracy, a transfer test was implemented, whereby participants were tested pre-post intervention on shooting while a defender was present or after receiving a pass. During the intervention, however, MI content did not include details on the defender or the pass. From an NLP perspective, the key principles of representative learning and information-movement coupling suggest that practice should simulate critical elements of the performance context (i.e., defensive pressure or the presence of other team members) to help learners become better attuned to relevant information to establish information-movement couplings that support successful performance (Chow et al., 2022). Applied to MI, this could entail MI content that refers to important aspects of the performance environment, such as the presence of defenders in an attacking situation during soccer. Thus, the key point highlighted here is that MI practice can be designed to be executed in alternative ways. Specifically, MI practice that can be supported by NLP principles to facilitate individualised skill development.

Overall, imagery scripts tend to prescribe a particular technical model of the skill being practiced. In a systematic review, (Cooley et al., 2013) identified four main sources of information in the development of MI scripts: physical task, research experience, and participants. Regarding physical task, scripts provided a general description of the task, the location, and technical details of the task provided by an expert performer. Individuals' experience of the task also emerged as a source of script information, with researchers, elite coaches, and elite athletes all being identified as providing details for the formation of MI scripts. These findings suggest that MI instructions tend to be designed around a pre-determined optimal expert model, often derived from researchers, elite coaches, or elite athletes.

Such an approach to MI interventions is not ineffective, as the previous section shows, with a number of studies demonstrating its efficacy (Simonsmeier et al., 2021). However, a key feature of skilled behaviour is *adaptability* (Button et al., 2020), with highly skilled athletes being able to adapt to varied performance environments to find optimal task solutions. This notion is supported by observational research in elite athletes. Akkuş (2012) observed that seven elite-female weightlifters all demonstrated different movement patterns, some considered 'sub-optimal', but maintained high levels of performance (i.e., gold medals). These results suggest that reproducing 'optimal' technique is not a prerequisite for skilled behaviour, rather the capacity to adapt and produce stable individualised performance solutions in competitive environments is critical (Button et al., 2020). Therefore, the aim of developing skilled behaviour may not necessarily be confined to reproducing expert technical models, but rather to facilitate exploration of individualised performance solutions (Chow et al., 2022; Renshaw & Chow, 2019). From this perspective, an alternative approach to skill development may be a fruitful line of enquiry to contribute to our understanding of how practitioners can design MI interventions to encourage the development of individualised, adaptable performance solutions. In the following section we will discuss the potential application of a Nonlinear Pedagogy (NLP) approach to the development of MI interventions.

4.2.4. Taking a nonlinear pedagogy approach to skill acquisition

The implementation of a NLP approach to practice design requires a shift in thinking regarding how skill behaviour is conceptualised. NLP adopts an ecological dynamics rationale to skill acquisition that advocates for the considered incorporation of movement variability into practice to amplify exploratory behaviour and facilitate learners to develop individualised performance solutions that match individual capacities (Chow et al., 2022) This approach to skill acquisition emphasises the performer-environment relationship in practice design, where individual, task, and environmental constraints interact to produce skilled behaviour (Chow et al., 2022). NLP embraces movement variability in developing coordinated behaviour as a major feature of skill acquisition.

4.2.4.1. Ecological dynamics perspective of skill

Traditionally, the development of skilled behaviour has been defined as a process focused on “the enrichment and acquisition of mental representation that lead to changes in internal states that underpin the development of accurate and consistent actions through practise in specific performance domains” (Renshaw & Chow, 2019, p. 105). Similar to the construction of MI scripts (Cooley et al., 2013), the focus of such an approach is that skilled behaviour is developed through the regular repetition and replication of a predetermined mental representation of what constitutes ‘optimal’ technique (Renshaw & Chow, 2019). Therefore, practice is designed to strengthen motor programs that can be utilised across a variety of movement situations (Spittle, 2021).

An alternative ecological perspective and one that underpins a NLP approach is that skill acquisition is a process of developing the capacity to adapt actions in dynamic environments leading to specific, relevant performance solutions. Therefore, learning is more a process of developing the ability to adapt behaviour to the environment (i.e., an emphasis on learner-environment mutuality), rather than acquiring a specific pattern of movement (Renshaw & Chow, 2019). Practitioners become designers of practice environments to encourage learners to explore and exploit functional relationships with the performance environment, rather than trying to enforce a predetermined ‘expert’ technique (Chow et al., 2022). Practice, therefore, should focus of facilitating learners to better attune to opportunities for action (i.e., affordances which pertains to an invitation to act) and develop relevant performance solutions that match individual abilities, experiences and skills (Renshaw & Chow, 2019). Captured this way, skill acquisition may be more appropriately referred to as *skill adaption,* described as an improvement in a learner’s ability to operate effectively within a performance environment, which is constantly being updated and improved (Renshaw & Chow, 2019).

4.2.4.2. Theoretical underpinnings of nonlinear pedagogy

NLP is grounded in principles of ecological psychology and dynamical systems theory, which highlights the importance of coupling information and movement together to facilitate skilled performance, designing practice to create invitations for action (affordances), simulating critical aspects of competitive environments to make practice representative of performance, manipulation of task constraints to facilitate self-organisation processes, and the functional role of movement variability (Chow et al., 2022). This section will briefly summarise these key concepts to provide a theoretical foundation for the application of NLP to MI interventions.

4.2.4.3. Information-movement coupling

From an ecological perspective, sporting environments contain critical information that can be perceived and acted on by learners to constrain their movement patterns. In this way, learning becomes a process of exploring, perceiving, and acting on relevant information sources that serve to guide movement. Gibson (1979, p. 223) summarises this concept by explaining that “we must perceive in order to move, but we must also move in order to perceive”. Subsequently, information in the performance environment regulates motor processes and motor processes directly influence detection of information sources in the performance context, referred to as information-movement coupling (Gibson, 1979). For example, initiation of technical factors (e.g., backswing of bat and front foot movement) in junior cricketers was significantly later when facing a bowling machine, relative to an actual bowler (Pinder et al., 2009). The absence of critical information (i.e., hand and arm position of the live bowler) was explained to contribute to a weakening of information-movement couplings to achieve optimal performance. This study highlights the need to incorporate critical sources of information that are present in the performance environment to facilitate learners to attune to relevant information. Therefore, information-movement couplings do not become available unless practice design includes critical aspects of competitive environments.

4.2.4.4. Affordances

For each individual, their learning environment consists of properties that afford action and can be exploited to achieve particular task solutions (Gibson, 1979). Practitioners can design practice environments in such a way to present affordances to learners and invite particular actions. Within a performance context a large number of affordances exist, but whether a learner perceives these as opportunities for action is dependent on the learner's unique capabilities. A professional basketballer may perceive an opportunity for a 3-point shot from the baseline, whereas an amateur player may not perceive the same opportunity. Therefore, affordances do not share a causal relationship with action, rather they act as constraints (Gibson, 1979). Subsequently, practitioners can manipulate constraints within the practice environment to provide opportunities for action. For example, scaling down the size of a tennis racquet provides opportunities to play forehand or backhand shots in 6 to 7 year olds, whereas a full-size racquet would not afford the same actions (Buszard et al., 2016). This highlights that practitioners can design affordances into practice by careful and considered manipulation of key features of the practice environment to guide exploration of alternative actions.

4.2.4.5. Constraint manipulation

Constraints are defined as the parameters that facilitate a learner's self-organisation processes and are categorised into three types: individual (e.g., physiological make-up, past experiences), task (e.g., scaling of equipment, number of learners involved in task), and environment (e.g., size of playing field) (Chow et al., 2022). Task constraints are of particular interest to practitioners as they can be intentionally manipulated with relative ease. The intentional manipulation of task constraints allows practitioners to guide and invite specific movements from individual learners. In this way, modifying constraints can perturb established behaviours by amplifying movement variability to encourage them to exploration and attunement to key information sources that guide action. In this way, practitioners can guide learners to realise new opportunities for action that align unique individual experiences, development and skills (Renshaw & Chow, 2019).

4.2.4.6. Movement variability

From an ecological dynamics perspective, movement variability, often referred to as exploration, plays a critical role in developing adaptable actions that can achieve relevant performance outcomes (Chow et al., 2022). This process of exploration and adaption is an important part of skill development from a NLP perspective as it facilitates learners to engage with a range of movement patterns, rather than attempt to attain a singular 'optimal' model of performance (Chow et al., 2022). Movement system degeneracy facilitates achievement of different movement solutions for the same task and improves the capacity of learners to perform under varied practice environments (Button et al., 2020). For example, Lee et al. (2014) reported that in novice tennis players, the implementation of task constraints in a training intervention aimed at amplifying movement variability suggested that the ability to harness degeneracy can be trained. Learners exposed to training with manipulated task constraints (e.g., varied net height, court size, and task rules) demonstrated a higher number of movement patterns, relative to a linear pedagogy condition (i.e., repetitive practice), yet, both conditions showed equivalent improvement in performance accuracy (Lee et al., 2014). Practice designed in this way enables practitioners to cater for individual differences by allowing learners to adapt movement by exploring alternate behaviours to achieve performance outcomes (Chow et al., 2022).

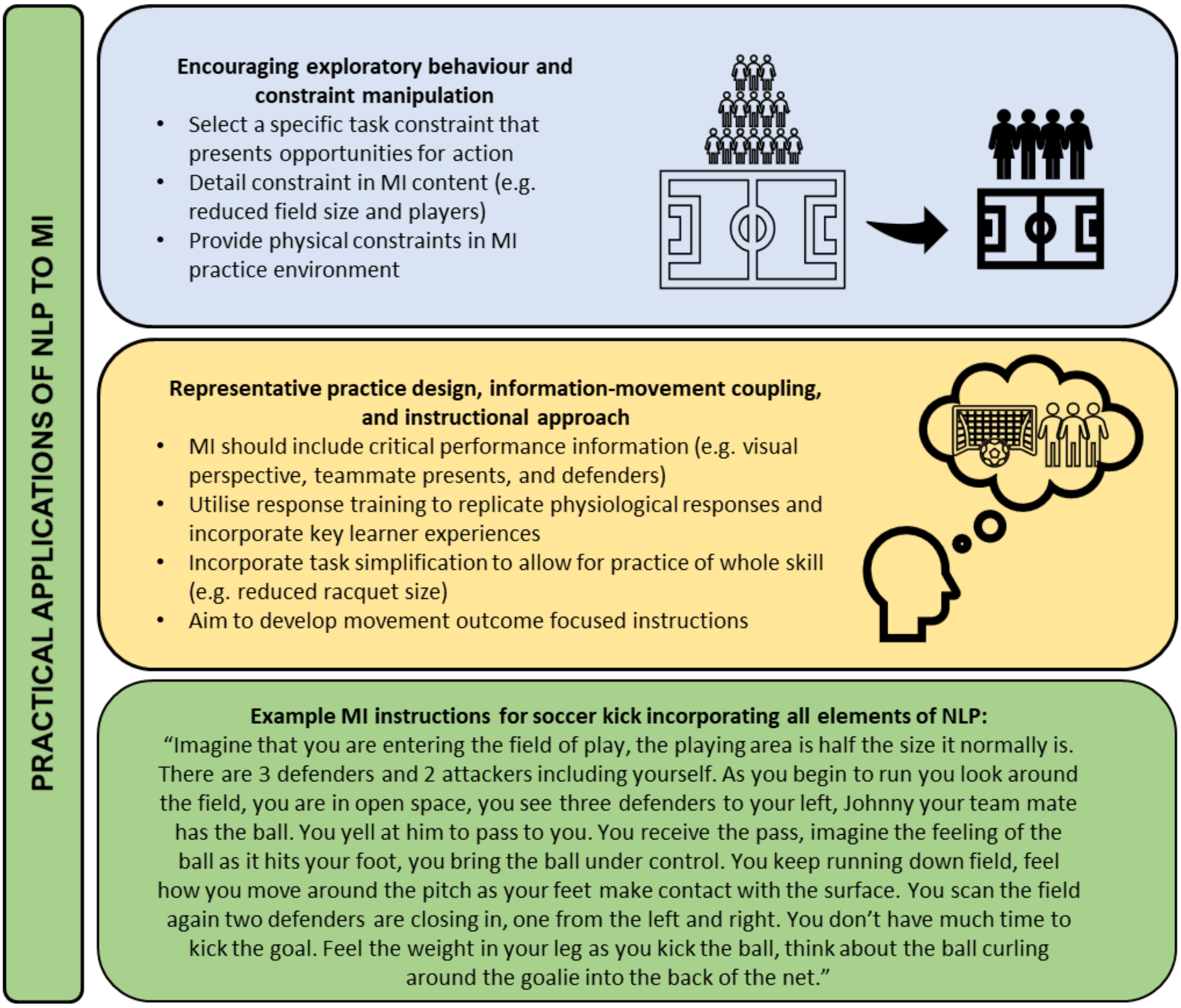
4.2.4.7. Representative practice environments

Finally, an ecological dynamics rationale highlights the importance of accurately simulating critical features of performance contexts in practice environments to develop learner skills (Button et al., 2020). When practice accurately represents the demands of performance, learners are able to better attune to opportunities for action and develop stronger information-movement couplings with reliable and relevant information sources that are present in the actual competition context. For example, practicing attacking plays in rugby without defensive pressure allows for consistent and accurate execution of the plays. But players are only becoming attuned to teammate information under these task constraints. When transferred into a competition environment, the presence of defensive pressure may not provide enough time to perceive the position and movement of defenders to appropriate time and select the appropriate pass. Further information about defenders is necessary in this example to provide a more representative practice environment. Therefore, a key task for coaches and practitioners is to consider whether learning environments look and feel like actual performance and are similar affordances present in practice that are available in competition to facilitate the emergence of functional information-movement couplings (Chow et al., 2022).

The NLP approach aims to draw key concepts of ecological dynamics together into a framework that practitioners can apply to facilitate the development of individualised and adaptable movement skills to enable learners to better deal with varied performance contexts (Button et al., 2020). Therefore, to enhance the functional equivalence between MI practice and the competitive performance and practice environments of the actual skill being developed it may be beneficial to incorporate principles of NLP practice design in MI alongside already existing guidelines (e.g., PETTLEP). It is proposed that practitioners may want to consider conceptualising skill development within MI as an adaptive, rather than acquisition process. From this perspective, the goal for MI interventions is to design practice that presents opportunities for action to guide learners to explore and exploit relevant information to develop individualised movement solutions. The following section presents five NLP design principles and how they may be practically applied in MI interventions.

4.2.5. Practical application for MI practice design: five considerations from a nonlinear pedagogy approach

The NLP approach provides a practical framework for practitioners to appropriately consider and deal with individual differences and varied learning environments. To appropriately apply a NLP in practice, it is important to follow key design principles that supports a NLP approach, such as: (1) manipulation of constraints –practitioners should aim to guide learners to opportunities for action to allow for exploration and exploitation of functional movement solutions through careful manipulation of task constraints; (2) encourage exploratory behaviour - learning design should leverage functional variability to amplify exploratory behavior to facilitate the development of individualised movement solutions; (3) information-movement coupling – task simplification in learning design can be implemented it should support the strengthening of the information-movement coupling; (4) representative design – task design should aim to simulate critical aspects of the performance environment to provide the learner with key information to appropriately regulate their movements; (5) attentional focus – instructions should be developed to focus on movement outcomes (external focus), rather than specific body positions (internal focus), as this facilitates self-organising processes (Chow et al., 2022). Consistent with an ecological dynamics rationale, it is proposed that the aim of skill acquisition shifts towards the concept of *skill adaption* (see section on Ecological dynamics perspective of skill). From this perspective, we will unpack each of the above principles in turn and its practical applications to MI interventions. Figure 4.1 provides a summary of the recommendations for each principle and a practical example of MI instructions that have incorporated all NLP elements.


PRACTICAL APPLICATIONS OF NLP TO MI

Encouraging exploratory behaviour and constraint manipulation

- Select a specific task constraint that presents opportunities for action
- Detail constraint in MI content (e.g. reduced field size and players)
- Provide physical constraints in MI practice environment

Representative practice design, information-movement coupling, and instructional approach

- MI should include critical performance information (e.g. visual perspective, teammate presents, and defenders)
- Utilise response training to replicate physiological responses and incorporate key learner experiences
- Incorporate task simplification to allow for practice of whole skill (e.g. reduced racquet size)
- Aim to develop movement outcome focused instructions

Example MI instructions for soccer kick incorporating all elements of NLP:

"Imagine that you are entering the field of play, the playing area is half the size it normally is. There are 3 defenders and 2 attackers including yourself. As you begin to run you look around the field, you are in open space, you see three defenders to your left, Johnny your team mate has the ball. You yell at him to pass to you. You receive the pass, imagine the feeling of the ball as it hits your foot, you bring the ball under control. You keep running down field, feel how you move around the pitch as your feet make contact with the surface. You scan the field again two defenders are closing in, one from the left and right. You don't have much time to kick the goal. Feel the weight in your leg as you kick the ball, think about the ball curling around the goalie into the back of the net."

Figure 4.1. Recommendations for incorporating principles of NLP to MI. A practical example is provided in the last panel that has incorporated all principles of NLP into MI instructions for a soccer kick.

4.2.5.1. Encouraging exploratory behaviour and constraint manipulation

Competitive performance presents dynamic information-rich environments, in which a variety of movement solutions are available to achieve task goals. As mentioned in earlier sections, skill development can often focus on the prescription of 'optimal' models of technique, aiming to produce accurate and consistent movement patterns that reduce variability, traditionally viewed as noise. From a NLP perspective, movement variability – termed exploration – is an important component of practice that can be leveraged to facilitate learners to attune to critical information and discover movement solutions that appropriately match individual constraints (i.e., specific abilities, anthropometric factors) (Komar et al., 2019). Practitioners can manipulate task constraints to amplify exploratory behaviour of relevant affordances in the perceptual-motor landscape. When selecting the type of task constraints to use, practitioners have a number of options available, such as numbers of players on field, contact time between shooting and goalie in soccer, initial starting distance between defending players in rugby, and modifications to the size of equipment and playing area (e.g., racquet and ball size) (Renshaw & Chow, 2019). When deciding how to manipulate constraints it is important to consider whether the specific task constraint provides learners both the opportunity to attune to relevant affordances and execute associated movements. Given that MI training occurs within a simulated environment, practitioners and learners can 'manipulate' task constraints through the scripts delivered during MI practice. For example, when looking to develop tennis return shots, scripts may 'manipulate' the height of the net to describe target areas to hit the ball that change as practice progresses. Aligning with the Physical component of PETTLEP, practitioners may also set up the actual constraint in the area that MI training takes place to provide a concrete representation of its dimensions. Practically speaking, this may look something like the following: "As you set up to receive serve, take note of the height of the net, it is higher than usual. As the serve approaches you and you set up for your return shot, take note of where your opponent is standing, trying and hit the ball up and over the net to the space outside your opponent's reach". In this way, the aim of the script it to include information to provide a performance context for the learner to explore, rather than describing a specific movement pattern to reproduce.

4.2.5.2. Representative practice design and information-movement coupling

An important task for practitioners utilising MI for skill development is to understand the degree that practice transfers to the competitive performance environment. Creating representative practice environments is a fundamental principle of NLP and can be applied to MI by evaluating whether imagery content (i.e., simulated practice environment) provides relevant affordances that can be utilised to regulate actions, and presenting these opportunities for action at a level of difficulty that is representative of competition (Renshaw & Chow, 2019).

The first consideration for MI practitioners is the choice of visual perspective. From a NLP approach, first-person perspective may provide a more authentic representation of relevant affordances in the performance environment, allowing learners to become better attuned to critical information to strengthen information-movement couplings that underlie the achievement of performance goals (Chow et al., 2022). For example, an attacker carrying the ball in Australian Rules Football perceiving information from the first-person perspective can use this information to determine the space between defenders and accurately judge viable passing options to teammates. As such, MI content could describe the scene as follows: “You bring the ball down after taking a mark, take your time as you look around the field, you see three defenders in front of you, Sam is in space just to the left of the defenders, Alex is moving to a gap on the right…”. The emphasis here is to describe the scene as the player would perceive it on the field, presenting multiple opportunities for action but allowing the learner to decide which option to take.

Other important consideration in creating representative practice is the inclusion of emotional stimuli in the performance context. Existing MI frameworks provide excellent guidelines advocating the inclusion of emotional components of MI and the subsequent psychophysiological responses to increase the efficacy of imagery practice. Notably, response training (i.e., bio-informational theory) advocates for the inclusion of stimulus propositions (i.e., information about the environment) and response propositions (i.e., actual response to a particular situation) to induce relevant physiological responses during MI (Morris et al., 2005). For example, this may be when an athlete hears the crowd yelling while they are lining up for a penalty kick in soccer (stimulus proposition) and the response is an elevated heart rate. To check the representativeness of MI content, practitioners can reflect and evaluate by asking themselves "does this content present information that looks and feels like actual performance?" and "does this content present relevant affordances that are representative of competition, including intensity and difficulty?". Further, these questions should be extended to the learner as well to understand how well MI content reflects their experiences in the competitive performance environment. In this way, the development of MI content is a collaborative process between the practitioner and learner. This process can be facilitated by the application of response training (Morris et al., 2005), which gathers information about the learner's experiences when utilising MI and whether their responses are integrated into content.

Consistent with the key principle of information-movement coupling, the accurate simulation of emotion and relevant responses allows for the emergence of representative information that regulates movement and movement that influences the perception of critical information sources (i.e., information-movement couplings) (Renshaw & Chow, 2019). From a NLP perspective, these are critical details for inclusion in MI content as they create representative competition intensity, which can generate different emotions, action intention, perceptions, and subsequently different information-movement couplings. Under no pressure, an athlete may easily perceive a 3-point shot from the baseline, but when the game is tied and time is running out, a 3-point shot may not be perceived as an opportunity for action based on the different emotions experienced at that moment. Relevant to the principle of information-movement coupling, is the structure of the practiced task. Traditional practice approaches often structure practice task decomposition, whereby a skill is practiced in a progressive format (Chow et al., 2022). For example, when practicing netball shooting, the learner will practice the task from one distance until they achieve a predetermined performance criteria (i.e., number of successful shots) before progressing to the next drill. Such an approach disrupts the coupling between information and movement. An alternative method advocated by a NLP approach is task simplification. Task simplification aims to maintain information-movement couplings by preserving coherence between movement patterns and critical aspects of performance information that regulate these movements (Chow et al., 2022). For example, task decomposition of a soccer pass (or any passing skill) would be to practice the skill using isolated skill drills (e.g., stationary passing between partners) until it reaches a predetermined success criteria (i.e., certain number of successful passes) before being integrated back into a game context (Spittle, 2021). In contrast, task simplification would entail practicing the passing skill through a simplified game scenario, such as 3 vs 2, in which the task constraints are manipulated (e.g., reduced players on field) to challenge learners, yet, simplify the perceptual and action elements of complete game context (Chow et al., 2022; Spittle, 2021) Applied within MI practice, this would involve imagining the skill within a game, or game-like situation, rather than isolated, repetitive technical execution of the skill.

4.2.5.3. Instructional approach

In a NLP approach, instructions tend to be more exploratory in nature, aiming to guide the learner toward the overall movement outcomes rather than prescribing a specific movement form (i.e., internal focus). The rationale behind this approach is that instructions that focus more on movement outcomes rely less on conscious processes, which can be beneficial for performing in pressure situations (Spittle, 2021). Further, movement outcome focused instructions can facilitate inherent self-organisation processes to guide movement patterns, encouraging the development of more individualised movement solutions (Chow et al., 2022). Applied to MI this could achieved using analogy-based instructions (Lee et al., 2014). For example, imagery scripts may include statements like following: "Imagine striking the ball in the shape of a rainbow" or "Shoot the ball like you are reaching into a cookie jar on the shelf". Captured this way, MI practitioners may want to design scripts that detail movement outcomes rather than prescription of a specific movement form. This approach may provide learners with the freedom to explore and exploit individually appropriate actions and move away from 'optimal' movements that may be mismatched to their abilities, skills, and physiological make-up (Button et al., 2020).

An important task for the sport psychologist in designing and delivering MI interventions is to understand how to accurately simulate the performance context in practice. Even though a learner may be able to accurately and consistently produce a specific movement form in practice this does not ensure such behaviours will be transferred into competitive environments. MI interventions informed by principles of NLP provide a viable framework for developing practice that effectively deals with the dynamic demands of the performance environment through the incorporation of variability to encourage exploration and facilitate the development of adaptable, individualised skills.

4.2.6. Future directions

The idea of a NLP informed approach to MI is yet to be formally tested. Subsequently, future sport psychology research should look to explore how key principles of

NLP learning design can be implemented to facilitate transfer from MI practice to physical performance environments. In addition, understanding how NLP informed imagery may be practically applied across different skill classifications and skill levels would also be beneficial.

4.2.7. Conclusion

Given the emphasis that has been placed on creating MI interventions that mimic physical training as closely as possible, the examination of physical training approaches to skill acquisition is important to further understanding about MI design for skill development. The present paper does not attempt to portray NLP as a ‘superior’ framework to current MI approaches, but rather to provide alternative considerations for practitioners when designing MI interventions. Overall, practitioners could use a NLP approach to frame the design of MI practice sessions to meet the dynamic demands of sport in a way that allows for the development of individualised movement without compromising overall performance.

Chapter 5: Is prescription of specific movement form necessary for optimal skill development? A nonlinear pedagogy approach

Background

In the review of literature conducted in Chapter 2, it was found that NLP informed studies predominately examine open, game-like skills (e.g., soccer and football), where movement outcomes (e.g., scoring a goal or completing a pass) are the primary determinant of success. Therefore, the influence of NLP designed practice for self-paced, movement-form based skills (e.g., gymnastics) is relatively unknown. Therefore, the present chapter specifically aimed to examine the impact of NLP practice on exploratory behaviour and performance relative to traditional, prescriptive type practice for beginners learning a movement form-based skill, an Olympic weightlifting derivative known as the PC. Further, the present study aimed to provide practical findings related to NLP in physical practice to inform the design and delivery of the MI intervention presented in Chapter 6.

This chapter is presented in pre-publication format of an article that was recently published titled:

Lindsay, R., Komar, J., Chow, J-Y., Larkin, P., Spittle, M. (2022). Is prescription of specific movement form necessary for optimal development? A nonlinear pedagogy approach. *Research Quarterly for Exercise and Sport,* https://doi.org/10.1080/02701367.2022.2054925

5.1. Abstract

Purpose: Nonlinear Pedagogy (NLP) proposes that skill development is a nonlinear process, advocating the integration of variability into practice to facilitate individualised movement patterns. However, the influence of a NLP for skills that emphasise a specific movement form is relatively unknown. This study aimed to investigate the impact of a NLP approach when learning a movement form based skill.

Method: Sixteen beginners in the power clean (PC), were randomly assigned into a linear pedagogy (LP) condition receiving instructions that prescribed explicit movement form, and a NLP condition presented with analogy-based instructions and two task constraints. Both conditions completed seven lessons across 4-weeks.

Results: There were no significant differences in the quantity of exploration, with both conditions demonstrating a similar range of movement patterns. These findings were coupled with a significant improvement in performance accuracy (reduced forward movement of the barbell; F×D) for both conditions. No significant differences were detected in the distribution of barbell trajectory types, with type one, three and four trajectories being exhibited to a similar degree in both conditions.

Conclusion: Findings from this study suggests both NLP and LP pedagogies can successfully develop movement form based skills. Overall, both NLP and LP approaches appear to positively influence skill development. These findings have important implications for practitioners suggesting that deviations from instructed technique in learners (i.e., LP approach) do not negatively impact performance. However, further research is needed to determine whether these approaches can more effectively facilitate learners' search for movement solutions that ‘fit’ their individual abilities.

Keywords: Nonlinear pedagogy; motor exploration; skill acquisition; task constraint; motor skills

5.2. Introduction

When designing practice environments, a key challenge for sports practitioners is to appropriately cater to individual factors, such as physiological makeup and previous experience (Button et al. 2020). Underpinned by ecological dynamics, Nonlinear Pedagogy (NLP) addresses individual differences by infusing practice variability to encourage learner exploration and adoption of individualised movement solutions (Chow et al. 2019). Fundamental NLP practice design principles include: (1) learning in representative performance situations to present perceptual information to guide movement; (2) constraint manipulation to encourage exploration and exploitation of functional movement patterns; (3) variability in practice to support exploratory and adaptive behaviour in exploring different movement patterns, guiding the learner to functional movement solutions for the task problem; and (4) instructions should focus attention on movement outcomes rather than specific body positions, as this may facilitate the development of personal movement patterns that more appropriately align with individual abilities, skills and experiences (Chow et al. 2019; Komar et al., 2014).

According to NLP, skill development is nonlinear, and movement variability is posited to serve a functional role in guiding the learner toward individualised task solutions (Chow et al. 2019). Movement patterns emerge from interactions between learner constraints (e.g., skill level, previous experience, physiological makeup) and constraints in the perceptual-motor landscape. Continuous shaping of the perceptual-motor workspace releases new movement opportunities to explore (Newell 1985). Exploration involves engaging with various movement solutions to meet specific task goal requirements, measured through movement variability, whereas movement exploitation involves coordination pattern replication leading to behaviour stabilisation (Komar et al. 2019). Captured this way, learning comprises exploring, compiling, and stabilising adaptable, expert behaviours (Komar et al.

2019). Consistent with this reasoning, Akkuş (2012) found that seven elite-level female world champion weightlifters, across weight classes, each utilised different movement patterns (barbell trajectory) and arrived at the same outcome (i.e., gold medal). These findings suggest that expertise is characterised by achieving specific goals through stable, yet highly individualised, movement solutions rather than acquiring a specific ideal coordination pattern (Renshaw and Chow 2019).

NLP research has predominantly focused on open and game-like motor skills, where movement form may not be the primary determinant of successful performance (Spittle 2021), such as tennis (Buszard et al. 2016), field hockey (Brocken et al. 2020), and soccer (Chow et al. 2008). In these skills, performance outcome (scoring the goal, completing the pass) is more important than producing an ideal movement form ('textbook' technique or style) (Breed and Spittle 2020). Open skills occur in dynamic, changing performance contexts and require learners to make active decisions and constantly adapt to external stimuli (e.g., defensive pressure in football) (Spittle 2021). A key finding from NLP research in open skills is that increased exploratory behaviour plays a functional role in learning rather than compromising performance outcomes. For example, Lee et al. (2014) found that 10-year-old children displayed greater exploration (i.e., a high number of movement patterns) practicing under NLP compared to a linear pedagogy (LP) (i.e., a focus on repetition and replication of 'ideal' technique). This suggests that successful performance can be attained through multiple movement solutions, rather than a single 'optimal' technique.

Although NLP can facilitate exploration in open and game-like skills, the impact of NLP on learning closed skills that emphasise movement form for performance is relatively unknown. Closed skills are typically self-paced, performed in a relatively stable context, with lower decision making and cognitive demands (Spittle 2021). Learners performing closed skills attempt to reproduce similar efficient and consistent movement patterns with low levels of variability (Lee et al. 2014). Weightlifting movements (e.g., snatch and clean and jerk) can be characterised as movement form-based skills, demanding dynamic coordination of multiple joints during movement requiring specific execution of key technical elements (Storey and Smith 2012).

A commonly accepted ‘ideal’ technical model in weightlifting research is described as a type one barbell trajectory (Figure 5.1) (Cunanan et al. 2020). Compared with type two and three paths, it is considered the most efficient barbell path. It typically displays minimal ‘looping’ (i.e., movement away from the body) with the learner catching the barbell close to their base of support. From a biomechanical perspective, a type one trajectory demonstrates reduced forward barbell movement away from the body in successful power clean attempts (weightlifting derivative) (Kipp and Meinerz 2017). Therefore, coaches commonly focus on replicating barbell trajectories that reduce forward barbell movement through structured repetitious practice and regular verbal correction of deviation from the criterion barbell path (Everett 2012, Haug, Drinkwater, and Chapman 2015).

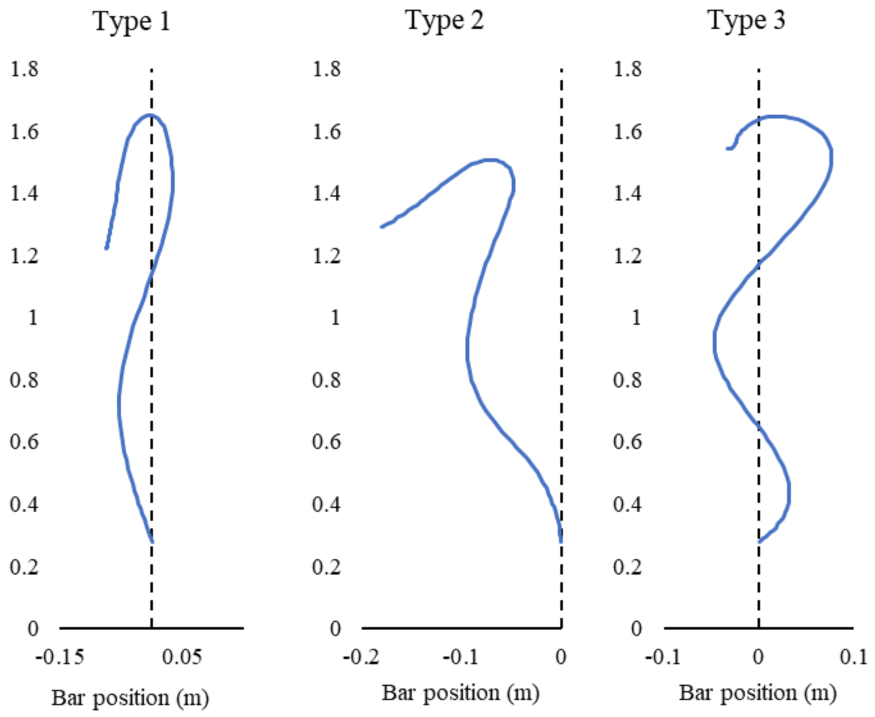


Figure 5.1. Barbell trajectory types observed in elite-level weightlifters (Adapted from Cunnan et al., 2020). Barbell trajectory is distinguished by whether it crosses the vertical reference line.

Research with expert performers, however, indicates that efficient coordination patterns are highly individualised and potentially subject to individual constraints such as body weight. Antoniuk et al. (2017) observed that elite female weightlifters used type two barbell path more frequently during the snatch movement in lightweight categories (48-58kg) and type three barbell path in the heavyweight category (75+kg). A recent case study by Verhoeff, Millar, and Oldham (2018) provides preliminary support for manipulating constraints to facilitate learning exploration in less skilled lifters. Results showed that learners explored more movement patterns, as measured by increased variability, and displayed overall performance improvements (i.e., forward and rearward barbell movement). In light of this evidence, NLP may be a viable pedagogical approach for movement form-based skills, such as weightlifting, in the early stages of learning to shape the perceptual-motor workspace and guide the learner toward individually shaped movement solutions.

The present study aimed to investigate the effectiveness of NLP practice in relation to LP practice for beginners learning a movement form-based skill, a weightlifting derivative known as the power clean (PC). It was hypothesised that: 1) LP would develop a higher prevalence of type one barbell trajectories in line with the prescribed technical model; 2) modifying constraints would help shape the perceptual-motor workspace to optimise exploratory behaviour and guide NLP learners toward task-relevant areas; and 3) both NLP and LP would improve performance accuracy, as measured by forward (F × D) and backward barbell movement (R × D).

5.3. Method

5.3.1. Participants

Nineteen healthy adults, all classed as beginners to weightlifting movements (i.e., snatch, clean, jerk), voluntarily participated in this study (G*Power calculation with a small to medium effect size (η_p^2=.10), alpha error probability set at .05, between-within comparison with 2 conditions and 4 measures and a power of .80 provided a required sample size of 14 participants). Study protocols were approved by a University Ethics Committee. Pivotal to study design was investigating participants in initial beginner stages of weightlifting movements. Consequently, participants had > 2 years resistance-based training but had < 3 months exposure to weightlifting movements. Participants were at weightlifting skill level 0 (Everett, 2012), during which learners must develop basic technical proficiency. Common technical characteristics of beginners are jumping forward, mainly due to the barbell being in front of the body causing forward imbalance and swinging the bar forward in the second pull due to improper hip extension (Everett 2012, Haug, Drinkwater, and Chapman 2015).

Participants were randomly assigned to either NLP or LP conditions. Three participants were unable to complete the movement from the correct starting position (i.e., floor) so were removed from the study. Consequently, 16 participants completed the intervention in either the NLP condition (*n* = 8; 1 female, 7 males; Age = 30.6 ± 5.2; Weight = 76.5 ± 7.8; Height = 174 ± 8) or LP condition (*n* = 8; 1 female, 7 males; Age = 26.5 ± 5.3; Weight = 78.1 ± 13; Height = 181.5 ± 7.8). All participants completed a medical screening form prior to starting the study to identify any pre-existing conditions that may prevent them from safely taking part in the study and gather other relevant information.

5.3.2. Experimental design

The present study comprised of an initial familiarization lesson followed by a 4-week intervention (seven lessons, each lasting approximately 30 minutes). All participants were taught a weightlifting derivative known as the power clean (PC). The PC involves lifting a barbell from the floor straight onto the shoulders (i.e., rack position) in one movement, with the lifter remaining higher than a parallel squat (Storey & Smith, 2012). Each lesson was separated by a minimum of 24 hours to reduce the effects of fatigue as much as possible. The familiarisation lesson was incorporated to ensure they could perform the movement without significant risk of injury and was not used for further analysis. As participants were beginners, a demonstration of the PC movement was provided to reduce injury risk. Participants then completed 3 × 5 repetitions, starting with an empty barbell and increasing in weight by 5kg each set (Sakadjian, Panchuk, and Pearce 2014). Participants were taught to adopt a hook-grip, a secure gripping technique used by elite weightlifters (Oranchuk et al. 2019). To avoid interaction between conditions, participants practised alone, under the supervision of the same researcher. The research team, comprising academics knowledgeable in NLP and LP, and an academic who is an experienced Olympic weightlifting coach, designed the interventions.

For each lesson, participants completed a standardised warm-up, 1×5 repetitions using the unloaded barbell, followed by 3×5 repetitions up to a total weight of 30 kg. Following each set, participants were provided 2-5 minutes rest to reduce the effects of fatigue. Sets and repetitions were based on National Strength and Conditioning Association (NSCA) recommendations for beginner level lifters (NSCA 2016). Due to participants being characterised as weightlifting skill level 0 (Everett 2012), and for participant safety, conservative weights were used in line with previous research, participant ability, and recommendations from an internationally experienced weightlifting coach (present for all lessons) (Sakadjian, Panchuk, and Pearce 2014). Furthermore, observations from pilot data indicated that 30kg was an appropriate level of resistance to accommodate proper technique practice while limiting technical breakdown from fatigue and reducing injury risk in beginner weightlifters. International Weightlifting Federation (IWF) standard barbells were used for every lesson (Female = 15kg; Male = 20kg). To create an ecologically valid learning environment, lessons were designed by a practising weightlifting coach with four years of experience competing at a national level and five years coaching and teaching experience, including at international competitions. Subsequently, lessons aimed to replicate similar practice structures and environmental constraints present when coaching weightlifting (Pinder et al. 2011).

Every lesson was recorded using a 14-camera (T-series T40) motion capture system (Vicon Inc., Denver, Co, USA) to track the 3-D trajectories of retroreflective markers. The rationale for this approach was to observe both lesson-to-lesson and trial-to-trial perturbations, represented by movement clusters, in a realistic coaching setting (Komar et al. 2019).

5.3.3. Practice design for each condition

NLP and LP interventions were grounded in the theoretical position that learners organise movement as either nonlinear or linear systems during skill development. The premise for NLP intervention design was that variability plays a functional role in exploring and discovering individualised movement solutions. Therefore, variability was infused into practice through modifying task constraints to encourage the learner exploration and establish an individualised movement pattern. Constraints were adopted from previous PC research, developed by an experienced international weightlifting coach, with participants blinded to the underlying purpose of each constraint manipulation (Verhoeff, Millar, and Oldham 2018). For example, manipulation of task constraints included chalk on the barbell and poles in front of the participant (full details in Supplemental material). Participants were reminded of the goal of each constraint (e.g., attempt not to hit the agility poles) in each set to manage adherence to constraints.

According to a NLP approach, instructions should avoid explicitly defining a specific movement form to allow for the development of personal movement technique (Renshaw et al., 2019). This can be achieved by using analogy-based instructions (i.e., movement form focused) to encourage implicit learning (Komar et al., 2014). Due to the inherent injury risk in performing weightlifting with poor posture, analogy-based instructions allowed for the incorporation of safe technique, without defining a specific technique. For example, 'Keep your back firm like a rod' or 'Think about sitting onto a chair' (Full instructions in Supplemental material).

LP involved explicit instructions, repetitious practice, and providing feedback to correct errors to direct learners toward an 'ideal' technique (Verhoeff, Millar, and Oldham 2018). Instructions were provided (see Supplemental material) according to different phases of the PC (Winchester et al. 2005, NSCA 2016): lift-off, first pull, transition, second pull, turnover, and catch. PC instructions were developed with an international level coach and best practice recommendations by the NSCA (2016). Instructions directed each learner toward the 'ideal' technique (i.e., type one trajectory), characterised by pulling the barbell toward the body and limited forward barbell movement (Figure 5.1). Feedback provided aimed to identify 'error' and redirect learners toward the prescribed technique.

5.3.4. Data processing

Thirty-six retroreflective markers were placed at the following anatomical locations; left and right shoulder (acromion process), left and right upper arm between shoulder and elbow, left and right elbow (lateral and medial epicondyle of the humerus), left and right anterior superior iliac spine, left and right posterior superior iliac spine, left and right knee (lateral and medial epicondyle, left and right thigh between the lateral epicondyle of the knee and the greater trochanter, left and right ankle (lateral and medial malleolus) left and right shank between the lateral epicondyle of the knee and lateral malleolus, left and right foot (first and fifth metatarsal head), and right and left heel (calcaneus). In addition, to measure horizontal barbell displacement, two other retroreflective markers were attached to each end of the barbell to trace barbell path. Out of a possible 1680 trials, 1672 were successful reconstructed for further analysis. For reconstructed trials, position data was processed using Vicon Nexus software (2.10.1) and then uploaded to Visual 3D software (C-Motion Inc). Based on previous research in weightlifting-based movements (Glassbrook et al. 2017, Sakadjian, Panchuk, and Pearce 2014), nine time-continuous kinematic variables were computed in a local reference: right and left shoulder flexion/extension, abduction/adduction, pelvis flexion/extension, right and left knee flexion/extension, and left and right ankle flexion/extension. All kinematic data were filtered with a fourth order low-pass Butterworth digital filter at a frequency of 10 Hz (Glassbrook et al. 2017; Trounson et al., 2020). Filtered position data were time-normalised to 100 data points for comparison across trials and participants.

5.3.4.1. Performance accuracy: horizontal barbell displacement

During each repetition, horizontal barbell displacement was assessed using Visual 3-D software from the start position to the most forward position during the lift (F×D) and the start position to the most rearward position of the barbell at the end of the lift (R×D) at lesson 1, 3, 5, and 7 (Winchester et al. 2005). Each of these variables represented performance indicators implemented to quantify the overall result of the movement pattern demonstrated by participants. Of a possible 960 barbell paths, 940 were successfully reconstructed. Of the reconstructed trials, the start of the lift was defined as the first frame where vertical position of the barbell was 0.05 m above initial start position, and end of the lift was defined as the first frame the vertical position of the barbell ceased to move downwards (Balsalobre-Fernández et al. 2020). Total distance in metres from the start position to the most forward position (F×D) and start position to most rearward position (R×D) was calculated to represent the performance accuracy scores used for further analysis.

5.3.4.2. Movement criterion: barbell trajectory type

Previous research indicates that elite level performers exhibit limited forward and rearward barbell displacement (i.e., F×D and R×D), yet display different overall barbell trajectories, with a type one barbell trajectory considered the most efficient pattern for the barbell to move (Cunanan et al., 2020). Subsequently, characterizing the overall shape of the barbell trajectory is considered an important part of measuring performance (Cunanan et al., 2020). Therefore, for each trial the pattern of the barbell only (i.e., irrespective of the movement pattern of the body) was categorized across all lessons using pre-determined barbell trajectory type criteria established by Cunanan et al. (2020) that place barbell patterns into three main categories (Figure 5.1). The following barbell trajectories were used: 1) Type one trajectory – initial movement toward the lifter, then movement away being caught close to the lifter's centre of gravity; 2) Type two – initial toward movement, then away but does not cross the vertical reference line at any point during the lift; 3) Type three trajectory – initial movement away from the lifter, then toward during second pull and finally away from the lifter; 4) Type four trajectory –established to categorise barbell paths that did not fit in the preceding categories. Each barbell trajectory was plotted using coordinate data normalised to 100 data points derived from 3-D markers attached to each barbell end. Trajectories that did not conform to the three described barbell trajectories were categorised as barbell trajectory four and considered a beginner movement pattern. Frequency of each barbell trajectory was summed for lessons 1, 3, 5, and 7 for each participant for further analysis.

5.3.4.3. Movement patterns exhibited

Cluster analysis was used to quantify different movement patterns exhibited by each learner (Komar et al. 2019). To compute the cluster analysis, one time series of each repetition time-normalised to 100 data points was established for all trials, participants, lessons, and conditions. This method of cluster analysis enables grouping of all trials into meaningful clusters, in which the 'actual' number of clusters is not known a priori. An iterative cluster algorithm, the Fisher-EM algorithm, was implemented in the analysis (Bouveyron and Brunet 2012). The Fisher-EM algorithm projects the data into a new subspace for each iteration in a manner that clusters emerging from the data set maximise the inter-cluster distance while minimising the intra-cluster distance (Bouveyron and Brunet 2012).

The number of movement clusters each participant visited was calculated to determine how many different movement patterns learners explored across the intervention. A visited movement cluster was registered for each coordination pattern displayed at least once throughout the seven sessions. To examine switching (exploration) or successive (exploitation) behaviours, a time series of movement clusters exhibited was created. All trials were plotted in order from first to last lesson. Exploitation was identified when the same movement cluster was repeated in two consecutive trials, whereas exploration was characterised by different movement clusters in two consecutive trials (Komar et al. 2019). This measure of exploration provided information about whether the pedagogical approach encouraged learners to leave initial patterns to search out new movement solutions. Instances of exploitation indicated when learners would continue to utilise an initial behaviour instead of exploring new coordination patterns (Komar et al. 2019). For further analysis, the exploration/exploitation ratio (E/E ratio) was calculated by dividing the number of exploration behaviours by the number of exploitation behaviours. Similar to previous research by Komar et al. (2019), a high E/E ratio denotes a participant engaging in more exploratory behaviour. In contrast, a E/E ratio of 1 is indicative of equal exploratory and exploitation behaviours. In the present study, the E/E ratio was used to indicate the impact of each pedagogical approach to perturb stable movement patterns and explore alternative movement solutions.

5.3.5. Data analysis

Performance accuracy scores were analysed using a 4 (lesson: 1, 3, 5, 7) × 2 (condition: NLP and LP) factorial design. The Shapiro-Wilk test was used to check for normality. Homogeneity of variance was calculated using the F_{max} test, with the assumption being met with a value less than 10 (Tabachnick and Fidell, 2013). After checking normality and homogeneity of variance, a mixed-design ANOVA was used to determine differences between conditions for two dependent variables: F×D and R×D. When deviations from sphericity occurred, p values were corrected using Greenhouse-Geisser epsilon (ε) correction when mean epsilon was lower than 0.75 and Hyun-Feld correction when mean epsilon was higher than 0.75. Post Hoc tests using Bonferroni correction were applied to analyse significant main effects and interactions to determine the location of differences within (session) and between (intervention) factors. Statistical difference was accepted at $p < .05$, and effect size was calculated using partial eta squared (η_p^2). Magnitude of effects were interpreted as: small 0.02; medium 0.13; and large 0.26 (Cohen (1988). When normality and/or homogeneity of variance was not observed, Mann-Whitney tests were used to compute pair-wise comparisons for independent samples. We used chi-square test-for-contingencies to analyse whether bar trajectory type was related to condition, chi-square tests within each condition to examine the distribution of barbell trajectories between lessons 1, 3, 5, and 7, and Bonferroni corrected z-tests to compare differences in barbell trajectory frequency between lessons (Field 2018).

5.4. Results

5.4.1. Performance accuracy: horizontal barbell displacement

For F×D, a main effect for lesson was observed, $F(3, 42) = 3.96$, $p = .01$, $\eta_p^2 = .22$. Post hoc analysis showed F×D was significantly lower from lesson 1 to lesson 5 ($p < .05$). The interaction effect between lesson and condition for F×D was not statistically significant, $F(3, 42) = 1.80$, $p = 0.16$, $\eta_p^2 = .11$. For R×D, the main effect for lesson was not significant, $F(3, 42) = 2.29$, $p = .09$, $\eta_p^2 = .14$. The interaction effect between lesson and condition for R × D, $F(3, 42) = 1.32$, $p = 0.28$, $\eta_p^2 = .09$). Descriptive statistics for each condition and lesson are presented in Table 4.

Measure	Lesson	NLP (*n* = 8)		LP (*n* = 8)	
		M	*SD*	*M*	*SD*
R×D (m)	1	-0.013	0.051	-0.015	0.054
	3	-0.053	0.046	-0.018	0.067
	5	-0.066	0.067	-0.024	0.047
	8	-0.044	0.073	-0.025	0.031
F×D (m)	1	0.098	0.040	0.100	0.032
	3	0.058	0.027	0.091	0.030
	5	0.058	0.030	0.095	0.029
	8	0.076	0.041	0.108	0.030

Table 4. Descriptive statistics for performance accuracy measures for Lesson 1, 3, 5 and 8 in NLP and LP conditions.

5.4.2. Movement criterion: barbell trajectory type

Figure 5.2 displays examples of each barbell trajectory type from representative participants. For NLP, 24% of total trials were type 1 trajectories (criterion model), 5% were type 2, 31% were type 3, and 40% were categorised as type 4 as they did not meet the criteria for other types. For LP 23% of total trials were type 1 trajectories, 31% were type 3, and 46% were type 4. The LP condition did not display type 2 trajectories across all 7 lessons, this was a unique barbell trajectory to the NLP condition and was omitted from subsequent analyses. A Pearson's chi-square test of independence was used to evaluate whether practice condition was

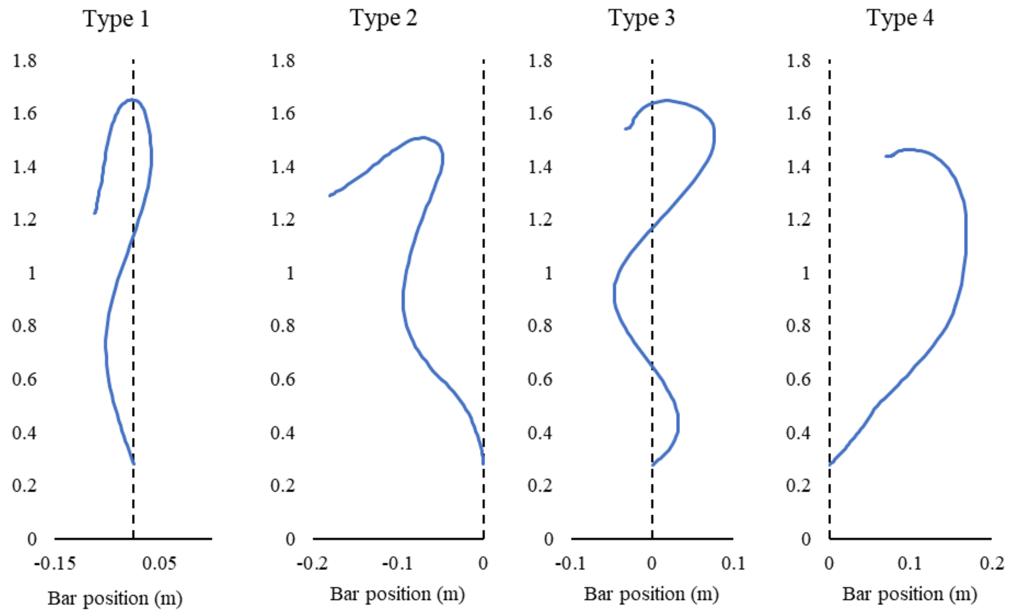


Figure 5.2. Example of each barbell trajectory from four individual learners. Each barbell trajectory was defined by its relationship to the vertical reference line (Cunanan et al., 2020). Each barbell trajectory was normalised to 100 data points and plotted using the Y (horizontal), and Z (vertical) coordinates extracted from visual 3 - D software.

associated to barbell trajectory type exhibited. No significant association between practice condition and the barbell trajectory exhibited was detected (χ^2(2, *n* = 917) = 1.60, *p* = .45, Cramer's *V* = .042). This indicates that the barbell trajectory exhibited (i.e., the frequency of type one, three, and four trajectories compared with each other) in the two practice conditions did not differ significantly across all sessions. Further, across all sessions, *Z*-tests revealed no significant differences in the frequency of each barbell trajectory exhibited for within both the NLP and LP condition (*p* = .48 - .76).

5.4.3. Movement clusters

5.4.3.1. Coordination profiling

Based on the Bayesian information criterion (BIC) indicator, the model that best represented the data set showed 13 emerging movement clusters for the 9 kinematic joint variables throughout the 4-week learning phase (Figure 5.3). The BIC values for 2 to 22 potential clusters showed that the values for 13 clusters represented the start of the plateau of BIC values.

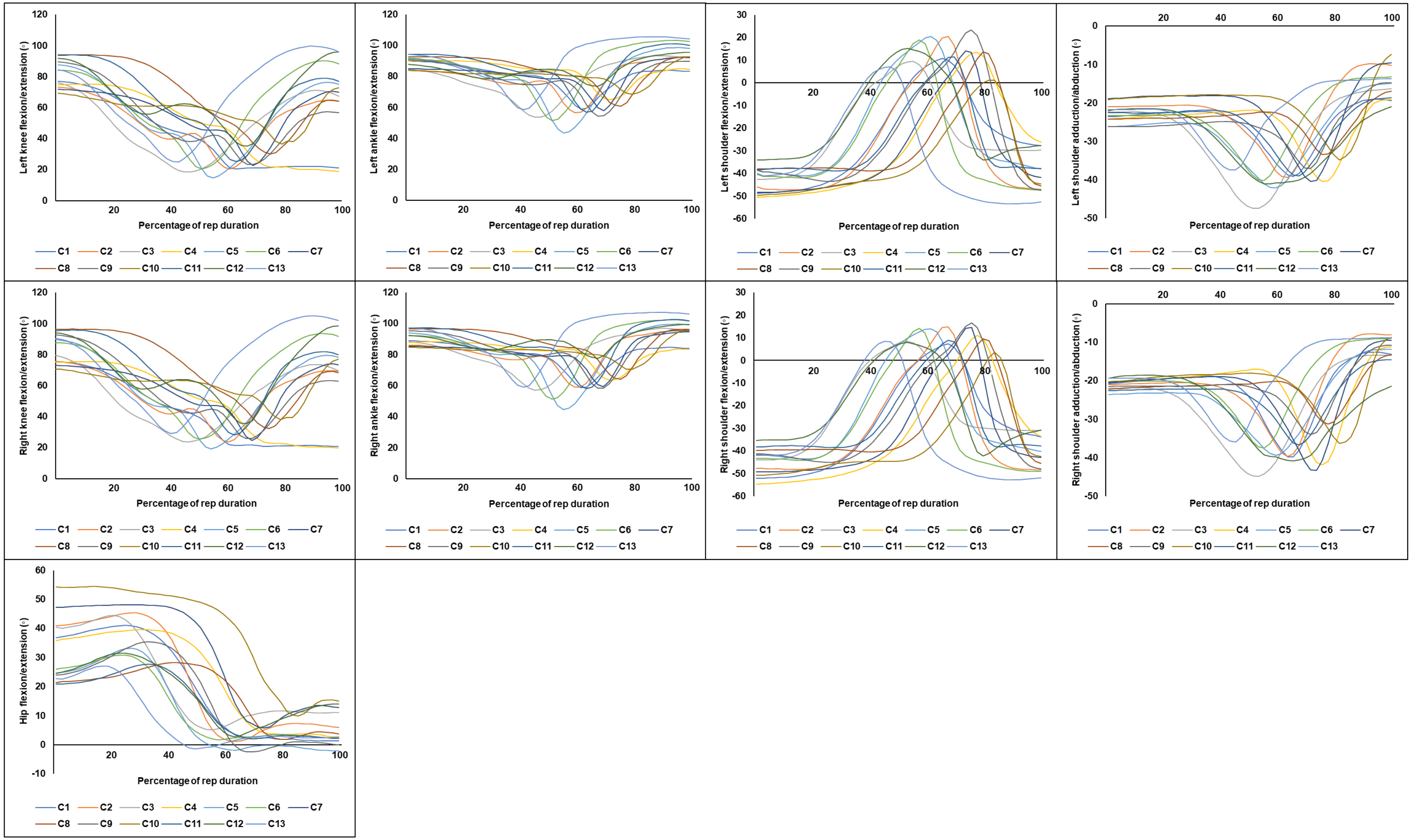


Figure 5.3. Mean movement patterns normalised to 100 data points for movement clusters of each kinematic variable across all seven lessons for NLP and LP conditions.

5.4.3.2. Movement patterns visited and exploited

The number of movement patterns visited and exploited by each participant is displayed in Table 4. Mann-Whitney tests showed visited patterns, and exploited patterns did not significantly differ between conditions (*p* = .96 and *p* = .20, respectively).

5.4.3.3. Exploration/exploitation ratio

Table 5 shows the exploration/exploitation ratio for NLP and LP. A Mann-Whitney test showed that the exploration/ratio was not significantly different between conditions (*p* = .44).

Table 5. The number of different movement clusters visited during seven lessons and the number of movement clusters exploited between at least two consecutive trials.

	Number of movement clusters visited									Number of movement clusters exploited								
	Participants									Participants								
Condition	1	2	3	4	5	6	7	8	Mean	1	2	3	4	5	6	7	8	Mean
NLP	6	9	7	7	10	8	4	6	7.12	3	1	4	3	5	5	2	3	3.25
LP	11	5	5	10	5	9	7	7	7.38	7	3	3	8	3	5	4	4	4.62

Table 6. Exploration/exploitation ratio for each participant for the NLP and LP conditions.

	Participants								
Condition	1	2	3	4	5	6	7	8	Mean
NLP	0.80	0.33	1.54	0.84	1.97	1.36	0.73	0.60	1.02
LP	1.94	0.81	1.42	3.96	0.60	0.76	0.92	1.29	1.46

5.4.3.4. Distribution of movement clusters

The NLP condition displayed five preferred clusters (C3, C6, C11, C12 and C13), the LP condition exhibited four preferred clusters (C2, C7, C9, C10), and four clusters were shared by both conditions (C1, C4, C5, C8). Across all trials, C3 and C11 comprised the highest frequency of trials for NLP (17% and 15%, respectively). One NLP participant (NLP2) exhibited a unique movement, C12 (11% of trials), that was not observed in the LP condition C9 (18%) and C2 (14%) represented the highest distribution of trials.

Figure 5.5 displays individual time series plots for a representative sample of NLP and LP participants. Patterns across both conditions did not appear substantially different, with NLP and LP participants demonstrating individualised shifts in behaviour, however, some interesting patterns were identified in each condition. Across both conditions some participants demonstrated a tendency to stabilise preferred movement clusters early in practice. For example, NLP3 exploited C12 early in practice (69% of early trials) and explored seven new clusters (C3, C5, C6, C7, C8, C11, C13) with the remaining trials (29%). Middle and late practice were characterised by an increase in exploitation of C12 (91%, respectively) and decreased exploration of 3 (middle = C1, C3, C11) and 2 (late = C3, C11) movement clusters. An alternative pattern of behaviour observed was the tendency to exhibit fewer practice trials within individually preferred clusters and higher distribution across multiple movement clusters throughout early, middle, and late practice periods. For example, LP9 preferred C5 early in practice (40% of trials) and explored six new clusters (C3, C6, C8, C9, C11, C13) in the remaining trials (60%). In middle practice, LP1 preferred C2 (29%), exploring seven clusters (C3, C6, C7, C8, C9, C10, C13) and in late practice showed a change to preferred C5 (35%) and exploration between six clusters (C2, C4, C5, C7, C9, C13).

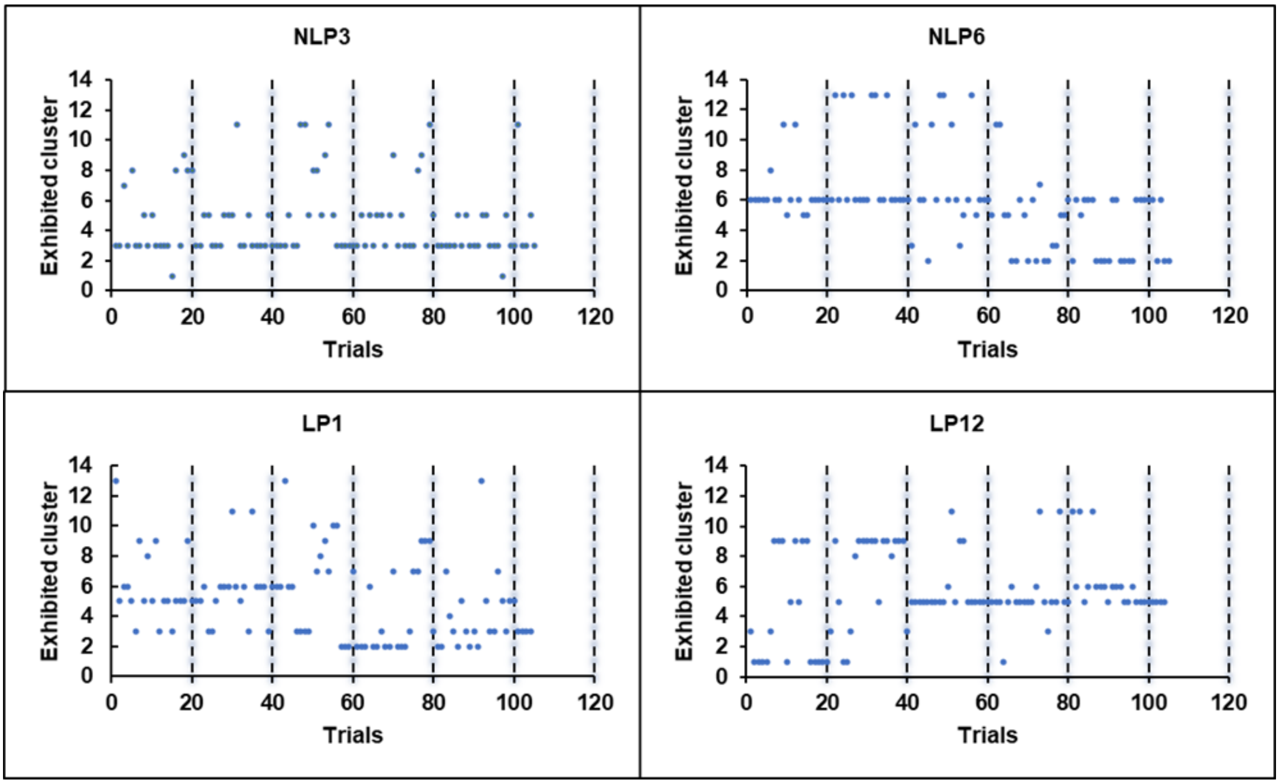


Figure 5.4. Example of movement behaviour exhibited for representative participants from NLP and LP conditions. Each point represents one trial.

5.5. Discussion

This study investigated the effectiveness of NLP practice for guiding exploratory behaviour of beginners while learning the PC, a closed skill. Contrary to our prediction, LP did not develop a higher prevalence of the prescribed technical model (i.e., type one barbell trajectory), with no significant association detected between practice condition and barbell trajectory, suggesting that barbell trajectory type did not differ between NLP and LP. Further, across all lessons, no significant differences were revealed between the frequency of each barbell trajectory for both conditions, indicating that NLP and LP conditions did not favour a specific trajectory and engaged in each trajectory to a similar degree. These findings indicate that pedagogical approach may not be a precondition for adopting a particular technique. The inherent individual (e.g., body weight, height) and task constraints of weightlifting movements may require learners to adopt a technique that more closely aligns with their specific abilities and skills (Chow et al., 2019). Previous research appears to support this contention, with Antoniuk et al. (2017) observing that bodyweight categories differentiated barbell trajectory of the snatch movement, with type two barbell trajectories used more frequently by lightweight categories (48 - 58kg), and type three barbell trajectories utilised primarily in the heavyweight category (75+). Future research should look to examine the prescription of technique based on individual characteristics such as body weight.

Both NLP and LP participants displayed a wide range of movement patterns. For example, LP predominantly exhibited patterns C2, C7, C9, and C10. The use of constraints in NLP appears to have limited the expression of these patterns in favour of alternative preferred movements (C3, C6, C11, C12 and C13). In addition, both conditions, significantly reduced forward barbell movement (F×D) representing increased biomechanical efficiency (Kipp and Meinerz 2017). These findings suggest that both prescriptive (LP) and exploratory learning strategies (NLP) allow for the expression of a range of movement patterns and can be implemented to improve performance outcomes. This has important implications for the attitude of the coach or teacher. For example, for prescriptive learning strategies (LP) the coach is expecting a specific movement, and the inability of the learner to exhibit the prescribed technique may be a source of frustration as the coach aims to produce a specific movement pattern. The current findings highlight to practitioners that although learners may be prescribed a specific technique, the inability of the learner to deliver this technique will not necessarily impact overall performance and, in fact, might represent an important part of the learning process for specific individuals. Such a change in attitude from the practitioner may help alleviate frustrations for the practitioner, and potentially create a more positive learning environment. It might be beneficial for future research to investigate the potential differences in attitudes of coaches or teachers when utilising different pedagogical approaches and how that impacts the learning experiences of individuals.

NLP was expected to facilitate more exploration by necessitating adaption to the constraints (barrier and chalk) for each trial, however, no significant differences were observed in the amount of exploration between LP and NLP, therefore, it seems these constraints were not a necessary precondition for exploratory behaviour. One explanation for these findings is that although the LP instructions aimed to direct learners to a specific technique, it is possible that these instructions did not completely narrow the field of affordances (opportunities for action) available to LP learners, meaning that movement corrections still allowed for some exploration of alternative techniques (Button et al., 2020; Chow et al., 2019). Although LP instructions encouraging movement corrections may aim to produce a particular technique, these types of instructions appear not to entirely constrain learners in exploring alternative techniques outside that prescribed by the practitioner. Considering the present results, the LP instructions appear to allow for a level of exploration that was beneficial for overall performance. An alternative explanation is that the exploratory behaviour in LP learners represented a process of attempting to stabilise the prescribed technical model. It could be that the instructions provide encouraged search strategies around attempts to reproduce the prescribed movement pattern, that is, switching between patterns was an attempt to develop the prescribed technique. This would suggest that whether a LP or NLP approach is adopted the learner engages in exploration, but for different reasons. Under LP, learners explore solutions to achieve the prescribed technique and in NLP exploration is to discover a individualised solution to meet the demands of the task constraints applied. This point highlights that the E/E ratio is limited to demonstrating the quantity of exploration in the form of switches between coordination patterns but does not account for the nature of learner exploration. Subsequently, findings of the present study are unable to determine whether the nature of exploration differed in any way between NLP and LP conditions. Given that both pedagogical approaches produced similar improvements in performance, an interesting line of inquiry for future research would be to investigate whether exploration of the perceptual-motor space (i.e., nature of exploration) differs between approaches.

5.6. Conclusion

In conclusion, the impact of a NLP approach relative to a LP approach for developing movement form based skills such as the PC is unclear. Results suggest that both approaches allow learners the ability to develop an individually appropriate technique and enhance overall performance outcomes. This was highlighted by non-significant differences in barbell trajectory type between groups, suggesting that LP participants utilised other 'less' effective techniques and equivalent improvements in performance outcomes. This has important implications for practitioners, as it suggests both NLP and LP pedagogies can successfully develop movement form based skills. From a practical point of view, when coaches or teachers experience deviations from instructed technique in learners (i.e., LP type approach), results from the present study indicate that this will not necessarily negatively impact performance. Overall, both NLP and LP approaches appear to positively influence skill development. Further research, however, is needed to determine whether these approaches can more effectively facilitate learners' search for movement solutions that 'fit' their individual abilities.

Chapter 6:Characterising exploratory behaviour during motor imagery practice: a nonlinear pedagogy approach

Background

Central to this thesis is the notion that MI should aim to replicate critical aspects of PP as closely as possible to maximise practice effectiveness (Wakefield & Smith, 2012). However, review of the MI literature has demonstrated a dearth of research directly investigating approaches using in PP for the purpose of skill development and how they may apply to MI design and delivery. Subsequently, the present chapter looks to address this gap in the literature. Drawing on the theoretical foundation provided in Chapter 4 and the empirical findings of Chapter 5, the present chapter aimed to investigate the practical application of NLP design principles in MI training and its influence on exploratory behaviour and performance for beginners learning a movement form-based skill, the PC. Further, the same study design and participant criteria was implemented in order to explore potential similarities between NLP conducted in PP and MI, allowing for discussion around the proposed functional equivalence between the two practice modalities.

This chapter is presented in pre-publication format of an article that is currently under review titled:

Lindsay, R., Komar, J., Chow, J-Y., Larkin, P., Spittle, M. (in review). Characterising exploratory behaviour during mental imagery practice: a nonlinear pedagogy approach. *PLOS ONE.*

6.1. Abstract

Cognitive training techniques such as motor imagery (MI) – cognitive simulation of movement, has been found to successfully facilitate skill acquisition. However, little research has investigated the how alternative approaches to skill acquisition, such as nonlinear pedagogy (NLP), can be applied to MI. NLP proposes that skill acquisition is a nonlinear, emergent process resulting from a learner–environment relationship. Captured this way, careful and considered manipulation of task constraints can leverage movement variability (exploration) to facilitate the adoption of individualised movement solutions. The aim of the present study was to explore the application of a NLP informed MI approach to skill acquisition. Fourteen beginner weightlifters (two female and 12 male) participated in a 4-week intervention involving either NLP (i.e., analogy-based instructions and manipulation of task constraints) or a linear pedagogy (LP; prescriptive instructions of optimal technique, repetition of same movement form) to learn a complex weightlifting derivative. Performance accuracy, movement criterion (barbell trajectory type), kinematic data, and quantity of exploration/exploitation were measured pre-mid-post intervention. Similar quantities of exploration were observed in both conditions, suggesting that prescription of a specific movement form (i.e., LP condition) may not necessarily ensure adoption of a particular technique as learners may inherently explore for movement patterns that match individual capabilities, skills and experiences. Equivalent improvements in performance accuracy (i.e., rearward barbell displacement) and the adoption of primarily 'sub-optimal' techniques by both conditions suggest that 'optimal' technique does not ensure improved performance. These findings suggest that producing a movement that satisfies the task goal may be more important than reproducing a movement that looks correct. When designing MI practice, it may be beneficial to consider scripts that are more outcome focused and incorporate task constraints to facilitate learners' inherent exploration of individual task solutions.

6.2. Introduction

Motor learning is often defined as a relatively permanent change in skill performance due to physical practice of a movement (Spittle, 2021), research, however, highlights that cognitive training techniques, such as mental imagery (MI), can also facilitate motor learning when combined with physical practice or alone (Lindsay et al., 2021; Schuster et al., 2011; Simonsmeier et al., 2021). MI refers to the ability to simulate perceptual and motor information in our mind without sensorimotor input (Moran & O'Shea, 2019). The efficacy of MI has typically been contextualised through motor simulation theory (MST) (Jeannerod, 1994). According to MST, MI draws on similar neural mechanisms to those utilised during actual motor execution, termed the *functional equivalence* hypothesis (Jeannerod, 1994, 2006), whereby MI and overt movement are functionally equivalent due to a shared mental representational system involved in creating motor actions (Frank & Schack, 2017). For example, studies have indicated substantial overlap of neural activity in motor and premotor areas (cerebellum, inferior frontal gyrus, and ventrolateral thalamus) during MI and motor execution (Burianová et al., 2013; Hétu et al., 2013; Munzert et al., 2009). MI practice has also been shown to elicit training-related adaptations in central neural structures, such as the corticospinal pathway, like what is observed in physical training. For example, Leung et al. (2013) compared the effect of physical training against MI training alone for a bicep-curl strength exercise. Following a three-week intervention period, both conditions demonstrated significant increases in strength (i.e., one-repetition maximum), coupled with equivalent increases in corticospinal excitability. Taken together, these findings suggest that MI and movement execution not only activate similar neural structures but can produce similar training-related cortical adaptations (Debarnot et al., 2014; Leung et al., 2013).

Applied MI in sports highlight the versatility and efficacy of such a technique for developing skills in real-world settings (Lindsay et al., 2021; Simonsmeier et al., 2021).

These skills include closed, self-paced actions such as dart throwing (Weber & Doppelmayr, 2016) and golf putting (Kim et al., 2017) as well as more complex movements requiring dynamic coordination of multiple joints, such as weightlifting (Lindsay et al., 2020), and/or reaction to other individuals, such as tennis return serves (Robin et al., 2007). Such studies have highlighted that for MI to be most effective, MI practice needs to replicate as many elements of the physical action as possible (Wakefield et al., 2013). Subsequently, MI *scripts* are regularly used to guide the simulated action by providing detailed information to generate and improve the functional equivalence of the mental representation (Moran & O'Shea, 2019). The PETTLEP model is a common approach to MI script development, with particular emphasis on the practical considerations for what details should be included in scripts (Wakefield & Smith, 2012). The PETTLEP acronym comprises seven elements: physical, environment, task, timing, learning, emotion, and perspective. According to this approach, MI scripts should seek to simulate these elements as closely as possible to facilitate accurate transfer of imagined and actual motor performance (Holmes & Collins, 2001; Wakefield & Smith, 2012).

MI approaches such as the PETTLEP model provide excellent guidelines for practitioners regarding how to replicate critical attributes of the performance environment (Wakefield et al., 2013). However, one aspect of skill acquisition that has received little attention in MI research is how to design practice environments that adequately account for individual factors, such as prior learning experience and physiological composition (e.g., limb length and bodyweight) (Button et al., 2020). Currently, imagery training approaches typically adopt a traditional definition of skilled behaviour. These definitions highlight that practice should be centred around the repetition of an 'optimal' mental representation of skilled movement, often determined by a coach. From this perspective, MI practice is primarily designed to present an 'optimal' technique that is repeated to strengthen motor programs and produce accurate movements that reduce movement variability, typically viewed as ‘errors’ that need correction (Renshaw et al., 2019). Observational studies in elite athletes indicate that the development of expertise may require a more individualised approach. Akkuş (2012) demonstrated that while seven elite-female weightlifters all utilised different coordination patterns (barbell trajectory) they all attained the same performance outcome (i.e., world championship gold medals). Subsequently, these findings support the idea that the aim of developing expertise may not be to replicate an ‘optimal’ mental model, but rather create an ability to adapt and produce stable individualised movements in the face of a dynamic performance environment (Renshaw & Chow, 2019). Similarly, Lindsay et al. (2020) noted that after 6-weeks of MI practice, power clean barbell trajectories were highly individualised in novice lifters, suggesting the need for further research to investigate the influence of movement variability in MI practice. These findings suggest that an alternative approach to skill acquisition may be a fruitful line of enquiry to contribute to our present understanding of how MI interventions can cater for individual factors that influence skill development.

One such approach is Nonlinear Pedagogy (NLP). Underpinned by an ecological dynamics perspective, Nonlinear Pedagogy (NLP) acknowledges the contribution of individual factors to skill acquisition by advocating careful and considered infusion of variability into the design of practice environments to encourage learners to explore relevant performance solutions (Button et al., 2020). According to NLP, skilled action is developed through an emergent process resulting from a learner–environment relationship, in which adaptive and functional connections are established between the learner and their environment (i.e., learner-environment mutuality) (Renshaw et al., 2019). Subsequently, skill acquisition may be considered more appropriately as *skill adaption.* This change in definition shifts the aim of practice from attaining an ‘optimal’ technique to providing opportunities for learners to explore and exploit the perceptual-motor workspace, facilitating the development of stable and adaptable coordination solutions (Button et al., 2020). The continuous development of the perceptual-motor workspace creates new coordination possibilities that can be explored (Newell, 1985). The exploration process can be formalised through the measurement of variability and defined broadly as the engagement in a range of different coordination solutions to arrive at a specific task goal (Chow et al., 2019; Komar et al., 2019). By contrast, exploitation involves consecutive reproduction of the same coordination pattern, facilitating behaviour stabilisation. Captured this way, skilled action is an iterative process of exploration, compilation, and stabilisation of coordination patterns that can adapt under dynamic conditions (Komar et al., 2019). Practice design informed by NLP should aim to carefully consider the following design principles; (1) representative practice simulations to performance situations that present critical aspects of competitive environments; (2) careful and considered manipulation of task/environmental constraints (e.g., playing surface, number of players, size of the field) to facilitate exploration and exploitation of perceptual-motor workspace; (3) leveraging variability in practice to encourage adaptive and exploratory behaviour, guiding the learner to explore individually relevant and appropriate performance solutions; and (4) implement instructions that encourage processes of self-organisation by focusing attention on movement outcomes as opposed to specific body positions(i.e., internal focus) (Chow et al., 2019).

Primarily, NLP studies have focused on open, match-like motor skills, where a particular movement technique may not be critical for successful performance (Spittle, 2021), such as soccer and hockey (Brocken et al., 2020; Chow, Davids, Button, & Rein, 2008). These skills occur in a changing performance environment that forces performers to adapt their actions in reaction to external perceptual information (e.g., defending goalkeeper in football) (Spittle, 2021). Evidence indicates that NLP informed practice of open skills facilitates exploratory behaviour (i.e., movement variability) during learning without negatively impacting performance. For example, Lee et al. (2014) demonstrated that novice learners practicing a tennis skill under NLP displayed greater exploratory behaviour than linear pedagogy (LP; repetitive practice of ‘optimal’ technique), even though both groups displayed similar performance improvements. These findings indicate that adherence to an ‘optimal’ technical model does not ensure superior performance and though commonly viewed as ‘errors’, exploration/movement variability could play a functional role in facilitating the development of individualised performance solutions.

Pertinent to the design of MI practice, NLP highlights the importance of manipulating task constraints to encourage exploration and facilitate the development of adaptable, individualised movement solutions (Renshaw & Chow, 2019). MI scripts are the only viable way to ‘manipulate’ task constraints, given that practice is performed in the mind. Therefore, the aim of a NLP informed MI script would be to describe critical aspects of the learning environment, such as task constraints (e.g., barrier in front of someone lifting a barbell), rather than presenting a description of the ‘optimal’ technique. Presently, no studies have formally assessed the influence of a NLP informed MI approach to skill development.

The present study aimed to explore the application of a NLP informed MI intervention in relation to a traditional linear style of MI intervention for beginners learning a movement form-based skill, a weightlifting skill known as the power clean (PC). It was hypothesised that: 1) the linear style of practice would develop a higher frequency of ‘optimal’ movement patterns; 2) modification of task constraints in NLP condition would help facilitate exploratory behaviour and guide learners toward performance relevant solutions; and 3) both conditions would demonstrate the same levels of performance accuracy, as measured by forward (F×D) and backward barbell movement (R×D).

6.3. Materials and methods

6.3.1. Participants

Sixteen healthy adult participants (3 female; 13 males) agreed to participate in the study. Due to personal reasons, two participants did not complete the study, leaving a total of fourteen participants (2 female, 12 male; 29.1±3.3 years). Therefore, participants were not randomly assigned to the LP or NLP conditions to maintain balanced groupings. Participants were reimbursed $100AUD in the form of supermarket vouchers for travel, parking expenses and time. All were healthy and free of acute/chronic injuries and provided written, informed consent. All participants had less than three months of formal experience learning the power clean movement and two years of general gym training experience (Sakadjian et al., 2014). Based on these criteria, participants were naïve to the proposed motor skill to be learned and considered beginners (Haug et al., 2015; Sakadjian et al., 2014), conforming to the control stage of motor learning (Newell, 1985). The university ethics committee approved the present study.

6.3.2. Procedure

The present study comprised of a pre-intervention technique assessment, followed by a 4-week intervention (eight MI sessions, each lasting 30 minutes), a mid-intervention (end of week 2) and post-intervention technique assessment approximately 24-hours after the intervention.

6.3.3. Technique assessment procedures

Prior to the commencement of the pre-intervention technique assessment, all participants completed the Movement Imagery Questionnaire-Revised (MIQ-R; Hall & Martin, 1997) to determine their ability to perform MI before beginning MI-based practice. The MIQ-R comprises eight items that aim to assess visual and kinaesthetic imagery ability (four items for each domain). Participants were required to imagine four different movements visually or kinaesthetically. After completing each movement, participants used a seven-point Likert scale (1 = very difficult to see or feel; 7 = very easy to see or feel) to rate their imagery performance. The ability to perform MI was based on attaining an average score above 4 (Neutral, not easy, not hard to see or feel) (Kim et al., 2017). The MIQ-R has high internal (visual subscale = 0.84; kinaesthetic subscale = 0.88) and test-retest reliability (visual subscale = 0.80; kinaesthetic subscale = 0.88) (Monsma et al., 2009).

Following completion of the MIQ-R reflective markers were placed on the following anatomical landmarks: left and right shoulder (acromion process), left and right upper arm between shoulder and elbow, left and right elbow (lateral and medial epicondyle of the humerus), left and right anterior superior iliac spine, left and right posterior superior iliac spine, left and right knee (lateral and medial epicondyle, left and right thigh between the lateral epicondyle of the knee and the greater trochanter, left, and right ankle (lateral and medial malleolus) left and right shank between the lateral epicondyle of the knee and lateral malleolus, left and right foot (first and fifth metatarsal head), and right and left heel (calcaneus) (Liu et al., 2018). Two reflective markers were also placed on the right and left side of the barbell to trace the trajectory (Rossi et al., 2007). Markers were needed to construct a 3-D model to extract kinematic movement data.

Prior to the beginning of the pre-intervention session participants were provided with a demonstration by an experienced international level coach (five years coaching and teaching experience, including at international competitions) of the PC movement. This was due to participants being at a beginner level to reduce the risk of injury. Following the demonstration, a standardised warmup of 5 trials with an empty barbell, followed by 3×5 repetitions up to a total weight of 30kg. The mid (approximately 24 hours after MI session 4) and post-intervention (approximately 24 hours after MI session 8) technique assessments comprised of a standardised warmup (5 trials with an empty barbell), followed by 3×5 trials with a total weight of 30kg. Observations from pilot data indicated that 30kg was an appropriate resistance level to limit the risk of injury for beginners. Following each set, participants were required to rest for 2 – 5 minutes to reduce the effects of fatigue.

6.3.4. Intervention

Following the pre-intervention technique assessment, the participants completed eight MI practice sessions (approximately 30 minutes), across a 4-week intervention period, to learn the PC using either a NLP or LP approach. For both conditions guidelines from the PETTLEP framework were followed to replicate elements of the performance environment as closely as possible (Wakefield & Smith, 2012). Therefore, participants were instructed to wear the same clothing and footwear they would use when usually performing the movement task and were physically standing in front of a barbell loaded with 30kg in a gym environment congruent with where the movement is usually performed. Prior to each session participants were guided through a standard physical warmup routine to raise the heart rate and psychologically prepare participants to engage in the session. When in the start position of the movement, participants would listen to either a LP or NLP constructed audio recorded script that guided them through 3×5 MI trials. After each MI trial was completed, participants were required to signal to the researcher that they had completed a trial. This meant that the volume of training could be accurately accounted for with both conditions completing 120 MI trials over 4 weeks. This was implemented to ensure the correct volume of practice was being completed. The intervention was developed by five academics knowledgeable in MI, NLP and LP, and Olympic weightlifting respectively. Both NLP and LP interventions were delivered by the same researcher based on the methodology constructed prior to the beginning of the intervention.

Both NLP and LP scripts were designed on the understanding that when performing the PC movement there is a heavy reliance on proprioceptive sensory information to regulate movement posture and control, as individuals performing these movements need to approximate their body positions spatially by "feeling" the movement as opposed to "seeing" themselves performing it (Storey & Smith, 2012). Therefore, kinaesthetic focussed MI was the primary form of practice in the present study. Kinaesthetic MI aims to elicit sensory aspects of the motor task from the first-person perspective, primarily focusing on the feel and timing of the action (White & Hardy, 1998). The audio recording also incorporated the initial visual aspects related to the physical movement, directing participants to focus on a specific point in front of them before performing the movement. For the present study, examples of the script given to participants included details such as "feel the rough grip of the bar as it sits in your hands" and "explosively shrug your shoulders".

For the NLP condition, scripts were analogy-based (i.e., focused on the movement outcome) to encourage self-organisation processes and limit conscious movement control, aligning with key NLP principles of practice design (Chow et al., 2019; Komar et al., 2014). This included MI instructions such as "try and flick the bottom of your shirt as you pull upwards" and "explode upwards like you are jumping straight up". Manipulation of constraints are informed by principles of NLP, such as task constraints, aim to encourage exploration of individualised movement solutions. The manipulation of task constraints in NLP scripts included chalk on the barbell and poles in front of the barbell (Table 6). Participants were blinded to the true purpose of each constraint and were only told to either not hit the poles in front of them or try and leave a chalk mark on their thighs with the barbell (Verhoeff et al., 2019; Verhoeff et al., 2018). These constraints were introduced to the NLP condition between sessions 3 – 6 and were also physically present for MI practice.

Conversely, the LP intervention was design on the understanding that during skill acquisition learners should be directed toward an ‘optimal’ technique and this is achieved through repetitive practice. In weightlifting research, the ‘optimal’ technical model is commonly described as a type one barbell trajectory (Cunanan et al., 2020). The type one barbell trajectory displays limited forward movement and more rearward pulling of the barbell toward the body, meaning the barbell is caught closer to the lifter’s base of support (Kipp & Meinerz, 2017). Therefore, LP scripts involved details of what is considered an ‘optimal’ PC technique (type one barbell trajectory) and were movement form orientated, aiming to have learners adopt a very specific movement form and leave little opportunity to explore alternate techniques (Lee et al., 2014). The LP condition received prescriptive MI scripts according to different phases of the lift. For example, the second pull phase: “As your lower body extends forcing you to be right up on your toes” and the turnover of the barbell onto the shoulders: “Bend your elbows and pull your body under the bar”. The PC instructions were developed and verified by an experienced weightlifting coach with international experience. MI instructions for the LP condition remained unchanged for the entire intervention.

Table 7. Summary of the constraints incorporated into NLP informed MI scripts

Task constraint	**Constraint details**	**Nonlinear Pedagogy design principle**
Chalk on the barbell	Chalk was applied to the bar to encourage participants to pull the bar back towards the body during the lift and keep the bar in contact with the thighs while transitioning from below to above the knee and into the *second pull* position. If participants were keeping the bar in contact with the thighs, chalk from the bar would show where contact was occurring.	*Effective manipulation of tasks constraints*. The chalk on the barbell aimed to facilitate exploration and exploitation of alternative movement solutions, such as different starting heights of the *second pull* position. *Leveraging functional variability.* The chalk aimed to amplify exploration of different positions of the *second pull* to facilitate the emergence of individualised solutions during this phase of the lift.
Poles in front of participant	Two poles were placed in front of the participant to restrict forward movement of the bar. Participants would lift in front of the poles while trying to avoid contacting them.	*Reducing conscious control of the movement.* The poles aimed to focus attention on the movement outcome, to encourage self-organising processes. *Leveraging functional variability.* The poles in front of the learner this aimed to amplify exploratory activity and guide the learner toward performance solutions that matched specific capabilities, skill and experience.

6.4. Apparatus and measurements

6.4.1. Movement patterns

The 36 retroreflective markers fitted on predetermined anatomical landmarks were captured by a 14-camera (T-series T40) motion capture system (Vicon Inc., Denver, Co, USA). Reconstructed trials were processed using Vicon Nexus software (2.10.1) and then analysed using Visual 3D software (C-Motion Inc). Nine time-continuous kinematic variables were identified from previous research (Glassbrook et al., 2017; Sakadjian et al., 2014) and were computed in a local reference: right and left shoulder flexion/extension, abduction/adduction, pelvis flexion/extension, right and left knee flexion/extension, and left and right ankle flexion/extension. A low pass Butterworth digital filter at a frequency of 10Hz was used on all kinematic data, and filtered position data was time-normalised to 100 data points to enable comparisons to be computed across trials and participants and cluster analysis (see section on data analysis).

6.4.2. Performance accuracy: horizontal barbell displacement

Performance accuracy was determined based on the overall distance the barbell travelled forward (F×D) and backward (R×D) was calculated. The start of the movement was defined as the first frame, the barbell moved vertically, and the end of the movement was defined as the first frame the vertical position of the barbell ceased to move downwards (Balsalobre-Fernández et al., 2020). This captured using the same camera set-up described above, capturing the trajectory of two retroreflective markers on the right – and left-hand side of the barbell.

6.4.3. Movement criterion: barbell trajectory type

Overall barbell patterns were assessed using adapted criteria by Cunanan et al. (2020) of elite weightlifting trajectories. The following categories were implemented: type one –

initial backward movement from the start, then away and being caught close to the centre reference line; type two – backward movement from the start position, and does not cross the vertical reference line during movement; type three – away movement from the start position followed by toward and then away from the body; and type four – classified as a beginner trajectory, capturing movements that do not adhere to the specifications of the preceding categories. Barbell trajectories were categorised using extracted X Y coordinate data normalised to 100 data points. The summed frequency of each trajectory was used for further analysis.

6.5. Data analysis

6.5.1. Statistical analysis: performance accuracy, movement criterion, imagery ability

A 3 (technique assessments: 1, 2, 3) × 2 (condition: NLP and LP group) factorial design was used to assess performance accuracy scores. Following the assessment of normality and homogeneity of variance, a mixed-design ANOVA was used to determine difference within and between groups for two dependent variables: F×D and R×D. When violations of sphericity were detected, p values were corrected using Greenhouse-Geisser epsilon (ε) correction when mean epsilon was less than .75 and Hyun-Feld when mean epsilon was greater than 0.75. Post Hoc tests were implemented with Bonferroni correction applied to analyse significant main effects and interactions to determine the location of differences within (technique assessment) and between (conditions) factors, with statistical differences accepted at $p < .05$. A one-way ANOVA was used to examine baseline differences in movement imagery ability between the two conditions for the combined visual and kinesthetic imagery scores. Partial eta squared (η_p^2) was used to express the magnitude of effects and interpreted as: small 0.02; medium 0.13; and large 0.26 (45). Mann-Whitney tests were used to compute pair-wise comparisons for independent samples when normality and/or homogeneity of variance was not observed. Chi-square test-for-independence was conducted to analyse whether the frequency of trajectory type was related to the condition, and Bonferroni corrected z – tests to compare differences in trajectory frequency between conditions and technique assessments (Field, 2018).

6.5.2. Cluster analysis: quantifying movement patterns exhibited

The number of different movement patterns demonstrated by each participant was quantified using a cluster analysis technique (Komar et al., 2019). The cluster analysis was calculated by establishing one time series of each trial (normalised to 100 data points), participants, technique assessments, and conditions. Subsequently, this cluster analysis method allows all trials to be grouped into meaningful clusters, where the number of ‘actual’ clusters is not known a priori. An iterative cluster algorithm (Fisher-EM) was utilised (Bouveyron & Brunet, 2012). The Fisher-EM algorithm projects data into a new subspace for each iteration so that clusters emerging from the data set maximise the inter-cluster distance while minimising the intra-cluster distance (Bouveyron & Brunet, 2012). This method enabled the identification of variability present in practice (i.e., number of movement patterns) and whether participants engaged in exploration of the movement, evidenced by high switching between movement patterns trial to trial (Komar et al., 2019).

6.5.3. Exploratory and exploitative behaviour

Building on previous MI research, the present study aimed to examine exploratory and exploitive behaviours exhibited during LP and NLP forms of MI practice. Therefore, the number of movement patterns visited by each participant was calculated to show the number of different coordination patterns explored across the intervention. A coordination cluster was defined as being visited when displayed at least once throughout the three technique assessments. Furthermore, to determine exploratory and exploitive behaviours, all trials with the associated coordination cluster were plotted in chronological order. Exploitation was demonstrated when the same cluster was displayed in two consecutive trials. Exploration was defined as different movement patterns exhibited in two consecutive trials (Komar et al., 2019). To establish whether participants engaged in more exploratory or exploitive behaviour, an exploration/exploitation ratio (EER) was calculated by dividing the number of exploration behaviours by the number of exploitation behaviours. Based on similar research by Komar et al. (2019), an EER of 1 denotes a balance between exploratory and exploitative behaviours, whereas a high EER (e.g., 1.5) indicates more significant levels of exploration. In the present study, the EER was implemented to examine potential differences in exploration and exploitation.

6.6. Results

6.6.1. Imagery ability

The analysis of general imagery ability showed that there was no main effect of condition for kinaesthetic imagery score, $F(1,13) = .530, p = .480$ (NLP: 5.14 ± 1.07; LP: 4.68 ± 1.30)., and the combined score $F(1,13) = 2.718, p = .125$ (NLP: 5.61 ± 0.73; LP: 4.68 ± 1.30). There was a significant main effect of condition for visual imagery score $F(1,13) = 5.438, p = .038$ (NLP: 6.07 ± 0.73; LP: 4.68 ± 1.40). However, both groups were above the acceptable average of 4 (neutral, not easy not hard) and were considered to have adequate MI ability (Kim et al., 2017).

6.6.2. Movement patterns: coordination profiling

From a potential 630 trials, 609 were successfully reconstructed for further analysis. According to the Bayesian information criterion (BIC) indicator, the model that was most representative of the present data set revealed 11 emerging movement patterns across the 9 kinematic joint variables for the 3 technique assessment sessions (Figure 6.1). The BIC values for 2 to 20 potential patterns indicated that the values for 11 patterns were the beginning of the plateau of BIC values* [BIC values for 2 to 20 potential patterns respectively = -1064006; -1040288; -1022128; -1007447; -995841.9; -985810.5; -978462.3; -9695021.4; -956089.7; **-944909***; -941363.4; -931305.9; -922973.3; -915530.7; -911633.4; -905570.3; -2904090.5; -897949.6; -894890.9].

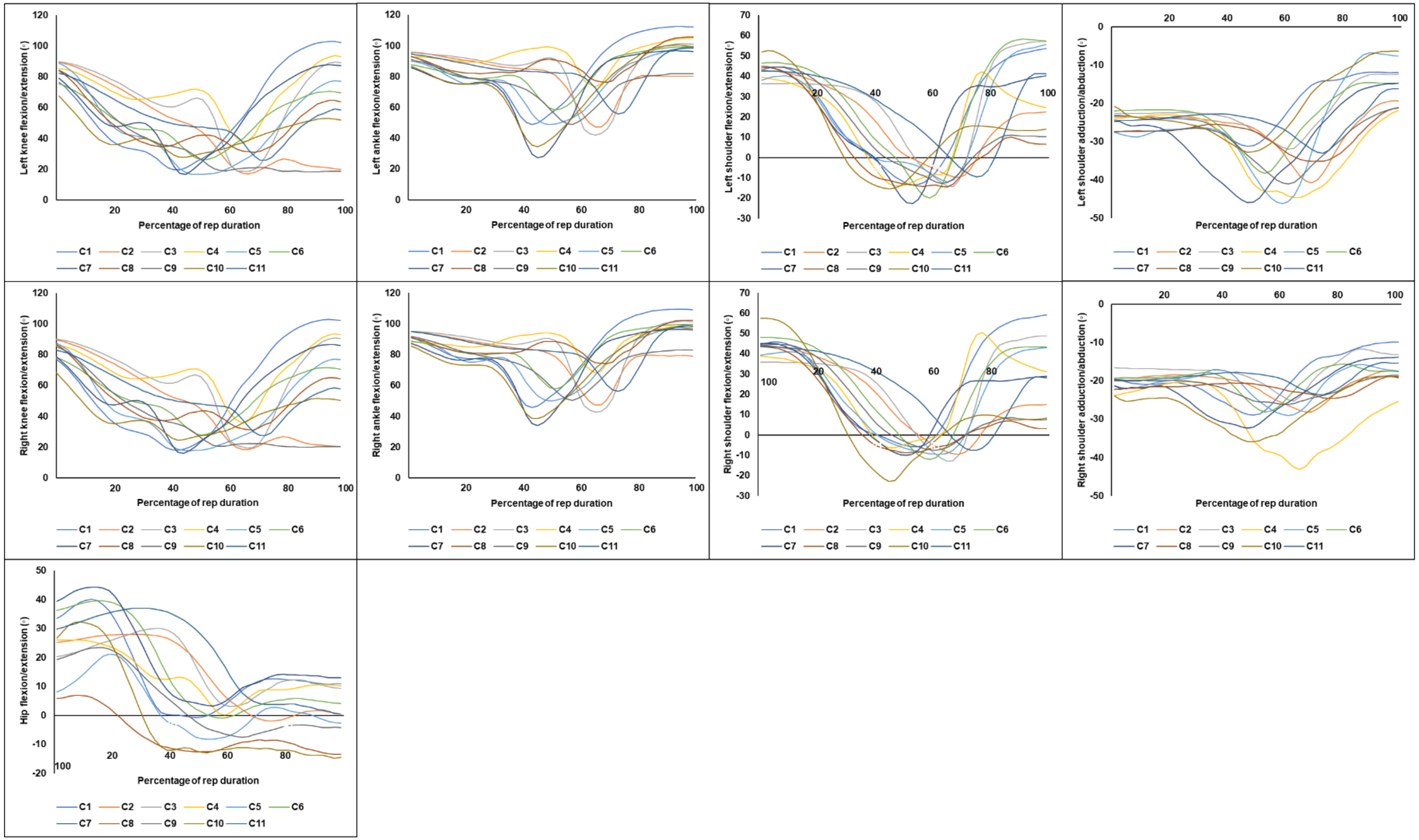


Figure 6.1. Mean movement patterns normalised to 100 data points for each cluster within all kinematic variables across all technique assessment sessions for NLP and LP conditions.

6.6.3. Distribution of movement patterns

Across all three technique assessment sessions the NLP condition (C2, C3, C5, C6, C10) and LP condition exhibited five preferred patterns (C1, C4, C8, C9, C11). The distribution of trials for each movement pattern within technique assessments 1, 2, and 3 are shown in Figure 6.2. It was found that C5 and C6 comprised the largest number of trials for the NLP condition (15% and 28%, respectively). C5 was found to be a unique movement to participant NLP 10, with 100% of trials utilising this movement pattern, suggesting strong initial behavioral tendencies that the task constraints could not successfully perturb. C11 and C4 comprised the highest number of trials (17% and 14%, respectively) for the LP condition. Similarly, C4 was only displayed by LP2 and comprised of 100% of trials, indicating no exploration.

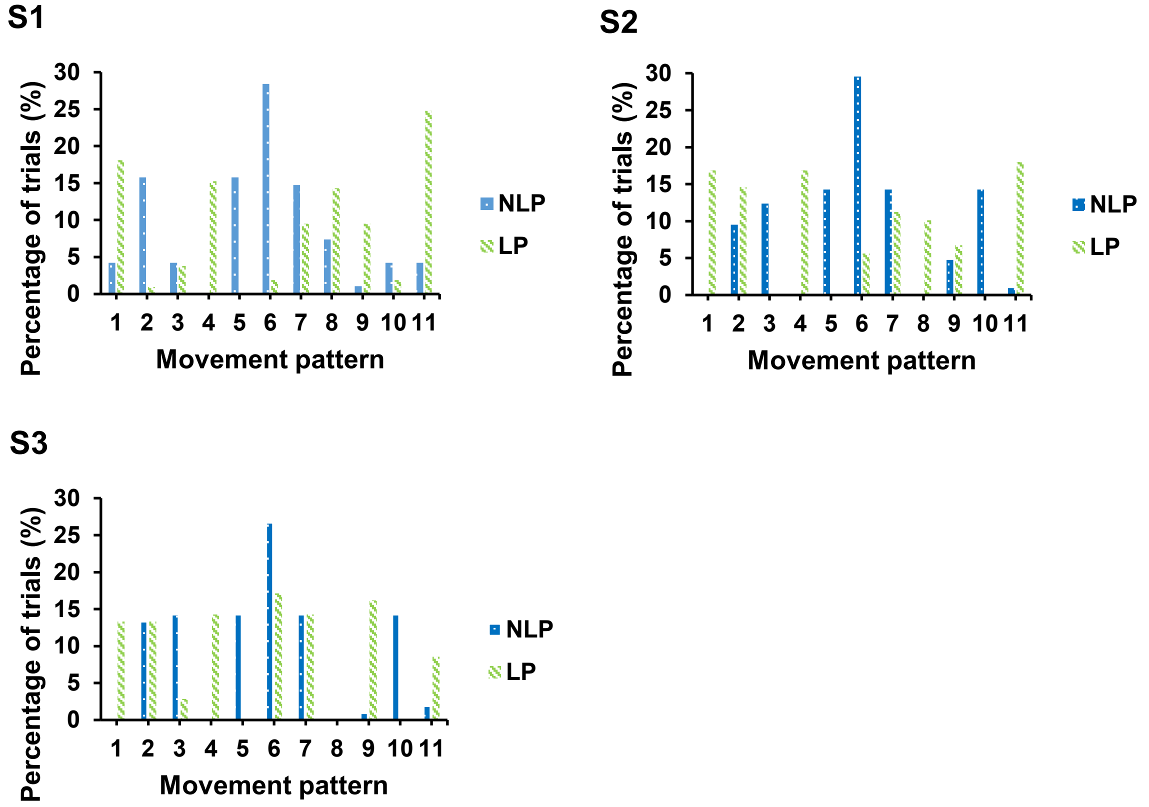


Figure 6.2. Percentage of trials for movement patterns in each technique assessment session. C6 comprised the most trials from session 1 (28%) to test 3 (27%) for the NLP condition. For the LP condition, C11 displayed the greater number of trials (25%) in session 1 and decreased in session 3 (9%), with C6 being the highest frequency movement in the final session (17%).

Across all trials and both conditions, it was found that C6 comprised the largest number of movements (37% of total trials; NLP = 28%; LP = 8%). C6 was found to have the lowest F×D and R×D, indicating a more effective movement pattern as the barbell did not travel excessively away from the learner's body (F×D = 0.07 ± 0.04m) and the barbell ended in a more stable position near the learner's base of support (R×D = 0.06 ± 0.04m). Figure 6.2 shows that 44% (NLP = 27%; LP = 17%) of movements were belonged to C6 in technique assessment 3.

Figures 6.3 A-D displays individual time series plots for a representative NLP and LP participant's sample. Four primary exploration/exploitation patterns were observed, with two being shared by both conditions (Figure 6.3C). Pattern A (Figure 6.3A) displayed by the LP condition was characterised by exploitation early in learning (technique assessment 1 & 2), concluding with increased exploration late in learning. For example, LP6 initially exploited C11 for 30 consecutive trials before exploring three new movement patterns (C1, C3 and C6). Pattern B (Figure 6.3B) displayed by the NLP condition was included exploration early in learning, followed by increased exploitation. NLP14 demonstrated pattern B, exploring four-movement patterns (C8, C9, C10 and C11) between trials 0 – 10, followed by exploitation of C10 from trials 13 – 45. Pattern C (Figure 6.3C) was shared by both conditions and was characterised by early exploitation of a movement pattern that served as a platform for brief periods of exploration and returned to the initially exploited pattern early in practice. For example, LP7 exploited C7 after 4 trials and subsequently explored C1 and C6 in technique assessment 2 before returning to C7 in technique assessment 3. Finally, Pattern D (Figure 6.3D) was demonstrated by both conditions and was characterised by no exploration, with participants completely exploiting one movement pattern.

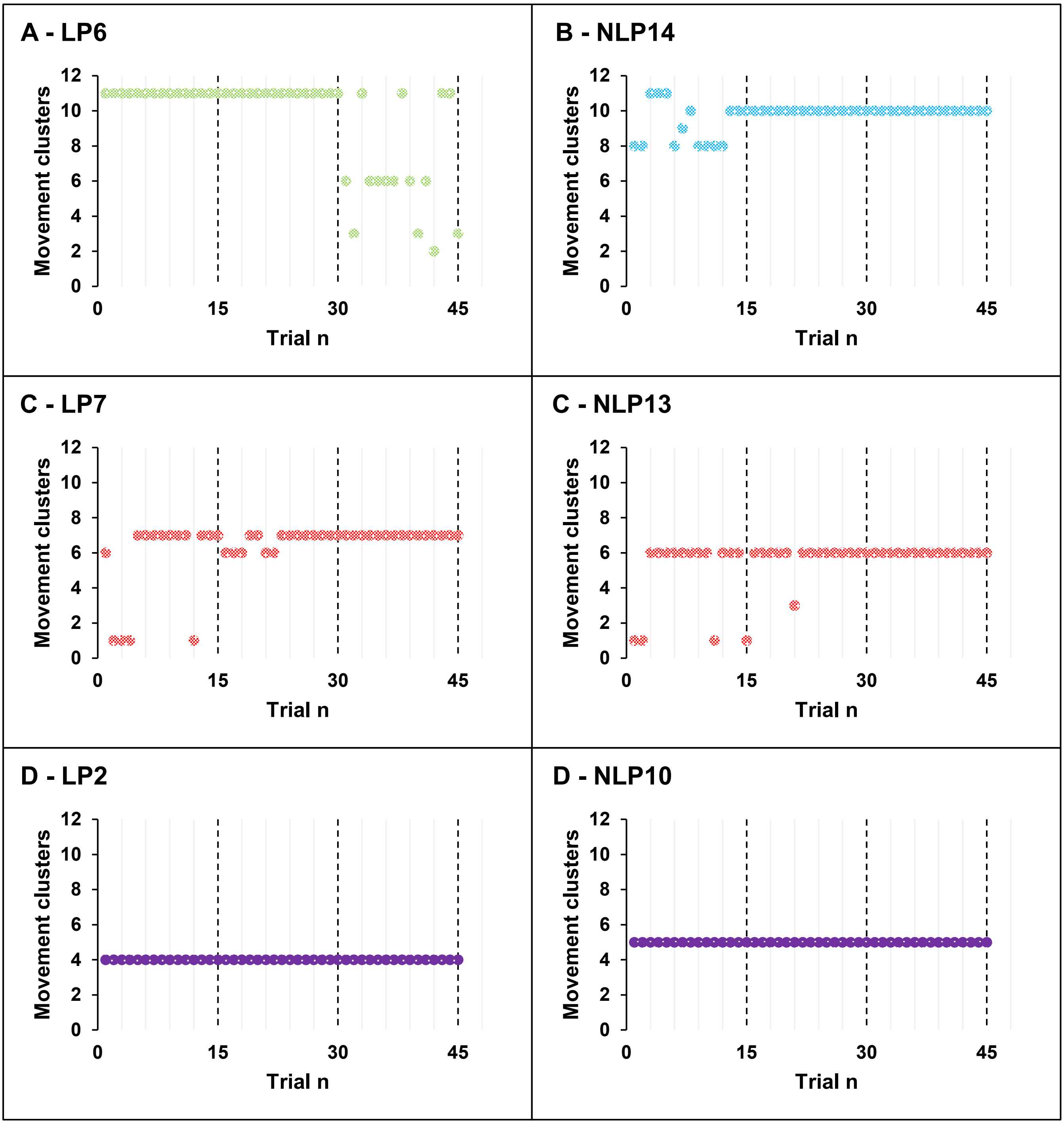


Figure 6.3. A, B: Time series plot of participants displaying exploration/exploitation pattern A (LP6) and B (NLP14) across technique assessment session 1, 2, and 3. Vertical dashed lines indicate the conclusion of each session. C, D: Time series plots of shared exploration/exploitation patterns C and D.

6.6.4. Performance accuracy: Horizontal bar displacement

From a potential 630 trials, 609 were successfully reconstructed for performance accuracy analysis. The two-way ANOVA revealed a significant interaction effect on rearward barbell displacement (R×D) between condition and time of technique assessment, $F(2, 22) = 5.040$, $p = .03$, $\eta_p^2 = .292$. Examination of means indicated that although there was a decrease in R×D for the NLP group from technique assessment 1 (0.06±0.43m) to 3 (0.05±0.32m), the LP condition showed an increase in R×D from technique assessment 1 (0.07±0.05m) to 3 (0.10±0.07m). Bonferroni post-hoc tests showed no significant differences between groups for technique assessments 1, 2, or 3 ($p = .13$ - .67). The main effects of time of technique assessment ($F(2, 22) = 1.03$, $p = .373$ $\eta_p^2 = .086$) and condition ($F(1, 11) = 0.78$, $p = .39$, $\eta_p^2 = .067$), were not significant, respectively. Further analysis showed that for F×D the main effects of time of technique assessment ($F(2, 22) = 1.31$, $p = .29$, $\eta_p^2 = .106$) and condition ($F(1, 11) = 0.22$, $p = .64$, $\eta_p^2 = .020$), were not significant, respectively. The time of technique assessment × condition interaction was not significant for F ×D ($F(2, 22) = .157$, $p = .856$, $\eta_p^2 = .014$).

6.6.5. Movement criterion: barbell trajectory type

Figure 6.4 shows examples of each barbell trajectory from representative participants. For the NLP condition, 72% of total trials were type 3 trajectories, 27% were type 4, and 2% were type 1 (criterion model). In the LP condition, 54% of total trials were type 3 trajectories, 23% were type 4, 22% were type 1 (criterion model), and 1% were type 2 trajectories. The NLP condition did not display type 2 trajectories and was therefore not included for further analyses. A Pearson's chi-square test of independence was used to evaluate whether barbell trajectory type was related to condition (NLP or LP). The chi-square test was statistically significant, $\chi^2(2, n = 586) = 56.311$, $p < .001$, Cramer's $V = .310$, indicating a moderate association. Z – tests with Bonferroni correction revealed that the frequency of type 1 trajectories was significantly higher for the LP condition (22% of trials) compared to the NLP condition (2% of trials) ($z = 5.1$, $p < .001$, two-tailed). A significant difference was detected for type 3 trajectories between the NLP (72% of trials) and LP condition (57% of trials) ($z = -1.6$, $p < .05$, two-tailed). Further analysis revealed that the frequency of type 3 trajectories was significantly greater than type 1 trajectories in both the LP ($z = - 2.0$, $p < .05$) and NLP conditions ($z = 2.0$, $p < .05$).

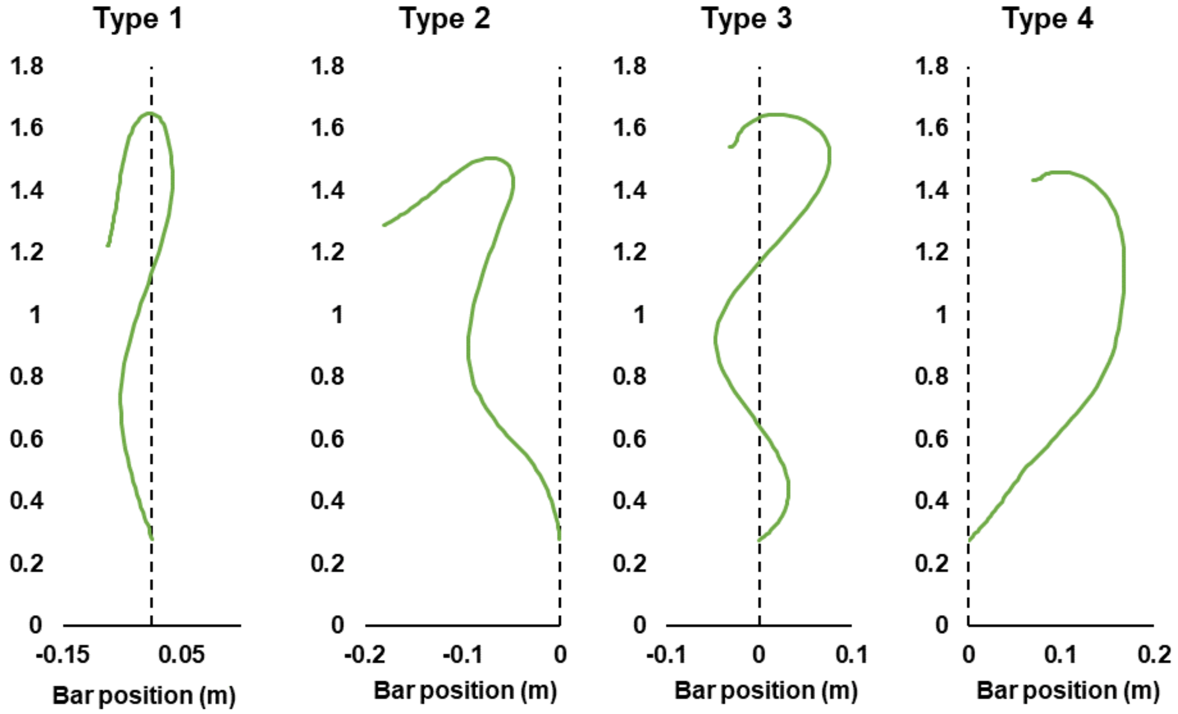


Figure 6.4. Example of each demonstrated barbell trajectory from three individual learners. Each barbell trajectory was defined by its relationship to the vertical reference line (Cunanan et al., 2020). Each barbell trajectory was normalised to 100 data points and plotted using the Y (horizontal), and Z (vertical) coordinates extracted from visual 3-D software. Type 2 trajectory was not exhibited by either condition.

6.6.6. Movement pattern: visited and exploited

Table 7 displays the number of movement patterns visited and exploited by each participant. Mann -Whitney tests revealed no significant differences in visited ($p = .315$) and exploited number of patterns ($p = .165$) between conditions.

6.6.7. Exploratory and exploitative behaviour: Exploration/exploitation ratio

The exploration/exploitation ratio was calculated to examine how two different approaches to skill acquisition may influence subsequent modes of behaviour following MI practice. No significant difference was found in the number of exploratory and exploitive behaviour between the LP and NLP conditions (*p* = .438; Table 8).

Table 8. The number of different movement patterns visited during three testing sessions and the number of movement patterns exploited between at least two consecutive trials.

	Number of movement patterns explored								Number of movement patterns exploited							
	Participants								Participants							
Condition	1	2	3	4	5	6	7	Mean	1	2	3	4	5	6	7	Mean
NLP	2	2	1	2	3	4	5	2.29	1	1	1	2	1	2	1	1.29
LP	4	1	3	2	4	6	2	3.14	3	1	2	1	2	2	2	1.86

Table 9. Exploration/exploitation ratio for each participant for the NLP and LP conditions.

	Participants							
Condition	1	2	3	4	5	6	7	Mean
NLP	0.52	0.22	0	0.27	0.28	0.51	0.06	0.26
LP	0.65	0	0.30	0.07	0.94	0.89	0.03	0.41

6.6.8. Impact of constraints on individual exploratory behaviour

Examination of EER indicates that the incorporation of constraints in the MI scripts of the NLP condition had a distinctly different impact on the individual exploratory behaviours as a function of time. For example, NLP9, NLP13, NLP14 and NLP16 displayed their peak EER in technique assessment 1 (EER = 0.25 – 4) and their lowest EER in technique assessment 2 after a period of MI practice with constraints present (EER = 0 – 0.67). By contrast, NLP5 and NLP12 displayed their highest EER in technique assessment 2 (EER = 1.5 – 3). NLP10 displayed complete exploitation (EER = 0) across all three assessments.

6.7. Discussion

The purpose of the present study was to investigate the application of a NLP informed MI approach to skill acquisition. Our aim was not to propose the extent of effectiveness for NLP informed MI. Rather, the goal of the present study was to provide preliminary findings to stimulate discussion around an alternative approach to skill acquisition utilising MI. Consistent with hypothesis (1), the LP condition displayed a higher frequency of the prescribed technical model (i.e., type one trajectory) than the NLP condition. However, in both conditions, the prevalence of type 3 trajectories was significantly greater than any other barbell trajectory. Partially consistent with hypotheses (2) and (3), exploration was observed in the NLP condition but not significantly more than LP. Practice and performance accuracy (R×D) improved equally for both conditions.

Type one barbell trajectories are touted as the most efficient and 'optimal' technique for weightlifting movements (Verhoeff et al., 2019). However, research suggests this particular trajectory is typically not the most utilised in elite competitions (Akkuş, 2012; Cunanan et al., 2020). Cunanan et al. (2020) observed that type 1 trajectories were displayed the least in both male (12% of lifts) and female lifters (12% of lifts) across all weight categories at the 2015 world weightlifting championships. Interestingly, despite supposed inefficiency, type 3 trajectories were demonstrated most frequently in males (51% of lifts) and females (56% of lifts). A similar pattern was observed in the present study in beginner level lifters with both the LP and NLP conditions demonstrating a significantly higher proportion of type 3 barbell trajectories than type one, despite the LP condition being explicitly instructed to perform a type one trajectory. These findings indicate that the 'optimal' technique may not be constrained to a particular barbell trajectory (i.e., type one barbell trajectory). The higher prevalence of type 3 trajectories for the LP condition suggests that regardless of what technical model is taught, individual movement constraints may require learners to search for coordination patterns that align with their capabilities and meet the task's demands (Chow et al., 2019). Previous MI research appears consistent with this contention, with Lindsay et al. (2020) reporting that PC technique was highly individualised in novice lifters following 6 weeks of MI practice, regardless of instructional approach (i.e., prescriptive or personalised).

One evident issue with comparing the present findings with observational data from elite performers is the obvious difference in overall performance outcome. The utilisation of 'sub-optimal' technique can be easily justified in elite performers when such high-performance levels are attained (i.e., gold medal; Akkus et al., 2012). Subsequently, the demonstration of sub-optimal technique is frequently viewed by practitioners to impede the development of expertise (Renshaw & Chow, 2019). Performance accuracy scores from the present study suggest that exploration of movement patterns that deviate from an 'optimal' technical model do not necessarily impede performance and may be an essential part of developing skilled behaviour. Participants in both the NLP and LP conditions demonstrated a preference for distinctly different coordination patterns. Within the LP condition, participants primarily exhibited C1, C4, C8, C9, and C11. By contrast, the incorporation of task constraints in the NLP condition limited the expression of these patterns, preferring C2, C3, C5, C6, and C10. Despite the use of distinctly different coordination patterns, improvements in R×D was the same for both groups, suggesting that more than one technique can produce the same overall performance outcome. These findings imply that the focus of MI practice for skill acquisition may be to facilitate learners in their search for individually appropriate coordination patterns rather than prescribe a specific way of performing a skill. If learners are inclined to deviate from the instructed technique, MI practice that allows exploration of less 'optimal' movements may provide necessary opportunities for learners to develop individually appropriate coordination patterns. As demonstrated in the present study, effective movement may not adhere to a prescribed technique. Instead, effective movement can be expressed as movement organisation that meets constraints of the perceptual-motor workspace while attaining improved performance (Chow et al., 2019). Subsequently, MI practitioners may want to consider the NLP design principle of instructions that encourage self-organising processes implicitly by implementing analogy or movement outcome focused imagery scripts, rather than defining an explicit movement model (Correia et al., 2019).

Regarding the quantity of exploration, no significant differences were observed between LP and NLP conditions, suggesting that the constraints incorporated into the MI scripts were not a precondition for exploration. One potential explanation is that exploratory behaviour in the LP condition demonstrates participants attempting to follow the prescribed movement, but may not have been individualised to their constraints (i.e., limb length and body weight) (Hacques et al., 2020). Exploration in the LP condition might be defined more appropriately as coordination instability where participants are 'caught' between an inherent self-organising process and the need to conform to a specific movement pattern. Whereas practice was designed for NLP participants to leverage functional variability by encouraging exploration and the emergence of individualised movement solutions (Button et al., 2020).

Examination of exploratory behaviour over time indicated that responses to constraints was highly individualised for NLP participants. NLP5 and NLP12 increased exploration between technique assessment 1, when constraints were absent (EER = 1 & 0) and assessment 2 after a period of practice with constraints present (EER = 3 & 1.5). Conversely, NLP9, NLP13, NLP14, NLP16 constraints appeared to restrict exploratory behaviour, with EER decreasing between technique assessment 1 (EER = 0.25 – 4) and 2 (0 – 0.67). Furthermore, when examining the distribution of trials for each preferred coordination cluster. NLP participants demonstrated a preference for C6, which was found to be the most ‘effective’ cluster displaying limited barbell movement away from the learner’s body (F×D = 0.07 ± 0.04m) and the barbell ended in a more stable position near the learner’s base of support (R×D = 0.06 ± 0.04m). These findings indicate that exploration quantity is not necessarily the determining characteristic for developing individually relevant coordination patterns. Instead, the important point is that the nature of exploration elicited by the constraints was functionally relevant for each individual, resulting in optimal task solutions (i.e., improved R×D). Similarly, in elite level divers, Barris et al. (2014) observed that coordination patterns' variability increased and decreased after a practice utilising variable take-off conditions, but performance outcomes improved under all conditions.

The individualised nature of exploration highlights an important limitation of the current study. The EER can only provide a measure of exploration/exploitation quantity and does not shed light on the nature of exploration for each learner, which the present study shows may be distinctly varied. This raises questions about what can be considered an optimal level of exploration. Hacques et al. (2020) explain that exploration is a process of attuning to reliable information throughout the movement, suggesting that the effectiveness of exploratory behaviour cannot be solely attributed to an increase in the amount of exploration. Rather, effective exploration may be an improved ability to attune to opportunities for action that align with the learners' capabilities and experiences (Hacques et al., 2020). Therefore, further research should consider how learners perceive information during MI practice when investigating exploratory behaviour. The individualised nature of exploration demonstrated raises an important issue for using constraints in MI scripts. It is possible that the constraints could not effectively perturb initially strong behavioural tendencies leading to a reduction in exploration. Therefore, to effectively facilitate exploration, constraints in MI scripts could be adjusted throughout practice more regularly. Although the initial presentation of constraints may have encouraged exploration, these constraints may have become 'outdated' and needed to be changed to perturb newly stabilised coordination patterns. This is in line with the idea that constraints can emerge and decay over time or with learning (Chow et al., 2022). The layered stimulus response approach to imagery script development is consistent with this idea, where script information is gradually layered over time (Cumming et al., 2017). A fruitful line of inquiry may be to examine the influence of gradually adjusting or removing constraints over time to challenge individual coordination patterns. A further limitation was the discrepancy in participant gender (Male = 12; Female = 2). Although, to the authors knowledge, there is no research to suggest gender related differences in the acquisition of the PC skill, it is possible that some of the findings of the present study could be related to differences in gender. Further research is needed to investigate these claims.

6.8. Conclusion

In summary, the present study provides preliminary findings on applying NLP principles of skill acquisition in MI practice. Similar quantities of exploration were observed in both conditions, indicating that regardless of instructions, learners may inherently explore opportunities for action that align with individual capabilities and information presented in the MI practice environment. The utilisation of 'sub-optimal' techniques by both conditions (i.e., type 3 trajectories) coupled with equivalent improvements in performance accuracy (i.e., rearward barbell trajectory) indicated that adhering to an ‘optimal’ technique does not ensure improved performance. These findings suggest that a movement's overall effectiveness for meeting the task goal may be of more importance than replicating a movement that looks correct in MI. The present study highlights the potential benefits of utilising a NLP approach to MI to encourage learners to explore movement solutions that align with a learner's capabilities without negatively impacting performance. It may be beneficial for MI practitioners to consider designing practice that allows deviations from prescribed technical models to facilitate learners' inherent exploration of individual task solutions. Future research should investigate further the efficacy of NLP informed MI to develop further understanding around how best to apply these principles of skill acquisition in MI practice.

Chapter 7: General Discussion

7.1. Introduction

Central to this thesis is the proposed similarities in neurophysiological and training-related adaptations between MI and PP, often referred to as the functional equivalence hypothesis (Moran & O'Shea, 2020). Given that MI and PP have been shown to share motor processes, this formed the rationale for investigating skill acquisition approaches implemented in PP to understand how these approaches may be applied to MI interventions. Specifically, this thesis aimed to enhance our understanding of how a contemporary skill acquisition approach, known as NLP, could be applied to MI intervention design for the purpose of skill development. The main aim of this thesis was not to investigate whether NLP was a 'better' approach but rather to provide preliminary findings that would hopefully stimulate further discussion and research about the incorporation of successful skill acquisition principles from PP into MI interventions. In addition, this thesis aimed to provide preliminary recommendations for the application of NLP practice design principles to MI training to facilitate the development of individualised, adaptable, skilled behaviour.

Prior to investigating the application of NLP to MI, an overview of the MI literature was necessary to establish an understanding about the efficacy of MI for skill development in sport and intervention variables that may moderate intervention effectiveness. The review of MI literature presented in Chapter 2 revealed a considerable amount of evidence to support the beneficial effects of MI for skill development (Simonsmeier et al., 2021; Toth et al., 2020). However, it was found these previous reviews included single session interventions, non-sport related skills (e.g., drawing and finger tapping tasks), and MI combined with other psychological techniques (e.g., relaxation) in overall effect size calculations. The inclusion of such studies made it difficult to ascertain the directly attributable effects of MI for sport-specific skills. Therefore, Study 1 was conducted to investigate the first aim of this thesis, which was to conduct a systematic and meta-analytic review of the MI literature to clarify the overall efficacy of MI interventions for improving sport-specific skills by excluding studies that implement MI for a single session, non-sport related skills, and combined with other psychological techniques. Furthermore, skill type was more closely investigated in Study 1 relative to previous meta-analytic reviews (Driskell et al., 1994; Toth et al., 2020). Various claims have been made in the MI literature about the differential effects of MI based on skill type, but this has included analysing skills categorised into broad categories, often combining skills with significantly different complexity demands (e.g., dart throwing and gymnastics). Given the focus of the present thesis on self-paced, movement form-based skills, it was important to develop a greater understanding of the differential effects of MI on skill complexity using a more nuanced approach (e.g., Gentiles' (2000) 2-D taxonomy).

A review of the MI literature highlighted MI training should mimic important aspects of physical movement as closely as possible (Wakefield & Smith, 2012), contextualised through the functional equivalence hypothesis (Moran & O'Shea, 2020). As demonstrated in Chapter 2, an ecological dynamics perspective of physical practice highlights the importance of adaptability in skilled action. Consistent with this notion, adaptability or behavioural flexibility was defined as a key attribute of skilled athletes, described as the ability to produce stable movement patterns consistently and efficiently, yet, flexible enough to adapt to dynamically changing environmental conditions (Ranganathan et al., 2020; Renshaw & Chow, 2019). Given the emphasis on replicating PP in MI, the need to focus on developing flexible or adaptable skills has important implications for the design of MI interventions, suggesting that MI interventions may benefit from considering an alternative skill acquisition perspective. An alternative approach to traditional views of skill acquisition was identified in nonlinear pedagogy (NLP), which encompasses the key principles of ecological dynamics into a practical framework to guide practice design. The second specific aim of this thesis was to discuss and provide practical recommendations for how principles of NLP can be incorporated into MI interventions for skill acquisition. In Study 2, an ecological dynamics perspective of skill development was outlined, and key practice design principles of NLP were discussed. Further, specific examples were provided for each NLP principle on how they could be practically applied to MI interventions for skill acquisition.

Chapter 2 demonstrated strong empirical evidence to support the use of NLP (Brocken et al., 2020; Buszard et al., 2016; Chow, Davids, Button, & Koh, 2008). However, studies focused primarily on open, game-like skills, in which movement form may not be considered a primary determinant of successful performance. The influence of a NLP approach on self-paced, movement form-based skills (i.e., weightlifting or gymnastics), where movement form is emphasised as a key aspect of performance, was relatively unknown. Further, a single study was identified that directly compared NLP with a traditional, linear approach to skill acquisition (Lee et al., 2014). Study 3 was designed specifically to examine the impact of NLP practice (physical practice, not MI) on exploratory behaviour and performance relative to traditional, prescriptive type practice for beginners learning a self-paced, movement-form based skill, an Olympic weightlifting skill known as the power clean (PC).

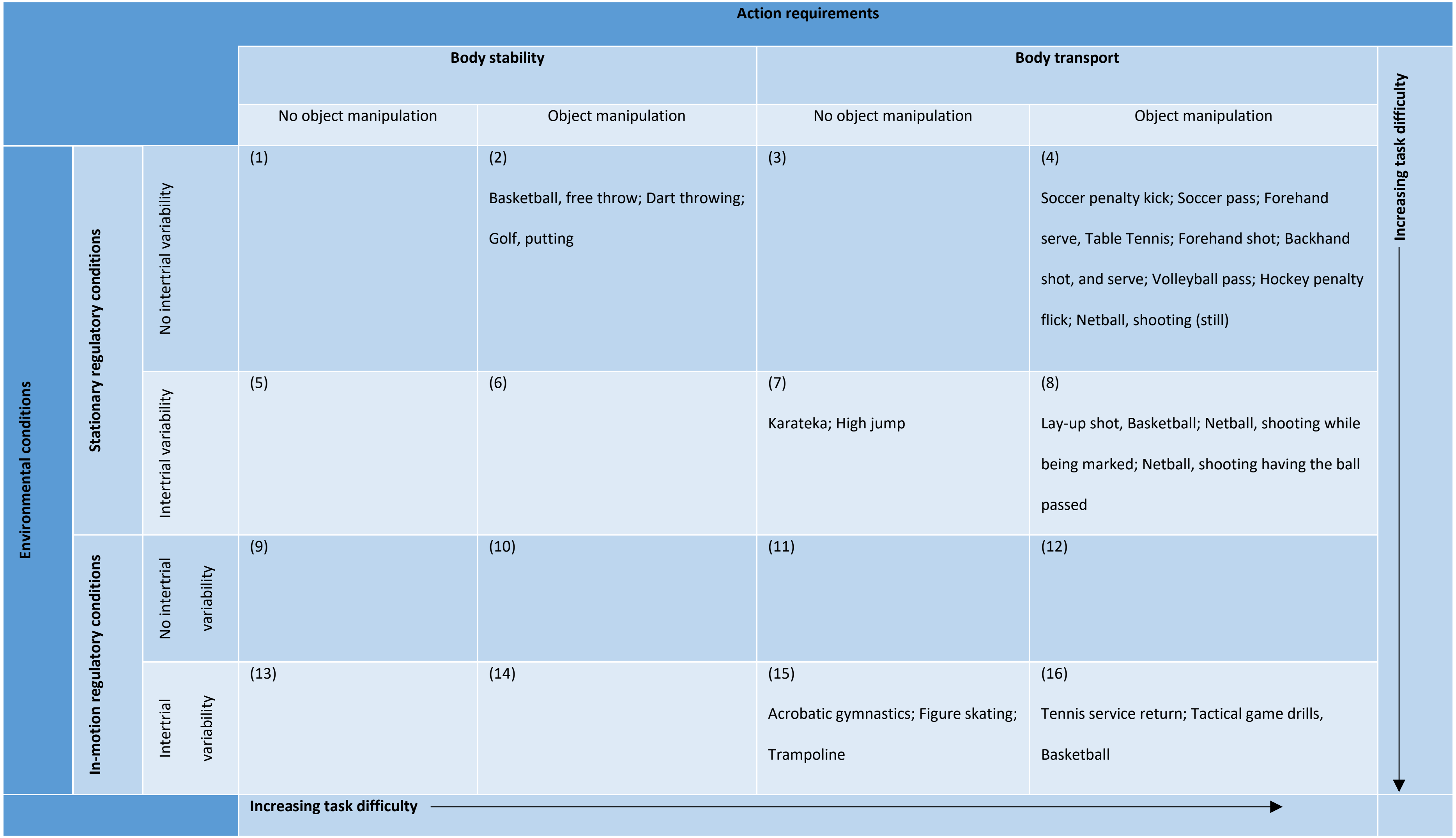
Assuming that MI is to some degree functionally equivalent with PP, no published research exists that has directly examined the incorporation of skill acquisition principles into MI interventions. Drawing on the findings of Study 2 and 3 of NLP applied in PP, the aim of Study 4 was to investigate the application of NLP practice design principles in MI and its influence on exploratory behaviour and performance for beginners learning the PC. This chapter will summarise the key findings, the practical implications of these findings, and the limitations of the research conducted are also discussed alongside recommendations for future research.

7.2. Conclusions

This thesis provides novel findings of an alternative perspective to MI intervention design for skill development. Firstly, Study 1 addressed some important limitations regarding the overall effect of MI interventions for sport-specific motor skills and moderating factors. Specifically, Study 1 excluded studies examining non-sport-related motor skills and combined MI with other psychological techniques. More broadly, previous meta-analytic reviews on motor and cognitive skills and sports yielded significant, moderate effect sizes of $d = 0.419$ (Toth et al., 2020) and 0.431 (Simonsmeier et al., 2021). Consistent with these past findings, Study 1 found that MI interventions focused on sport-specific motor skills had a moderate, significant effect on performance outcomes ($g = 0.476$).

Building on previous reviews, several moderator variables were identified to significantly influence the efficacy of MI interventions. These variables included how MI was delivered (i.e., combined with physical practice [PP] or alone), skill complexity, and performance measure (i.e., outcome or process). MI alone produced significantly greater performance improvements than control conditions regarding how MI was delivered. Previous studies are consistent with this finding showing that MI alone can develop a range of skills (Frank et al., 2014; Kim et al., 2017; Kraeutner et al., 2016; Smith et al., 2008). For example, Wright and Smith (2009) found that PETTLEP based MI independent of PP significantly increased maximal weight lifted (1RM) of a bicep curl task relative to the control condition. The evident efficacy of MI independent of PP demonstrated in Study 1 provided the foundation for utilising such a delivery method in Study 4.

Further findings from Study 1 showed that skill complexity, as classified by Gentile's two-dimensional taxonomy (Figure 7.1; displaying classification of skills reviewed in Study 1), had a differential impact on the effects of MI.



			Action requirements				
			Body stability		Body transport		Increasing task difficulty
			No object manipulation	Object manipulation	No object manipulation	Object manipulation	
Environmental conditions	Stationary regulatory conditions	No intertrial variability	(1)	(2) Basketball, free throw; Dart throwing; Golf, putting	(3)	(4) Soccer penalty kick; Soccer pass; Forehand serve, Table Tennis; Forehand shot; Backhand shot, and serve; Volleyball pass; Hockey penalty flick; Netball, shooting (still)	
		Intertrial variability	(5)	(6)	(7) Karateka; High jump	(8) Lay-up shot, Basketball; Netball, shooting while being marked; Netball, shooting having the ball passed	
	In-motion regulatory conditions	No intertrial variability	(9)	(10)	(11)	(12)	
		Intertrial variability	(13)	(14)	(15) Acrobatic gymnastics; Figure skating; Trampoline	(16) Tennis service return; Tactical game drills, Basketball	
			Increasing task difficulty				

Figure 7.1. Two-dimensional skill classification of studies reviewed in Study 1 (Chapter 3) (Lindsay et al., 2021). The number in the top left corner represents complexity classification.

Results showed that the magnitude of effect sizes was significantly greater for simple skills (1 – 4; *g* = 0.883) than complex skills (13 – 16; *g* = 0.212). A proposed explanation for these findings was the skill level of individuals performing each skill. Of the effect sizes contributing to the novice skill level, 11% were in complex skills (e.g., basketball lay-up shot, and netball shooting under pressure or passed). In contrast, almost half of the analysed studies (47%) examined moderate to high complexity skills (5 -8 and 13 – 16) for skilled performers. Overall, Study 1 highlighted the need for further research to examine the efficacy of MI interventions for developing complex skills in novice learners. Regardless of skill level, only 13% of extracted effect sizes were from studies classified as requiring high levels of complexity (e.g., acrobatic gymnastics, trampoline, and figure skating), involving in motion skill execution with intertrial variability and object manipulation (Gentile, 2000). The application of Gentiles' (2000) two-dimensional taxonomy allowed for a more nuanced examination of skill complexity, extending the work of previous MI reviews. However, there was a notable absence of self-paced, movement form-based skills across all included sport-specific motor skills. Three studies included in the review examined these types of skills (e.g., acrobatic gymnastics, figure skating, and trampoline) (Isaac, 1992; Marshall & Gibson, 2017; Rodgers et al., 1991). Similarly, in the review of skill acquisition literature in Chapter 2, the limited number of NLP based studies examining self-paced, movement form-based skills were evident.

Drawing on key principles of NLP, three practical considerations were proposed in Study 2 (Chapter 4) regarding the application of NLP for MI practice design. These considerations were as follows: (1) incorporating task constraints (e.g., various net heights in tennis) into MI scripts to encourage exploratory behaviour to facilitate the search for individually appropriate performance solutions; (2) creating representative practice environments by developing imagery content that provides relevant opportunities for action (affordances) that are used to regulate movement; (3) implementing instructions that emphasise movement outcomes to facilitate emergent movement patterns, such as analogy-based cues (Komar et al., 2014). These considerations formed the theoretical foundation for both Studies 3 and 4. Study 3 was conducted to understand further how NLP influences the acquisition of a movement form-based skill (i.e., PC), an important gap in the literature identified in Chapter 2.

In Study 3 and 4, learners were classified as being beginners in the PC (Everett, 2012; Haug et al., 2015). Both studies 3 and 4 comprised of a 4-week practice intervention, (eight lessons, each approximately 30 minutes). For Studies 3 and 4, learners were assigned to either a NLP or linear pedagogy (LP) condition. In Study 3, learners engaged in physical training of the PC. By contrast, in Study 4 learners were provided with identical instructions as Study 3, but they were used as an MI script (audio recording) to guide MI practice of the skill. No physical training was undertaken by learners in Study 4. NLP conditions for both studies were designed based on the idea that movement variability can be leveraged to encourage exploration and facilitate the discovery of individualised movement solutions. Therefore, task constraints were manipulated for the NLP condition to encourage exploratory behaviour. Based on previous constraints-based research in the PC (Verhoeff et al., 2018), task constraints included chalk on the barbell and poles in front of the learner. Table 9 details each task constraint implemented and the underpinning NLP design principles. To align with NLP design principles, analogy-based instructions were implemented to avoid prescribing a specific movement form and encourage the development of individualised movement patterns.

Lessons for the LP condition comprised of explicit instructions, repetitive practice, with feedback focused on correcting ‘mistakes’ and direct the learner toward the ‘optimal’ technique. Instructions were designed according to key phases of the PC identified in the literature and in line with industry standards set out by the National Strength and Conditioning association (NSCA), designed to direct learners to adopt a type one barbell trajectory, which has been identified in the literature as the optimal technique (Cunanan et al., 2020). Within weightlifting research, three main barbell trajectories have been identified that are commonly demonstrated in elite level weightlifters (Cunanan et al., 2020; Rossi et al., 2007). Type one barbell trajectories are considered the most biomechanically efficient and 'optimal' path the barbell can travel (Cunanan et al., 2020; Kipp & Meinerz, 2017) (Figure 7.1; Study 4).

Table 10. Summary of task constraints used in Studies 3 and 4 with underpinning NLP design principle

Task constraint	**Constraint details**	**Nonlinear Pedagogy design principle**
Chalk on the barbell	Chalk was applied to the bar to encourage participants to pull the bar back towards the body during the lift and keep the bar in contact with the thighs while transitioning from below to above the knee and into the *second pull* position. If participants were keeping the bar in contact with the thighs, chalk from the bar would show where contact was occurring.	*Effective manipulation of tasks constraints*. The chalk on the barbell aimed to facilitate exploration and exploitation of alternative movement solutions, such as different starting heights of the *second pull* position. *Leveraging functional variability.* The chalk aimed to amplify exploration of different positions of the *second pull* to facilitate the emergence of individualised solutions during this phase of the lift.
Poles in front of participant	Two poles were placed in front of the participant to restrict forward movement of the bar. Participants would lift in front of the poles while trying to avoid contacting them.	*Reducing conscious control of the movement.* The poles aimed to focus attention on the movement outcome, to encourage self-organising processes. *Leveraging functional variability.* By placing the poles in front of the learner this aimed to amplify

	exploratory activity and guide the learner toward performance solutions that matched specific capabilities, skill, and experience.

The measures in Studies 3 and 4 of this thesis included: (1) horizontal barbell displacement – labelled performance accuracy and measured the start to most forward position during the lift (F×D) and start to catch position (R×D); (2) barbell trajectory type – labelled movement criterion and characterised the overall pattern of barbell movement to quantify how well actual barbell trajectories matched prescribed technique; (3) Movement patterns exhibited – cluster analysis was carried out to quantify the number of different movement patterns used by each learner throughout practice, allowing for exploratory behaviours to be investigated.

In Studies 3 and 4, no significant differences were observed between conditions in the frequency of specific barbell trajectory types, suggesting that both NLP and LP conditions did not show a preference toward one specific barbell trajectory. This finding is interesting considering the LP condition was provided with explicit instructions on specific movement forms and feedback to correct errors according to the defined 'optimal' technique model (type one trajectory). These findings suggest using a specific pedagogical approach does not necessarily ensure learners establish a prescribed technique. From a NLP perspective, the interaction between the inherent constraints of the task and individual constraints may have meant that learners needed to search for an alternative movement solution to adequately satisfy the task's demands and match individual capacities (Chow et al., 2019). Observational data in elite level performers supports this interpretation, showing that individual constraints (i.e., bodyweight) appears to moderate the expression of specific techniques, lighter lifters (48 – 58kg category) utilising a type 2 trajectory and heavier athletes (75+ category) mainly using a type 3 trajectory (Antoniuk et al., 2017). Further, in novice lifters, Lindsay et al.

(2020) reported that following 6-weeks of either personalised or traditional MI practice, PC technique was like the present results, with participants in both groups demonstrating individualised techniques. An analysis of the technical development of the PC divided by weight categories for beginners might be fruitful, perhaps like categories utilised to study elite performers

Drawing comparisons between novice and elite performers can be problematic. Elite athletes produce world-class performance outcomes, making the use of ‘less’ efficient movements potentially more acceptable than when the same is observed in novices. Subsequently, when dealing with beginners, practitioners often try to reduce movement variability (i.e., sub-optimal movement patterns), favouring a prescribed ‘ideal’ technical model (Araújo & Davids, 2011; Renshaw & Chow, 2019). Performance scores from Study 3 and 4 suggest that deviation away from the prescribed technique – quantified as exploratory behaviour – does not negatively impact overall skill development. NLP and LP conditions demonstrated a range of different movement patterns for both studies, characterised using a novel cluster analysis technique. Table 11 displays the preferred movement patterns for Study 3 and 4.

Table 11. Preferred movement patterns for NLP and LP conditions across Study 3 and 4

	Study 3 (physical practice)					Study 4 (Mental imagery practice)				
	Preferred movement patterns					Preferred movement patterns				
NLP condition	C3	C6	C11	C12	C13	C2	C3	C5	C6	C10
LP condition	C2	C7	C9	C10	/	C1	C4	C8	C9	C11

Consistent with my predictions, NLP, and LP conditions in Study 3 and 4 significantly improved on measures of performance accuracy. This is a key finding when considered alongside the preferred movement patterns displayed by each condition. Across each study (Table 11), NLP and LP conditions demonstrated a wide variety of movement patterns, yet improvements in measures of performance accuracy were equivalent between conditions. In Study 3 forward barbell movement was significantly reduced (F×D) in both conditions, indicative of improved biomechanical efficiency (Kipp & Meinerz, 2017). For Study 4, a significant improvement was observed in rearward barbell movement (R×D), indicative of a more stable finish position, as the barbell is caught closer to the vertical reference line (i.e., learner's centre of gravity) (Everett, 2012). These findings highlight that developing individualised movement solutions is possible with both an explicit, prescriptive approach (i.e., LP) and an exploratory skill acquisition strategy (i.e., NLP) without negatively impacting performance outcomes. Though traditional coaching approaches of weightlifting based movements have often emphasised adherence to a coach prescribed 'optimal' model (Rucci & Tomporowski, 2010), the present findings suggest learners can utilise different movement forms to achieve successful performance outcomes.

The exploration/exploitation ratios (EER) in Studies 3 and 4 suggested participants engage in exploratory behaviour throughout physical and MI practice. Contrary to predictions, between-group differences for EERs were not significantly different for NLP and LP conditions. This was an interesting finding as it suggested that exploratory behaviour was not necessarily facilitated by manipulating task constraints, either integrated into the MI scripts or physically. Such a result was not expected as the LP condition was explicitly instructed to adopt an 'optimal' technique. It was hypothesised this would restrict exploration of alternative movements, evidenced by lower EERs. By contrast, manipulating task constraints and the use of analogy-based instructions (key principles of NLP) was expected to encourage NLP participants to engage in significantly more exploratory behaviours. These findings suggest learners will engage in exploratory behaviour regardless of the pedagogical approach used when acquiring a skill such as the PC. These findings are inconsistent with similar research conducted by Lee et al. (2014). They found that learners practicing under NLP demonstrated a greater number of movement clusters (i.e., explored a higher number of alternative movement patterns) – using the same clustering method in this thesis – relative to LP practice. However, Lee et al. (2014) investigated a tennis forehand stroke, a more dynamic, game-like skill, whereas Study 3 and 4 examined a movement form-based skill. Considered together with results from Study 4, it may be that the influence of pedagogical approaches, such as NLP or LP, may be impacted by the type of skill being practiced. Another potential explanation for the lack of differences in exploration is that the exploratory behaviour observed in LP conditions for both studies represented failed attempts to reproduce the prescribed technique. Captured this way, it is possible that the function of exploration served different purposes for each condition, whereby LP learners are attempting to stabilise the prescribed technical model and under NLP exploration is a process of searching for movement solutions to satisfy task demands.

7.3. Theoretical Implications

This thesis attempted to connect two fields of research, MI, and skill acquisition, subsequently, this thesis provides some interesting findings that add to theoretical perspectives in both areas. Firstly, it was hypothesised that exploratory behaviour would be facilitated to a greater degree for learners practicing under NLP relative to LP. The measurement of exploratory behaviour in previous research (e.g., tennis; Lee et al., 2014) suggested exploration could be encouraged through task manipulation more than traditional, prescriptive practice (i.e., LP). The lack of significant differences in exploration between NLP and LP conditions in Study 3 suggest for self-paced, movement-form based skills such as the PC, exploration may be a necessary function for learners to establish individualised, functional, movement patterns to overcome inherent individual (e.g., body weight, height) and task constraints of the movement. This idea appears consistent with the exploration observed in the LP condition in Study 3, whereby learners still explored alternative movement patterns despite engaging in practice designed to reduce movement variability.

A key theoretical consideration that arose was the way in which skills are categorised as movement outcome focused or movement-form based. In the present thesis, the PC was considered to be a self-paced, movement form based skill. The rationale behind this decision was based on key characteristics of the skill, such as, the movement is initiated by the individual, it must start from the floor, the barbell needs to be caught on the shoulders above parallel to be considered a PC (Everett, 2012). However, success of the movement was dependent in part on the external apparatus (i.e., horizontal barbell displacement) and a specific movement form (i.e., barbell caught above parallel). Subsequently, this highlights how such skills may not be considered as movement form or outcome focused in a binary sense, rather, it requires that movements be viewed on a continuum between purely outcome focused and movement form based motor skills (Spittle, 2021). This has important implications when considering the role of exploratory behaviour in the learning process for movements, such as the PC, that rely on both movement form and outcome for performance success. Movement form requirements (e.g., catching the barbell above parallel) may restrict the exploration of alternative movement solutions and subsequently influence alternative techniques that may be explored. Captured this way, exploration may be guided firstly by the individuals need to meet specific movement form requirements, before they are able to achieve a certain performance outcome. Future research should look to investigate this issue further.

A further theoretical contribution to skill acquisition from the present thesis is the significant improvement in performance (i.e., F×D) for both conditions coupled with equivalent levels of exploratory behaviour and expression of 'suboptimal' techniques (e.g., type 3 and 4 barbell trajectories). Despite LP learners practicing under conditions aimed to limit the expression of alternative techniques (i.e., type 3 and 4 trajectories), learners were not restricted to a specific technical model. However, deviations from prescribed technique were not detrimental and performance measures improved. These results challenge the emphasis of practice design focused on strengthening a centralised 'optimal' technique representation (i.e., motor program), often proposed by cognitive-based models of motor learning (e.g., generalised motor program theory) (Schmidt & Lee, 2019). However, it is important to note that prescription of specific movement form (i.e., LP condition) does not seem to noticeably restrict the exploratory behaviour and the development of individualised movement patterns. This is contrary to the theoretical position of a NLP approach, which suggests that practice should limit explicit instruction of specific body positions to encourage self-organisation processes and facilitate the emergence of individualised movement patterns (Chow et al., 2022). As mentioned earlier, it is possible exploratory behaviour, and the development of individualised movement patterns were a necessity for each learner to overcome the inherent individual and task constraints. Alternatively, these findings highlight important considerations around how exploration is theorised and quantified in skill acquisition research. It is possible LP learners were not technically engaging in exploration, but rather the switching between different movement patterns represented failed attempts to develop and stabilise the prescribed technique. However, conceptualising exploratory behaviour purely based on the quantity of switches or volume of exploration, as is the case with the EER, does not allow for a distinction to be made in the potential differences in exploration between NLP and LP conditions. Consistent with point, Hacques et al. (2020) suggest exploration cannot be measured by quantity, rather, a measure of perceptual accuracy is necessary to understand changes in learner's attunement to more relevant information in the perceptual motor landscape. This thesis did not specifically aim to investigate the perceptual accuracy of exploration, and so cannot determine whether LP learners were exploring alternative movement patterns or attempting to stabilise the prescribed technique.

Regarding the theoretical implications to MI, two main contributions are evident. Firstly, like in Study 3, describing an 'optimal' technique appears to not be necessary for improving technical performance, and in fact does not ensure the adoption of a specific technique. Results of Study 4 indicate learners may search for individualised movement patterns to align with their individual capacities and satisfy task demands even when using MI practice that explicitly describes a specific movement form that is reinforced through repetitive practice. Like Study 3, performance outcomes (i.e., R×D) were not significantly different between NLP and LP conditions, with both groups significantly reducing R×D. Taken together with non-significant differences in exploratory behaviour, these findings suggest that skills such as the power clean may inherently require the development of an individualised technique to effectively execute the movement. This notion is consistent with research by Lindsay et al. (2020), finding that regardless of MI instructions (i.e., prescriptive, or individualised) learners adopted a range of individualised barbell trajectories following practice. The individualised nature of learning demonstrated in Study 3 by both conditions suggests that a shift in thinking may be necessary when conceptualising the aims of MI for the development of movement-form based skills. Given learners appeared to inherently engage in exploration and development of individualised movement patterns, skill development using MI may be more appropriately conceptualised as a process aiming to facilitate inherent search behaviour (i.e., exploration). As such, the skill development process using MI may be considered as skill adaptation, whereby the focus shifts from acquiring a 'optimal' technique representation to encouraging exploration of the perceptual-motor landscape and facilitating the development of stable and adaptable movement patterns (Button et al., 2020).

Similarities in practice-related adaptations (e.g., EERs, barbell trajectories, and performance measures) between Studies 3 and 4 indicate that MI produces similar training related adaptations as PP (to a lesser magnitude), potentially supporting the functional equivalence hypothesis (McNeill et al., 2020). In both studies, regardless of pedagogical approach, there was a tendency to explore and utilise a range of different movement patterns (i.e., movement clusters) without compromising improvements in performance outcomes (e.g., F×D and R×D). However, due to the lack of neuroimaging in the present thesis it cannot be clearly stated that the behavioural outcomes demonstrated in the MI conditions resulted from shared activation of motor areas of the brain. Subsequently, the term behavioural matching proposed by Wakefield et al. (2013), appears to be a more appropriate explanation for the observed behavioural similarities in Studies 3 and 4. Behavioural matching refers to similarities between MI and PP at an experiential level rather than shared neurophysiological mechanisms. Therefore, MI that incorporates skill acquisition principles implemented in PP (i.e., NLP and LP) may successfully facilitate experiential/behavioural compatibility between physical movement and MI. This has important implications for what aspects of PP should be included in MI to facilitate behavioural matching. Existing MI guidelines, such as PETTLEP, have primarily emphasised the replication of pre-existing skill development elements (e.g., physical environment, emotions experienced) (Wakefield & Smith, 2012). For example, the Task element of the PETTLEP model aims to create instructions that provide a technically identical description of the skill as used in PP. Such details are important and have proven to be effective, however, there elements are limited to *what* is being imagined and not *how* an imagined skill can be progressively developed. The similarities in behavioural outcomes observed between MI and PP in Studies 3 and 4 suggest that the incorporation of skill acquisition principles may facilitate a greater focus on MI practice as a skill development process, rather than mentally recreating the physical properties of the skill. No previous studies have explicitly investigated the integration of skill acquisition principles to MI, so it is difficult to draw comparisons with other research. However, the present thesis suggest that approaches implemented in PP (e.g., LP and NLP) should be a primary source of MI intervention design and delivery to facilitate the development of behavioural outcomes that closely mimic those observed during PP.

7.4. Practical Implications

The lack of significant differences between LP and NLP approaches has important implications for skill development for both PP and MI. Studies 3 and 4 suggest that when prescribing a specific technical model (i.e., LP) for learning movement form-based skills (for both PP and MI), deviations from the prescribed technique are not necessarily detrimental to performance. Movement variability (i.e., exploratory behaviour) demonstrated by LP conditions in both studies appears to have facilitated improved performance. Therefore, practitioners may re-frame how they view ‘mistakes’ in practice, as failed attempts to replicate a prescribed movement could be an important part of the skill development process.

From an ecological dynamics perspective, even ‘failed’ movements contribute to the overall development process as learners attune to opportunities for action to achieve successful performance solutions (Hacques et al., 2020). Though LP conditions were designed with traditional, prescriptive learning approaches in mind, Studies 3 and 4 suggest that exploration plays a functional role even for LP approaches despite trying to limit movement variability (i.e., exploration) and adopt a specific technique. This has important implications for the mentality of both the practitioner and learner. For example, if the learner struggles to adopt a prescribed technique, this may lead to frustration for the learner and practitioner. Studies 3 and 4 highlight that the inability to produce a specific technique is not particularly detrimental to performance. From the learner's perspective, being aware that technical ‘mistakes’ do not necessarily impact overall performance may help reduce the self-evaluation of technique while performing. Given that NLP approaches advocate instructions that emphasise movement outcomes rather than adopting a technique that ‘looks’ correct, a fruitful line of inquiry would be to investigate whether NLP is associated with reduced self-evaluation.

Study 4 aimed to explore the influence of a NLP approach to MI in developing a movement form-based skill over a 4-week intervention. Given the emphasis placed on designing MI practice that replicates PP as closely as possible (Holmes & Collins, 2001; Wakefield et al., 2013), it is important to investigate the application of skill acquisition approaches to understand further how to deliver MI interventions effectively. Though Study 4 did not identify any significant differences between conditions, the significant improvements in performance accuracy suggest that NLP should still be considered a legitimate alternative approach for MI interventions focused on skill development. This is not to say that it is ‘better’ than other approaches but rather provides alternative considerations when designing MI practice. Specifically, practitioners may consider developing MI content that is less prescriptive, focusing on the movement outcome to facilitate emergent movement solutions. Practically, MI scripts could include statements like “Imagine pulling the barbell up like you would pull on your trousers”. The manipulation of task constraints – a key principle of NLP – did not facilitate exploratory behaviour more than the LP condition as hypothesised. This result suggests that constraint manipulation is not a precondition for facilitating exploratory behaviour. It is possible that the constraints introduced could not ‘push’ some learners out of their comfort zone, or were not challenged to a sufficient level where it was necessary for learners to de-stabilise current movement solutions to the changing practice environment. Relevant to this point is the concept of coadaptation, which is a key idea to the NLP approach to skill development (Chow et al., 2022). Coadaptation refers to the process of self-organisation that learners go through to adapt to altered conditions, often resulting in changes in movement patterns to satisfy task demands (Button et al., 2020; Renshaw & Chow, 2019). This process of coadoption often occurs when the learner is sufficiently challenged to explore alternative movement solutions, known as metastability (Button et al., 2020; Seifert et al., 2015). Metastability is a region of performance where the learner is not in a complete state of instability, but rather is a region that afford learners the flexibility to explore different movement solutions (Kelso, 1995; Orth et al., 2018). It is possible that the task constraints did not provide a strong enough challenge for some NLP learners in Studies 3 and 4 to push them into a meta-stable region and engage in coadapative behaviours. Subsequently, practitioners should consider modifying task constraints frequently to challenge learners and not let them settle into a comfort zone. Further research is required to understand the impact of constraint manipulation in MI practice.

7.5. Limitations and Directions for Future Research

This thesis is not without limitations and should be considered when interpreting the results presented. This section discusses these limitations, and directions for future research are proposed. The EER used in Studies 3 and 4 provided a general indication of exploratory behaviour but was limited to demonstrating the quantity of exploration. The impact of this limitation is highlighted by the inability to distinguish between the nature of exploration for each condition. As mentioned earlier, a proposed explanation for the equivalent quantities of exploration is that exploratory behaviour for LP learners represented failed attempts to adhere to the prescribed technical model. By contrast, NLP exploration was potentially facilitated by constraint manipulation and encouraged search strategies to find individualised movement solutions. However, the EER is unable to provide such a distinction. A potentially fruitful line of inquiry for future research would be to examine the quantity and the dynamics of exploration. This might involve identifying performance outcomes or behaviour that precede exploration. For example, Joh and Adolph (2006) investigated how children learned from falling experiences into a hidden foam pit. They found that after falling, children engaged in more exploration of the area close to the site of their previous fall, which helped distinguish the differences in the walking surface and led to the successful performance of the task. Falling in a previous trial stimulated an increase in exploration and facilitated the search for alternative movement solutions to satisfy the task demands, representative of exploration dynamics (Joh & Adolph, 2006).

An area for further investigation is accuracy of perception in relation to exploration. This would help to understand the effectiveness of exploration. In a study by Cardis et al. (2018), learners practicing a bimanual motor task under low movement variability conditions improved performance to a greater degree relative to high variability practice. These findings highlight that although learners may display more exploration, some exploration may be non-functional or unnecessary to achieve successful performance solutions. Therefore, it is not just about designing practice that produces more exploration. Instead, exploratory behaviour should successfully facilitate learners to attune to reliable information more accurately (i.e., specific affordances) that match their capacities and achieve performance outcomes (Hacques et al., 2020). It is recommended that researchers should consider examining perceptual elements of skill development, such as attunement, for movements such as the PC when practicing using PP or MI to further understand the accuracy of exploratory behaviour (Hacques et al., 2020)

A key limitation observed in Studies 3, and 4 was the ability of the task constraints (e.g., barrier in front of the lifter and chalk on the barbell) to perturb NLP learners from strong movement patterns effectively. In Study 4, exploration over time for the NLP condition indicated an individualised response to the constraints introduced. For example, two participants demonstrated an increase in explorations from unconstrained (EER = 1 and 0) to constrained practice (EER = 3 and 1.5). Whereas the remaining NLP learner's exploratory behaviour seemed to be restricted by the presence of constraints, with exploration decreasing from unconstrained (EER = 0.25 – 4) to constrained practice (0 – 0.67). Regarding the limitations of relying on the quantity of exploration, this raises some important issues that require further investigation. For example, does the reduction in exploration volume indicate that the constraints could not effectively perturb strong behaviours? Or does it represent improved perceptual accuracy, whereby learners can pick up reliable information to satisfy individual and task constraints? Therefore, it would be beneficial for future research to investigate the accuracy of exploration and its relationship with performance to understand changes in the efficiency of exploratory behaviour (Hacques et al., 2020). In addition, researchers could examine the impact of regularly updating task constraints throughout MI interventions. Although exploration may have been successfully encouraged early in practice, task constraints may have been 'outdated' and not strong enough to disrupt newly stabilised movement patterns. Such an issue could be investigated by applying Layered Stimulus Response Training (LSRT) to MI script development (Williams et al., 2013), advocating for the gradual layering of MI content throughout the practice period. Therefore, LSRT could be adapted to introduce or remove task constraints into MI content to understand the impact of specific constraints on exploratory behaviour. Overall, Studies 3 and 4 did not clearly delineate the influence of NLP on developing movement form-based skills like the PC. A possible factor that may have impacted the clarity of results was sample size. Although G*Power calculations and similar past studies indicated sample sizes were adequate, further studies with larger samples may help to bring more clarity to the subject. It should be noted that the final stages of data collection for this thesis were conducted at the beginning of the COVID-19 pandemic. This meant that the recruitment of further participants was restricted.

The participants recruited for Studies 3 and 4 were beginners and had not competed in an official weightlifting competition. Subsequently, it was deemed inappropriate to expose individuals of this level to the high risk of injury of competitive conditions due to ethical considerations. In addition, level of resistance was a limitation, with the skill level of participants requiring a lighter level of resistance be used to reduce the risk of injury and ensure participant safety. To further understand the skill development process as heavier weights are introduced, future research could focus on implementing a longer study design to follow learners through the initial stages of learning and then begin progressively increasing weight as learners become more capable and the risk of injury is reduced. Given learners in Study 4 conducted all their practice using MI, it was deemed inappropriate to use heavier resistance and assess the transfer of skill changes from the practice interventions to competitive conditions. The degree that practice transfers to competitive performance, related to representative design, is a key principle of NLP. To advance the findings of Studies 3 and 4, future research could examine the transfer of NLP and LP practice of the PC to competitive conditions with more experienced learners, where the risk of injury is reduced.

Finally, there was an evident discrepancy in participant gender in Studies 3 (Male = 14; Female = 2) and 4 (Male = 12; Female= 2). Gender related performance differences have been identified in national level weightlifters, with males being found to lift more than females, and females reaching peak performance earlier (Males = 26.5 years; Females = 25.9 years) (Huebner & Perperoglou, 2020). These findings indicate that weightlifting performance may be differentiated by sex. However, there is no research to the authors knowledge that has investigated gender related differences in the acquisition of weightlifting based skills, such as the PC. It is acknowledged that the discrepancy in participant gender may have influenced the learning processes exhibited, however, further research is needed to substantiate these claims.

7.6. Concluding Remarks

This thesis aimed to enhance our understanding of applying a NLP approach to MI intervention design. Therefore, this thesis did not aim to investigate whether NLP was 'better' but rather to provide preliminary findings and hopefully stimulate further discussion about incorporating established skill acquisition principles from PP into MI. This involved reviewing and analysing the MI literature on sport-specific skills, reviewing, and developing recommendations on how principles of NLP could theoretically be applied to MI, investigating the actual impact of NLP practice in PP and MI on the development and performance of a movement form-based skill.

Findings from this thesis significantly contribute to the literature in several ways. Firstly, previous reviews on the overall efficacy of MI interventions for skill development have been strengthened by way of meta-analysis (Study 1), providing further evidence to support the use of MI for sport-specific motor skills independent of studies that combine psychological techniques or examine non-sport related skills. In addition, moderating MI intervention variables such as skill complexity and MI delivery type have been identified as important considerations for practitioners.

This thesis attempted to address gaps identified in the literature regarding the application of alternative skill acquisition approaches, such as NLP, in MI intervention design. Study 2 presented an alternative ecological dynamics perspective on the development of skilled behaviour, establishing a view of skill acquisition that emphasises the emergent, nonlinear qualities of skilled behaviour. Underpinned by an ecological dynamics rationale, principles of NLP were described, and recommendations were presented for how these could be applied to MI interventions. Study 2 is the first to engage with the potential application of a NLP approach to MI for skill development.

A significant contribution of this thesis is the implementation of NLP practice design in MI interventions. Results do not suggest that NLP is a superior form of practice relative to LP. However, the overall improvement in performance outcomes in Study 3 and 4 suggests NLP is a legitimate consideration for future interventions. Although no significant differences were detected between LP and NLP conditions across the two training studies, this is an important finding in and of itself. It suggests that although learners may deviate from a prescribed movement form (i.e., LP), this will not necessarily be detrimental to performance outcomes. Such a finding has important implications for a practitioner's overall learning philosophy. Even in activities considered to rely upon a specific movement form (i.e., PC), practitioners might want to distinguish between effective techniques and movement patterns that look correct. That is, the movement's effectiveness for producing specific outcomes may be a more important consideration than reproducing the ideal ‘aesthetic’ or movement style (i.e., what the movement looks like). Finally, the similarities in findings between Studies 3 and 4 suggest a functional equivalence between MI and PP, with similar training-related adaptations being observed (i.e., behavioural and performance measures). This represents an important contribution to the literature. It highlights that it is possible to reproduce (to a lesser degree) the observed impacts of NLP and LP approaches using MI. Therefore, it would be beneficial for researchers in the future to consider looking toward established practice models implemented in PP when designing MI practice. I hope that the findings of this thesis encourage future research on incorporating NLP into MI to supplement existing models and further our understanding of how to create MI practice that closely replicates real-world experiences and enhances overall skill development.

Chapter 8: References

Abraham, A., & Collins, D. (2011). Effective skill development: how should athletes' skills be developed. In D. Collins., A. Button., & H. Richards (Eds.), *Performance psychology: A practitioner's guide* (207-229). Elsevier.

Afrouzeh, M., Sohrabi, M., Torbati, H. R. T., Gorgin, F., & Mallett, C. (2013). Effect of PETTLEP imagery training on learning of new skills in novice volleyball players. *Life Science Journal*, *10*(SUPPL.1), 231-238.

Ahsen, A. (1984). ISM: The Triple Code Model for imagery and psychophysiology. *Journal of Mental Imagery, 8*(4), 15–42.

Akkuş, H. (2012). Kinematic analysis of the snatch lift with elite female weightlifters during the 2010 World Weightlifting Championship. *Journal of Strength and Conditioning Research*, *26*(4), 897-905. https://doi.org/10.1519/JSC.0b013e31822e5945

Antoniuk, O., Vynogradskyi, B., Pavlyuk, O., Chopyk, T., Pavlyuk, Y., & Soltyk, O. (2017). Peculiarities of barbell motion trajectory during snatch lift of elite female weightlifters. *Journal of physical education and sport, 17*(1), 402-406. https://doi.org/10.7752/jpes.2017.01059

Araujo, D., & Davids, K. (2011). What exactly is acquired during skill acquisition? *Journal of Consciousness Studies*, *18*, 7-23.

Baker, J., & Young, B. (2014). 20 years later: deliberate practice and the development of expertise in sport. *International Review of Sport and Exercise Psychology*, *7*(1), 135-157.

Bakker, F. C., Boschker, M. S., & Chung, T. (1996). Changes in muscular activity while imagining weight lifting using stimulus or response propositions. *Journal of Sport and Exercise Psychology*, *18*(3), 313-324.

Balsalobre-Fernández, C., Geiser, G., Krzyszkowski, J., & Kipp, K. (2020). Validity and reliability of a computer-vision-based smartphone app for measuring barbell trajectory during the snatch. *Journal of Sports Sciences*, *38*(6), 710-716.

Barris, S., Farrow, D., & Davids, K. (2014). Increasing functional variability in the preparatory phase of the takeoff improves elite springboard diving performance. *Research Quarterly for Exercise & Sport*, *85*(1), 97-106.

Björkstrand, S., & Jern, P. (2013). Evaluation of an imagery intervention to improve penalty taking ability in soccer: A study of two junior girls teams. *Nordic Psychology*, *65*(4), 290-305. https://doi.org/10.1080/19012276.2013.851444

Blair, A., Hall, C., & Leyshon, G. (1993). Imagery effects on the performance of skilled and novice soccer players. *Journal of Sports Sciences*, *11*(2), 95-101.

Borenstein, M., Cooper, H., Hedges, L., & Valentine, J. (2009). Effect sizes for continuous data. In H. Cooper., L. Hedges., & J. Valentine (2nd Ed.), *The handbook of research synthesis and meta-analysis* (pp. 221-235). Russell Sage Foundation.

Bouveyron, C., & Brunet, C. (2012). Simultaneous model-based clustering and visualization in the Fisher discriminative subspace. *Statistics and Computing*, *22*(1), 301-324.

Breed, R., & Spittle, M. (2020). *Developing game sense in physical education and sport.* Human Kinetics Publishers.

Brocken, J. E. A., van der Kamp, J., Lenoir, M., & Savelsbergh, G. J. P. (2020). Equipment modification can enhance skill learning in young field hockey players. *International Journal of Sports Science and Coaching, 15*(3), 382-389. https://doi.org/10.1177/1747954120918964 .

Brouziyne, M., & Molinaro, C. (2005). Mental imagery combined with physical practice of approach shots for golf beginners. *Perceptual and Motor Skills*, *101*(1), 203-211.

Burianová, H., Marstaller, L., Sowman, P., Tesan, G., Rich, A. N., Williams, M., Johnson, B. W. (2013). Multimodal functional imaging of motor imagery using a novel paradigm. *Neuroimage*, *71*, 50-58.

Buszard, T., Reid, M., Masters, R. S. W., & Farrow, D. (2016). Scaling tennis racquets during PE in primary school to enhance motor skill acquisition. *Research Quarterly for Exercise and Sport*, *87*(4), 414-420.

Button, C., Seifert, L., Chow, J. Y., Davids, K., & Araujo, D. (2020). *Dynamics of skill acquisition: An ecological dynamics approach*. Human Kinetics Publishers.

Caliari, P. (2008). Enhancing forehand acquisition in table tennis: The role of mental practice. *Journal of Applied Sport Psychology*, *20*(1), 88-96.

Cardis, M., Casadio, M., & Ranganathan, R. (2018). High variability impairs motor learning regardless of whether it affects task performance. *Journal of Neurophysiology*, *119*(1), 39-48.

Carson, H. J., & Collins, D. J. (2017). Commentary: motor imagery during action observation: A brief review of evidence, theory and future research opportunities. *Frontiers in Human Neuroscience*, *11*, 25.

Cashin, A. G., Lee, H., Bagg, M. K., O'Hagan, E., Traeger, A. C., Kamper, S. J., McAuley, J. H. (2020). A systematic review highlights the need to improve the quality and applicability of trials of physical therapy interventions for low back pain. *Journal of Clinical Epidemiology*, *126*, 106-115.

Chow, J. Y. (2013). Nonlinear learning underpinning pedagogy: Evidence, challenges, and implications. *Quest*, *65*(4), 469-484.

Chow, J. Y., Davids, K., Button, C., & Koh, M. (2008). Coordination changes in a discrete multi-articular action as a function of practice. *Acta Psychologica*, *127*(1), 163-176. https://doi.org/10.1016/j.actpsy.2007.04.002.

Chow, J. Y., Davids, K., Button, C., & Rein, R. (2008). Dynamics of movement patterning in learning a discrete multiarticular action. *Motor Control*, *12*(3), 219-240. https://doi.org/10.1123/mcj.12.3.219.

Chow, J. Y., Davids, K., Button, C., & Renshaw, I. (2022). *Nonlinear pedagogy in skill acquisition: An introduction* (2nd ed.). Routledge.

Chow, J. Y., Shuttleworth, R., Davids, K., & Araújo, D. (2019). Ecological dynamics and transfer from practice to performance in sport. In N. Hodges., & M. Williams (3rd Ed.), *Skill acquisition in sport: Research, theory and practice* (pp. 331-344). Routledge.

Coelho, R. W., De Campos, W., Silva, S. G. D., Okazaki, F. H. A., & Keller, B. (2007). Imagery intervention in open and closed tennis motor skill performance. *Perceptual and Motor Skills*, *105*(2), 458-468.

Cohen, J. (1988). The effect size. *Statistical power analysis for the behavioral sciences*, 77-83.

Cooley, S. J., Williams, S. E., Burns, V. E., & Cumming, J. (2013). Methodological variations in guided imagery interventions using movement imagery scripts in sport: A systematic review. *Journal of Imagery Research in Sport and Physical Activity*, *8*(1), 13-34.

Correia, V., Carvalho, J., Araújo, D., Pereira, E., & Davids, K. (2019). Principles of nonlinear pedagogy in sport practice. *Physical Education and Sport Pedagogy*, *24*(2), 117-132. https://doi.org/10.1080/17408989.2018.1552673.

Cumming, J., Cooley, S. J., Anuar, N., Kosteli, M.-C., Quinton, M. L., Weibull, F., & Williams, S. E. (2017). Developing imagery ability effectively: a guide to layered stimulus response training. *Journal of Sport Psychology in Action*, *8*(1), 23-33.

Cumming, J., & Williams, S. E. (2013). Introducing the revised applied model of deliberate imagery use for sport, dance, exercise, and rehabilitation. *Movement & Sport Sciences-Science & Motricité*(82), 69-81.

Cunanan, A. J., Hornsby, W. G., South, M. A., Ushakova, K. P., Mizuguchi, S., Sato, K., Stone, M. H. (2020). Survey of Barbell Trajectory and Kinematics of the Snatch Lift from the 2015 World and 2017 Pan-American Weightlifting Championships. *Sports*, *8*(9), 118.

Cuthbert, B. N., Vrana, S. R., & Bradley, M. M. (1991). Imagery: Function and physiology. In J. Jennings., P. Ackles., & M. Coles (Eds.), *Advances in psychophysiology: a research annual* (Vol. 4, pp. 1-42). Jessica Kingsley Publishers.

Dana, A., & Gozalzadeh, E. (2017). Internal and external imagery effects on tennis skills among novices. *Perceptual and Motor Skills*, *124*(5), 1022-1043.

Debarnot, U., Sperduti, M., Di Rienzo, F., & Guillot, A. (2014). Experts bodies, experts minds: How physical and mental training shape the brain. *Frontiers in Human Neuroscience*, *8*(280). https://doi.org/10.3389/fnhum.2014.00280.

Douvis, S. J. (2005). Variable practice in learning the forehand drive in tennis. *Perceptual and Motor Skills*, *101*(2), 531-545.

Driskell, J. E., Copper, C., & Moran, A. (1994). Does mental practice enhance performance? *Journal of Applied Psychology*, *79*(4), 481.

Duval, S., & Tweedie, R. (2000). Trim and fill: a simple funnel-plot–based method of testing and adjusting for publication bias in meta-analysis. *Biometrics*, *56*(2), 455-463.

Everett, G. (2012). *Olympic weightlifting: A complete guide for athletes & coaches* (3rd ed.). Quali Books, Inc.

Fazel, F., Morris, T., Watt, A., & Maher, R. (2018). The effects of different types of imagery delivery on basketball free-throw shooting performance and self-efficacy. *Psychology of Sport and Exercise*, *39*, 29-37. https://doi.org/10.1016/j.psychsport.2018.07.006.

Field, A. (2018). *Discovering statistics using IBM SPSS Statistics* (5th Ed.). Sage.

Fitzpatrick, A., Davids, K., & Stone, J. A. (2018). Effects of scaling task constraints on emergent behaviours in children's racquet sports performance. *Human Movement Science*, *58*, 80-87. https://doi.org/10.1016/j.humov.2018.01.007.

Follmann, D., Elliott, P., Suh, I., & Cutler, J. (1992). Variance imputation for overviews of clinical trials with continuous response. *Journal of Clinical Epidemiology*, *45*(7), 769-773.

Fontani, G., Migliorini, S., Benocci, R., Facchini, A., Casini, M., & Corradeschi, F. (2007). Effect of mental imagery on the development of skilled motor actions. *Perceptual and Motor Skills*, *105*(3), 803-826. https://doi.org/10.2466/pms.105.3.803-826.

Frank, C., Land, W. M., Popp, C., & Schack, T. (2014). Mental representation and mental practice: experimental investigation on the functional links between motor memory and motor imagery. *PLoS One*, *9*(4), e95175. https://doi.org/10.1371/journal.pone.0095175.

Frank, C., Land, W. M., & Schack, T. (2013). Mental representation and learning: the influence of practice on the development of mental representation structure in complex action. *Psychology of Sport and Exercise*, *14*(3), 353-361. https://doi.org/https://doi.org/10.1016/j.psychsport.2012.12.001.

Frank, C., Land, W. M., & Schack, T. (2016). Perceptual-cognitive changes during motor learning: The influence of mental and physical practice on mental representation, gaze behavior, and performance of a complex action. *Frontiers in Psychology*, *6*(JAN), Article 1981. https://doi.org/10.3389/fpsyg.2015.01981

Frank, C., & Schack, T. (2017). The representation of motor (inter) action, states of action, and learning: three perspectives on motor learning by way of imagery and execution. *Frontiers in Psychology*, *8*, 678.

Gaggioli, A., Morganti, L., Mondoni, M., & Antonietti, A. (2013). Benefits of combined mental and physical training in learning a complex motor skill in basketball. *Psychology, 4,* 1-6.

Gentile, A. M. (2000). Skill acquisition: Action, movement, and the neuromotor processes. In J. Carr & R. Shepherd (2nd Ed.), *Movement science: Foundations for physical therapy in rehabilitation* (pp. 111-180). Aspen Publishers.

Gentili, R., Papaxanthis, C., & Pozzo, T. (2006). Improvement and generalization of arm motor performance through motor imagery practice. *Neuroscience*, *137*(3), 761-772.

Gibson, J. J. (1979). *An ecological approach to visual perception*. Houghton-Mifflin.

Glassbrook, D. J., Brown, S. R., Helms, E. R., Duncan, J. S., & Storey, A. G. (2017). The high-bar and low-bar back-squats: A biomechanical analysis. *Journal of Strength Conditioning Research, 33,* S1-S18. https://doi.org/10.1519/jsc.0000000000001836

Goble, M. S., Raison, N., Mekhaimar, A., Dasgupta, P., & Ahmed, K. (2021). Adapting Motor Imagery Training Protocols to Surgical Education: A Systematic Review and Meta-Analysis. *Surgical Innovation, 28*(3) 329-351.

Goldstein, E. B. (2014). *Cognitive psychology: Connecting mind, research and everyday experience*. Cengage Learning.

Grosprêtre, S., Jacquet, T., Lebon, F., Papaxanthis, C., & Martin, A. (2018). Neural mechanisms of strength increase after one-week motor imagery training. *European Journal of Sport Science*, *18*(2), 209-218.

Grosprêtre, S., Lebon, F., Papaxanthis, C., & Martin, A. (2019). Spinal plasticity with motor imagery practice. *The Journal of physiology*, *597*(3), 921-934.

Grouios, G., Mousikou, K., Hatzinikolaou, K., Semoglou, K., & Kabitsis, C. (1997). The effect of a simulated mental practice technique on free throw shooting accuracy of highly skilled basketball players. *Journal of Human Movement Studies*, *33*(3), 119-138.

Guillot, A., Desliens, S., Rouyer, C., & Rogowski, I. (2013). Motor imagery and tennis serve performance: the external focus efficacy. *Journal of Sports Science & Medicine*, *12*(2), 332.

Guillot, A., Genevois, C., Desliens, S., Saieb, S., & Rogowski, I. (2012). Motor imagery and 'placebo-racket effects' in tennis serve performance. *Psychology of Sport and Exercise*, *13*(5), 533-540. https://doi.org/10.1016/j.psychsport.2012.03.002.

Guillot, A., Lebon, F., Rouffet, D., Champely, S., Doyon, J., & Collet, C. (2007). Muscular responses during motor imagery as a function of muscle contraction types. *International Journal of Psychophysiology*, *66*, 18-27.

Guillot, A., Nadrowska, E., & Collet, C. (2009). Using Motor Imagery to Learn Tactical Movements in Basketball. *Journal of Sport Behavior*, *32*(2), 189–206.

Hacques, G., Komar, J., Dicks, M., & Seifert, L. (2020). Exploring to learn and learning to explore. *Psychological Research*, *85*(4), 1367-1379. https://doi.org/10.1007/s00426-020-01352-x.

Hall, C. R., & Martin, K. A. (1997). Measuring movement imagery abilities: a revision of the movement imagery questionnaire. *Journal of Mental Imagery, 21(1-2)*, 143–154..

Hall, N. D., & Fishburne, G. J. (2010). Mental imagery research in physical education. *Journal of Imagery Research in Sport and Physical Activity*, *5*(1), 1-17.

Hardwick, R. M., Caspers, S., Eickhoff, S. B., & Swinnen, S. P. (2018). Neural correlates of action: Comparing meta-analyses of imagery, observation, and execution. *Neuroscience & Biobehavioral Reviews*, *94*, 31-44.

Haug, W. B., Drinkwater, E. J., & Chapman, D. W. (2015). Learning the Hang Power Clean: Kinetic, Kinematic, and Technical Changes in Four Weightlifting Naive Athletes. *The Journal of Strength & Conditioning Research*, *29*(7), 1766–1779. https://doi.org/10.1519/JSC.0000000000000826.

Hecker, J. E., & Kaczor, L. M. (1988). Application of imagery theory to sport psychology: Some preliminary findings. *Journal of Sport and Exercise Psychology*, *10*(4), 363-373.

Hétu, S., Grégoire, M., Saimpont, A., Coll, M.-P., Eugène, F., Michon, P.-E., & Jackson, P. L. (2013). The neural network of motor imagery: An ALE meta-analysis. *Neuroscience & Biobehavioral Reviews*, *37*(5), 930-949. https://doi.org/https://doi.org/10.1016/j.neubiorev.2013.03.017.

Holmes, P., & Collins, D. (2001). The PETTLEP Approach to Motor Imagery: A Functional Equivalence Model for Sport Psychologists. *Journal of Applied Sport Psychology*, *13*. https://doi.org/10.1080/10413200109339004.

Isaac, A. R. (1992). Mental practice: Does it work in the field? *The Sport Psychologist*.

Jackson, P. L., Lafleur, M. F., Malouin, F., Richards, C. L., & Doyon, J. (2003). Functional cerebral reorganization following motor sequence learning through mental practice with motor imagery. *Neuroimage*, *20*(2), 1171-1180. https://doi.org/https://doi.org/10.1016/S1053-8119(03)00369-0

Jacobson, E. (1932). Electrophysiology of mental activities. *The American Journal of Psychology*, *44*(4), 677-694.

Jeannerod, M. (1994). The representing brain: Neural correlates of motor intention and imagery. *Behavioral and Brain Sciences*, *17*(2), 187-202.

Jeannerod, M. (2004). Actions from within. *International Journal of Sport and Exercise Psychology*, *2*(4), 376-402.

Jeannerod, M. (2006). *Motor cognition: What actions tell the self*. Oxford University Press.

Joh, A. S., & Adolph, K. E. (2006). Learning from falling. *Child Development*, *77*(1), 89-102.

Kelso, J. S. (1995). *Dynamic patterns: The self-organization of brain and behavior*. MIT press.

Kim, T., Frank, C., & Schack, T. (2017). A Systematic Investigation of the Effect of Action Observation Training and Motor Imagery Training on the Development of Mental Representation Structure and Skill Performance. *Frontiers in Human Neuroscience*, *11*(499). https://doi.org/10.3389/fnhum.2017.00499.

Kim, T. H., Cruz, A., & Ha, J. H. (2011). Differences in learning facilitatory effect of motor imagery and action observation of golf putting. *Journal of Applied Sciences*, *11*(1), 151-156. https://doi.org/10.3923/jas.2011.151.156.

Kipp, K., & Meinerz, C. (2017). A biomechanical comparison of successful and unsuccessful power clean attempts. *Sports Biomechanics*, *16*(2), 272-282, https://doi.org/10.1080/14763141.2016.1249939.

Komar, J., Chow, J.-Y., Chollet, D., & Seifert, L. (2014). Effect of analogy instructions with an internal focus on learning a complex motor skill. *Journal of Applied Sport Psychology*, *26*(1), 17-32. https://doi.org/10.1080/10413200.2013.771386.

Komar, J., Potdevin, F., Chollet, D., & Seifert, L. (2019). Between exploitation and exploration of motor behaviours: unpacking the constraints-led approach to foster nonlinear learning in physical education. *Physical Education and Sport Pedagogy*, *24*(2), 133-145. https://doi.org/10.1080/17408989.2018.1557133

Kornspan, A. S., Overby, L. Y., & Lerner, B. S. (2004). Analysis and performance of pre-performance imagery and other strategies on a golf putting Task. *Journal of Mental Imagery*, *28*(3-4), 59-74.

Kraeutner, S. N., MacKenzie, L. A., Westwood, D. A., & Boe, S. G. (2016). Characterizing skill acquisition through motor imagery with no prior physical practice. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(2), 257.

Kremer, P., Spittle, M., McNeil, D., & Shinners, C. (2009). Amount of mental practice and performance of a simple motor task. *Perceptual and Motor Skills*, *109*(2), 347-356.

Lafleur, M. F., Jackson, P. L., Malouin, F., Richards, C. L., Evans, A. C., & Doyon, J. (2002). Motor learning produces parallel dynamic functional changes during the execution and imagination of sequential foot movements. *Neuroimage*, *16*(1), 142-157.

Lamirand, M., & Rainey, D. (1994). Mental imagery, relaxation, and accuracy of basketball foul shooting. *Perceptual and Motor Skills*, *78*(3), 1229-1230. https://doi.org/10.2466/pms.1994.78.3c.1229.

Lang, P. J. (1979). A bio-informational theory of emotional imagery. *Psychophysiology*, *16*(6), 495-512.

Lebon, F., Collet, C., & Guillot, A. (2010). Benefits of motor imagery training on muscle strength. *The Journal of Strength and Conditioning Research*, *24*(6), 1680-1687. https://doi.org/10.1519/JSC.0b013e3181d8e936.

Lebon, F., Guillot, A., & Collet, C. (2012). Increased muscle activation following motor imagery during the rehabilitation of the anterior cruciate ligament. *Applied Psychophysiology and Biofeedback*, *37*(1), 45-51.

Lee, M. C. Y., Chow, J. Y., Komar, J., Tan, C. W. K., & Button, C. (2014). Nonlinear Pedagogy: An Effective Approach to Cater for Individual Differences in Learning a Sports Skill. *PLoS One*, *9*(8), e104744. https://doi.org/10.1371/journal.pone.0104744.

Leung, M. C., Spittle, M., & Kidgell, D. J. (2013). Corticospinal excitability following short-term motor imagery training of a strength task. *Journal of Imagery Research in Sport and Physical Activity*, *8*(1), 35-44.

Lindsay, R. S., Larkin, P., Kittel, A., & Spittle, M. (2021). Mental imagery training programs for developing sport-specific motor skills: a systematic review and meta-analysis. *Physical Education and Sport Pedagogy*, 1-22.

Lindsay, R. S., Oldham, A. R., Drinkwater, E. J., Spittle, M., & Storey, A. G. (2020). Effects of personalised motor imagery on the development of a complex weightlifting movement. *International Journal of Sport and Exercise Psychology*, 1-22.

Liu, G., Fekete, G., Yang, H., Ma, J., Sun, D., Mei, Q., & Gu, Y. (2018). Comparative 3-dimensional kinematic analysis of snatch technique between top-elite and sub-elite male weightlifters in 69-kg category. *Heliyon*, *4*(7), e00658. https://doi.org/https://doi.org/10.1016/j.heliyon.2018.e00658.

Magill, R., & Anderson, D. (2021). *Motor learning and control* (12th ed.). McGraw-Hill Publishing New York.

Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical therapy*, *83*(8), 713-721.

Marshall, E. A., & Gibson, A.-M. (2017). The effect of an imagery training intervention on self-confidence, anxiety and performance in acrobatic gymnastics–a pilot study. *Journal of Imagery Research in Sport and Physical Activity*, *12*(1).

Martin, K. A., Moritz, S. E., & Hall, C. R. (1999). Imagery use in sport: a literature review and applied model. *The Sport Psychologist*, *13*(3), 245-268.

McNeill, E., Toth, A. J., Harrison, A. J., & Campbell, M. J. (2020). Cognitive to physical performance: a conceptual model for the role of motor simulation in performance. *International Review of Sport and Exercise Psychology*, *13*(1), 205-230.

Memmert, D. (2006). Long-term effects of type of practice on the learning and transfer of a complex motor skill. *Perceptual and Motor Skills*, *103*(3), 912-916.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of internal medicine*, *151*(4), 264-269.

Monsma, E. V., Short, S. E., Hall, C. R., Gregg, M., & Sullivan, P. (2009). Psychometric properties of the revised Movement Imagery Questionnaire (MIQ-R). *Journal of Imagery Research in Sport and Physical Activity*, *4*(1).

Moran, A., Guillot, A., MacIntyre, T., & Collet, C. (2012). Re-imagining motor imagery: building bridges between cognitive neuroscience and sport psychology. *British Journal of Psychology*, *103*(2), 224-247.

Moran, A., & O'Shea, H. (2020). Motor imagery practice and cognitive processes. *Frontiers in Psychology*, *11*, 394.

Moran, A., & O’Shea, H. (2019). Motor imagery practice and skilled performance in sport: From efficacy to mechanisms. In N. Hodge, & M. Williams (3rd Ed.), *Skill Acquisition in Sport* (pp. 61-76). Routledge.

Morris, T., Spittle, M., & Watt, A. P. (2005). *Imagery in sport*. Human Kinetics.

Munzert, J., Lorey, B., & Zentgraf, K. (2009). Cognitive motor processes: the role of motor imagery in the study of motor representations. *Brain Research Reviews*, *60*(2), 306-326.

Murphy, S. M. (1994). Imagery interventions in sport. *Medicine & Science in Sports & Exercise, 26(*4), 486–494. https://doi.org/10.1249/00005768-199404000-00014.

Newell, A., & Rosenbloom, P. (1981). Mechanisms of skill acquisition. In J. Anderson (Eds.), *Cognitive skills and their acquisition* (pp. 55). Psychology Press.

Newell, K. M. (1985). Coordination, control and skill. In D. Goodman, R. Wilberg, & I. Franks (Eds.), *Advances in psychology* (Vol. 27, pp. 295-317). Elsevier.

Nordin, S. M., & Cumming, J. (2005). Professional dancers describe their imagery: where, when, what, why, and how. *The Sport Psychologist*, *19*(4), 395–416.

Nordin, S. M., & Cumming, J. (2008). Types and functions of athletes' imagery: testing predictions from the applied model of imagery use by examining effectiveness. *International Journal of Sport and Exercise Psychology*, *6*(2), 189-206.

Olsson, C. J., Jonsson, B., & Nyberg, L. (2008). Internal imagery training in active high jumpers. *Scandinavian Journal of Psychology*, *49*(2), 133-140.

Oppici, L., Panchuk, D., Serpiello, F. R., & Farrow, D. (2018a). Futsal task constraints promote transfer of passing skill to soccer task constraints. *European Journal of Sport Science*, *18*(7), 947-954. https://doi.org/10.1080/17461391.2018.1467490

Oppici, L., Panchuk, D., Serpiello, F. R., & Farrow, D. (2018b). The influence of a modified ball on transfer of passing skill in soccer. *Psychology of Sport and Exercise*, *39*, 63-71. https://doi.org/10.1016/j.psychsport.2018.07.015

Orth, D., Davids, K., & Seifert, L. (2018). Constraints representing a meta-stable régime facilitate exploration during practice and transfer of learning in a complex multi-articular task. *Human Movement Science*, *57*, 291-302. https://doi.org/10.1016/j.humov.2017.09.007.

Pacheco, M. M., Hsieh, T.-Y., & Newell, K. M. (2017). Search Strategies in Practice: Movement Variability Affords Perception of Task Dynamics. *Ecological Psychology*, *29*(4), 243-258. https://doi.org/10.1080/10407413.2017.1368354.

Pain, M. A., Harwood, C., & Anderson, R. (2011). Pre-competition imagery and music: The impact on flow and performance in competitive soccer. *The Sport Psychologist*, *25*(2), 212-232.

Paivio, A. (1975). Perceptual comparisons through the mind's eye. *Memory & Cognition*, *3*(6), 635-647.

Paivio, A. (1985). Cognitive and motivational functions of imagery in human performance. *Canadian Journal of Applied Sport Sciences. Journal Canadien des Sciences Appliquées au Sport*, *10*(4), 22S-28S.

Pastora-Bernal, J. M., Estebanez-Pérez, M. J., Lucena-Anton, D., García-López, F. J., Bort-Carballo, A., & Martín-Valero, R. (2021). The effectiveness and recommendation of motor imagery techniques for rehabilitation after anterior cruciate ligament reconstruction: A systematic review. *Journal of Clinical Medicine*, *10*(3), 428.

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *Journal of Sport and Exercise Psychology*, *33*(1), 146-155.

Post, P. G., Wrisberg, C. A., & Mullins, S. (2010). A field test of the influence of pre-game imagery on basketball free throw shooting. *Journal of Imagery Research in Sport and Physical Activity*, *5*(1), 1-15. https://doi.org/10.2202/1932-0191.1042.

Quinton, M. L., Cumming, J., Allsop, J., Gray, R., & Williams, S. E. (2018). Imagery meaning and content in golf: Effects on performance, anxiety, and confidence. *International Journal of Sport and Exercise Psychology*, *16*(4), 382-397.

Quinton, M. L., Cumming, J., & Williams, S. E. (2018). Investigating the mediating role of positive and negative mastery imagery ability. *Psychology of Sport and Exercise*, *35*, 1-9.

Raison, N., Ahmed, K., Abe, T., Brunckhorst, O., Novara, G., Buffi, N. M., Gavazzi, A. (2018). Cognitive training for technical and non-technical skills in robotic surgery: a randomised controlled trial. *BJU international*, *122*(6), 1075-1081.

Ramsey, R., Cumming, J., Edwards, M. G., Williams, S., & Brunning, C. (2010). Examining the emotion aspect of PETTLEP-based imagery with penalty taking in soccer. *Journal of Sport Behavior*, *33*(3), 295-314.

Ranganathan, R., Lee, M.-H., & Newell, K. M. (2020). Repetition without repetition: challenges in understanding behavioral flexibility in motor skill. *Frontiers in Psychology*, *11*, 2018.

Renshaw, I., & Chow, J. Y. (2019). A constraint-led approach to sport and physical education pedagogy. *Physical Education and Sport Pedagogy*, *24*(2), 103-116. https://doi.org/10.1080/17408989.2018.1552676.

Renshaw, I., Chow, J. Y., Davids, K., & Button, C. (2015). *Nonlinear pedagogy in skill acquisition: An introduction*. Routledge.

Renshaw, I., Davids, K., Newcombe, D., & Roberts, W. (2019). *The constraints-led approach: Principles for sports coaching and practice design*. Routledge.

Robin, N., Dominique, L., Toussaint, L., Blandin, Y., Guillot, A., & Her, M. L. (2007). Effects of motor imagery training on service return accuracy in tennis: The role of imagery ability. *International Journal of Sport and Exercise Psychology*, *5*(2), 175-186.

Rodgers, W., Hall, C., & Buckolz, E. (1991). The effect of an imagery training program on imagery ability, imagery use, and figure skating performance. *Journal of Applied Sport Psychology*, *3*(2), 109-125.

Romano-Smith, S., Wood, G., Wright, D. J., & Wakefield, C. J. (2018). Simultaneous and alternate action observation and motor imagery combinations improve aiming performance. *Psychology of Sport & Exercise*, *38*, 100-106.

Romano Smith, S., Wood, G., Coyles, G., Roberts, J. W., & Wakefield, C. J. (2019). The effect of action observation and motor imagery combinations on upper limb kinematics and EMG during dart-throwing. *Scandinavian Journal Of Medicine & Science In Sports*. https://doi.org/10.1111/sms.13534.

Rossi, S., Buford, T., Smith, D., Kennel, R., Haff, E., & Haff, G. (2007). Bilateral comparison of barbell kinetics and kinematics during a weightlifting competition. *International Journal of Sports Physiology and Performance*, *2*, 150-158. https://doi.org/10.1123/ijspp.2.2.150.

Rucci, J. A., & Tomporowski, P. D. (2010). Three types of kinematic feedback and the execution of the hang power clean. *The Journal of Strength and Conditioning Research*, *24*(3), 771-778.

Sakadjian, A., Panchuk, D., & Pearce, A. J. (2014). Kinematic and kinetic improvements associated with action observation facilitated learning of the power clean in Australian footballers. *Journal of Strength and Conditioning Research*, *28*(6), 1613-1625. https://doi.org/10.1519/JSC.0000000000000290.

Schmidt, R., & Lee, T. (2019). *Motor learning and performance: From principles to application* (6th ed). Human Kinetics.

Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological Review*, *82*(4), 225.

Schmidt, R. A., Lee, T. D., Winstein, C., Wulf, G., & Zelaznik, H. N. (2018). *Motor control and learning: A behavioral emphasis*. Human Kinetics.

Schuster, C., Hilfiker, R., Amft, O., Scheidhauer, A., Andrews, B., Butler, J., Ettlin, T. (2011). Best practice for motor imagery: a systematic literature review on motor imagery training elements in five different disciplines. *BMC Medicine*, *9*(1), 75.

Seifert, L., Boulanger, J., Orth, D., & Davids, K. (2015). Environmental design shapes perceptual-motor exploration, learning, and transfer in climbing. *Frontiers in Psychology*, *6*(NOV), Article 1819. https://doi.org/10.3389/fpsyg.2015.01819.

Silverman, S., Tyson, L., & Krampitz, J. (1992). Teacher feedback and achievement in physical education: Interaction with student practice. *Teaching and Teacher Education*, *8*(4), 333-344.

Simonsmeier, B. A., Androniea, M., Buecker, S., & Frank, C. (2021). The effects of imagery interventions in sports: a meta-analysis. *International Review of Sport and Exercise Psychology*, 1-22. https://doi.org/10.1080/1750984X.2020.1780627.

Smith, D., & Holmes, P. (2004). The effect of imagery modality on golf putting performance. *Journal of Sport and Exercise Psychology*, *26*(3), 385.

Smith, D., Holmes, P., Whitemore, L., Collins, D., & Devonport, T. (2001). The effect of theoretically-based imagery scripts on field hockey performance. *Journal of Sport Behavior*, *24*(4), 408.

Smith, D., Wright, C., Allsopp, A., & Westhead, H. (2007). It's all in the mind: PETTLEP-based imagery and sports performance. *Journal of Applied Sport Psychology*, *19*(1), 80-92. https://doi.org/10.1080/10413200600944132.

Smith, D., Wright, C. J., & Cantwell, C. (2008). Beating the bunker: the effect of PETTLEP imagery on golf bunker shot performance. *Research Quarterly for Exercise and Sport*, *79*(3), 385-391.

Spittle, M. (2021). *Motor learning and skill acquisition: Applications for physical education and sport* (2 ed.). Macmillian Education UK.

Storey, A., & Smith, H. K. (2012). Unique aspects of competitive weightlifting: performance, training and physiology. *Sports Medicine*, *42*(9), 769-790. https://doi.org/10.2165/11633000-000000000-00000.

Timmerman, E. A., Savelsbergh, G. J. P., & Farrow, D. (2019). Creating appropriate training environments to improve technical, decision-making, and physical skills in field hockey. *Research Quarterly for Exercise and Sport*, *90*(2), 180-189. https://doi.org/10.1080/02701367.2019.1571678.

Toth, A. J., McNeill, E., Hayes, K., Moran, A. P., & Campbell, M. (2020). Does mental practice still enhance performance? A 24 year follow-up and meta-analytic replication and extension. *Psychology of Sport and Exercise*, *48*, 101672. https://doi.org/https://doi.org/10.1016/j.psychsport.2020.101672.

Verhoeff, W., Millar, S.-K., Oldham, A., & Cronin, J. (2019). Coaching the power clean: A constraints-led approach. *Strength and Conditioning Journal*, *42*, 1. https://doi.org/10.1519/SSC.0000000000000508.

Verhoeff, W., Millar, S. K., & Oldham, T. (2018). Constraints-led approach to coaching the power clean. *ISBS Proceedings Archive*, *36*(1), 1036.

Viechtbauer, W., & Cheung, M. W. L. (2010). Outlier and influence diagnostics for meta-analysis. *Research synthesis methods*, *1*(2), 112-125.

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

Wakefield, C., Smith, D., Moran, A., & Holmes, P. (2013). Functional equivalence or behavioural matching? A critical reflection on 15 years of research using the PETTLEP model of motor imagery. *International Review of Sport and Exercise Psychology*, *6*(1), 105-121.

Wakefield, C. J., & Smith, D. (2009). Impact of differing frequencies of PETTLEP imagery on netball shooting performance. *Journal of Imagery Research in Sport and Physical Activity*, *4*(1).

Wakefield, C. J., Smith, D., Hogard, E., Ellis, R., & Parry, C. (2020). Using PETTLEP imagery as a simulation technique in nursing: Research and guidelines. *Nurse Education in Practice*, *43*, 102700. https://doi.org/10.1016/j.nepr.2020.102700.

Weber, E., & Doppelmayr, M. (2016). Kinesthetic motor imagery training modulates frontal midline theta during imagination of a dart throw. *International Journal of Psychophysiology*, *110*, 137-145.

White, A., & Hardy, L. (1998). An in-depth analysis of the uses of imagery by high-level slalom canoeists and artistic gymnasts. *The Sport Psychologist*, *12*(4), 387-403.

Williams, S. E., Cooley, S. J., & Cumming, J. (2013). Layered stimulus response training improves motor imagery ability and movement execution. *Journal of Sport and Exercise Psychology*, *35*(1), 60-71.

Wilson, C., Smith, D., Burden, A., & Holmes, P. (2010). Participant-generated imagery scripts produce greater EMG activity and imagery ability. *European Journal of Sport Science*, *10*(6), 417-425.

Woolfolk, R. L., Parrish, M. W., & Murphy, S. M. (1985). The effects of positive and negative imagery on motor skill performance. *Cognitive Therapy and Research*, *9*(3), 335-341. https://doi.org/10.1007/BF01183852.

Wright, C. J., & Smith, D. (2009). The effect of PETTLEP imagery on strength performance. *International Journal of Sport and Exercise Psychology*, *7*(1), 18-31.

Wulf, G., & Prinz, W. (2001). Directing attention to movement effects enhances learning: A review. *Psychonomic bulletin & review*, *8*(4), 648-660.

Wulf, G., & Shea, C. H. (2002). Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychonomic bulletin & review*, *9*(2), 185-211.

Ziegler, S. G. (1987). Comparison of imagery styles and past experience in skills performance. / Comparaison des styles de representation mentale et de l' experience passee et de leurs effets sur la performance motrice. *Perceptual and Motor Skills*, *64*(2), 579-586.

Chapter 9: Appendices

Appendix A: Information statement – Study 3

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

INFORMATION TO PARTICIPANTSINVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled: The influence of a nonlinear pedagogy approach on functionaloutcomes when learning a complex movement skill.

This project is being conducted by a student researcher Mr Riki Lindsay as part of a Doctor of Philosophy at VictoriaUniversity under the supervision of Associate Professor Michael Spittle from the College of Sport and Exercise.

Project explanation

When learning a new skill using physical practice, a common approach that coaches use to teach new skills is linear pedagogy. This is when a coach will explain how to perform a movement and have the learner practice the movement until they are able to perform it efficiently without any mistakes. The purpose of this coaching method is to guide the learner towards a “perfect” technique. Recently an alternative approach to learning is being used by coaches known as Nonlinear pedagogy. Nonlinear pedagogy is a new approach to learning that uses different constraints to help people find their own individualised movement patterns. This research aims to use a nonlinear pedagogy to teach the power clean and compare this with a traditional linear pedagogy to see which method is more effective.

What will I be asked to do?

This study involves being a part of a 4-week training intervention. You will be placed in one of two groups; nonlinear or linear group. Prior to beginning the 4-week training you will then be required to undertake a power clean technique pre- test. This will be to establish your baseline power clean technique. This will be a 20-minute testing where you will be video recorded using 3-D and 2-D motion capture software in the Biomechanics laboratory at Victoria University, Footscray Park campus. Before testing can commence you will be required to have 36 reflective markers placed on bodyand 2 markers placed on either end of the barbell (Figure 1). Locations of the markers are as follows a) left and right shoulder (acromion process), b) left and right elbow (lateral epicondyle of the humerus), c) left and right hip (vertex of greater trochanter), d) left and right knee

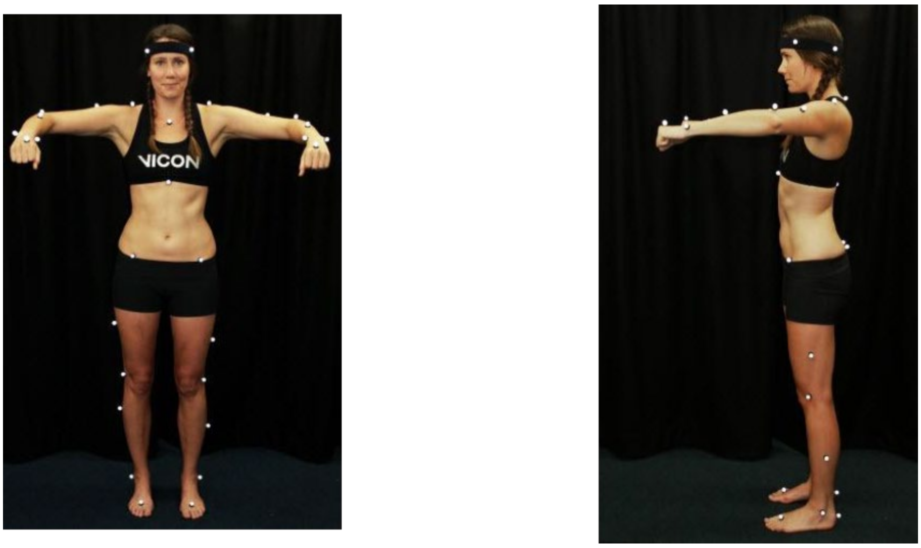


Figure 1. 3-D marker joint locations

(lateral epicondyle of femur), e) left and right side of the barbell, f) left and right ankle (lateral malleolus), g) top of heal ofthe lifting shoe, and h) the base of the fifth metatarsal left and right side. You will have the option of either a male or female to place the 3-D markers. Once markers have been placed you will be asked to perform 4 sets of 5 repetitions of 30kg. Between sets you will be given 2-5 minutes of rest before you perform the next set. Following the pre-test, you willbe required to come in to the Biomechanics laboratory 2 times per week for 4 weeks (8 sessions) and perform 4 sets of5 repetitions of the power clean. During these training sessions you will have 3-D markers placed on the body in the same locations described above (Figure 1). Once all power clean training sessions have been completed you will be asked to come back into the laboratory to complete a final power clean technique post-test. This will be to see what changes in technique have taken place over the course of the 4-week training intervention. The testing procedures will be the same as the pre-test described above with 3-D markers being placed in the body in the same locations as the pre-test and training sessions (Figure 1).

To participate in this study, you will be asked to refrain from any physical training 24 hours prior to all testing and trainingsessions. Additionally, you will be asked to refrain from performing any additional power clean practice outside of the prescribed sessions in the study.

What will I gain from participating?

The benefits of taking part of this study will be the expert coaching during the intervention in the power clean by anOlympic weightlifting coach with international experience. You will be contributing to research in the field of skill acquisition that could help to improve coaching methods used for athletes involved in higher level sport.

How will the information I give be used?

The information you provide initially be coded to ensure that your data is anonymous and that you cannot not be personally identified. Once your information has been coded it will be analysed and used initially to contribute towards the completion of a dissertation as part of the Doctor of Philosophy programme at Victoria University. Additionally, the information you provide will contribute to research reports and journal article publications that will be produced from this research project. All data that is collected will only be available to the research team. No information identifying you as the participant in this research will be included in any of the research reports or publications.

What are the potential risks of participating in this project?

You will be required to perform light exercise over the course of the training intervention where there is a potential risk of injury. Firstly, there is the potential risk of an adverse cardiovascular event because of completing the exercise in this study. Furthermore, there is the potential risk of muscular injury from completing the power clean exercise. To minimize these risks the following processes have been implemented. Firstly, an international level Olympic weightlifting coach has been consulted in the design process of the testing and training procedures. From this consultation process the volume of work (sets and repetitions) is deemed to be at an appropriate level and not exposing those training to unnecessary strain that could lead to muscular injury or adverse cardiovascular event. All training will be supervised by an international level Olympic weightlifting coach that is first-aid trained. If an adverse cardiovascular event is to occur during training in this study, the ambulance will be called immediately, and the supervising investigator will begin to perform CPR. If participants do incur a muscular injury (i.e. strain or tear) because of taking part in the following researchthey will be withdrawn from the study and provided with the details of a physiotherapist so that they can make an appointment to diagnose the injury and get appropriate treatment. As the participant, you will be compensated for any medical expenses incurred due to your involvement in this study.

How will this project be conducted?

The current study will comprise of a pre-test, followed by a 4-week intervention, where every practice will be recorded (8sessions, each lasting 20 minutes), and a post-test. To participate in this study, you will need to refrain from any physical training 24 hours prior to all testing and refrain from any additional power clean practice outside of the prescribed 12 sessions. The pre and post testing will comprise of a power clean technique session carried out using 3-D and 2-D motion capture. The procedures used for the power clean technique sessions are described above in *What will I Be asked to do?* Following this, you will have the power clean demonstrated to them by an experienced Olympic Weightlifting coach and participant will need to imitate the movement during the demonstration. Two practice trials will beallowed each participant, followed by 3 sets of 5 repetitions to perform the power clean.

Following the pre-test, you will learn the power clean by completing a 4-week practice intervention, with 20-minute sessions three times a week using either the nonlinear or linear pedagogy approach. Each of the conditions will practicethe power clean as follows:

- **Nonlinear Pedagogy:** Nonlinear pedagogy aims to provide learners with the freedom to explore multiple movement solutions through the manipulation task constraints. Subsequently, task constraints in the nonlinear condition will be manipulated in the following ways: participants lifting with two poles on either side of them and having chalk on the barbell and being told they need to leave chalk marks on their thighs. The latter is particularly important for power clean performance, being able to maintain contact with the thighs and produce contact with the hips are important for generating adequate power to get the bar onto the shoulders (catch position). In addition, through consultation will an expert Olympic weightlifting coach, outcome focused instructions have been formulated that allow the learner to develop their own personal movement pattern. These instructions are: 1) Sit your hips down like sitting onto a chair, 2) Keep your back firm like a rod, 3) Slide the bar up your legs, 4) Elbows high like a scarecrow, 5) Throw your elbows into the roof.
- **Linear Pedagogy:** this style of learning is based on traditional coaching models where there is one perfect wayto perform a movement and all learners should work towards this “optimal” movement model. The instructions that will be used for the linear pedagogy

condition will be based upon the bar path model of the "perfect" power clean from the National Strength and Conditioning Association (NSCA) cues for the power clean.

Each practice session for both conditions will consist of 20 power clean trials using a standard Olympic barbell weighing 20kg with an additional 10kg. The total volume of practice for both conditions will comprise of 240 minutes of practice over 4 weeks with 240 repetitions being performed. Practice will consist of 4 sets of 5 repetitions.

All testing and training sessions will be carried out in the biomechanics laboratory at Victoria University, Footscray Parkcampus.

Who is conducting the study?

Chief Investigator: Associate Professor Michael Spittle, Michael.spittle@vu.edu.au

Student Investigator: Riki Lindsay, riki.lindsay@live.vu.edu.au, 0452125056

Any queries about your participation in this project may be directed to the Chief Investigator listed above.
If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary,Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

Appendix B: Consent form – Study 3

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study into the following study: The influence of a nonlinear pedagogy

approach on functional outcomes when learning a complex movement

This research aims to use a nonlinear coaching method to teach the power clean and compare this with a traditional linear coaching method to see which method is more effective. This will require you to complete 8 power clean sessions where each session will be recorded using 3-D motion capture. To complete 3-D motion capture we will need to place 36 reflective markers on specific joints on the body. Each power clean session will be 20 minutes in duration and require you to complete 3 sets of 5 repetitions of the power clean. All sessions will be completed in the biomechanics laboratory at Victoria University, Footscray Park campus. The power clean movement is a high velocity movement with potential for injury. Potential injuries include muscular strains or tears, and adverse cardiovascular events.

CERTIFICATION BY PARTICIPANT

I, (Participant name)

of (Participant suburb)

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study:

The influence of a nonlinear pedagogy approach on functional outcomes when learning a complex movement

being conducted at Victoria University by: Associate Professor Michael Spittle

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Riki Lindsay

and that I freely consent to participation involving the below mentioned procedures:

- Power clean testing sessions pre and post intervention, comprising of 3-D and 2-D motion capture.
- Placement of 3-D markers on the following joints: 1) left and right shoulder (acromion process), 2) left and right elbow (lateral epicondyle of the humerus), 3) left and right hip (vertex of greater trochanter), 4) left and right knee (lateral epicondyle of femur, 5) left and right ankle (lateral malleolus), 6) top of heal of the lifting shoe, and 7) the base of the fifth metatarsal left and right side. You will be given to option to have markers placed by either a male or female depending on preference.

- Eight power clean training sessions over 4-weeks comprising of 3 sets of 5 repetitions of the power clean each session, with all sessions being recorded using 3-D and 2-D motion capture.

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:

Any queries about your participation in this project may be directed to the researcher

Associate Professor Michael Spittle

03 9919 9512 or,

Mr Riki Lindsay

0452125056

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email Researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

Appendix C: Medical Screening form

Medical Screening Form

Project: The Influence of a nonlinear pedagogy approach on functional outcomes when learning a complex movement skill

This is to be completed to identify any possible medical conditions that may put you at risk while performing exercise. It is important that you disclose ALL existing medical conditions so that we can determine whether further medical advice is needed before commencing the training involved in this study. This form does not provide medical advice and is not a substitute advice from a suitably qualified medical professional.
Please return this form and direct any queries to:

Chief Investigator: Associate Professor Michael Spittle, Michael.spittle@vu.edu.au

Student Investigator: Riki Lindsay, riki.lindsay@live.vu.edu.au, 0452125056

NAME:	**DOB:**		
ADDRESS:	**GENDER:**	**M / F**	
Postcode:	**AGE:**		**Years**
TELEPHONE (Home):	**WEIGHT:**		**Kg**
TELEPHONE (Mobile):	**HEIGHT:**		**cm**
EMAIL:			
EMERGENCY CONTACT PERSON INFORMATION **NAME:**			
RELATIONSHIP TO YOU:			
TELEPHONE (Mobile):			
TELEPHONE (Home):			
TELEPHONE (Work):			

MEDICAL HISTORY:

In the past have you ever had (tick No or Yes)

Medical Condition	NO	YES	Medical Condition	NO	YES
Heart Attack	☐	☐	Congenital Heart Disease	☐	☐
Chest Pain (angina)	☐	☐	Disease of Arteries/Veins/Heart	☐	☐
Heart Murmur	☐	☐	Asthma	☐	☐
Heart Rhythm Disturbance	☐	☐	Lung Disease (e.g. emphysema)	☐	☐
Heart Valve Disease	☐	☐	Epilepsy	☐	☐
Stroke	☐	☐	Injuries to back, knees, ankles	☐	☐

- **Please provide details if you responded yes to any of the above medical conditions**

- **List any prescribed or un-prescribed medications and vitamins being taken**

- **List any surgical procedures that you have had (write the year in brackets):**

- **List any injuries in your past medical history**

ALLERGIES: Do you have any allergies **NO** ☐ **YES** ☐
If yes, give details:

Because of exercise, have you ever experienced any of the following:

Symptom During Exercise	NO	YES	Symptom During Exercise	NO	YES
Pain or discomfort in the chest, back, arm, or jaw	☐	☐	Palpitations (heart rhythm disturbance)	☐	☐
Severe shortness of breath or problems with breathing during mild exertion	☐	☐	Pain in the legs during mild exertion	☐	☐
Dizziness, nausea or fainting	☐	☐	Severe heat exhaustion	☐	☐

CARDIOVASCULAR RISK FACTORS

Do you have (tick NO, YES or circle ? for DON'T KNOW)

Cardiovascular Risk Factors	NO	YES	DON'T KNOW
High Blood Pressure	☐	☐	**?**
High Blood Cholesterol/Triglycerides	☐	☐	**?**
Diabetes	☐	☐	**?**
Current Smoker	☐	☐	Average/day =
Ex-smoker	☐	☐	Average/day =
Do you drink alcohol regularly?	☐	☐	Average/day = drinks

Please provide details if you responded yes to any of the above symptoms or risk factors

……………………………………………………………………………………………………
……………………

……………………………………………………………………………………………………
……………………………………………………………………

……………………………………………………………………

Have members of your immediate family ever had any of the following conditions: (tick NO, YES or circle ? for DON'T KNOW). If you answer Yes or ?, write beside this the member of the family affected (F=father, M=mother, B=brother, S=sister, GM=grandmother, GF=grandfather).

FAMILY MEDICAL HISTORY	**NO**	**YES**	**?**	**FAMILY MEMBER**	**AGE (Years)**	**ALIVE NOW?)**
Heart Attack	☐	☐	**?**	_____	_____	_____
Chest Pain (Angina)	☐	☐	**?**	_____	_____	_____
Stroke	☐	☐	**?**	_____	_____	_____
High Blood Pressure	☐	☐	**?**	_____	_____	_____
High Blood Cholesterol/Triglycerides	☐	☐	**?**	_____	_____	_____
Diabetes	☐	☐	**?**	_____	_____	_____
Seizure, epilepsy or convulsions	☐	☐	**?**	_____	_____	_____

Participant Declaration

I declare that the above information is to my knowledge true and correct and that I have not omitted any information that is requested on this form.

Signed:

……………………………………………………

Date: ………../……………/…………….

Appendix D: NLP and LP Instructions experimental – Study 3

LP condition

Start position: Place your feet hip width apart with toes out slightly and knees over your feet. Squat down and hold the bar with a pronated grip and hands slightly wider than shoulder width apart, with your arms fully extended.

First pull: To begin, extend the hips and knees, but keep the angle of your torso the same to make sure that your hips do not come up to quickly. Keep your back in a neutral position. Keep your elbows fully extended, as your pull the barbell, be sure to keep your shoulders over or slightly in front of the bar. Keep the bar close to the shins.

Transition: When the bar gets just above the knees, forcefully push the hips forward with a slight bend in the knees. Shift your body weight onto the middle of the foot, keep your heels on the floor.

Second Pull: Keeping the bar in contact with the thighs, forcefully extend the hips, knees and ankles upwards. While you extend your lower body, explosively shrug your shoulders, with your elbows pointed high. As you get to the top of your pull, begin flexing your elbows and pull your body under the bar.

Catch: Pull the body under the bar by rotating the arms and hands under the bar with the hips and knees flexed. The bar should be caught on the front of the shoulders with head facing forward, back neutral, feet flat on the floor and body weight over the middle of the foot.

Example of NLP condition analogy-based instructions

- Think about staying connected to the bar and moving together throughout the movement.
- Keep your back firm like a rod.
- Moving the bar in the shape of a hook to bring the bar to the shoulders.
- Think about sitting onto a chair.
- Pull the bar like pulling up your pants and flick the bottom of your shirt with the bar.
- Throw the bar into the roof.
- Bring the bar up like lifting it onto a shelf.

Appendix E: Information statement – Study 4

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled: The influence of a nonlinear pedagogy approach to imagery on learning a complex motor skill

This project is being conducted by a student researcher Mr Riki Lindsay as part of a Doctor of Philosophy at Victoria University under the supervision of Associate Professor Michael Spittle from the College of Sport and Exercise.

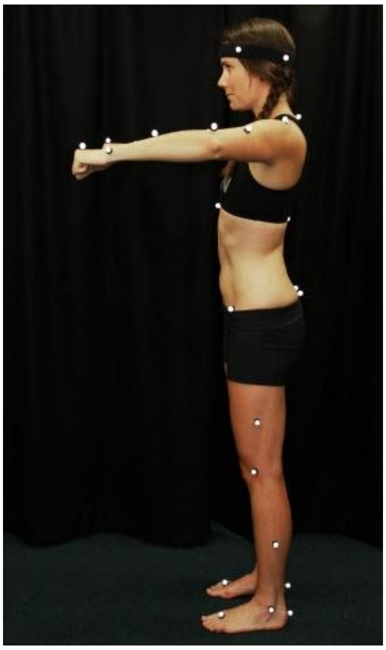
Project explanation

This project aims to examine the effectiveness of two different approaches when learning a complex skill. Imagery is defined as the generation of a physical experience in the mind, in the absence of physical practice. Recent research has highlighted the value of imagery for skill development. Imagery works by activating the same brain areas as physical practice, this is called functional equivalence. When learning a new skill using physical practice, a common approach that coaches use is linear pedagogy. This approach is also commonly used to teach new skills using imagery. The purpose of this method is to guide the learner towards a “perfect technique” Recently an alternative approach to learning is being used by coaches known as nonlinear pedagogy. Nonlinear pedagogy uses different constraints to help people develop their own individualised movement patterns. This research aims to use a nonlinear approach to imagery to help teach the power clean and compare this with a traditional linear approach to imagery to see which method is more effective.

What will I be asked to do?

This study involves being a part of a 4-week training intervention. You will be placed in one of two groups; nonlinear or linear group. Prior to beginning the 4-week training you will then be required to undertake a power clean technique pre-test. This will be to establish your baseline power clean technique. This will be a 30-45-minute testing where you will be video recorded using 3-D and 2-D motion capture software in the Biomechanics laboratory at Victoria University, Footscray Park campus.

Once markers have been placed you will have an expert weightlifting coach demonstrate the power clean movement where you will be asked to imitate the movement alongside the coach. You will then be given two practice trials before starting the testing. You will be asked to perform 3 sets of 5 repetitions of the power clean. Between sets you will be given 2-5 minutes of rest before you perform the next set. During these testing sessions you will have 3-D markers placed on specific landmarks on the body to measure angles at the shoulder, elbow, hip, knee and ankle (see diagram above). Once this is finished you will be asked to fill out a movement imagery questionnaire. This assesses your ability to imagine movements and provides a measure to determine how your imagery ability is progressing over the training period. Following the pre-test, you will be required to come in to the Biomechanics laboratory 2 times per week for 4 weeks (8 sessions) and perform 20 minutes of imagery training of the power clean. During these training sessions you will guided through instructions that have been designed to help you imagine the power clean and develop technique. At the half way point at the conclusion of week 2 a mid-intervention test will be conducted. This will be to see what changes in technique are happening during the training period. Once all imagery training sessions have been completed you will be asked to come back into the laboratory to complete a final power clean technique post-test. This will be to see what changes in technique have taken place over the course of the 4-week training intervention.



Marker Placement (Note that head markers will not be used in this study)

What will I gain from participating?

You will be reimbursed a total of $100AUD in the form of Coles Group and Myer gift card for participating in this study. After completing session 4 you will receive 1x$50 gift card and after the completion of session 8 you will then receive the final $50 gift card. Furthermore,this study will give you the opportunity to learn how to use imagery and effectively implement it in a practical setting. Additionally, athletes and coaches commonly implement weightlifting movements and variations, such as the power clean, due to the kinematic similarities that exist between the propulsive phases of weightlifting and athletic movements such as jumping, sprinting and change of direction tasks. Technical proficiency of performing the power clean is a key component when trying to maximise the force and power benefits of this exercise. Subsequently, this study will give participants the opportunity to improve their technical proficiency in the power clean under the coaching of Olympic weightlifting coach with international experience.

How will the information I give be used?

The information you provide initially be coded to ensure that your data is anonymous and that you cannot not be personally identified. Once your information has been coded it will be analysed and used initially to contribute towards the completion of a dissertation as part of the Doctor of Philosophy programme at Victoria University. Additionally, the information you provide will contribute to research reports and journal article publications that will be produced from this research project. All data that is collected will only be available to the research team. No information identifying you as the participant in this research will be included in any of the research reports or publications.

What are the potential risks of participating in this project?

You will be required to perform light exercise over the course of the training intervention where there is a potential risk of injury. Firstly, there is the potential risk of an adverse cardiovascular event because of completing the exercise in this study. Furthermore, there is the potential risk of muscular injury from completing the power clean exercise. To minimize these risks the following processes have been implemented. Firstly, an international level Olympic weightlifting coach has been consulted in the design process of the testing and training procedures. From this consultation process the volume of work (sets and repetitions) is deemed to be at an appropriate level and not exposing those training to unnecessary strain that could lead to muscular injury or adverse cardiovascular event. All training will be supervised by an international level Olympic weightlifting coach that is first-aid trained. If an adverse cardiovascular event is to occur during training in this study, the ambulance will be called immediately, and the supervising investigator will begin to perform CPR. If participants do incur a muscular injury (i.e. strain or tear) because of taking part in the following research they will be withdrawn from the study and provided with the details of a physiotherapist so that they can make an appointment to diagnose the injury and get appropriate treatment.

As the participant, you will be compensated for any medical expenses incurred due to your involvement in this study.

How will this project be conducted?

The current study will comprise of a pre-test, followed by a 4-week intervention, mid-intervention test and a post-test. To participate in this study, you will need to refrain from any additional power clean practice outside of the prescribed 8 sessions. The pre, mid and post testing will comprise of a power clean technique session carried out using 3-D and 2-D motion capture followed by a movement imagery questionnaire. Prior to all testing sessions you will have the power clean demonstrated to them by an experienced Olympic Weightlifting coach and participant will need to imitate the movement during the demonstration. Two practice trials will be allowed each participant, followed by 3 sets of 5 repetitions to perform the power clean.

Following the pre-test, you will learn the power clean by completing a 4-week imagery practice intervention, with 20-minute sessions two times a week using either the nonlinear or linear pedagogy approach. Each of the conditions will practice the power clean as follows:

Nonlinear imagery condition: Through consultation with an expert Olympic weightlifting coach, imagery instructions have been formulated that aim to recreate a mental image of the task constraints that are being manipulated during physical practice. Through consultation will an expert Olympic weightlifting coach, outcome focused instructions have been formulated that allow the learner to develop their own personal movement pattern. These instructions are: 1) Sit your hips down like sitting onto a chair, 2) Keep your back firm like a rod, 3) Slide the bar up your legs, 4) Elbows high like a scarecrow, 5) Throw your elbows into the roof. In addition, consultation with each participant will occur to add any information to the instructions that they deem to be personally relevant to the power clean movement.

Linear imagery condition: The linear imagery condition will also aim to use imagery the closely resembles a linear learning approach used for physical practice. Linear pedagogy operates on the premise that an “ideal” movement model exists and all learners should strive to attain this “ideal” movement pattern. Subsequently, the imagery instructions that will be used for the linear pedagogy condition will be based upon the bar path model of the “perfect” power clean [11]. The instructions that will be used follow a sequential phase by phase approach to learning the power clean. These instructions are based on the National Strength And Conditioning Association (NSCA) cues for the power clean [12]

Each imagery practice session for both conditions will consist of 15 power clean trials, lasting approximately 20 minutes.
All testing and training sessions will be carried out in the biomechanics laboratory at Victoria University, Footscray Park campus.

Who is conducting the study?

Chief Investigator: Associate Professor Michael Spittle, Michael.spittle@vu.edu.au

Student Investigator: Riki Lindsay, riki.lindsay@live.vu.edu.au, 0452125056

Any queries about your participation in this project may be directed to the Chief Investigator listed above.
If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

Appendix F: Consent form – Study 4

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:
We would like to invite you to be a part of a study into the following study:
The influence of a nonlinear pedagogy approach to imagery on learning a complex motor skill

This research aims to use a technique called imagery to teach the power clean to investigate the influence this specific technique has on developing a complex movement. This will require you to complete 8 power clean sessions where each session where you will use imagery to develop your power clean technique. There will be three testing sessions involved at the beginning, middle and end of the intervention. This will require you to physically perform the power clean while being recorded using 3-D motion capture. To complete 3-D motion capture we will need to place 36 reflective markers on specific joints on the body. Each power clean session will be 20 minutes in duration and require you to complete 3 sets of 5 repetitions of the power clean. All sessions will be completed in the biomechanics laboratory at Victoria University, Footscray Park campus. The power clean movement is a high velocity movement with potential for injury. Potential injuries include muscular strains or tears, and adverse cardiovascular events.

CERTIFICATION BY PARTICIPANT

I, (Participant name)
of (Participant suburb)

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study:
The influence of a nonlinear pedagogy approach on functional outcomes when learning a complex movement
being conducted at Victoria University by: Associate Professor Michael Spittle

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Riki Lindsay

and that I freely consent to participation involving the below mentioned procedures:

- Power clean testing sessions pre, mid and post intervention, comprising of 3-D and 2-D motion capture.
- Placement of 3-D markers on the following joints: 1) left and right shoulder, 2) left and right upper arm, 3) left and right elbow (lateral and medial), 4) left and right forearm, 5) left and right wrist (thumb and pinkie side), 6) left and right anterior superior iliac spine, 7) left and right posterior superior iliac spine, 8) left and right knee (lateral and medial), 9) left and right thigh, 10) left and right ankle (lateral and medial), 11) left and right outer tibia, 12) left and right foot (1st , 5th metatarsal, heel and Achilles). You will be given to option to have markers placed by either a male or female depending on preference.
- Eight imagery power clean training sessions over 4-weeks comprising of 3 sets of 5 repetitions of the power clean each session.

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:

Any queries about your participation in this project may be directed to the researcher
Associate Professor Michael Spittle
03 9919 9512 or,
Mr Riki Lindsay
0452125056
If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email Researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

Appendix G: MI instructions for LP and NLP conditions – Study 4

LP condition

Welcome to your 4-week power clean training program. You will complete 3 sets of 5 repetitions of the power clean movement with 2-5minutes rest in between each set.

Get ready for ready for your first set

Imagine yourself in the set-up position… Bring your attention to what you see in the room around you. Find a point in the room to focus your attention throughout the duration of this set. As you set up you move your feet to hip width apart with your toes slightly turned out. Feel the tension in your muscles as you are in a squat position….. feel the rough grip of the bar as it sits in your hands. You grip the bar with your hands slightly wider than shoulder width apart.

Feel the muscles in your body tighten as you prepare to pull the bar. As you pull the bar from the floor your shoulders are over the bar, eyes looking forward and the bar is close to your shins. Your hips and knees are extending and the angle of your torso stays the same keeping your hips from rising too quickly.

As the bar passes your knees you push your knees forward keeping the bar in contact with your thighs, in this position you forcefully extend the hips, knees and ankles upwards contacting the bar with your hips.

As your lower body extends you explosively shrug your shoulders, pointing your elbows straight upwards.

As you reach the top of your pull your arms flex your elbows rotating your arms and hands as you pull your body under the bar. As you catch the bar your hips and knees are flexed, your head is facing forwards, back neutral, feet flat on the floor with your body weight resting over the middle of your feet.

You have completed your first repetition! You have 4 more repetitions to go.

In your own time complete the remaining 4 repetitions and signal to the coach once you have completed the remaining repetitions.

NLP condition (Weeks 1 and 4)

Welcome to your 4-week power clean training program. You will complete 3 sets of 5 repetitions of the power clean movement with 2-5minutes rest in between each set.

Get ready for ready for your first set

Imagine yourself in the set up position…. Bring your attention to what you see in the room around you. Find a point in the room to focus your attention throughout the duration of this set. Feel the tension in your muscles as begin your set up. As you set up think about leaning forward like you are just about to sit on a chair. As you set up and reach down to hold the bar… feel the rough grip of the bar as it sits in your hand. At this point think about staying connected to the bar keeping it as close and connected to your body throughout the movement.

Feel the muscles in your body tighten as you prepare to pull the bar. As you begin to pull the bar from the floor you feel your body become firm like a steel rod. As the bar moves from the floor you feel the bar is staying connected to your body as you pull the bar upwards. At this point you are moving upwards and the bar is moving like a train on a track staying close to the body and moving in the shape of a hook. You are connected to the bar pulling straight up like you are pulling your pants up and giving yourself a wedgie. As the bar moves you flick the bottom of your shirt, from here you explode jumping straight up. You pull the bar upwards like you are throwing it into the roof as the bar comes down in rests on your shoulders which act like a shelf for the bar to rest on.

You have completed your first repetition! You have 4 more repetitions to go.

In your own time complete the remaining 4 repetitions and signal to the coach once you have completed the remaining repetitions.

NLP condition (Constraints, Weeks 2 and 3)

Welcome to your 4-week power clean training program. You will complete 3 sets of 5 repetitions of the power clean movement with 2-5minutes rest in between each set.

Get ready for ready for your first set

To begin your set up think about leaning forward like you are just about to sit on a chair. As you set up and reach down to hold the bar think about staying connected to the bar keeping it as close and connected to your body throughout the movement. Imagine yourself in the set up position… Bring what you see in the room around you. Find a point in the room to focus your attention throughout the duration of this set Feel the rough grip of the bar as it sits in your hands. Now bring your attention to the two poles on your left and right side placed in front of the bar. Throughout lift avoid hitting the poles with the bar. Still in the set-up position become aware of the chalk that is on the bar. As you lift leave a chalk mark from just above your knee to the top of your thigh.

As you begin to pull upwards avoid hitting the two poles that are on your left and right, as the bar continues to move upward keep it connected to your body. As the bar continues to move upwards think about the bar following a train track staying close to the body, aiming to move the bar in the shape of a hook. At this point pull the bar upward the same way you would pull up a pair of pants, as you do this become aware of the bar contacting the body and leaving a chalk mark on your pants as you pull the bar upwards. Staying connected to the bar try and flick the bottom of your shirt as you pull the bar upwards. You now explode upwards like you are jumping straight up, throwing the bar into the roof. The bar finishes on your shoulders like a shelf for the bar to rest on.

You have completed your first repetition! You have 4 more repetitions to go.

In your own time complete the remaining 4 repetitions. Once you have completed each repetition signal to the coach and proceed to the next repetition.