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Motor imagery as a potential tool for improvement of musculoskeletal function in physiotherapy practice

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Motor imagery as a potential tool for improvement of musculoskeletal function in physiotherapy practice

By

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Summary

Motor imagery (MI) is a cognitive simulation technique with increasing importance in psychology, sport psychology and applied therapeutic domains (Dickstein & Deutsch, 2007; Guillot & Collet, 2008; Moran, Guillot, MacIntyre, & Collet, 2012). MI can be described as executing specific actions/tasks mentally, without any bodily movement, by adopting different sensory modalities (e.g. Collet & Guillot, 2010; Cumming & Ramsey, 2008; Jackson, Lafleur, Malouin, Richards, & Doyon, 2001). In the last two decades, a considerable amount of work has been performed to introduce MI as an effective rehabilitation tool for motor function, especially in the neurorehabilitation setting (Braun et al., 2006; Dickstein & Deutsch, 2007; Malouin & Richards, 2013; Mulder, 2007; Schuster, Butler, Andrews, Kischka, & Ettlin, 2012; Zimmermann-Schlatter et al., 2008). Despite the accumulating evidence supporting the benefits of cognitive techniques (e.g. MI) for patients with various neurological conditions, relatively little attention has been paid to the effects of imagery applications on the musculoskeletal system (Pelletier, Higgins, & Bourbonnais, 2015a, 2015b; Snodgrass et al., 2014). Consequently, the general objective of this thesis is to explore the potential role of MI as a therapeutic tool to be used as an alternative or adjunct to the traditional physiotherapeutic exercise for musculoskeletal parameters.

The thesis is written as a collection of research studies committed to the objective described above. ***Chapter 1*** represents a review of the literature exploring the potential role of imagery in musculoskeletal rehabilitation. Although the review chapter shows encouraging findings from the recent literature, it reveals the need to improve and develop the existing imagery intervention protocols for muscle strength outcomes to be used as a physiotherapeutic tool. Based on this need, our thesis comprises two experimental studies examining imagery's efficacy on maximal force production in larger muscle groups, which is relevant in physiotherapy practice. In addition, this thesis builds on the potential expansion of research activities using imagery in Arabic countries by translating the vividness movement imagery questionnaire (VMIQ-2) to the Arabic language.

Chapter 2 describes outcomes of a randomised control study examining the efficacy of cognitive imagery training on hip abductor strength in healthy individuals. In the study, two newly developed imagery protocols with specific imagery modalities, namely kinaesthetic with visual (KIN+VI) and kinesthetic only (KIN), were used and compared with a control group (no practice). The results demonstrated the efficacy of the imagery intervention for increasing strength in the hip abductor muscles and emphasised superior outcomes for the combined protocol (KIN+VI) for strength gains. In addition, the study revealed the efficacy of the KIN+VI imagery intervention for improving imagery ability (vividness).

Chapter 3 reports the results of the second experimental study, which examines the efficacy of imagery practice (using the KIN+VI protocol from study 1) on the maximal isometric strength and electrical activity (EMG) of hip abductors (i.e. the efficacy of the ipsilateral training effect and bilateral transfer effects) compared with exercise in healthy individuals. In this study, the results showed a significant ipsilateral increase in strength and EMG amplitude in the trained hip abductor muscles of the imagery group (KIN+VI), while the exercise group did not show considerable gains. In addition, this chapter reports a novel finding concerning a bilateral transfer effect occurring after unilateral imagery training of the tested muscle group, with no strength gains occurring following exercise training. Finally, this study shows a clear indication that the home-imagery intervention protocol should be favoured over the home-exercise training due to the higher level of commitment in the imagery group; this illustrates the possibility of using imagery practice as a self-management intervention.

Chapter 4 reports on the translation and validation of the VMIQ-2 to Arabic among Arabic native speakers living in the United Kingdom and Saudi Arabia. The chapter provides information about the translation process, cognitive debriefing test and initial reliability of the VMIQ-2 Arabic version. The study used an advanced analytical procedure to evaluate factorial validity by employing Bayesian structural equation modelling (BSEM) for each country's dataset. The findings of this study provide initial support for the newly translated VMIQ-2-A with adequate psychometric properties; hence, it represents the first imagery ability questionnaire that has been translated into Arabic.

Chapter 5 provides a summary of the thesis findings and clarifies the novelty of the current thesis. In addition, it outlines the future implications of the findings from the application and research perspectives. Furthermore, this chapter addresses the strengths and limitations of the thesis. Finally, it presents the conclusion of the current work.

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List of Abbreviations

Frequently Used Imagery Terms

CG	Cognitive General
CS	Cognitive Specific
EVI	External Visual Imagery
GI	Guided Imagery
IMC	Imagined Maximal Contraction
IVI	Internal Visual Imagery
KIN	Kinaesthetic Imagery
LSRT	Layered Stimulus and Response Training
MG-A	Motivational General-Arousal
MG-M	Motivational General-Mastery
MP	Mental Practice
MI	Motor imagery
MS	Motivational specific
PETTLEP	Physical, Environment, Task, Timing, Learning, Emotion, Perspective
SP	Stimulus Proposition
SRP	Stimulus and Response Proposition
VI	Visual Imagery

Questionnaires

IPAQ	International Physical Activity Questionnaire
KVIQ	Kinaesthetic and Visual Imagery Questionnaire
MIQ-3	Movement Imagery Questionnaire-3
MIQ-R	Revised Movement Imagery Questionnaire
VMIQ	Vividness of Movement Imagery Questionnaire
VMIQ-2	Vividness of Movement Imagery Quesitonnaire-2
VMIQ-2-A	Vividness of Movement Imagery Quesitonnaire-2- Arabic

Analysis Terms

ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
BSEM	Bayesian Structural Equation Modelling
CFA	Confirmatory Factor Analysis
CI	Confidence Interval
CR	Composite Reliability
CTCU	Correlated Trait Correlated Uniqueness
ICC	Intraclass Correlation Coefficient
ICM	Independent Clusters Model
ML	Maximum likelihood Estimator
MTMM	Multitrait Multimethod
PPP	Posterior Predictive p Value
PSR	Potential Scale Reduction Factor
r	Correlation Coefficient
RMS	Root mean Square
SD	Standard Deviation

SEM	Structural Equation Modelling
SPSS	Statistical Package for Social Sciences

Physiological Measures and Units

ANS	Autonomic Nervous System
BA6	Brodmann Area 6
EEG	Electroencephalogram
EMG-Amp	Electromyography amplitude
EMG	Electromyogram
fMRI	Functional Magnetic Resonance Imaging
hMNS	Human Mirror Neuron System
HR	Heart Rate
mV	Millivolts
MNS	Mirror Neuron System
MRCP	Movement-Related Cortical Potential
M1	Primary Motor Cortex
NIRS	Near-infrared Spectroscopy
SMA	Supplementary Motor Area

Functional Measures and units

DM	Deltoideus Medius
GM	Gluteus Medius
HGS	Handgrip Strength
Kg	Kilograms
MIT	Maximal Isometric Torque
MR	Maximum Number of Repetitions
MVC	Maximal voluntary contraction
N.m	Newton*Metre

Medical and therapeutic terms, and others

ACL	Anterior Cruciate Ligament
AORD	Arthritis and other Rheumatic Diseases
BMI	Body Mass Index
CDC	Centers for Disease Control and Prevention
CNS	Central Nervous System
CST	Conventional Strength Training
CTRL	Control Group
ISPOR	International Society for Pharmacoeconomics and Outcomes Research
KSA	Kingdom of Saudi Arabia
MET	Motor effort training
MIIMS	Motor Imagery Integrative Model in Sport
MSDs	Musculoskeletal Disorders
PAWB	Physical Activity and Wellbeing Centre
PMR	Progressive Muscle Relaxation

PP	Physical Practice
RICE	Rest, Ice, Compression, and Elevation Protocol
SENIAM	Surface Electromyography for the Non-Invasive Assessment of Muscles
TCA	Translation and Cultural Adaptation group
UK	United Kingdom
Wks	Weeks
yrs	Years

Chapter 1: Potential applications of imagery practice in musculoskeletal physiotherapy: Literature review

Introduction

Mental practice using imagery is a promising tool that could be integrated into various fields of physiotherapy as an alternative or complement to the traditional tools for optimisation of patients' recovery. The application of imagery as an intervention method has shown promising results across various fields of application. In the sport domain, imagery has been explored as an effective intervention strategy that enhances performance and motor skill acquisition (e.g. Cumming & Williams, 2012; Driskell, Copper, & Moran, 1994; Feltz & Landers, 1983; Morris, Spittle, & Watt, 2005).

In rehabilitation settings, it has been suggested that the feasibility of using imagery as an adjunctive technique in physical therapy should be explored to optimise its efficacy on motor function restoration and/or improving the physical performance capacity of the patient population (Warner & McNeill, 1988). In the last two decades, considerable efforts have been made to transfer the concept of motor imagery (MI) from sports psychology to rehabilitation, especially neurorehabilitation (Braun et al., 2006; Dickstein & Deutsch, 2007; Dijkerman, Ietswaart, & Johnston, 2010; Dijkerman, Ietswaart, Johnston, & MacWalter, 2004; Jackson, Lafleur, Malouin, Richards, & Doyon, 2001; Johnson-Frey, 2004; Lotze & Halsband, 2006; Malouin & Richards, 2013; Mulder, 2007; Schuster, Butler, Andrews, Kischka, & Ettlin, 2012; Sharma, Pomeroy, & Baron, 2006; Tamir, Dickstein, & Huberman, 2007; Zimmermann-Schlatter et al., 2008). In addition, these studies examined the potential therapeutic effect of MI on enhancing motor function and gait relearning in the contexts of various neurological conditions (e.g. chronic stroke, Parkinson's disease, multiple sclerosis, spinal cord injury); they showed promising results and improvements for different assessment outcome methods compared with a control group or standard physiotherapy intervention alone. Furthermore, Dickstein and Deutsch (2007) recommended using evidence from the sports domain showing the efficacy of MI on improving motor skills learning and performance with healthy participants as background support for future imagery applications on physiotherapy for patients with neurological conditions.

In addition to the substantial evidence supporting the efficacy of imagery practice in neurological conditions, the efficacy of using imagery practice on musculoskeletal system function (e.g. muscle strength, physical function) in patients with musculoskeletal disorders (MSDs; i.e. injury or disease) is still under development. Nevertheless, multiple studies have examined the effectiveness of imagery with musculoskeletal system functions and shown encouraging results, which are detailed below.

In this review, we give an overview of imagery's definitions, terminology, and types and functions, as well as applications of imagery interventions in various settings. In addition, this review summarises studies that examined the efficacy of imagery training on specific functions of the musculoskeletal system (i.e. muscle strength) in participants who were healthy and free from any central nervous system (CNS) disorders. This review also explores the efficacy of imagery practice on patients with MSDs (disease or injury) in relation to specific musculoskeletal outcomes, like muscle strength or physical function. Furthermore, it provides an overview of the importance of imagery ability evaluation and its effects on imagery interventions. Finally, we describe future research directions to enable a better understanding of our thesis direction.

Imagery: definitions and key terms

Imagery studies derive from different areas of research, such as sport psychology, cognitive psychology, rehabilitation and cognitive neuroscience. Each area has specific terminology, which can sometimes create confusion. Some examples of the diverse definitions of imagery considered in this review are given below.

Mental imagery refers to the formation (or re-formation) of a mind image related to an experience using varied sensory modalities (e.g. auditory, visual, tactile, olfactory, gustatory, kinaesthetic; Dickstein & Deutsch, 2007). White and Hardy (1998) explained that 'we can be aware of "seeing" an image, feeling movements as an image, or experiencing an image of smell, taste or sounds without experiencing the real thing' (p. 389). Thus, mental imagery is a cognitive simulation approach that can be defined as 'a symbolic sensory experience that may occur in any sensory mode' (Hardy et al., 1996, p. 28). A key application of mental imagery is 'mental practice' (MP;

also known as MI), which is the systematic use of mental imagery processes to rehearse a movement or skill symbolically without executing the movements involved (Moran, 2009).

Jackson et al. (2001) suggested that the term *motor imagery* should be preferred when the human body is involved. This corresponds to an active process during which the representation of a specific action of the body is internally reproduced in working memory without any motor output. Similarly, MI has been defined as a dynamic mental state during which the representation of a given motor act or movement is rehearsed in working memory without any overt motor output (Collet & Guillot, 2010). Furthermore, MI has been described as 'an experience that mimics real experience, and involves using a combination of different sensory modalities in the absence of actual perception' (Cumming & Ramsey, 2008, p. 5).

Defining imagery is difficult as seen from the example definitions above. Indeed, there are multiple definitions that can be adopted, however, 'the focus of each definition varies depending on the purpose for which the imagery description is used' (Morris et al., 2005). Selecting a specific definition to represent imagery is therefore challenging.

At the imagery terminology level, there is an issue across the imagery literature that should be considered in future work. For example, various imagery terms have been used interchangeably as synonyms or may be confused with each other or imagery modality names across imagery literature (e.g., MP, MI, imagery practice, movement imagery, mental imagery, kinaesthetic imagery, and visualisation); thus, readers will be confused as to which terms are appropriate for use and whether they can be combined in different applications.

Moran et al. (2012) highlighted the problem within imagery terminology; as *motor imagery* is frequently used synonymously with *movement imagery* (e.g. Nam, Jeon, Kim, Lee, & Park, 2011; Roberts, Callow, Hardy, Markland, & Bringer, 2008), or *imagery of movement* (e.g. Isaac, Marks, & Russell, 1986). However, differences in imagery terms may even extend to the concept level; indeed, they favoured the term MI with kinaesthetic modality (KIN) (e.g. kinaesthetic MI); while on the concept level MI is defined as KIN modality (e.g. bodily sensations of movement), with no or little consideration of other sensory modalities.

Another confusing issue in the imagery terms involves the interchangeable usage of 'visualisation' and 'mental practice' in imagery studies. Some authors have regarded these terms are referring to related but distinctly different concepts (e.g. Morris et al., 2005; Murphy & Martin, 2002). Imagery must be distinguished from MP, as imagery is a precise mental process that can be practiced mentally, while MP represents a rehearsal of imagery, and it may also denote other types of mental processes (e.g. self-talk and modelling; Murphy & Martin, 2002). While imagery comprises all varied 'quasi-sensory or quasi-perceptual experiences' (Cumming & Ramsey, 2008, p. 6), visualisation represents a specific sensory modality (vision). Thus, using the term *imagery* in imagery training with athletes is better than using *visualisation*, as athlete's images are not restricted to the experience in their mind's eye (visualisation), and they can used varied modalities that can be fit under the rubric of imagery (e.g. Munroe et al., 2000).

The current thesis adopts the terms 'imagery training' and 'imagery practice' as synonyms of the previously mentioned term 'motor/movement imagery', and these terms are used interchangeably in the thesis chapters.

Imagery types

Imagery types have not been clearly described across the imagery intervention literature. Thus, the following section attempts to present examples of imagery types from various domains.

Murphy, Nordin and Cumming (2008) suggested the descriptions of the imagery type as the content of an image (e.g. the visual image of oneself executing a skill), function as the reason or purpose why an athlete uses imagery (e.g. for skill improvement) and outcome as the real result of the imagery (e.g. enhanced skill performance). Four different types of imagery practice have been described in studies targeting injured athlete, as follows: Cognitive imagery is used to rehearse rehabilitation exercises; motivational imagery is used to set goals, control arousal levels and increase self-confidence; healing imagery entails imagining the physiological processes taking place during rehabilitation (e.g. tissue and/or bone healing); and pain management imagery involves images of pain dissipating or images that can help the athlete in coping with the pain associated with an injury (Driediger, Hall, & Callow, 2006; Sordoni, Hall, & Forwell, 2002).

Guillot and Collet (2008) proposed the MI integrative model in sport (MIIMS), which lists different MI types used to achieve various goals. The MIIMS model includes the following MI types:

- Cognitive specific (CS): This type is used to develop skills and techniques for improving performance;
- Cognitive general (CG): This includes strategy planning, development and execution;
- Motivational general – mastery (MG-M): This is when an athlete uses imagery for measures like staying focussed, confident and mentally tough;

- MG – arousal (MG-A): This involves using imagery to regulate emotions and arousal levels, such as psyching up or relaxing;
- Motivational specific (MS): The purpose of this MI type is to help athletes understand what it will take to achieve their goals.

The imagery categories may be practiced by adopting the sensory modalities (internal or external visual imagery perspective, as well as kinaesthetic, tactile, auditory or olfactory) shown in Figure 1. Guillot and Collet (2008) suggested the possibility of using single imagery type alone to achieve a specific goal or using a combination of various imagery types to enhance the achievement of the objective by forming a multimodal, comprehensive mental representation of the trained actions or task. They reviewed a considerable number of MI intervention studies, and they found four imagery outcomes that may be considered, as follows: (a) motor learning and performance; (b) motivation, self-confidence and anxiety; (c) strategies and problem solving; and (d) injury rehabilitation.

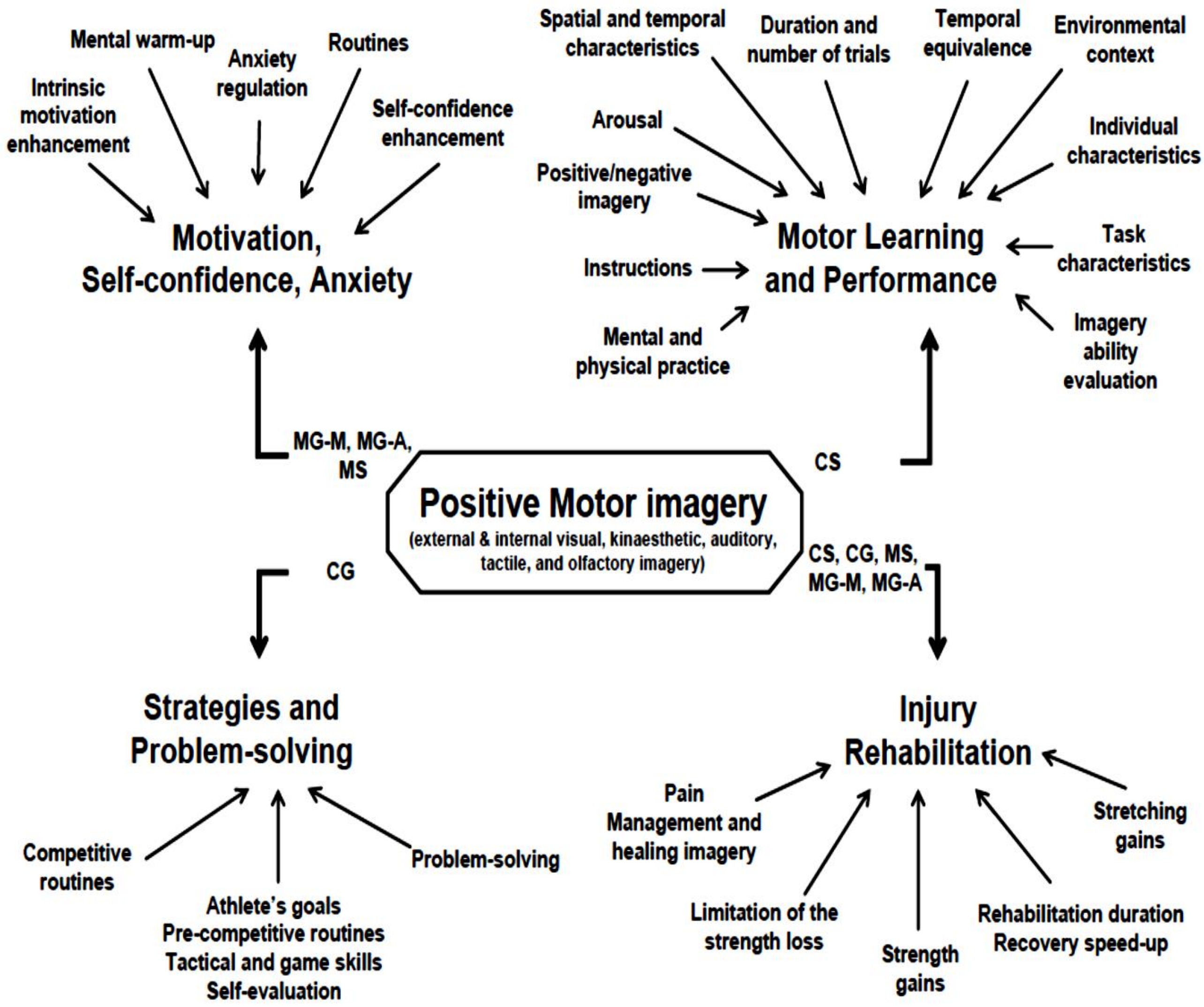


Figure 1. Motor Imagery Integrative Model in Sport (MIIMS) considering four specific imagery outcomes and depicting each motor imagery (MI) function into several subcategories. The key components that need to be controlled to ascertain the MI's effectiveness are described. CS: cognitive specific; CG: cognitive general; MG-M: motivational general-mastery; MG-A: motivational general arousal; MS: motivational specific. (Guillot and Collet, 2008)

Imagery practice can be classified according to the sensory modalities adopted during imagery practice. Although the MIIMS model suggests using varied imagery sensory modalities with the different MI types proposed by Guillot and Collet (2008), the focus of movement/motor imagery is usually on visual and kinaesthetic imagery sensory modalities (Williams et al., 2012). The kinaesthetic imagery modality has been described as 'how it feels to perform an action, including force and effort' (Callow & Waters, 2005, p. 444), while visual imagery modality is simply defined as what the individual views in the image, including seeing movements performed by oneself or others (Holmes & Calmels, 2008; Ruby & Decety, 2001).

Moran et al. (2012) recommended using MI as the term for imagery training that delineates the following imagery modalities and perspectives: kinaesthetic imagery, external visual imagery (EVI) and internal visual (IVI). In the same way, movement imagery at the experimental level has been differentiated into KIN or VI modalities that accompany movement (e.g. Cumming & Ste-Marie, 2001; Hardy & Callow, 1999; Guillot et al., 2009). In addition, VI's further separation into two VI perspectives (EVI and IVI) refers to whether imagery is experienced from outside or inside of one's body (Callow & Roberts, 2012; Morris et al., 2005). Specifically, the IVI perspective is defined as when the imaginer is looking out through his or her eyes while performing the action, while the EVI perspective is when the imaginer is watching him or herself performing the action from an observer's position, as if watching him or herself on television (Callow & Roberts, 2012).

Imagery types based on specific adopted imagery modalities and perspectives may potentially influence the efficacy of imagery training, and this may differentially affect the strength/performance outcomes. For example, White and Hardy (1995) found that varied perspectives of imagery could demonstrate different aspects of a motor performance task (wheelchair slalom task), and the results suggested that the EVI group focussed on the speed of performance, while the IVI group focussed on the accuracy of performance. Callow, Roberts, Hardy, Jiang and Edwards (2013) showed that the IVI condition produced superior performance on slalom-based tasks compared with the EVI or control condition. In addition, their finding supported the notion that kinaesthetic imagery can be experienced with both visual perspectives. Furthermore, Callow, Jiang, Roberts, and Edwards (2017) found that the combined IVI and KIN group achieved significantly quicker lap times (enhancement in performance) than the IVI and control groups did. In a similar way, on a muscle strength task, the effects of internal imagery training (defined as a combination of IVI with KIN) were better than those of EVI when it came to achieving the maximal isometric strength of the elbow flexors (Yao, Ranganathan, Allexandre, Siemionow, & Yue, 2013).

Finally, guided imagery (GI), also known as 'mental simulation' or 'visualisation', is another type of imagery that is usually used as adjunct therapy for patients complaining of arthritis and other rheumatic diseases (AORD). This is a cognitive approach used by psychologists to help individuals cope with pain, anxiety and trauma; it is specifically defined as 'a quasi-perceptual, multisensory, and conscious experience that resembles the actual perception of some object, scene, or event but occurs in the absence of external stimuli' (Giacobbi et al., 2015, p. 2). It is commonly used with MSDs in combination with breathing or progressive muscle relaxation exercises, proceeding to images of movement and physical activity free of pain and stiffness (Baird & Sands, 2004; Giacobbi et al., 2015).

Reasons for using imagery training in applied practice

There are important benefits to integrating imagery training into treatment for specific clinical populations as alternatives or complements to traditional therapeutic exercise. Patients can practice imagery training for specific motor tasks, and they can increase the number of imagery training repetitions during the imagery protocols to improve the subsequent physical performance capacity in a safe, self-directed way with less exhaustion and load on the muscles and/or joints (Dickstein & Deutsch 2007; Malouin & Richards, 2013; Tamir et al., 2007). Compared with physical training, imagery training does not induce neuromuscular fatigue following training (Rozand et al., 2014). Moreover, imagery training enables patients to mentally simulate motor skills that may be essential for the rehabilitation process (e.g. functional activity, walking, climbing stairs, balancing) in the early weeks of rehabilitation when it is not possible to perform the motor tasks physically due to various medical conditions (e.g. surgery, immobilisation, severe pain, paresis). In such contexts, motor imagery can be used to keep the sensorimotor circuitry functional and promote faster recovery once physical practice becomes possible (Malouin & Richards, 2013). In addition, other important factors that could support the integration of imagery with future physiotherapy interventions are that imagery is inexpensive, easy to learn, applicable without the need for any instruments at various places and potentially useful as a self-management tool (Dickstein & Deutsch, 2007; Tamir et al., 2007).

Possibility of imagery training application for musculoskeletal rehabilitation

The musculoskeletal system is an important system in the human body; it provides the support, stability and movement of the body. It comprises different components, such as muscle, bone, ligaments, joints, cartilage and other connective tissue. It can be affected by various external or internal factors that cause musculoskeletal system abnormality. The Centers for Disease Control and Prevention (CDC) define MSDs as injuries or disorders of the muscles, nerves, tendons, joints, cartilage and supporting structures of the upper and lower limbs, neck, and lower back (Piper et al., 2016). Consequently, MSDs can be caused by injury or disease that occurs in various contexts (e.g. work, community, sport). The main features of MSDs are severe pain, reduction of physical performance, loss of physical function, and a decline in mental health (Dall et al., 2013). In addition, the reduction of muscle strength leads to a further limitation of physical function (Pedersen & Saltin, 2006).

MSDs are traditionally treated via musculoskeletal rehabilitation using a pathology-structure paradigm that directs the intervention toward functional, biological and structural abnormalities in the musculoskeletal system, for example, by using therapeutic exercise. The effects of the current interventions may be mediated through peripheral and central changes, but they may not specifically address all the underlying neuroplastic changes in the CNS that are potentially associated with chronic MSD. Hence, musculoskeletal rehabilitation professionals can use different tools that address neuroplastic changes across distributed areas of the nervous system and affect outcomes in patients with chronic MSDs, including top-down cognitive-based interventions (e.g. education, cognitive behavioural therapy, mindfulness meditation, motor imagery) and bottom-up physical interventions (e.g. motor learning, peripheral sensory stimulation, manual therapy; Pelletier, Higgins, & Bourbonnais, 2015a, 2015b).

Snodgrass et al. (2014) suggested combining the expertise of clinicians and researchers working in the areas of neurological and musculoskeletal physiotherapy to integrate neuroplasticity intervention approaches used in neurological physiotherapy (e.g. imagery, task specificity and feedback) into the future treatment plans focussing on musculoskeletal conditions. In addition, other researchers have demonstrated that musculoskeletal physiotherapists appreciate the importance of using psychological intervention techniques (e.g. imagery, relaxation, positive self-talk and goal setting) during the rehabilitation process, although the report showed that most of the participating physiotherapists had an inadequate understanding of these interventions, which reduced their utilisation in physiotherapy practice (Alexanders et al., 2015). However, it is suggested that the efficacy of imagery interventions across patients with musculoskeletal injury is still under development and requires further experimental investigation (Guillot & Collet, 2008).

Future integration of imagery interventions into musculoskeletal rehabilitation services can only be supported by evidence. Using previous studies that have targeted muscle-related functions with healthy participants (e.g. showing that muscle strength/activation outcomes are one of the most important physiological outcomes in musculoskeletal rehabilitation) is an important starting point. Thus, reviewing imagery interventions with strength-related outcomes could serve as background support for future imagery intervention implementation in varied clinical musculoskeletal conditions. The second line of evidence in this review is clinical studies that have used imagery interventions in connection with other therapeutic approaches in MSDs, specifically those with outcomes related to strength and physical function. However, the current review excludes studies related to neurological conditions, as well as those exploring the efficacy of imagery on pain outcome with MSDs, unless the pain outcome was used together with other physical function and/or strength outcomes.

Effects of Imagery on Muscle Functions

Imagery and muscle strength outcomes.

This section of the review explores the efficacy of imagery training on muscle strength outcomes (e.g. for different muscle groups) with diverse participants across the previous imagery intervention literature. Table 1 lists all the current studies examining the role of imagery training on muscle strength outcomes and their key findings.

Yue and Cole (1992) performed one of the first investigations showing the efficacy of imagery training for strength improvement of the abductor muscles of the fifth digit's metacarpophalangeal joint. Concurrently, several studies have explored the role of imagery training on muscle strength gains with varied methods and goals. These studies have indicated that imagery training (i.e. with different intervention periods and settings) can improve the muscle strength in various muscle groups, in this case, the upper limb muscle groups, comprising the elbow flexor (Leung, Spittle, & Kidgell, 2013; Ranganathan et al., 2004; Yao et al., 2013), dorsal extension and ulnar abduction and fifth finger abductor digiti minimi muscle (Ranganathan, Siemionow, Liu, Sahgal, & Yue, 2004; Smith & Collins, 2004; Smith, Collins, & Holmes, 2003; Yue & Cole, 1992). In addition, strength gains have been revealed following imagery training with lower limb muscle groups, namely the plantar flexor (Zijdewind, Toering, Bessem, van der Laan, & Diercks, 2003), ankle dorsiflexor (Sidaway & Trzaska, 2005), hip flexor (Shackell & Standing, 2007) and knee extensor muscles (De Ruiter et al., 2012). Furthermore, it was found that maximal strength improvements were significantly greater for the distal than the proximal muscle groups after imagery training (Ranganathan et al., 2004). This difference could probably be attributed to the more frequent use of proximal muscles, which are considered 'highly trained', during daily activities (Ranganathan et al., 2004).

Imagery training also improved the performance capacity of specific motor skills tasks; for example, Olsson, Jonsson and Nyberg (2008) examined whether the use of MI (IVI with KIN) could affect high jumping performance for active high jumping athletes. The results demonstrated that coupling MI with physical training (6 weeks of training) could positivity improve the jump task performance of athlete participants (elite level) compared with physical training alone. In addition, Fontani et al.'s (2007) findings showed a significant improvement of maximal strength performance of karate action (makiwara) after 4 weeks of mental training compared with a no training group.

The previous studies, which showed improvements in strength/performance outcomes, mostly adopted a cognitive imagery type of intervention comprising mental simulation of the physical task that would be used during muscle strength assessment, without any overt movement. In addition, some researchers instructed participants during imagery training (e.g. as a part of the imagery script) to adopt various imagery modalities and perspectives (e.g. visual, kinaesthetic, stimulus and response propositions), while other researchers did not instruct participants to adopt specific sensory modalities or perspectives during imagery training (see Table 1).

Imagery training can be used alone or combined with other training methods, whether these approaches are mental or physical. For example, the efficacy of combined intervention training (physical exercise and MI during rest time) concerning muscle strength improvement was better than that of physical exercise alone (Lebon, Collet, & Guillot, 2010). Although the results did not fully support the efficacy of combined interventions compared with the traditional exercise alone on all examined muscle strength outcomes, this study supported the importance of MI's contribution to the improvement of lower limb performance by enhancing the technical execution of the movement and individuals' intrinsic motivation.

Reiser, Büsch and Munzert (2011) examined the combination of imagined maximal isometric contraction with real maximum voluntary contraction; their results showed that high-intensity strength training sessions can be partly replaced by imagined maximal isometric contraction training sessions without any considerable reduction of strength gains. Similarly, a recent study that examined the efficacy of combined intervention (low-intensity [30%] of maximal voluntary contraction [MVC] plus the same time mentally urged the forearm to push upward (elbow flexion) maximally against the force transducer used for the pre-training strength measurement employed visual and kinaesthetic modalities) compared with exercise alone. The results showed the exercise-alone group had the highest strength gain (17.6%, $p < 0.001$); the combined mental training plus exercise group also showed a significant strength gain (13.8%, $p < 0.001$). This was not statistically different from that of the exercise-only group, although the exercise intensity for the combined group was only at the 30% MVC level (Jiang, Ranganathan, Zhang, Siemionow, & Yue, 2016).

Non-physical training approaches can also be combined with imagery training; for example, some techniques, like video observation (watching the physical task before imagery training), can be combined with imagery. Such an approach showed significant plantar-flexor torque improvement following 7 weeks of a combined mental training intervention (Zijdewind et al., 2003). Other psychological methods like a relaxation technique combined with visualisation training for intervention sessions has shown the superiority of the control group on knee extensor muscle strength improvement compared with the combined visualisation group (Tenenbaum et al., 1995).

However, coupling diverse training tools (physical or non-physical) with imagery training may influence the strength gains with positive or negative results; the specific role of imagery practice is unknown, as the imagery was not the sole component in the combined intervention programmes.

Most previous studies used simple imagery intervention protocols (e.g. cognitive imagery) alone or in combination with other intervention methods. Although other imagery intervention models were proposed to improve the efficacy of imagery intervention training on skills and performance, Holmes and Collins (2001, 2002) proposed considering seven elements when planning imagery interventions, as follows: physical, environment, task, timing, learning, emotion and perspective (PETTLEP). This model is based on the notion that a functional equivalence exists between imagery and motor performance (for a review, see Holmes, Cumming, & Edwards, 2010).

Indeed, considerable evidence suggests that adopting a PETTLEP imagery approach to practice leads to enhanced improvements in the performance of existing motor skills (e.g. Callow, Roberts, & Fawkes, 2006). This review will report on studies that used the PETTLEP approach for strength performance outcomes. For example, Wright, and Smith (2009) revealed that the PETTLEP imagery, physical practice and combination groups (PETTLEP and physical exercise) all showed significant improvements in weight lifting from the pre-test to post-test. The improvements achieved in the imagery practice (with a short relaxation) group was not significantly larger than that of the control group.

An additional application of imagery training in MSD and rehabilitation concerning relevant areas could be used as a preventive intervention approach for reducing strength loss occurring after short periods of joint immobilisation. Some previous experimental studies with healthy participants have been conducted, such as that of Newsom, Knight and Balnave (2003), which examined the efficacy of imagery training (i.e. imagined squeezing of a ball for three sessions of 5 min per day over 10 days) on muscle strength with healthy adults wearing an immobilisation cast. Their results revealed no significant change in wrist-flexion or extension strength in the mental-imagery group, while the control group experienced a significant decrease in wrist-flexion and extension strength during the immobilisation period. Moreover, Clark, Mahato, Nakazawa, Law and Thomas (2014) revealed that imagery training (5 days/week during 4 weeks of immobilisation) can attenuate the strength loss of wrist-hand muscle by ~50% compared with a control group (no practice during the immobilisation period).

As the application of imagery training during immobilisation showed encouraging results with healthy individuals, it was transferred to clinical populations. For example, Stenekes, Geertzen, Nicolai, De Jong and Mulder (2009) examined the efficacy of MI with patients who had been immobilised after flexor tendon injuries. The goal of this study was to determine whether MI during the immobilisation period after flexor tendon injury resulted in faster recovery of the central mechanisms of hand function. The participants in the MI group were instructed to mentally practice the flexion and extension movements during the immobilisation period without actually moving the fingers; they performed eight 5-min MI sessions per day for 6 weeks. The results indicated that the subjects in the MI group had a significantly lower increase in preparation time after the splinting period than the control group did, providing indirect evidence for a central effect of MI. Repeated mental performance of movements may prevent the impairment of central control, at least in terms of the speed of information processing. Therefore, imagery training could be used in future applications as promising preventive tool in the clinical population (as participants' physical contractions may be limited or unavailable during the early weeks after injury or surgery) to prevent any potential muscle strength loss during the immobilisation phase.

Some investigations have not supported the role of imagery training on improving muscle strength. For example, Herbert et al (1998) revealed that the strength gains of the elbow flexor following imagery training were comparable to the improvements gained in the control group, indicating that the imagery training failed to produce strength gains over and above the effect of no practice. In addition, Tenenbaum et al. (1995) revealed that the control group (no treatment) showed a significantly greater improvement (39.1%) in peak force compared with two treatment groups – a positive statements group (24.6%) and a mental training group (9.0%) – following 4 weeks of intervention. The discrepancy between these studies and previous studies could be explained by varied factors, such as the characteristics of the interventions, including the imagery type, function, modalities, length of intervention, task characteristics, assessment procedure, imagery ability and ambiguity of intervention scripts.

Potential mechanisms involved in strength gains using imagery training.

Slimani et al. (2016) proposed that the underlying mechanism of strength gain following imagery training could be explained by neural adaptations and peripheral physiological responses. They suggested that the neurological mechanisms (neural adaptations) most likely occur at the cortical level, arguing against peripheral physiological factors that are key determinants of muscle strength/weakness (loss). In their imagery-based training study, they could record improvement in muscle strength, but the result was largely explained by neural factors rather than changes on the muscular level (Ranganathan et al., 2004; Yao et al., 2013). Specifically, Ranganathan et al.'s (2004) electromyography (EMG) data from the triceps muscle (antagonist) of the elbow flexor muscles did not change after training, suggesting that the antagonist muscle did not play a significant role in the strength increase of the elbow flexors following imagery training.

Mulder (2007) and De Vries and Mulder (2007) suggested that MI is a promising technique for motor rehabilitation that could activate the motor system ‘offline’; they identified potential mechanisms based on the similarity concerning enhanced plastic changes in the motor system (neural reorganisation) between MI and physical execution, which led to “the simulation hypothesis”. They suggested that the neural reorganization in MI would take place in a comparable manner as would have occurred following physical practice. The parts of the neural system most frequently described to be involved in MI are areas of the brain that are related to functions of planning and control of movements, including the premotor cortex, dorsolateral prefrontal cortex, inferior frontal cortex, posterior parietal cortex, cerebellum and basal ganglia. However, the role of the primary motor cortex in MI remains a matter of debate that requires further research. The central mechanisms are assumed to be as follows: Imagery organises central motor programmes and activates neurons in various areas of the brain responsible for priming the execution of the motor command. This is suggested to lead to the observed increase in performance and learning through repeated imagery use. Slimani et al. (2016) stated that the theory proposed by Mulder (2007) is the most relevant in the literature and accounting for the effects of mental imagery on muscle performance.

Yue and Cole (1992) suggested that possible origins of strength increase following imagery training may include programming/ planning levels of a hierarchically organized motor systems. Similarly, the recent experimental study by Grosprêtre, Jacquet, Lebon, Papaxanthis and Martin (2018) showed a significant improvement of the plantar flexors’ maximal force and rate of force development after short-term imagery training and they directly linked the strength gain to the greater cortical descending command and the increase of resting spinal excitability. However, some evidence indicates that changes in the neural control of muscles may underlie the effect of imagery training on muscle force production, for example, a change in muscle coordination or an increase in the activation levels of the target muscles (Zijdewind et al., 2003).

Slimani et al. (2016) proposed: “If the imagery shares neural mechanisms with those responsible for motor programming, then brain activation during imagined action should be reflected, in some way, at the peripheral effector level”. The peripheral effectors of the autonomic nervous system (ANS) are activated by imagery as well (Lang, 1979). Imagination and observation of exercise has been shown to cause changes in the cardiovascular system with significant changes in blood pressure, heart rate, and respiration, which occur in the absence of muscle contraction or movement were reported (Beyer, Weiss, Hansen, Wolf, & Seidel, 1990; Fusi et al., 2005; Paccalin & Jeannerod, 2000; Wang & Morgan, 1992; Williamson et al., 2002). Additionally, Slimani et al. (2016) reported heart rate change in imagery training, which could be attributed to the degree of imagined effort and mental imagery perspectives. The mechanisms underlying the cardiovascular effect of imagined exercise is not known, but it is possible that the CNS and activation of the cortex cause an increase in the sympathetic outflow and reciprocal inhibition of parasympathetic activity (see the review by Slimani et al., 2016).

A further possible outcome of neural plasticity effects in imagery and exercise are related to the bilateral training effect phenomenon (also called cross-transfer, cross-education, or intermanual transfer). This is an inter-limb phenomenon that transfers the effect from the trained limb to the homologous contralateral untrained limb following unilateral motor training (Land, Liu, Cordova, Fang, Huang, & Yao, 2016; Lee, & Carroll, 2007; Munn, Herbert, & Gandevia, 2004). The bilateral transfer effect may be used to better understand the imagery's underlying mechanisms and it could be used in future rehabilitation practice. The bilateral transfer effect has been less explored with strength outcomes following imagery training. However, Yue and Cole (1992) addressed the role of the bilateral transfer effect in muscle strength following imagery training. They examined the role of imagery training on both trained and untrained muscle groups (little finger muscle). They found significant muscle strength increases in the trained muscle groups, at 22% for the imagining group and 30% for the contraction group. In addition, the results showed a significant maximal strength improvement of the untrained finger muscle in both the imagining and contraction groups after the training period (10 and 14%, respectively), but not in the control group (2.3%).

Table 1: Effects of Imagery training on Muscular Strength/Performance

Authors, dates	**Characteristics (age, N, sex)**	**Participants' Health status**	**Intervention used**	**Method of strength/ performance outcome measured**	**Key findings**
Wright and Smith (2009)	20.74 ± 3.71 years, N = 50, NR	Healthy university students	PETTLEP Combined (PETTLEP&PP) Traditional imagery PP (6 wks/2 days)	Muscle strength: Bicep curl machine, 1-repeated maximum (RM)	PETTLEP, PP, and combination groups all showed a significant improvement in weight lifted from the pre-test to the post-test. However, the improvement shown by the traditional imagery group was not significantly larger than that of the control group.
Yao, Ranganathan, Allexandre, Siemionow and Yue (2013)	18–35 years, N = 18, NR	Healthy volunteers.	Internal motor imagery (IMI; combined IVI+KIN) External MI (EMI) (6 wks/5 days)	Maximal elbow-flexion contraction (right arm elbow flexion force)	The IMI group showed significant strength gained (10.8%), while the EMI (4.8%) and control (−3.3%) groups did not.
Lebon, Collet, and Guillot (2010)	19.75 ± 1.72 years, N = 19, NR	Healthy sport students	MI (KIN with IVI) & PP PP alone (4 wks/3 days), 12 sessions	Maximal voluntary contraction (MVC) and maximum number of repetitions (MR)	MI and PP groups enhanced their strength through the training sessions. Leg press MVC was significantly higher in the MI group than in the PP group ($p < 0.05$). The interaction between the leg press MR and the group was marginally significant ($p = 0.076$). However, no difference was found between the MI and PP groups, either in the bench press MVC or MR.
Yue and Cole (1992)	21–29 years, N = 30, NR	Healthy subjects	Imagery training (mental simulation of the physical task with no specific modality) PP (4 wks/5 days)	Maximal isometric contraction of the abductor muscles of the left and right fifth digit's meta-carpophalangeal joint	The abduction force of the left fifth digit increased by 22% for the imagining group and 30% for the contraction group. The mean increase for the control group was 3.7%. The maximal abduction force of the right (untrained) fifth digit increased significantly in both the imagining and contraction groups after training (10 and 14%, respectively), but not in the control group (2.3%).

Zijdewind, Toering, Bessem, van der Laan and Diercks (2003)	19–27 years, $N = 29$, 18 female	Healthy subjects	Imagery training (video of specific task actions & mental simulation of the physical task) PP (7 wks/5 days)	Maximal voluntary muscle strength of the plantar-flexors of both legs was measured	At the end of a 7-week training programme, significant differences were observed between the maximal voluntary torque production of the imagery training group (136.3 ± 21.8% of pretraining torque) vs. the low-intensity training group (112.9 ± 29.0%; $p < 0.02$) and control group (113.6 ± 19.2%; $p < 0.02$).
Fontani et al. (2007)	35 ± 8.7 years, $N =$ 30, all male	Healthy karateka players	Mental imagery (IVI&KIN) PP (action trained) (4 wks/5 days)	Maximal strength (karate action: makiwara)	The values of maximum strength recorded in the action trained and mental imagery groups were higher than those recorded in the untrained group. Both groups showed improved maximum strength (9.2 and 8.4% for the imagery and physical groups, respectively).
Shackell, and Standing (2007)	20.1 ± 1.69 years, $N =$ 30, all male	Healthy university students	Mental practice (imaginary rehearsal of the physical exercise; confounded visual with kinaesthetic) PP (2 wks/5 days)	Hip flexor task	Physical strength was increased by 24% through mental practice (MP; $p = .008$). Strength was also increased through physical training, by 28%, but it did not change significantly in the control condition. The strength gain was greatest among the football players given mental training.
Herbert, Dean and Gandevia (1998)	NR, $N = 54$, 31 female	Healthy students	Imagery training (mental simulation of the physical task with no specific modality) PP (8 wks/3 days)	Maximal isometric contractions (elbow flexor); voluntary activation, interpolated twitch	The PP, imagined training and control groups showed increased voluntary isometric elbow flexor strength; the PP group increased in strength significantly more than the imagined training and control groups did. No significant difference was found between imagery and control groups for strength gains. Voluntary activation did not change significantly with training, and there were no significant differences between the groups.

Reiser, Büsch and Munzert (2011)	22.7 ± 2.3, N = 43, 20 female	Healthy sports students	Three groups with different combinations of real maximum voluntary contraction (MVC) and imagined maximal contraction (IMC; M75, M50, M25; numbers indicate percentages of mental trials using the KIN modality) MVC-only training group (M0) Control condition without strength training (CO) (8 wks/ 12 sessions)	Maximum isometric voluntary contraction force (MVC; bench pressing, leg pressing, triceps extension and calf raising)	IMC groups (M25, M50 and M75) showed slightly smaller increases in MVC (3.0–4.2%) than M0 (5.1%), but significantly stronger improvements than CO (–0.2%).
Smith, Collins and Holmes (2003)	29.33 ± 8.72 years, N = 18, all male	University staff and students	Mental practice (MP: subjects imagine their personal feelings reported in the responses on the prior pre-test) PP (4 wks/2 days)	Isometric abduction force (right abductor digiti minimi muscle) and EMG activity	There were no significant differences in the pre-test abduction force, but the post-test scores of the PP (53.36%) and MP (23.27%) groups were significantly greater than those of control participants (–5.36%). EMG revealed significant muscle activity during MP, but its magnitude was not significantly correlated with the degree of performance enhancement.

Ranganathan, Siemionow, Liu, Sahgal and Yue (2004)	29.7 ± 4.8 years, N = 30, 12 female	Healthy untrained subjects	Mental training (imagined performing the physical task by combined VI and KIN) PP (12 wks/5 days)	-Fifth finger abductor (distal muscle) -Elbow flexors (proximal muscle)	Mental training groups increased finger abduction strength (35%), and elbow flexion strength (13.5%). The PP group increased the finger abduction strength (53%).
De Ruiter et al. (2012)	18–24 years, N = 40, 21 female	Healthy subjects playing recreational sports for several hours (2–12) a week	Imagery training (mentally rehearsed approximately 10 fast knee extensor contractions. The imagery scripts were designed to include different senses and contain both stimulus and response propositions to enhance the quality of the participants' imagery experience) PP Placebo training (4 wks/3 days)	Isometric torque measurement (knee extensors of the right leg)	At a 90° knee angle, maximal torque increased by 9.3% in the imagery group, 6.6% in the physical training group and 7.2% in the placebo group, but it did not increase in the control group (–5.4%)

Tenenbaum et al. (1995)	24.7 ± 3.6 years, N = 45, all male	Healthy students	Mental training (relaxation, visualisation, autogenic training). Positive statements (4 wks/1 day)	Bilateral knee extension – peak force	The control group (no treatment) showed a significantly greater improvement (39.1%) in peak force than both treatment groups, namely the positive statements group (24.6%) and mental training group (9.0%).
Smith and Collins (2004).	30.44 ± 7.79 years, N = 18, all male	Healthy students	Stimulus proposition (SP) MP Stimulus and response proposition (SRP) MP PP (3 wks/2 days)	MVC of the abductor digiti minimi (meta-carpophalangeal joint of the right fifth digit)	The peak abduction force of the PP group participants increased by 56.28%, that of the SRP group improved by (55.68%) and that of the SP group improved by 53.97%. All participants in the PP and SRP groups showed an improvement on the post-test, whereas only four of the SP participants improved, with two participants showing slight decreases in performance on the post-test.

Jiang, Ranganathan, Zhang, Siemionow and Yue (2016)	75 ± 7.9 years, N = 27, 8 females	Healthy elderly people	Motor effort training (MET) group (low-intensity, 30% MVC combined with mentally urging the forearm to push upward (elbow flexion) maximally against the force transducer used for the pre-training strength measurement; can be practiced using visual and kinaesthetic modalities) Conventional strength training (CST) (12 wks/ 5 days).	Elbow flexion strength of the right arm and EMG activity	The CST group had the highest strength gain (17.6%, $p < 0.001$); the MET group also had a significant strength gain (13.8%, $p < 0.001$), which was not statistically different from that of the CST group, although the exercise intensity for the MET group was only at 30% of the MVC level. The control group did not exhibit significant strength changes.

Sidaway and Trzaska (2005)	19–26 years, $N = 24$, 18 female	Healthy university physiotherapy students	Imagery training (imagine the assessment procedures used in the baseline testing phase on the Biodex dynamometer by using the KIN modality) PP (4 wks/3 days)	Maximal isometric contractions of ankle dorsi-flexor torque	Differences in raw torque production after training in the two practice groups resulted in significant percentages of improvement for the PP group (25.28%) and MP group (17.13%), but not the control group (−1.77%).

PP: physical practice. MI: motor imagery. IVI: internal visual imagery. EVI: external visual imagery. KIN: kinaesthetic imagery. NR: not reported. Wks: weeks. MVC: Maximal voluntary contraction. MR: Maximal number of repetitions. PETTLEP model of imagery intervention that considered seven elements when planning imagery interventions, as follows: physical, environment, task, timing, learning, emotion and perspective

Imagery and muscle activity (EMG).

As discussed above, imagery training's ability to enhance strength and performance is driven by central programming of the motor system and activating specific brain areas. Although some authors have suggested that the imagery process could involve muscles during training without any signs of actual contractions, such as overt changes in muscle shape, force and/or EMG (De Ruiter et al., 2012). Previous researchers have demonstrated the presence of subliminal electrical muscle activity during the mental simulation of a movement directed toward the production of force (see the review by Guillot & Collet, 2005b). The psycho-neuromuscular theory proposes that feedback produced during imagery training helps in strengthening the motor programme corresponding to a motor task (Jacobson, 1932). Some studies reported that imagery training can be accompanied by elevated EMG activity (e.g. Harris & Robinson, 1986). Indeed, the maximal isometric strength gains following imagery training have been attributed to augmented motor unit activation (Brody, Hatfield, Spalding, Frazer, & Caherty, 2000; Guillot & Collet, 2005a). An increase in the number of active motor units and/or firing frequencies can explain the augmentation of the magnitude of EMG following imagery training (Jeannerod, 1994).

Some researchers require an absence of any EMG activity during imagery training for specific tasks as a prerequisite (Brody et al., 2000; Herbert et al., 1998; Naito et al., 2002; Yue & Cole, 1992). These authors have suggested that the absence of EMG activity during imagery training is a necessary indicator for the exclusion of any peripheral physical action. In support of this, Ranganathan et al. (2004) found that simultaneous EMG recordings from the finger abductor or elbow flexor muscles showed no apparent muscle activities during mental MVCs. Moreover, Yao et al. (2013) demonstrated that EMG signals from the major elbow flexor muscle during imagery training sessions remained well below 2% of the maximal contraction level.

The variance in the previous observations can be explained by methodological differences across the imagery literature. For example, Bakker, Boschker and Chung (1996) examined EMG activity during imagery training on one arm, showing that the 'active' arm exhibited higher EMG activity than the passive arm did; the EMG activity was even higher when imagining a heavy object compared with a lighter object (9 kg vs. 4.5 kg, respectively). Furthermore, other work recorded the EMG activity during the imagery training of all muscles involved in the movement, considering the type of muscle contraction, function and weight to be lifted; the results revealed the highest amplitude being recorded during concentric contraction, the lowest amplitude during eccentric contraction and the 'intermediate' amplitude during isometric contraction. Greater EMG activity was reported during imagery rehearsal of a heavy concentric contraction (80% of the one-repetition maximum [1RM]) compared with imagery rehearsal of a light concentric condition (50% of the 1RM; Guillot et al., 2007). Physiological responses to imagery are specific to a response system and reflect the spatial differentiation and quantitative characteristics of the image (Guillot et al., 2007). Some studies have considered the relationship between imagery perspectives and EMG activity; the internal imagery perspective improved EMG activity more than the external imagery perspective of this same movement did (Bakker et al., 1996; Hale, 1982; Harris & Robinson, 1986). Hale (1982) reported that while the internal perspective caused muscle activity during the imagery training of an arm movement, the external perspective did not.

Role of imagery in musculoskeletal disorders (MSDs)

Disease population.

In musculoskeletal disease conditions, studies that have used imagery interventions and measured strength or physical functions as primary outcomes are sparse. Some studies have examined the efficacy of GI in combination with progressive muscle relaxation (PMR); for example, GI has been examined in patients with osteoarthritis (Baird & Sands, 2004, 2006). The GI intervention begins with progressive muscle relaxation exercises and then proceed to images of movement and physical activity free of pain and stiffness. Baird and Sands (2004), found the participants in the intervention group reported a significant reduction in mobility difficulty at week 12, favouring the GI group. Furthermore, Baird and Sands (2006) revealed that GI increased patients' quality of life compared with that of the control group, even after controlling for changes in pain and mobility. Thus, the effects of GI are not limited to improvements in pain and mobility; rather, GI may also be an easy-to-use self-management intervention to improve quality of life in older adults with osteoarthritis.

Baird, Murawski and Wu (2010) showed that GI had a significant influence in terms of reducing pain and improving in mobility compared with sham controls in patients with osteoarthritis; it also resulted in other positive outcomes unrelated to physical function. GI with relaxation may be useful for pain management, subsequently improving physical disability–related outcomes. The results of a systematic review of randomised control trials on the role of GI on individuals suffering from AORD showed significant improvements in pain, physical functions and psychological outcomes like anxiety, depression and quality of life (Giacobbi et al., 2015).

Hoyek, Di Rienzo, Collet, Hoyek and Guillot (2014) examined MI for the first time as a preventive tool for musculoskeletal disease conditions. They examined the efficacy of MI in the rehabilitation of stage II shoulder impingement syndrome before surgery; this comprised a standard physiotherapy intervention plus MI protocol (the therapeutic exercise of four shoulder movements was mentally imagined during each session using both the IVI and KIN modalities). The assessment measures included shoulder functional assessment, range of motion and pain; the findings showed higher function, greater movement amplitude and greater pain relief in the imagery group. The researchers concluded that the MI intervention appears to alleviate pain and enhance mobility, perhaps owing to variations in muscle control, and subsequently, in joint amplitude (Hoyek et al., 2014). Altogether, using either GI or MI with musculoskeletal disease has shown promising results in previous studies, albeit with limited evidence.

Injured populations.

Imagery interventions after musculoskeletal injuries are still rare, but some previous studies have explored various imagery practice types with different goals and outcomes across specific musculoskeletal injury conditions. For example, Cupal and Brewer (2001) examined the efficacy of imagery practice on knee strength, re-injury anxiety (fear of re-injury) and pain with patients following anterior cruciate ligament (ACL) reconstructive operation at a sport medicine clinic. The study comprised three groups, as follows: an imagery practice group (cognitive imagery training combined with relaxation), placebo standard group (received attention support, motivation) and no treatment for a control group. All the study groups received the normal course of physiotherapy. The imagery sessions were spaced approximately 2 weeks apart over the course of a 6-month recovery period. In addition, the patients were asked to listen to imagery scripts at least once a day until the next session. Furthermore, the imagery scripts were audiotaped, and they were identical for the imagery participants. The imagery sessions included mental rehearsal of physiotherapy goals according to the sports medicine facility's protocol for physiotherapy management after ACL reconstruction. The results (at the 24-week post-surgery assessment) displayed significant improvements in knee strength, a lower level of re-injury anxiety and less pain in the imagery group compared with the placebo and control groups. Thus, this study illustrated the therapeutic effect of relaxation and imagery combined with traditional physiotherapy intervention to facilitate recovery after ACL reconstruction, with substantial effects on both the psychological and physical rehabilitation outcomes.

Maddison et al. (2012) examined the efficacy of GI on functional outcomes with post-ACL repair patients; all patients were randomised into GI plus standard rehabilitation or standard rehabilitation alone (control). The results revealed that the intervention group (GI with relaxation) achieved a reduction in stress levels and improved healing, but not with improved knee strength. The lack of effect on knee strength is contrary to previous research, which found improvements in knee strength following a similar intervention (Cupal & Brewer, 2001).

Christakou, Zervas and Lavallee (2007) examined the efficacy of imagery practice on muscle endurance, dynamic balance and functional ability with volunteering injured athletes with grade II ankle sprains. The participants in the intervention group received 12 individual imagery sessions, lasting 45 minutes each, in addition to physiotherapy sessions; the control group received only physiotherapy sessions. The participants were asked to imagine the same exercise that they received during the physiotherapy session. The results of the study showed better overall improvement in muscular endurance, dynamic balance and functional stability in the imagery group compared with the control group. Using imagery in addition to a physiotherapy programme during the functional rehabilitation of ankle sprain was clearly beneficial for the rehabilitation outcomes. This study adopted a concept of using treatment imagery (also known as the cognitive imagery type; i.e. using imagery to imagine and feel the exercise of the physiotherapy exercise programme), which confined to only imagining the same rehabilitation exercise they received in a preceding physiotherapy session rather than using another imagery type (e.g. motivational, GI, healing).

Christakou and Zervas (2007) examined the efficacy of imagery on pain, oedema and range of motion in injured athletes (who sustained a grade II ankle sprain). The study comprised two groups an intervention group (combined imagery with relaxation), in addition to normal course of physiotherapy, and a control group (receiving only the physiotherapy treatment). After 12 imagery sessions, the results did not show any effects on pain, oedema or range of motion. The researchers suggested that further research could examine the relationship between different types of imagery and rehabilitation for injury conditions using standardised imagery instruments.

Lebon, Guillot and Collet (2012) examined the therapeutic effect of MI on pain, lower limb muscle activation measured using EMG, functional recovery, effusion resorption and range of motion on patients after ACL reconstruction surgery. Twelve patients were randomly assigned to the MI group or control group. All participants in both groups received the same amount of traditional physiotherapy (a 30-min session every 2 days). Participants in the MI group received MI training, while no mental training was provided for the control group participants, and they received neutral tasks (e.g. mental calculation or crosswords). The study programme lasted for 5 weeks and comprised 12 sessions of 15 min each (3 blocks of 10 imagined contractions, with a 10-s rest period between rehearsals and 2-min rest period between blocks for each session). The examiner instructed the MI participants to adopt KIN rather than pure VI during the MI sessions. The results showed a significant improvement of muscle activation in the MI group compared with the control after the intervention programme. No significant differences between the MI and control groups in subjective daily function, range of motion or pain were found. Furthermore, the quadriceps size was similar in both groups of participants; hence, these results supported the authors' hypothesis that MI is driven by neural effects rather than structural modulations (Ranganathan et al., 2004; Zijdewind et al., 2003). The muscle strength activation in this study may have originated in the reorganisation of central neural activity, as Lebon et al. (2012) did not find any significant change on anthropometric measurement of the lower limb muscle after imagery sessions. Thus, their results established a facilitator role for MI on muscular property recovery after motor impairment during the rehabilitation process.

Altogether, although previous studies showed a potential effective role of cognitive imagery practice (i.e. mental rehearsal of physiotherapy exercise protocol) on muscle function properties (e.g. strength, endurance and activation), the efficacy of GI with relaxation is still unclear due to the lack of research. In addition, previous studies have adopted various methodologies, imagery types, instructions and musculoskeletal conditions, and they did not use a specific musculoskeletal outcome that was matched with a specifically used imagery type. This may have reduced the efficacy of the imagery interventions accordingly. The methodological variability in previous works may increase the difficulty of replicating recent findings related to motor function outcomes in the injured population.

Imagery ability evaluation

Imagery interventions may be considered as a promising training tool for improving physical performance with a varied population; however, the efficacy of imagery interventions may be influenced by participants' imagery ability (Cumming & Ramsey, 2008). Consequently, determining the ability of participants to generate an image of any movement task is one of the common difficulties that practitioners may face when they use imagery training in their intervention protocol. Indeed, previous studies showed that people with higher imagery ability display superior performance improvements after a skill-based imagery intervention (e.g. Goss, Hall, Buckolz, & Fishburne, 1986; Rodgers, Hall, & Buckolz, 1991).

Vergeer and Roberts (2006) examined the effect of movement and stretching imagery on flexibility, they found significant increases in flexibility over time, and they presented a positive association between vividness ratings in the movement imagery group and flexibility gains. Thus, they suggested a potential for enhancing physiological effects by maximising imagery vividness (imagery ability).

Additional evidence that supported a role of imagery ability as a moderating factor for the efficacy of imagery interventions on strength performance was reviewed by Slimani et al. (2016). Furthermore, the efficiency of imagery as a performance-enhancing approach has been found to depend on the participant's imagery ability (Martin, Moritz, & Hall, 1999). Guillot and Collet (2008) suggested evaluating the imagery ability for all potential participants (either athletes or injured patients) prior to MI training to tailor the MI sessions' content. In addition, they proposed evaluating each participant's imagery ability over the training period to assess the enhancement of participant's imagery capacities and adjust the imagery sessions' content.

Imagery ability has been suggested in previous evidence as a mediator of imagery intervention efficacy with healthy participants; consequently, the issue of imagery ability may be more important with the patient population, especially stroke patients. Chronological characteristics of MI may change after stroke, as evidence has demonstrated a slowing of the imagery process after a stroke event (Malouin, Richards, Desrosiers, & Doyon, 2004; Sabaté, González, & Rodríguez, 2004). Other evidence suggests that some neurological patients (stroke, Parkinson's disease) may be unable to engage in imagery training, which may reduce the benefits from imagery practice (Heremans et al., 2011; Sharma et al., 2006). Therefore, evaluation of the imagery ability in the patient population prior to administering imagery interventions is recommended (Jackson et al., 2001).

Personnier, Ballay and Papaxanthis (2010) found that MI accuracy (i.e. the temporal correspondence between executed and imagined movements) deteriorates significantly in elderly adults. Thus, using imagery training with elderly people in rehabilitation should be considered with caution. Furthermore, di Nuovo, de la Cruz, Conti, Buono and di Nuovo (2014) reported evidence suggesting that the efficacy of using imagery training in cases of cognitive deterioration in the elderly came up with contradictory results, emphasising the importance of evaluating the imagery ability prior to the imagery intervention.

Altogether, imagery ability concerns have been raised in previous studies with various populations, leading to the use of imagery ability questionnaires as an inexpensive option for assessing individuals' imagery ability. Various questionnaires measured the imagery ability in general or with neurological populations; for example, Malouin et al. (2007) introduced a

Kinaesthetic and Visual Imagery questionnaire (KVIQ) for assessing motor imagery in persons with physical disabilities. Moreover, Roberts et al. (2008) developed, revised and validated the Vividness of Movement Imagery questionnaire-2 (VMIQ-2) in accordance with contemporary imagery modalities and perspectives (EVI, IVI, KIN). Williams et al. (2012) further validated and developed the Movement Imagery questionnaire-3 (MIQ-3), which assesses the ease of imagery ability in healthy populations.

Conclusions and future research directions

The current review highlighted the importance of imagery training as a potential physiotherapy intervention tool with various goals (e.g. muscle strength–related and physical activity functions). The points outlined below suggest directions for future imagery research and possible imagery implementation in future musculoskeletal physiotherapy practice.

Future directions for muscle function–related studies

Our review showed considerable evidence that supported the efficacy of imagery practice for muscle strength outcomes; however, previous studies used various imagery types, modalities, outcomes, intervention periods and study methods, while they focussed less on larger muscle groups. Hence, the replication of previous findings will be challenging in future works (i.e. either with healthy or clinical populations) due to the discrepancies between the previous study methods. Furthermore, no clear comparisons have been made between specific imagery modalities and perspectives on the effects of imagery muscle strength outcomes (e.g. comparing the efficacy of using KIN alone with other visual perspectives, either as a single modality or as combined imagery modalities). Some previous works confounded the kinaesthetic imagery with VI modality; indeed, only a few studies used kinaesthetic imagery separately from VI. In addition, some studies did not adopt the principle of using sensory modalities during imagery training. Therefore, it is important to examine the role of cognitive imagery training (mentally simulating physical exercise) by using the kinaesthetic imagery modality and compare this with a combination of visual plus kinaesthetic imagery modalities involving larger muscle groups, as larger muscle group will be more relevant to musculoskeletal rehabilitation. The imagery script need to be detailed using audio imagery scripts that clearly specify the imagery training process. In addition, as imagery ability is an important mediator of the efficacy of imagery interventions, it is important to add an imagery ability assessment in imagery intervention studies, as this has not been addressed sufficiently in previous works.

The bilateral transfer effect has been explored relatively little in previous imagery interventions in the strength-related literature; in future work, it will be important to examine the role of imagery training on the bilateral transfer phenomenon with muscle strength outcomes for understanding the underlying mechanisms of the role of imagery on strength gains and the potential of imagery training in rehabilitation. These considerations will contribute to the efficacy of imagery intervention in strength-related outcomes for clinical populations.

Future directions for musculoskeletal condition studies

Previous studies examined the efficacy of GI and MI with or without relaxation techniques in addition to normal physiotherapy intervention protocols in various musculoskeletal conditions (disease, injury) with outcomes related to strength, physical function or psychological status. This review reported encouraging findings that support the role of using imagery to optimise the efficacy of physiotherapy intervention, although the previous studies used various imagery interventions in terms of their types, function and modalities, making the generalisation of the results difficult.

Therefore, the application of imagery practice in musculoskeletal conditions needs to be improved by implementing the following recommendations: First, the features and efficacy of cognitive imagery training on muscle strength outcomes need to be investigated using clear imagery scripts with clear instructions that describe the entire imagery intervention process. Second, the GI needs to be implemented using relevant outcomes (e.g. pain and other psychological outcomes); GI should be used separately from cognitive imagery training. In addition, creative delivery options should be employed, like using new technology platforms that include the internet, telephone or pre-recorded compact discs (CDs); alternative, the imagery intervention can be integrated with new technologies, such as virtual reality or illusion mirrors, or combined with other intervention methods, like action observation. In addition, objective measurements of mobility and physical function, like muscle strength, should be used. Finally, the feasibility and acceptability of imagery training within populations of interest need to be explored.

Direction of the current thesis

According to the insights from the review, the imagery practice needs to be developed and tested with healthy population before it is introduced as a promising strength-training tool for musculoskeletal physiotherapy. Hence, our thesis goals are to improve the efficacy of the imagery training protocol for musculoskeletal system functions, especially in terms of strength outcomes with healthy subjects. The thesis will achieve these aims by conducting the works outlined below.

Study 1 – Randomised control study: Based on the review recommendations, the current study has been designed to address the following objectives: As there is no direct comparison in previous studies between using the KIN modality and the KIN with VI modality on strength outcomes, the first objective of study 1 is to examine the efficacy of imagery training on hip abductor strength using two imagery intervention groups (a group with combined KIN with VI intervention and a group with only KIN) and a control group (no practice group). Specifically, the current study will examine the results of using a clear imagery script that instructs participants to mentally rehearse the training exercise without any physical execution (cognitive imagery), and at the same time, adopt a specific sensory modality for each group (KIN versus KIN + VI). An identical audio imagery script will be used for each imagery group.

The imagery script content will be developed in this study in accordance with the notion that 'what you see is what you get'; in other words, the imagery content should correspond with the intended consequences. For example, Moritz et al. (1996) have suggested that an athlete who wishes to develop, maintain or regain sport confidence (i.e. function) should image being confident (i.e. content). Hence, as our main aim in the study is to improve muscle strength, participants should imagine being trained by instructing them in the imagery script (imagined performing the maximal isometric contractions) to improve their subsequent strength during each imagery training session. In addition, the nature of the practice situation (e.g. training and rehabilitation) will be considered, and our participants will receive the imagery training in the rehabilitation lab to expect positive effects.

As our thesis works will serve as background support for future imagery application in musculoskeletal physiotherapy, we consider muscle groups relating more to physiotherapy daily management protocols by selecting the hip abductor muscles group. Moreover, in our imagery intervention protocol, the individual's imagery ability will be considered by checking the imagery ability prior to administering the imagery training protocol, which may mediate the study outcomes (i.e. strength). Therefore, the imagery ability will be evaluated during a pre- and post-intervention assessment in the current thesis, which can be used to check whether the imagery training is influenced by imagery ability, as well as whether the imagery ability is affected by the imagery training intervention.

Study 2 -Experimental controlled trial study: This study will re-examine all specifications scrutinised in study 1 with consideration of the review recommendations. In addition, according to the review recommendations, this study will explore another important point, which is the bilateral transfer effect on strength outcomes after imagery training, and it will use an additional objective assessment tool (e.g. EMG). Thus, we will examine the role of cognitive imagery training that combines two modalities (KIN + VI, which results in better strength improvement in study 1) in the muscle strength and activity (EMG) production of hip abductor muscles and compare it with an isometric exercise protocol (exercise group). An additional aim is to examine the bilateral transfer effect of both intervention groups (imagery and exercise) in homologous, contralateral, untrained hip abductors and shoulder abductors in the untrained muscle group.

Study 3 - Translation projects: Following the review recommendations, imagery ability evaluation is an important assessment tool during various imagery intervention protocols with diverse goals and populations. However, there is no Arabic imagery ability assessment questionnaire in literature, which means that it is important to translate an imagery questionnaire to Arabic; this may help Arabic researchers in developing imagery research in the future. Thus, the rationale behind translating and validating the VMIQ-2 for Arabic is to set up a research basis for imagery practice in Saudi Arabia and other Arabic-speaking countries; this could serve as background support for establishing future imagery research among these countries. Therefore, the present study will translate, culturally adapt and validate the VMIQ-2 for classical Arabic by assessing its factorial validity using Bayesian structural equation modelling (BSEM). This project will be conducted in two parts in Saudi Arabia and the United Kingdom with native Arabic speakers.

Chapter 2: Mental training approaches in physiotherapy: Exploring the role of imagery practice on hip abductors muscle strength—a randomised controlled trial

Abstract

Purpose: Recent imagery intervention studies have shown variable outcomes regarding muscle strength improvements. One possible reason for this might be the variability of used imagery modalities and perspectives. Therefore, this research investigated the efficacy of imagery training on maximal force production in a larger muscle group (hip abductors), comparing the effect of the kinaesthetic imagery modality versus that of the kinaesthetic-plus-visual imagery modality (KIN vs. KIN+VI).

Methods: The study was conducted as a randomised control trial with three groups: a kinaesthetic imagery practice (KIN) group (n=16), a kinaesthetic-plus-visual imagery practice (KIN+VI) group (n=16), and a control group (CTRL) with no practice (n=15). The two intervention groups of the study performed the imagery practice, which involved mental simulating of the task that was used to assess muscle strength (imagined performing maximal isometric hip abductor contractions). One intervention script instructed participants to adopt only the KIN modality, and the other instructed participants to adopt a combination of the KIN and visual imagery (VI) modalities during imagery training. Imagery groups attended 10 individual imagery practice sessions (~30 min/day, 5 days/week for 2 weeks.). The control group did not receive any intervention. Maximal hip abduction isometric torque was measured on the right limb before and after the training period. The Vividness of Movement Imagery Questionnaire-2 (VMIQ-2; Roberts et al., 2008) was used to assess participants' imagery capability.

Results: Mixed-model ANOVA analysis showed a significant interaction between intervention groups and time (muscle strength) (F (2, 43) =6.85, p=0.003, η^2 =0.242). Further analysis (t-test) revealed that, while both imagery groups tended towards muscle strength improvement compared with baseline levels, the only group which achieved a significant increase was the KIN+VI group (t (15) = -2.63, p=0.019; approximately 8% increase). In addition, a significant interaction between group and time (imagery ability) was found (F (2, 43) =5.12, p =0.010, η^2 =0.192). Further analysis (t-test) revealed that only the KIN+VI group showed a significant improvement in imagery ability compared with the baseline level (t (15) = 2.22, p =0.003).

Conclusions: The results reveal that large lower-limb muscle strength can be improved following two weeks of imagery training; a combination of kinaesthetic training and visual imagery seemed to be particularly effective. This may have important implications for future physiotherapy research and imagery practice.

Introduction

Muscle strengthening exercise (also known as therapeutic exercise) is an essential intervention approach used by health professionals in rehabilitation and physiotherapy services. It is regularly applied to patients with various conditions during daily management protocols (Artz et al., 2015; Ayotte, Stetts, Keenan, & Greenway, 2007; Bolgla & Uhl, 2005; Boudreau et al., 2009; Lowe, Barker, Dewey, & Sackley, 2007; Michaleff et al., 2014; Taylor, Dodd, Shields, & Bruder, 2007; Torstensen et al., 1998). For example, 98% of Irish physiotherapists and 100% of UK physiotherapists use muscle strengthening exercise for chronic lower back pain (Liddle et al., 2009) and knee osteoarthritis management (Walsh & Hurley, 2009). It is also beneficial for older people's general physical wellbeing (Christie, 2011).

The effectiveness of therapeutic exercise varies and may be influenced by poor adherence to exercise (Campbell et al., 2001; Vasey, 1990). In addition, the frequency, mode and intensity of exercise have noticeable effects on functional outcomes and may influence the adherence to training (Millar, 2014). Furthermore, pain that is experienced while performing exercise and the subject's low self-efficacy may reduce the ability and desire to perform the exercise (Petursdottir, Arnadottir, & Halldorsdottir, 2010). Additional factors, such as fatigue and physical exhaustion can limit the exercise efficiency, especially in older patients (Hutton et al., 2010; Petursdottir et al., 2010). Consequently, the therapeutic exercise efficacy could be impaired by the factors mentioned above, as well as other disease-related conditions (e.g., paralysis, immobilisation due to injury and postsurgical conditions). Hence, interventions need to be developed that do not necessarily rely on changing perception/sensation and patient attitude regarding physical exercise and are effective in increasing muscle strength without performing exercise training.
Imagery practice, as explained in more detail below, could be suggested as a potential complementary or alternative approach for improving muscle strength under various conditions when there are difficulties in performing strengthening exercise. Imagery practice possesses advantages compared with the traditional physiotherapeutic protocols used to improve muscle strength (e.g. exercise, electrical stimulation). Imagery training can be accomplished with more

repetitions to increase the force production capacity without inducing progressing neuromuscular fatigue (Rozand et al., 2014). In addition, due to the lack of mechanical strain, less pain is expected during imagery training when imagining performing physical tasks. Moreover, imagery is a self-administered technique that is easy to learn and does not require sophisticated equipment. It also engages individuals in the therapy process (unlike, e.g., electrical stimulation and other passive therapy techniques), and it does not have any known side effects.

Mental imagery is a cognitive simulation technique, and one of its key applications is imagery practice (also known as, e.g., motor imagery or movement imagery); this consists of a systematic use of a mental image to rehearse a motor skill mentally, without performing the movements involved (British Association of Sport and Exercise Sciences [BASES], 2013). As there is confusion in imagery terminology across the literature (Moran et al., 2012), in the current study, we adopt the terms imagery practice, movement imagery, and motor imagery (MI) interchangeably, as discussed in the review in Chapter 1. MI has been defined as 'an experience that mimics real experience and involves using a combination of different sensory modalities in the absence of actual perception' (Cumming & Ramsey, 2008, p. 5). Although imagery can occur in different sensory modalities (e.g. visual, auditory, olfactory), the emphasis of MI is usually on visual and kinaesthetic imagery modalities (Cumming & Ste-Marie, 2001). Consequently, the MI practice (e.g. cognitive imagery) can be performed using the kinaesthetic imagery (KIN) modality, which is defined as 'how it feels to perform an action, including force and effort' (Callow & Waters, 2005, p. 444). The former can be performed with or without the visual imagery (VI) modality, which involves the visual experience while imagining the action. VI can be simply defined as what the individual views in the image, including seeing movements performed by the self or others (Holmes & Calmels, 2008; Ruby & Decety, 2001). VI is further separated into two VI perspectives. First, there is an internal VI (IVI) perspective, which is described as generating an image from an inside or first-person perspective. Second, there is the external VI (EVI) perspective, described as generating an image from an outside or third-person perspective. (Callow & Roberts, 2012; Roberts et al., 2008).

The imagery intervention study structure typically comprises the following: the imagery script, type, outcomes, target population and comparison groups or conditions. Imagery interventions are usually delivered under experimenter supervision by using predefined imagery scripts with various formats (e.g. written, oral, audio) that include an instruction detailing the imagery training process with specific sessions/durations. The scripts help participants to follow a scenario, thereby enabling them to produce an image of the specific task. Imagery interventions can be used alone (e.g. specific imagery type) or in combination with other training approaches (e.g. goal setting, action observation, relaxation, physical practice) to examine their effects on specific outcomes (e.g. strength, motor skills) in various populations (e.g. athletes or non-athletes).

Imagery interventions need to specify the appropriate intervention components (e.g. duration of the training and imagery scripts) and define the goals, population, imagery ability and parameters for optimising the efficacy of imagery training. These factors are likely to influence outcomes, and they are variable and controversial in the literature. For example, imagery ability can affect the outcomes of imagery training interventions, as the effectiveness of imagery practice for enhancing movement performance has been shown to depend on the individual's ability to create and preserve vivid imagery (e.g. Martin, Moritz, & Hall, 1999). Thus, assessment of imagery ability is necessary to ensure that its moderating influence can be considered among the study groups in imagery interventions. Another factor that needs to be considered is the duration and frequency of imagery during the intervention. The length of the intervention may be a moderating factor in the relationship between imagery efficacy and strength/ performance gain (Slimani et al., 2016).

The clarity and details in the imagery scripts may influence the efficacy of imagery practice. Effective imagery scripts should provide details that describe all the processes of performing the task (including modality and perspective) and specify the type of imagery function (e.g. cognitive, pain management, arousal and motivation). Most studies that previously investigated the effect of imagery interventions on muscle strength used a cognitive imagery intervention (i.e. imagined performing the strength task that was used in the pre-assessment session, but without any physical execution); however, it did not consider the role of imagery modalities and perspectives (e.g. Reiser, Büsch, & Munzert, 2011; Sidaway & Trzaska, 2005; Tenenbaum et al., 1995).

A limited number of studies have compared the effect of including different VI perspectives (i.e., internal or external) in intervention scripts. In addition, further examinations of the efficacy of specific VI perspectives in imagery interventions on muscle strength are sparse. Yao et al. (2013) demonstrated EVI’s ineffectiveness for muscle strength gains compared with internal visual perspectives, although the IVI was a combination of IVI and kinaesthetic imagery, which is reminiscent of other studies that confound the IVI with kinaesthetic imagery, such as that of Ranganathan et al. (2004). Other studies used only one of the imagery modalities (i.e. visual or kinaesthetic) in their intervention scripts, without any further comparison between modalities. For example, adding the visual modality alone to the imagery scripts showed a significant strength improvement in the upper and lower muscle groups following the mental training period (e.g. Shackell & Standing, 2007; Yue & Cole, 1992). Likewise, adding the kinaesthetic modality to the imagery scripts showed a significant improvement in the maximal torque of the dorsiflexor muscles (e.g. Sideway & Trzaska, 2005). However, other previous studies that did not provide more information regarding the imagery intervention scripts (e.g. type of imagery, modalities used) showed less efficacy of mental training on muscle strength compared with the control groups with no imagery practice (e.g. Herbert et al., 1998; Tenenbaum et al., 1995). In Herbert et al.'s (1998) study, the subjects in the control group attended the same number of sessions in the laboratory; where they performed tasks with standardised instructions ('Get ready to keep the weight of your feet evenly distributed. Now, keep the weight of your feet evenly distributed, keep the weight of your feet evenly distributed. Now stop'). The role of imagery intervention in improving muscle strength is still undeveloped. (As we proposed in the review in Chapter 1, more research is needed before the routine use of imagery training is recommended as a therapeutic tool in physiotherapy practice).

Several studies have shown muscle strength improvement following mental training interventions (by using imagery practice either alone or in combination with other approaches) in various muscle groups. However, those studies did not include some critical practical aspects that are crucial in applied physiotherapy; instead, they mainly examined muscle groups that are usually less affected in patients and of minor importance for functional training by physiotherapists. For instance, Smith et al. (2003) and Yue and Cole (1992) both examined the abductor digit minimi muscle; although this muscle may be still necessary for future upper limb rehabilitation by an occupational therapist, it is rarely a target in physiotherapy. Ranganathan et al. (2004) examined both a small muscle group exercise (little finger abduction) and a larger muscle group exercise (elbow flexion), and they found that both muscle groups improved significantly in strength. However, the larger muscle group showed less improvement. Conversely, Herbert et al. (1998) failed to find any significant difference between an imagery practice group and a control group in the muscle strength of the elbow flexor muscles. Moreover, Tenenbaum et al. (1995) found that the control group showed more significant improvement in peak force of knee extensor compared with the group that received a mental visualisation and muscle relaxation intervention.

Clearly, variability in outcomes, goals, methodology and adopting specific imagery modalities and perspectives may explain differences in the effectiveness of former studies. While building an important theoretical background for future applications, this variability creates a challenge for the direct replication of those studies. Therefore, the effect of imagery practice on muscle strength needs to be investigated further and replicated with larger muscle groups. The current study will address and re-examine the effects of imagery training on a muscle strength task in a larger lower limb muscle group. The gluteus medius muscle has been chosen for examination in the current study, as it works as a primary abductor of the hip joint (Kumagai et al., 1997). In addition, it is of clinical importance in physiotherapy, as hip abductor muscle weakness contributes to lateral hip pain (Strauss, Nho, & Kelly, 2010), iliotibial-band friction syndrome (Lee, Souza, & Powers, 2012), patellofemoral pain syndrome (Cichanowski, Schmitt, Johnson, & Neimuth 2007; Magalhães et al., 2010; Nakagawa, Moriya, Maciel, & Serrão, 2012) and osteoarthritis of the knee (Hinman et al., 2010). In addition, it is an essential muscle during walking, and it works as a pelvis stabiliser in a unilateral stance against gravity (Al-Hayani, 2009; Gottschalk, Kourosh, & Leveau, 1989). Therefore, the primary objective of the current study is to examine whether imagery practice can be used to increase the hip abductor muscle's strength (i.e., gluteus medius muscle). The results of the current study will provide evidence for future applications of imagery practice for various musculoskeletal conditions in physiotherapy and rehabilitation services.

Based on the findings showing that the details of imagery scripts can influence the effectiveness of imagery interventions, as mentioned above, the second objective of the current study was to examine the efficacy of different imagery scripts on hip abductor muscle strength and imagery ability. We developed two separate scripts for two intervention groups. Each script included clear instructions that directed participants to imagine all the details of the task: The first script instructed participants to adopt KIN modality alone, while the second script instructed participants to adopt a combination of KIN and VI modalities during imagery training. We compared the efficacy of the imagery scripts on hip abductor muscle strength and imagery ability in the intervention groups (KIN vs. KIN+VI).

The research questions were as follows:

1 Does imagery practice (mental simulation of a muscle strength task by imagining pushing the dynamometer arm without physical execution with specific repetition, frequency and duration) improve the muscle strength of hip abductor muscles (gluteus medius)?
2 Is there any difference in muscle strength improvement between an imagery intervention group using the KIN imagery modality alone and one using a combination of KIN and VI imagery modalities?
3 Is there any difference in imagery ability between an imagery intervention group that uses KIN alone and a group that combines KIN with VI?

Methodology

Participants

Fifty-one participants (26 women and 25 men; age mean ± SD: 24.43±5.75 years) were recruited from the student population at Bangor University and the local community of Bangor city using email lists, web advertisements, posters and announcements. To be eligible for this study, participants needed to be healthy adults and free from lower limb injuries in the previous six months. The Ethics Board at the School of Sport, Health and Exercise Science (SSHES), Bangor University approved the study. Participants were reimbursed for their time (e.g. £50 for the experimental groups and £20 for the control group, so that participants were approximately equally compensated for their time investment). In addition, University students received course and employment credit. Written informed consent was given by all participants prior to the start of study participation.

Design and experimental groups

The study was conducted as a randomized control trial with three arms: Kinaesthetic imagery practice (KIN) group, kinaesthetic plus visual imagery practice (KIN+VI) group, and control group (CTRL) with no practice. Participants were randomized to one of the three study groups by one of the principal researchers using a random number generator. The study procedure comprised three phases: an introduction and initial assessment phase, an intervention phase (i.e. two weeks of imagery practice, five sessions per week, each session lasted~ 30 minutes), and a post-intervention assessment phase. The control group received neither physical practice nor imagery practice during the intervention phase, and they were contacted only for the initial and post assessment sessions.

Imagery intervention and scripts

The two intervention arms of the study performed imagery practice, which involved cognitive imagery practice (i.e. mental simulating of the task that was used to assess muscle strength, shown in Figure 1), by repetitively imagining performing the task ("imagine pushing the dynamometer arm") without any physical execution, with the intention to improve the subsequent muscle strength. The imagery practice was conducted by using different imagery modalities and perspectives with explicit instructions in specific scripts. The imagery scripts were designed to produce an effective imagery practice by enhancing components that influence muscle strength improvement. Scripts were developed in accordance to the literature review findings and particularly Sideway and Trzaska (2005) study, which including a simulation of the strength task and recall of the participant feeling, sensation and experience during maximal muscle contraction at the strength test.

The KIN group script detailed the strength task using kinaesthetic imagery modality by retrieving the sensation of the muscle strength task that derived from apparatus lever resistance, the participant's leg muscle contractions and from the task action. The script directed participants to create an image of the strength task using the sensory feeling to practice it in a systematic manner as vividly as possible without any physical contraction, by the following instruction: "Imagine that you are lying on your side on the isokinetic machine. Think back to your own sensations you felt as you performed your maximal contraction of your thigh. Feel your top leg rise to meet the fixed dynamometer arm. Feel the cushion of the dynamometer touch the side of your thigh just laterally above the knee…" (for complete script see Appendix C-1).

The KIN+VI group script integrated the visual imagery modality in addition to the kinaesthetic modality. Thus, the KIN+VI group's script was identical to the KIN script, except for the additional instruction to include the visual imagery modality, without specifying the perspective to be used. The flexibility on selecting visual perspectives allowed participants to use their preferred perspective, either internal or external. Thus, the script directed the participant to create an image of the muscle strength task by both retrieving the feeling of the strength task (i.e. the sensations extracted from the muscle contraction, action and apparatus resistance), and seeing the action (i.e. watching yourself performing the muscle strength task). This was practiced in a systematic manner using the following instruction: "Imagine that you are lying on your side on the isokinetic machine. Think back to the sensations you felt and your own visual image as you performed your maximal contraction of your thigh…" (*I.e. Participants were told during muscle strength assessment specifically to look at their own body to build up a visual experience of the task*) (For complete script see Appendix C-2).

The order in which kinaesthetic or visual imagery instructions were presented in the KIN+VI group's scripts was counterbalanced across participants to overcome order effects (Appendix C-2). The scripts were provided both as an audio recording and in written format. The preference for external or internal perspective of imagery was assessed after the intervention (see below).

Procedure

Prior to initiation into the study process, an information sheet was provided. Each participant provided written informed consent and was randomly allocated to one of the study groups. On the first day of participation, a session lasting for approximately 60 minutes included introduction and familiarization of the study assessments and intervention structure. Additionally, questionnaires were completed, and the muscle assessment test was performed.

Participants were asked to complete a Physiology Informed Consent and Medical Questionnaire (Appendix B-1) and asked to report their physical activity level using the International Physical Activity Questionnaire (see "www.ipaq.ki.se" and Craig et al., 2003). To control for potentially confounding factors, participants were instructed to maintain their usual daily physical activity levels and were instructed not to take part in any unaccustomed exercise programme over the duration of the study. In addition, at the end of the first assessment session, an initial schedule for daily imagery training visits was produced for each participant of the intervention groups and the time for the post-assessment visit was assigned for participants who were in the control group.

Participants in both imagery groups received the imagery practice programme individually under the principal experimenter's supervision in a quiet laboratory at the School of Sport, Health and Exercise Science. All intervention groups conducted the training at the same place, and with the same amount of practice time. In addition, all participants received the same amount of encouragement and instructions during imagery sessions through specific audio imagery script instructions for each group and equal amounts of verbal commands.

In the first imagery session, the experimenter explained the nature, terminology, and concepts of the imagery training to the participants. Then, the imagery practice for performing the maximal imagined isometric contraction task without any physical execution was explained and practiced. Participants also received written information material explaining the training protocol (Appendix C-3) and the imagery script specific to their group. After this, participants started to practice the imagery-training programme by using a variety of methods (i.e. verbal, audio and written instructions) under the experimenter supervision (see below).

The procedure of imagery practice sessions across the intervention period was as follows:

- At the beginning of each session, participants were instructed to be ready for imagery practice by wearing a heart rate monitor, choosing a comfortable position and reading the training protocol (Appendix C-3).

- Then the session started by listening to the audio recording that detailed the imagery script and instructed the participant to perform imagery practice of the muscle strength task with specific modalities, according to each imagery group (i.e. KIN alone, or combined KIN+VI).
- Participants were asked to start imagery practice while listening to the audio recording. Next, when the audio recording stopped, they were asked to perform one imagery practice trial, *(i.e. they do one imagery trial while listening to the recording and then one after the recording stopped).*
- Following the first trial, the experimenter asked the participant if he/she could perform the imagery practice easily and discussed any issues or difficulties.
- After the practice training, participants were asked to perform five imagined maximal contractions of hip abductor muscles; each lasted for ~15 s, followed by 15 s rest. The experimenter timed the whole imagery practice process. Participants performed the imagery practice with their eyes closed.
- The second set of imagery practice began with reading the imagery script to enable participants to refresh their memories. Participants were asked not to perform the imagery practice while reading the script. Following the reading, participants performed the same five imagined contractions with the same time pattern as before.
- The third set of imagery practice was performed by playing the imagery audio script again. Following listening to the imagery script, participant performed five imaginary contractions each for ~15 s followed by 15 s rest.
- Then participants had a one-minute rest break, before the imagery protocol was repeated (see protocol summary in Appendix C-3).

During each session lasting ~30 minutes, participants imagined the maximum isometric contraction of right hip abductors/ 35 times over seven sets of imagery training. The intervention protocol for each participant comprised of 10-imagery practice sessions/one session per day, 5 days per week over a two-week period. Throughout the imagery practice sessions, the experimenter monitored participants for any physical contraction of hip abductor muscles. If any contractions were visible the experimenter immediately provided feedback to the participants to let their muscles relax during the imagined contraction practice. The control group did not receive any practice during the two weeks.

The post-experimental assessments were performed after approximately three weeks post the baseline assessments, immediately following the intervention period. Again, a measurement of the right hip abductor muscles strength was taken by using the dynamometer. In addition, each participant was asked to complete the VMIQ-2 questionnaire and post-experimental questionnaires.

Assessments and Measurement

Muscle strength measurement.

The primary measure in the current study was the strength measurement of right hip abductor muscles (i.e. gluteus medius muscle). Muscle strength measurement (i.e. MIT**:** Maximal isometric torque) was assessed at two-time points (i.e. at baseline, and immediately following two weeks of intervention period) with the same procedure at both assessment points. The muscle strength was measured by using a Humac dynamometer (Humac Cybex Norm 2004, Computer Sports Medicine Inc., MA, USA), and strength data were analyzed and processed by using AcqKnowledge software (Biopac System, Inc., California, USA) that interfaced with the Humac dynamometer. All participants received instructions and familiarization including information about test commands, apparatus, safety and practice trials of the strength assessment protocol.

The measurement procedure involved the following setting according to the manufacturer's instructions for the dynamometer (see Figure 1). Each participant lay down on the left side (i.e. non-tested leg), facing away from the dynamometer, with the right leg (tested) on the top of the non-tested leg, with 0˚ of flexion and external rotation of the hip joint, while the non-tested leg had approximately 30˚ hip flexion and 30˚ knee flexion for more comfort and stability. The non-tested leg and trunk were also stabilized by being strapped to the bed that was attached to the apparatus. The position of the bed and dynamometer were adjusted to measure the hip abductor muscles in the following setting: the dynamometer setting, the dynamometer tilt at 0˚, height at 23 ˚, rotation at 0˚, and monorail at 0˚, the chair setting; the rotation scale at 0˚, forward/backward position at 25˚ and the seatback tilt fully reclined. The tested hip joint was placed and supported at 15° of abduction (Jan et al., 2004) which attached with dynamometer static arm at same degree of abduction, see Figure 1. The lever pads of the dynamometer were placed and stabilized by a strap on the distal, lateral portion of the thigh, just proximal to the patient's lateral femoral condyle. The length of the lever was adjusted according to each participant's size. The dynamometer's rotation axis was aligned with the midpoint of the line linking the posterior superior iliac spine and the greater trochanter (Correia et al., 2013).

Prior to muscle testing, participants performed a warm-up and familiarization protocol consisting of five minutes of cycling on a stationary bike followed by four submaximal contraction trials that were distributed equally, with two contractions each at 25% and at 50% of maximal contraction force. Then, after two minutes rest to eliminate muscle fatigue, participants performed three maximal isometric contractions against static dynamometer arms at 15° of abduction, with verbal encouragement from the experimenter. Each maximal contraction was held for five seconds, followed by one-minute rest periods between each maximal contraction (the experimenter timed the procedure). During the muscle strength assessment participants were told specifically to look at their own body (i.e. look at examined leg, this clarified that participants had a visual experience of the task while physically performing it, that they could then retrieve during imagery training). The maximal isometric torque of hip abduction task was recorded and the highest of the three values was used for statistical analysis (Jan et al., 2004) and was record in newton meter (Nm).

Figure 1: Muscle strength task assessment tools (HUMAC dynamometer) connected AcqKnowledge software (Biopac System). Photo of one participant was used with permission

Figure 1: Participant from study 1 on HUMAC dynamometer's table connected with the dynamometer arm at 15°

Imagery ability measurement.

The secondary outcome in the current study was the Vividness of Movement Imagery Questionnaire-2 (VMIQ-2; Roberts et al., 2008) that was administered at baseline and following intervention periods to assess participants' imagery ability.

The VMIQ-2 is a suitable psychometric measurement tool of movement imagery ability with acceptable factorial, concurrent and construct validity (Roberts et al., 2008). It was designed to assess the imagery ability for different imagery modalities and perspectives. Using this questionnaire enabled us to assess the visual and kinesthetic modalities. The visual imagery modality is further delineated into two perspectives; the internal visual imagery perspective (IVI; an image obtained from an internal point of view, as if you were looking out through your own eyes whilst performing the movement), and the external visual imagery perspective (EVI; an image obtained from watching yourself performing the movement from an external point of view). The kinaesthetic imagery modality (KIN) is an image obtained by imaging the feel of the movement. The questionnaire consists of 12 items that assess imagery ability for a variety of movements (e.g. running upstairs, kicking a stone). Each of the 12 imaged items is rated separately for each of the three imagery modalities using a 5-point Likert scale with values from 1 (*perfectly clear and vivid*) to 5 (*no image at all; you only know that you are "thinking" of the skill*). (See Appendix. B-3).

Heart rate.

Earlier work on mental imagery training showed that effective mental training is accompanied by raised physiological responses (e.g. heart rate, blood pressure and skin temperature) (Decety, Jeannerod, Germain, & Pastene, 1991; Deschaumes-Molinaro, Dittmar, & Vernet-Maury, 1991; Wang & Morgan,1992; Wuyam et al., 1995). In addition, heart rate (HR) has been shown to be increased during kinaesthetic imagery of muscle strength tasks (Ranganathan et al., 2004), which might be used as a manipulation check for participants' engagement with the imagery practice. Therefore, the HR was recorded during all imagery sessions using a HR monitor (Polar FS1 Heart Rate Monitor watch, Polar Electro FS1; Kempele, Finland). Mean readings of the participants' HR were taken during each imagery session: HR was taken at pre-imagery (resting HR) and again during imagined contractions. HR was recorded every five minutes during each session for each participant (six times per session). HR in the pre-imagery training stage was compared with HR recorded during the imagery training stage within groups.

Post intervention questionnaire.

A post intervention questionnaire was administered following the final imagery practice session for all participants in the experimental groups, to assess compliance with the imagery practice instructions, and to obtain participants' feedback regarding the imagery intervention efficacy (see

Appendix B-4). Additionally, following the post-intervention muscle assessment test, further questions were administered to all study groups to investigate whether participants used imagery outside the experimental imagery sessions, or during pre-and post-muscle strength assessments. Moreover, compliance with instructions regarding maintaining physical activity levels during the study was reported.

Motivation and effort questions.

Further questions were included to check if there was any variation in participants' motivation and effort for the strength task. However, only 20 participants across all study groups were asked to answer the questions (as those questions were admitted later because we were concerned about less motivational experience in the control group, which was raised later).

The level of effort in performing the muscle strength assessment was assessed at pre and post time points by a numerical scale (0-150), where zero represents "*No* effort at all" and "110" and above represents "*Extreme* effort".

The level of motivation during performing muscle strength assessments at pre and post time points was assessed by using a Likert scale to answer the question "How motivated were you to succeed in that task?" with zero representing "Not motivated at all" and 10 representing "very highly motivated". Additionally, following post muscle test assessment all participants were asked to rate on a Likert scale "to what extent did the presence of the experimenter increase your motivation to perform well on the muscle strength task" with zero representing "Not at all" and 10 representing "Greatly".

Statistical Analysis

Baseline variables and post intervention questionnaires were assessed between groups by one-way Analysis of Variance (ANOVA) and Analysis of Covariance (ANCOVA) controlling for gender and further analysed with Tukey's post-hoc test. The alterations of the muscle strength and imagery ability were assessed using a mixed model repeated measure ANCOVA. Significant main effects or interactions were further analysed with paired-samples *t*-tests. All values were reported in means ± SD. A significance level of $P < 0.05$ was used for all statistical comparisons. All statistical procedures were performed using Statistical Package for Social Sciences (IBM SPSS) 22.0 version. Armonk NY: IBM United States. IBM Corp. 2013.

Results

The following section reports outcomes of participants who successfully completed the two weeks training intervention (i.e. two weeks of imagery intervention training or no practice intervention).

Participants

47 of the 51 participants recruited completed the study and were included in the analysis; however, four data sets of participants were excluded based on exclusion criteria (one had a leg injury, one was sick and missed more than two sessions, one had upper limb injury and pain affected her performance and one missed more than two sessions). Demographic and body characteristics of the 47 participants at pre-test are shown in Table 1; One-way ANOVA reported no significant differences between groups for age, height, mass or BMI.

The gender distribution in this study was shown [% women, KIN+VI 68.8%, KIN 43.8%, CTRL 33.3%], however the Pearson Chi-Square result χ (2) = 4.147, p = 0.126, revealed no significant association between gender distribution across study groups which is both male and female distributed equally across study group.

Table 1. Demographic characteristics of the study groups

Parameter	KIN+VI (n=16)	KIN (n=16)	CTRL (n=15)
Age (yrs)	24.06 ± 4.95	24.00 ± 5.69	26.20± 6.97
Gender (% women)	68.8%	43.8%	33.3%
Height (cm)	172.42 ± 7.36	174.47 ± 8.28	175.70 ± 7.45
Mass (kg)	68.49 ± 9.46	72.81 ± 8.05	74.91 ± 5.72
BMI (kg/m^2)	22.94 ± 1.79	23.94 ± 2.41	24.36 ± 2.56
Physical activity scores	1.94 ± 0.57	2.06 ± 0.44	2.20 ± 0.77

The categories of physical activity scores 1 = low, 2 = moderate, 3 = high activity.

Study Outcomes

Compliance with the imagery practice instructions.

All participants took part in all imagery sessions (compliance 100%). At the end of the study, three questions were asked to assess participants' intensity of using specific imagery modalities.

Those data were used to assess participants' commitment to implement the use of specific imagery modalities according to the instruction.

Participants' usage of kinaesthetic imagery modality was rated with a Likert scale (0 representing "No kinaesthetic imagery use" and 10 representing "High kinaesthetic imagery use). Table 2 showed high usage of kinaesthetic imagery modality during imagery practice by all participants in both imagery groups and the t-test result did not show any significant difference between the imagery intervention groups in KIN modality used (t (30) =- 0.722, p = 0.48).

Participants' usage of visual imagery modality during imagery practice was also rated with a Likert scale (0 representing "No visual imagery use" and 10 representing "High visual imagery use"). Table 2 showed high usage of visual imagery by participants in the KIN+VI groups, and moderate usage of VI modality by participants in KIN group, although they were not instructed to use visual imagery during practice. The t-test result showed a significant difference between study groups in using the visual modality (t (30) =3 .554, p = 0.001) with higher usage in KIN+VI group than in KIN group, which is consistent with study instruction.

A further question was used to investigate which visual imagery perspective was adopted while using visual imagery, rated on a Likert scale (0 representing "Completely internal perspective", 5 "switched regularly" and 10 representing "Completely external perspective"). Table 2 showed that participants in both intervention groups who used visual imagery tended to use an internal visual imagery perspective rather than using an external visual imagery perspective, and the t-test result did not show any significant difference between imagery groups in IVI usage (t (30) = - 0.499, p = 0.621).

Table 2: Participant's compliance data during imagery intervention

Parameter	**KIN+VI (n = 16)**	**KIN (n = 16)**
KIN usage	7.19 ± 1. 91	7.63 ±1.50
VI usage	7.44 ±1.50	5.25 ± 1.95*
VI Perspectives	3.31 ± 2.33	3.75 ±2.62

KIN usage: participants self-report the intensity of using kinaesthetic imagery modality during the imagery training. VI usage: participants self-report the intensity of using visual imagery modality during the imagery training. VI perspectives: participants reported intensity of using different visual imagery perspectives (IVI: internal visual imagery or EVI: external visual imagery). *Significance level (p = < 0.05).

Baseline muscle strength and VMIQ-2 questionnaire.

Results of the baseline assessment are shown in Table 3. Levels of the strength measure and imagery ability subscales were not significantly different between groups (One-Way ANOVA) as shown in the table 3.

Table 3: Primary outcomes (i.e. the maximal isometric torque (MIT) of right hip abductors and the average score of imagery ability measured by VMIQ-2) at baseline assessment

Outcomes	**KIN+VI (n=16)**	**KIN (n=16)**	**CTRL (n=15)**	**F-value**	***p*-value**
MIT (GM) (Nm)	120.70 ± 38.37	126.06 ± 39.62	141.70 ± 44.25	1.102	0.341
VMIQ-2 Score					
EVI	30.63 ± 9.19	29.56 ± 9.01	28.27 ± 10.41	0.237	0.790
IVI	28.13 ± 7.02	24.56 ± 8.55	23.47 ± 9.55	1.315	0.279
KIN	27.63 ± 9.82	28.38 ± 9.24	22.93 ± 6.88	1.730	0.189
Total	86.38 ± 16.58	82.50 ± 20.72	74.67 ± 20.92	1.444	0.247

MIT: Maximal isometric torque. **GM:** gluteus medius (hip abductor muscles). **Nm:** newton*metre. **VMIQ-2:** Vividness of Movement Imagery Questionnaire-2. **Total**: Summation of all VMIQ-2 subscales scores. **EVI:** External visual imagery subscale. **IVI:** Internal visual imagery subscale. **KIN:** Kinaesthetic imagery subscale. *Significance level (p = < 0.05).

Muscle strength.

As in the KIN+VI group, there are two different orders for the imagery scripts, thus the first script order used KIN first during imagery instruction and the second script order used VI first in the instructions. The result of the split order in the KIN+VI group showed there is no difference between KIN+VI sub-order instruction (visual first or kinaesthetic first) on strength and total VMIQ-2 (P>0.05); therefore, data on KIN+VI group were pooled together.

The muscle strength outcomes during all assessment points are shown in Table 4. Potential muscle strength alteration in the hip abductor muscles due to the imagery training was analysed using a mixed-model Group (KIN, KIN+VI, CTRL) × Time (pre-assessment, post-assessment) ANCOVA with muscle strength as the dependent variable, controlling participant's gender as covariate factor, due to the large differences in gender distribution between groups.

The statistics showed no significant main effects of group (F (2, 43) =0.287, p =0.752, η^2 =0.013) or time (F (2, 43) =0.206, p =0.652, η^2 =0.005); however, a significant time x group interaction was found (F(2, 43) =6.85, p=0.003, η^2 =0.242). It is visible in Figure 2 Panel A that the strength alterations of both imagery groups are positive, while the control group seem to decline, emphasizing a difference in response over time between the groups. Panel B of Figure 2 shows changes in force pre-post intervention, revealing a clear increase in strength for the imagery groups but not for the control group.

The interaction was further explored using paired t-tests (Zijdewind et al., 2003) to analyse the actual maximal isometric muscle strength alterations within each study group from baseline level to post-intervention level (see Table 4 and Panel B). Results show that the CTRL group produced significantly strength decline at post-test t (14) = 2.27, p=0.039, while the increase in strength was only significant in the KIN+VI group t (15) = -2.63, p=0.019, but not in the KIN group, t (15) = -1.93, p=0.073. Accordingly, the KIN+VI group was the only group that demonstrated a significant improvement of muscle strength between time 1 and time 2 following two weeks of supervised imagery practice intervention. Furthermore, the results did not show significant interaction between gender and strength outcomes across time (F (2, 43) =0.038, p =0.846, η^2 =0.001).

Table 4: Right hip abductor muscles strength levels across all study groups at pre- and post-assessments

Study groups	**MIT (Nm)**		***t*-value**	***p*-value**
	Pre-GM	**Post-GM**		
KIN+VI (n = 16)	120.70±38.37	128.75±36.15	-2.625	0.019*
KIN (n = 16)	126.06±39.62	132.94±41.44	-1.932	0.073
CTRL (n = 15)	141.70±44.25	132.29±42.85	2.271	0.039*

Data of paired sample t-test (within group comparison). **MIT:** Maximal isometric torque. GM: gluteus medius (hip abductor muscles). **Nm:** Newton*meter. *, significant difference (P < 0.05) between pre and post assessment within each group.

Figure 2. Graph of the group × time interaction effect on hip abductors strength at pre-and post-intervention phase

Panel A

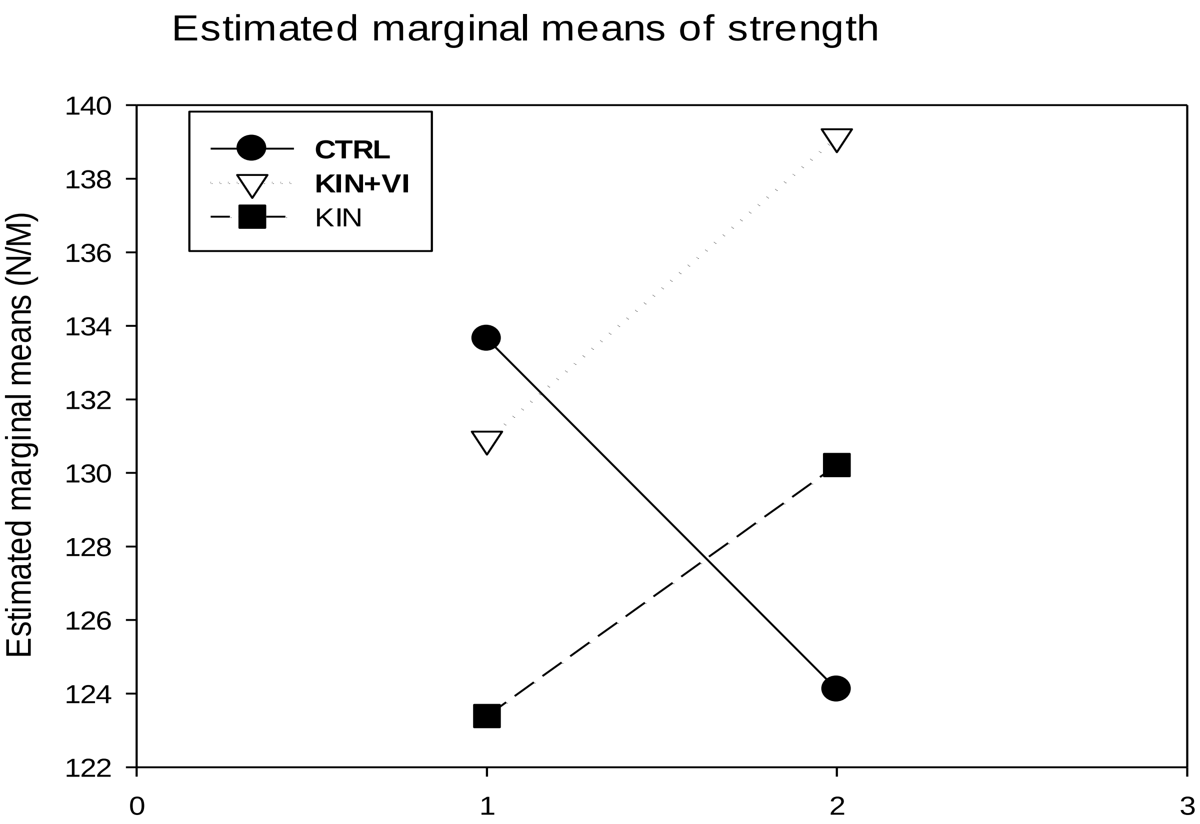


Figure 2-A: Estimated marginal means of strength pre (1) and post (2) intervention. **KIN+VI:** combined kinaesthetic imagery with visual imagery training; **KIN:** kinaesthetic imagery training; **CTRL:** control group.

Panel B

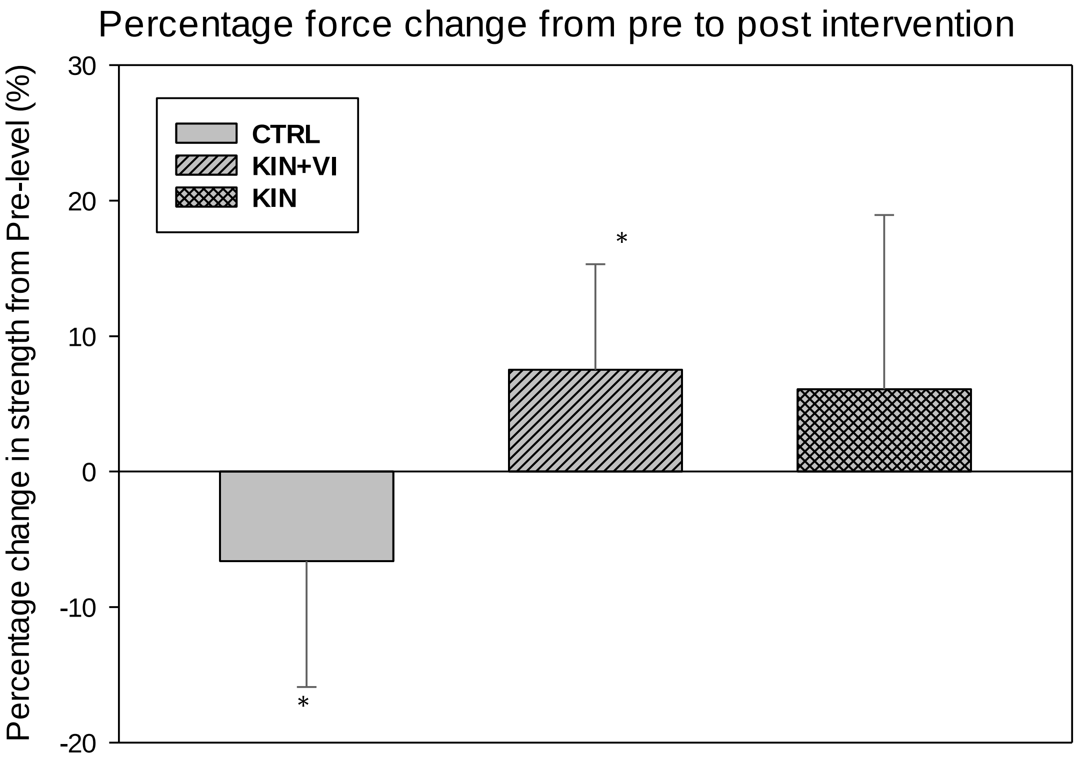


Figure 2-B: Percentage change in strength values from pre-to post-training for study groups. **KIN+VI:** combined kinaesthetic imagery with visual imagery training; **KIN:** kinaesthetic imagery training; **CTRL:** control group. * Significance (P < 0.05).

Imagery ability.

The scores of all VMIQ-2 subscales and total scores during all assessment points are shown in Table 5. The total score of VMIQ-2 (i.e. produced by summation of all three VMIQ-2 subscales) was used to examine if the imagery ability was influenced following the training period (i.e. either following imagery training or no practice) by using a mixed-model Group (KIN, KIN+VI, CTRL) × Time (pre vs. post) ANCOVA, with the total VMIQ-2 score as dependent factor and gender as covariate factor.

There were no significant main effects of group (F (2, 43) =0.626, p =0.539, η^2 =0.028) or time (F (2, 43) =0.058, p =0.811, η^2 =0.001); however, a significant interaction between group and time was found (F (2, 43) =5.12, p =0.010, η^2 =0.192).

The graph shown in Figure 3 displays the significant interaction between group and time (i.e. Total VMIQ-2 score profile at pre and post intervention assessments). It is visible in Panel A that the total VMIQ-2 alteration in KIN+VI imagery group shows improvement while the CTRL group and KIN group seem to decline in ability, emphasizing the difference in response over time between the groups. Panel B of Figure 3 shows a clear increase in imagery ability of only KIN+VI group but not for CTRL or KIN groups.

Paired t-tests (within groups) were performed as a post-hoc test for further explanation of the interaction results. This showed no signficant change in the CTRL or KIN group following the training period in any post-test VMIQ-2 subscales compared with pre-test outcomes, while the KIN+VI group showed significant improvement of the total VMIQ-2, t (15) = 2.22, p =0.003 and IVI subscale, t (15) = 3.61, p =0.003) at post-test compared with baseline level as shown in Panel B and Table 5. Consequently, the result confirms that only combined KIN with VI imagery practice produced a positive effect on overall imagery ability scores, as well as on the internal visual imagery subscale. Furthermore, results did not show significant interaction between gender and time (total imagery ability) (F (2, 43) =0.166, p =0.686, η^2 =0.004).

Table 5. The vividness of movement imagery questionnaire subscales data of all participants across study groups at pre and post assessment points

	KIN+VI (n = 16)		**KIN (n = 16)**		**CTRL (n = 15)**	
Parameter	Pre	Post	Pre	Post	Pre	Post
EVI	30.63±9.19	29.00±7.66	28.93±8.96	30.47±9.20	28.27±10.41	28.00±10.66
IVI	28.13±7.02	23.50±6.61*	23.53±7.75	26.60±8.14	23.47±9.55	25.93±8.59
KIN	27.63±9.82	24.63±5.83	27.27±8.39	27.13±7.99	22.93±6.88	26.80±9.57
Total score	86.38±16.58	77.13±12.05*	79.73±18.13	84.20±21.14	74.67±20.92	80.73±23.05

VMIQ-2: Vividness of Movement imagery Questionnaire-2; **EVI:** external visual imagery subscale; **IVI:** internal visual imagery subscale; **KIN:** kinaesthetic imagery subscale. **Total score**: the total score result from summation of three VMIQ-2 subscales. Data are presented as means ± standard deviation. * P = < 0.05 for differences from pre to post intervention test.

Figure 3. Graph of the group × time interaction effect on the total score of VMIQ-2 at pre-and post-assessments points

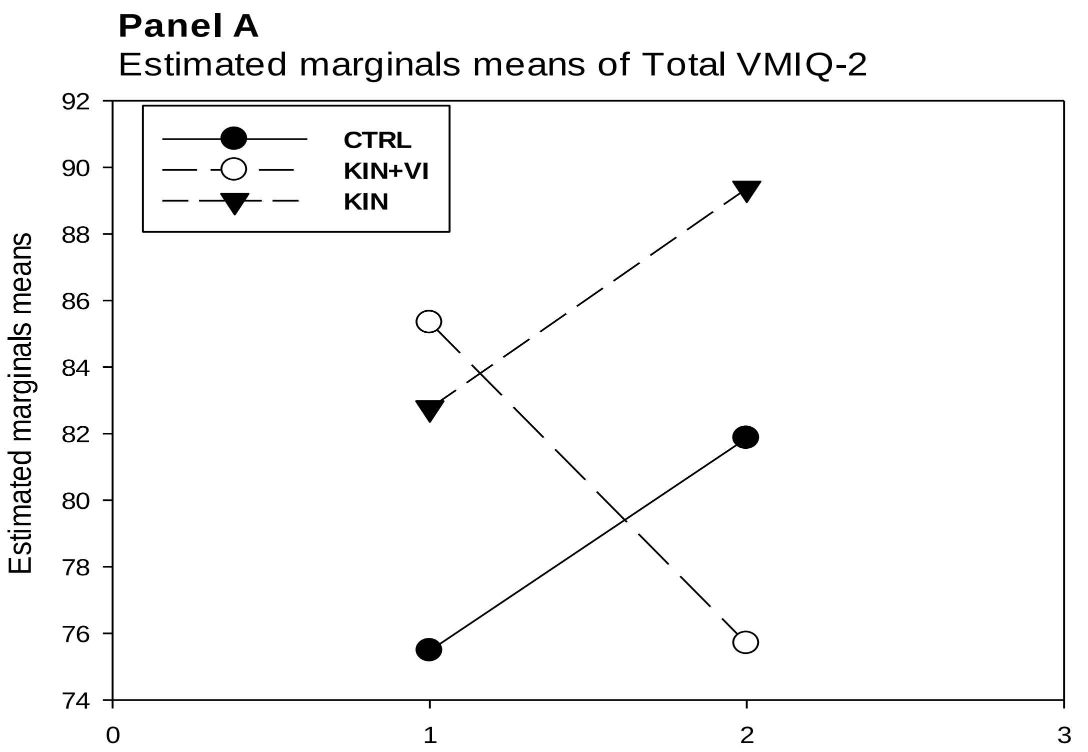


Figure 3-A: Estimated marginal means of total VMIQ-2 pre (1) and post (2) intervention. Lower scores represent with better imagery ability. **KIN+VI:** combined kinaesthetic imagery with visual imagery training; **KIN:** kinaesthetic imagery training; **CTRL:** control group.

Panel B

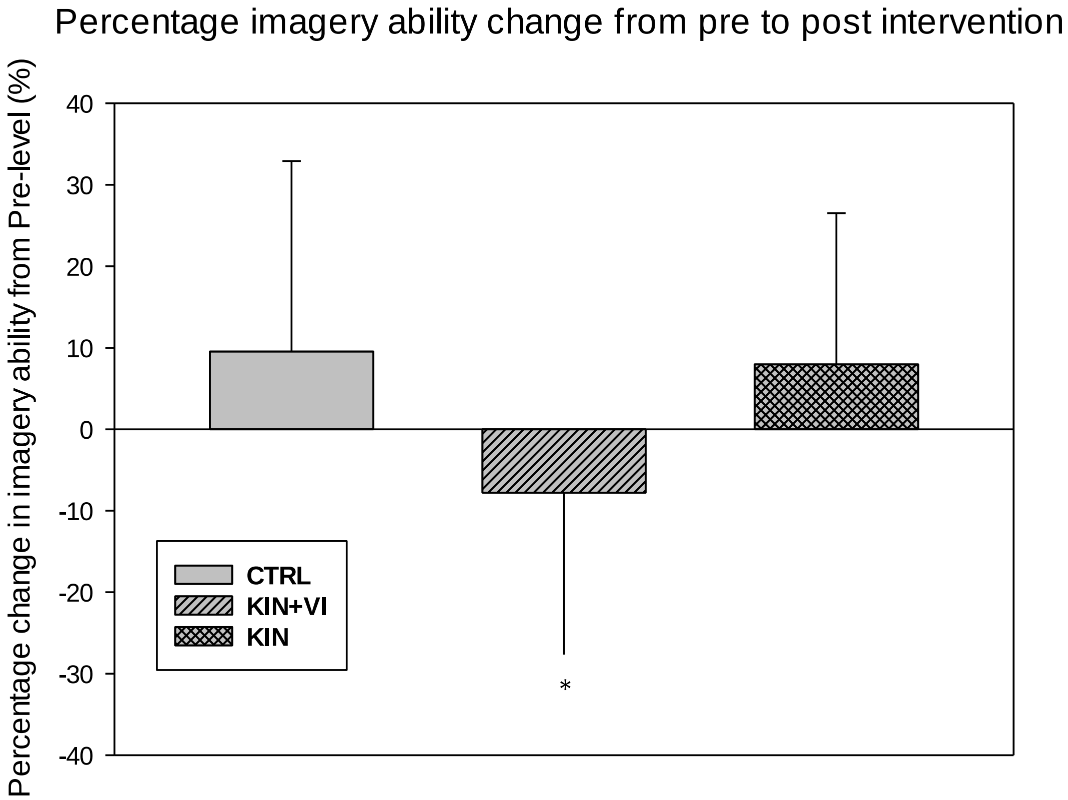


Figure 3-B: percentage change in total VMIQ-2 score from pre-to post-training for study groups. Negative percentage change represents increasing imagery ability KIN+VI: combined kinaesthetic imagery with visual imagery training; KIN: kinaesthetic imagery training; CTRL: control group. *significance ($P < 0.05$).

In addition, Pearson's correlation analyses were performed to examine any associations between the three imagery compliance questions data (i.e. intensity usage of KIN, VI, and IVI vs. EVI) with strength parameter and the VMIQ-2 score at post-test. Results show no significant correlation between the three compliance questions data with post-muscle strength and muscle strength alterations. There was a significant correlation between the intensity of using visual modality and post-IVI subscale; ($r(30) = -0.47$, p=0.007), and post-total VMIQ-2, ($r(30) = -0.44$, p=0.012), while there were no significant correlations between the other compliance questions and VMIQ-2 total or subscales. This shows that participants who used the visual imagery more intensively had a larger improvement in internal visual subscale and a better outcome on the total VMIQ-2 score.

Additionally, there were no significant correlations between the following variables; percentage of total VMIQ-2 alteration, post VMIQ-2 subscales, percentage of strength alteration, and post-strength level.

Heart rate.

The heart rate (HR) during imagery practice of both groups (change in mean HR during imagery vs. rest) was monitored and recorded as a proxy-measure for engagement in imagery. The potential HR variation due to the imagery training was analysed using a mixed-model (Group x Time) ANCOVA, with gender as covariate factor. The statistics showed no significant main effect of group (F (1, 29) =0.168, p =0.685, η^2 = 0.006), and no significant interaction between group and time (F (1, 29) =2.235, p =0.146, η^2 = 0.072). However, there was a significant main effect of time on HR, which increased across the groups following imagery training (F (1, 29) =7.44, p =.011, η^2 = 0.204). Furthermore, the result did not show significant interaction between gender and time (F (1, 29) =1.011, p =0.323, η^2 = 0.034).

Post-study questionnaire data.

Participants' feedback about their experience with the imagery intervention was assessed with three different questions (see methods). The first question focused on the ability to memorize the imagery script, the second question addressed how strongly they believed in the efficacy of imagery training for strength changes and the third asked about how much the imagery prepared them for the strength task.

Outcomes showed that participants could remember all components of the imagery script well (Likert scale 0-10, 0 "**Not at all**" and 10 "**Greatly**) and no difference between the imagery groups were found ((KIN+VI group [Mean ± SD, 6.94 ± 1.69]; KIN group [Mean ± SD, 6.88 ±1.96]; (t (30) = 0.096, p = 0.92)).

Outcomes of the second question showed that participants had a moderate belief in the imagery efficacy on enhancing subsequent muscle strength (Likert scale, 0 "**Not at all**" and 10 "**Greatly**) and no difference between the imagery groups was found (KIN+VI group [Mean ± SD, 6.31± 2.09]; KIN group [Mean ± SD, 6.06 ± 1.98]; (t (30) = 0. 35, p = 0.73)).

Scores on the third question showed that participants felt that imagery practice could prepare them for the muscle strength task very well (Likert scale 0 "**Not at all**" and 10 "**Greatly**) and no difference between the imagery groups was found (KIN+VI group [Mean ± SD, 7.00 ± 1.89]; KIN group [Mean ± SD, 7.71 ± 1.79]; (t (11) =- 0.696, p = 0.50)). Correlation analysis showed no association of the above question scores with subsequent strength improvement and strength alterations.

Effort and Motivation Questions.

Motivation to perform the strength task and the subsequent effort into the performance of the strength task was assessed via questionnaire (see methodology). This was included to investigate the contribution of motivation and effort to the change in muscle strength. These questions were introduced later in the study, so data were only collected for 20 participants with the following distribution across study groups (KIN+VI=6, KIN=7, CTRL=7). Therefore, the results are reported with the caution of being potentially underpowered. Consequently, in addition, we report effect size if trends are found (eta square power estimation).

The change in effort scores following imagery training or no practice was examined by using a mixed-model (Group × Time) ANCOVA, with gender as co-variate factor. There were no significant main effects of group (F (2, 16) =0.375, p =0.693, η^2 =0.045), or time (F (2, 16) =0.301, p =0.591, η^2 =0.018), and no significant interaction between group and time (F (2, 16) =0.584, p =0.569, η^2 =0.068). In addition, there was no significant interaction between gender and time (F (2, 16) =0.079, p =0.783, η^2 =0.005).

The scores on motivation questions were tested in the same way as above. There were no significant main effects of time (F (2, 16) =1.225, p =0.285, η^2 =0.071), however, a significant interaction between group and time was found F (2, 16) =4.32, p =0.032, η^2 =0.35, and marginal main effects of groups (F (2, 16) =2.992, p =0.08, η^2 =0.272). Furthermore, the result did not show significant interaction between gender and time (F (2, 16) =0.728, p =0.406, η^2 =0.044).

Follow-up paired t-tests (within groups) were performed as a post hoc test for further explanation of the interaction results. Result showed there was no signficant change in CTRL or KIN+VI groups following the training period on post motivation score compared with pre-test outcomes, while the KIN group showed a trend improvement of the motivation score, t (6) = -2.07, p=.084 at post-test compared to baseline level (as shown in Table 6). Consequently, the results suggest that there is only a trending improvement of motivation following KIN imagery. However, based on the very small sample size, we have underpowered the statistical analysis, hence, we suggest possibly no real effect.

Correlations between motivation scores and post-training muscle strength and muscle strength alteration over time were examined. The only significant correlation was between percentage muscle strength change and post-training motivation score, Spearman's rho (20) =0.475, p=0.034. However, when analysing each group separately there were no correlations in imagery groups between the post-strength score, percentage muscle strength change and post-motivation score, but there was a significant positive correlation in the control group (Spearman's rho= (7) =0.8, p=0.031). The alteration of muscle strength thus cannot be explained by a change in motivation.

Additionally, following post muscle test assessment, participants were asked about the presence of the experimenter in the post-test to indicate the extent of external motivation that participants were exposed to during the study. Participants in all three groups demonstrated a high score of motivation during the presence of the experimenter, although the one-way ANOVA revealed there is no significant difference between the study groups on the average scores (CTRL group [Mean ± SD, 7.43 ± 1.81]; KIN+VI group [Mean ± SD, 8.83 ± 1.33]; and KIN group [Mean ± SD, 8.50 ± 0.84]; $F(2, 17) = 2.057$, $p = 0.158$).

Table 6: The level of motivation and effort reported by participants across all groups

	KIN+VI (n = 6)		**KIN (n = 7)**		**CTRL (n = 7)**	
Parameter	Pre	Post	Pre	Post	Pre	Post
Effort level	108.33±9.31	107.50±7.42	106.10±23.62	112.36±11.49	102.86±10.74	108.21±18.75
Motivation level	9.17±0.75	9.67±0.82	8.43±1.40	9.57±0.79‡	8.29±1.38	7.71±1.89

Data are presented as means ± standard deviation. ‡ indicate a marginal difference from pre to post intervention test.

Participants' feedback regarding imagery training feasibility and training schedule.

Participants' feedback about the technical/cognitive challenge of the intervention and study schedule consisted of two questions. The intervention difficulty was assessed using a Likert scale (0 = "Easy to conduct imagery"; 10 = "Difficult to conduct imagery"). Results showed participants perceived the imagery practice to be easy during listening to the audio imagery script [Mean ± SD; KIN+VI, 2.31±2.27; KIN, 2.25±1.95]; after listening to audio imagery script [Mean ± SD; KIN+VI, 2.31±2.18; KIN, 3.00±1.75] and after reading the imagery script [Mean ± SD; KIN+VI, 3.44 ±2.66; KIN, 3.94±2.14]. The second question reported participants' preference regarding the study programme schedule. The result showed 78.1% of the participants liked daily imagery sessions every weekday for 2 weeks, while 21.9% of the participants preferred to attend three imagery sessions per week over a period of 4 weeks.

Discussion

The primary research objective of the current study was to investigate the effectiveness of imagery practice for larger lower limb muscle groups by examining the practicability and effectiveness of cognitive imagery training (i.e. imagined performing the maximal isometric contractions of the hip abduction task) on hip abductor muscles strength. Using a research design with two imagery groups, one with kinaesthetic (KIN) and one with a combination of visual and kinaesthetic (KIN+VI) imagery training, plus a non-training control group, our results showed a significant interaction of intervention group with time. Although both imagery groups showed a trend to muscle strength improvement compared with the baseline levels, the only group which reached a significant increase in muscle strength (approximately 8%) compared to the baseline level was the KIN+VI group. Moreover, the KIN+VI group revealed significantly improved imagery ability compared with no improvement in the KIN and the control group.

Muscle strength improvement

Previous studies that examined the effect of mental practice (i.e., by using imagery practice alone or combined with other approaches) on muscle strength showed various outcomes. In particular, some of the studies demonstrated a positive response and encouraged the use of imagery training alone or combined with other mental training approaches for muscle strength improvement. For example, Sidaway and Trzaska (2005) demonstrated significant muscle strength improvement (~17%) in ankle dorsiflexor muscles following 4 weeks of imagery training (using kinaesthetic modality) or physical training (~25%), but not for a control group (~-2%), although the improvement in muscle strength did not differ significantly between the two intervention groups. Similarly, Zijdewind et al. (2003) found, following seven weeks of imagery training, that combined motor imagery with video observation of the strength task resulted in improved voluntary torque production of the ankle plantar-flexor muscles (~20% above control level).

Further studies showed an improvement of finger muscle strength following imagery training; although those studies examined small muscle groups and were designed to explore the mechanisms by which imagery training can mediate increases in motor performance. For instance; Yue and Cole (1992) used imagery training with the visual modality (participants were instructed to imagine producing effortful isometric contraction of the abductor muscle of the fifth digit's metacarpophalangeal joint) for 4 weeks, five sessions per week, and the results revealed an increase of abduction force of the trained fifth digit by 22%.

Similarly, Smith et al. (2003) found an increase in the abductor digiti minimi strength by ~23% following four weeks of mental practice in the kinaesthetic modality (imagining the feeling of the task action). In addition, they found increased strength by ~53% from pre- to post-test in the physical practice group, while the control group showed strength reduction by ~5%.

Although the imagery intervention period in the current study was less than the average intervention duration of the imagery studies on muscle strength studies listed above (range 4-7 weeks), the strength increment percentage in the current study was ~8% in the hip abductor muscles group following ten imagery sessions of ~30min over two weeks of training. An imagery training study with a similar intervention period (internal imagery training) has shown a significant hip flexor muscle improvement by 24% increment, following ten imagery sessions of ~15min over two weeks of training (Shackell & Standing, 2007). Therefore, both studies showed successful muscle strength increases following shorter imagery training periods, although our study result showed a smaller percentage of muscle strength alteration compared to Shackell and Standing (2007).

The following factors could be suggested to explain the discrepancy between those studies in strength achievement. The hip abduction task could be a more difficult motor task to be performed than the hip flexion task which is more commonly performed in daily life activity. Thus, the task difficulty might be considered as a moderating factor for strength increase following imagery training. In addition, the Shackell and Standing (2007) study tested participants who were student athletes, compared to our active participants which was a cross section of a non-athletic population. Certainly, subjects with more experience in motor learning might have responded quicker to the imagery training. In addition, another potential source of variation in Shackell and Standing results is the sample size (i.e. 30 participants distributed over three groups), while our study had 47 participants over three groups. Moreover, information about the strength assessment protocol, such as whether participants performed a pre-training of the strength assessments (e.g. familiarization) or was not included in the publication. Thus, the strength increment might be confounded by motor learning rather than being a sole outcome of imagery training.

Imagery modalities and perspectives effects on muscle strength

This section discussed the effects of different imagery modalities/perspectives on muscle strength gain. Previous studies adopted different methods and instructions, combined imagery training with other mental practice approaches and used various imagery modalities and perspectives during the imagery intervention practice. Accordingly, outcomes can often not be conclusively linked to a specific technical feature of a training programme. However, Yao et al. (2013) was the first study that examined the efficacy of internal imagery (defined as a combined KIN+IVI) compared with external imagery (also known as third-person visual imagery) on elbow-flexion muscle strength over 6 weeks of training (15min/day,5 days/week). The result showed significant muscle strength gain in the internal imagery group (~11%), while the external imagery group did not show significant increase (~5%), as well as the control group (~−3%). Internal perspective during imagery practice seems to be relevant for achieving better strength outcomes. This is emphasized by our results; the muscle strength alteration demonstrated a significant hip abductors improvement by approximately 8% compared with baseline in the group that used KIN+VI imagery training, while the improvement in KIN group was ~6% which was not significant compared to pre-intervention level. Thus, imagery practice might be considered as an effective tool to improve strength in different muscle groups and combining internal visual modality with KIN modality might be the most promising approach for muscle strength enhancement.

However, some studies that examined imagery training for relatively large muscle groups found the practice to be ineffective in producing muscle alterations compared with the control groups. For example, in the Herbert et al. (1998) study, after training for eight weeks, no differences between imagery group (i.e., imagined isometric exercise) and control group were found on strength in elbow flexor muscle (~6.8% and ~6.5%, respectively). In addition, Tenenbaum et al. (1995) found a greater improvement in knee extensor muscle in the control group (~39%) compared with the imagery group (~9.0%). However, the mental training was totally different from our protocol, comprising relaxation-visualization and autogenic training for four sessions. As both former studies did not find any significant muscle strength improvement following mental training, apparent discrepancies in the protocols of the two, without clear shared features, did not point to a clear interpretation and explanation of the difference from the outcome of our and other successful studies. Nevertheless, some factors have been suggested to potentially explain the differences in both studies listed above. Yao et al. (2013) suggested that using different imagery protocols might influence outcomes, comparing their protocol with the study of Herbert et al. (1998) and other previous studies that showed positive strength improvement (e.g. Ranganathan et al., 2004; Shackell & Standing, 2007; Sidaway & Trzaska, 2005; Smith et al., 2003; Yue & Cole 1992; Zijdewind et al., 2003). Moreover, they anticipated that participants in the Herbert et al. study (1998) adopted an external imagery perspective during their mental training (as they were not instructed to adopt particular modalities or perspectives). This may contribute to less effective muscle strength improvement, as Yao et al. (2013) found efficacy of internal imagery in improving muscle strength of the elbow flexor was better than external imagery perspective.

Moreover, the efficacy of internal imagery perspective (i.e., KIN+IVI) compared with external imagery perspective was confirmed by Ranganathan et al. (2002), as the preliminary data showed greater muscle performance improvement in the group that used internal imagery compared with external imagery (10% vs. 5%, respectively).

In addition, precise instructions in imagery scripts (i.e. including detailed description of how participants perform the imagery practice with using a particular imagery modality and perspective) might be essential factors to improve imagery training efficacy. Ambiguity in the imagery scripts (missing an explicit instruction) could be a reason for the discrepancies in subsequent strength outcomes in Herbert et al. (1998) and Tenenbaum et al. (1995).

Furthermore, Tenenbaum et al. (1995) included Progressive Muscle Relaxation (PMR) combined with mental training, however, no details were given. PMR was used here to enable participants to relax their muscle prior to imagery practice sessions. In general, PMR allows participants to achieve a relaxed state by performing alternate repetitive contraction and relaxation of a muscle group, recognising the tension in the muscles and then voluntarily relaxing the target muscle group. Relaxation conditions might distract from the imagery of performing the muscle strength task towards the presumably easier task of relaxation. Baird et al. (2004) suggested that PMR works as an important adjunct technique that needs to be combined with guided imagery practice to reduce osteoarthritis pain. They proposed PMR can cause both physiological and psychological relaxation by “reducing the response to stress, reducing skeletal muscle contraction and decreasing the sensation of pain”; goals which could impair imagery of muscle contractions.

In addition, according to Rushall and Lippman (1998), relaxation could be a reasonable prerequisite “if the goal is imagery control for the purpose of mental rehearsal of a developing skill, skill acquisition, which might facilitate attention to the details of an intended performance alteration or adjustment”. However, they suggest that during performance preparation, it is rare to attempt relaxation, as it is not compatible with ideal levels of arousal. They suggested that the level of physiological arousal that accompanies the imagery training is fundamental to enhance the mental practice efficacy to improve performance. Indeed, PMR could reduce the arousal state in favour of relaxation and therefore diminish imagery effectiveness for strength tasks.

Therefore, failing to adopt a specific imagery modality and perspective, as well as using relaxation techniques in addition to imagery training, might lead to ambiguity in the protocol and training, which might contribute to the inconsistent findings in imagery studies on muscle strength. Thus, future research should consider these issues when designing empirical studies.

Imagery ability

Due to the possibility, that individuals' imagery ability and its improvement might influence the strength outcomes in imagery studies, our current study is one of the first studies in the field of imagery intervention with muscle strength related outcomes that used an imagery ability assessment at pre-and post-assessment study stages (i.e., VMIQ-2 questionnaire). Findings showed that only the imagery training group that used “KIN+VI” demonstrated a significant improvement of the subsequent imagery ability (VMIQ-2 scores), while the KIN imagery group and CTRL group demonstrated a lower imagery ability on all VMIQ-2 sub-scale scores following the intervention period compared to pre-intervention level. In addition, a higher intensity in the use of visual imagery modality during training showed a significant positive correlation with subsequent improvement of imagery ability. Thus, adding visual imagery modality to the imagery training may play an essential role in improving imagery ability and capability to perform imagery protocols related to strength tasks. Imagery ability may influence the efficacy of using imagery training as it is assumed that subjects with greater imagery ability will practice imagery training more efficiently (Guillot et al., 2008). Imagery ability was described as a skill that individuals could continually improve by training and investing time (Hall, 2001).

Across the literature of imagery interventions, little research has examined approaches to improve the imagery ability and investigated subsequent improvements in targeted outcomes. Williams, Cooley, and Cumming (2013) examined the effects of Layered Stimulus and Response Training (LSRT) compared to Motor Imagery (MI) practice, and Visual Imagery (VI) “control” on imagery ability and performance of a motor skill (golf putting) with novice players, who were poor in imagery ability. Imagery ability was assessed using the Movement Imagery Questionnaire-3 (MIQ-3; Williams et al., 2012). The only difference of LSRT from the MI group was that the LSRT group were given a script to try to build the image up and make it as realistic and life-like as possible. The results showed the MI group improved only the visual ability subscale (i.e. ease of imagery), while the LSRT group showed a significant imagery ability improvement on both visual and kinaesthetic subscales. Moreover, the visual imagery improved in the internal visual perspective rather than external visual perspective for all participants. Although Williams et al. (2013) used different methodology compared to our current study (i.e., type of intervention, questionnaire and outcomes), their results might be used to support the current findings that showed significant improvement of visual imagery ability (i.e. imagery vividness) particularly in the internal imagery subscale, but no significant improvement in external subscales, following two weeks of imagery training in the "KIN+VI" group.

Imagery ability is an essential factor for the success of imagery intervention, as individuals with higher imagery ability benefit more from imagery interventions compared with individuals with lower ability (e.g., Hall, Buckolz, & Fishburne, 1992; Robin et al., 2007). Therefore, instead of excluding individuals who failed to meet some specific imagery ability criteria during an imagery screening phase, we suggest using imagery training during a pre-intervention stage to teach subjects and prepare them for the imagery training programme.

Underling mechanisms of imagery muscle strength alteration

Although the current study was designed to examine the effect of imagery training on muscle strength gain as well as to inform future physiotherapy applications, some explanations are discussed here to relate our findings to underlying mechanisms.

The current study displayed a strength alteration of hip abductors following imagery training without any physical execution after two weeks. The effect of the short period training on muscle strength capacity could be explained by neural adaptation rather than hypertrophy of muscle fibre. Morphological changes (i.e., muscle hypertrophy, myofibrillar growth and proliferation) occurs only in the late stage of training and needs longer training periods (Komi, 1986). Additionally, mechanisms related to fibre growth are connected to mechanical strain (Yin, Price, & Rudnicki, 2013). However, muscle strength alteration that occurred in the early weeks of training has been contributed to neural adaptation mechanisms (Komi, 1986; Sale, 2008).

Ranganathan et al. (2004) explained the demonstrated improvement in muscle strength for both distal and proximal muscles of human upper extremities following mental training “internal imagery” by an induced enhancement in the central command to the muscle based on Maximal Voluntary Contraction-related Cortical Potential (MRCP). They suggested that the imagery training primarily trained higher-order motor cortical region by repetitive mental attempts that maximally activate the muscle. Specifically, cortical centres lead to generate a stronger activation of the brain areas (i.e. supplementary motor area (Cz), contralateral (C3) and ipsilateral (C4) sensorimotor regions, and central location of the prefrontal cortex (Fz)) that have resulted in generating stronger and more co-ordinated signals from motor neurons to the trained muscles leading to increase strength.

The current data show that the combined “KIN+VI” group, by adding the visual modality to the KIN modality, tended to have a better muscle strength outcome than the group using KIN alone. In addition, all participants in this group (KIN+VI) tended to use internal visual perspective rather than external visual perspective. Few mechanistic studies examined the effect of specific imagery modalities on strength alteration. The combination of "KIN+VI" in the current study was analogous to the mental training called “internal imagery” or “mental training” by Yao et al. (2013) and Ranganathan et al. (2004), respectively. Ranganathan et al. (2004) and Yao et al. (2013) explained the strength improvement following imagery training by neural adaption. Specifically, they both demonstrated an improvement of motor command and activation of specific brain areas (i.e. supplementary motor area (Cz), contralateral (C3)) following imagery training, as indicated by altered MRCP in the trained muscle.

Yao et al. (2013) showed a significant elevation of the MRCP (primary motor (M1) and supplementary motor cortices) following muscle improvement in the internal imagery group only. Hence, they suggested the central nervous system reacts differently from the internal imagery and external imagery training. Further findings demonstrated that the MRCP during internal imagery activates motor cortical areas involved in the planning and execution of movement [somatosensory areas and M1] more than external imagery. This process might reinforce the neural circuitry and send stronger signals to the target muscles than external imagery. This study thus provides the potential neural mechanisms underlying the effect of internal imagery on muscle strength improvement.

To aid the understanding of the mechanism for the additive benefit of combined KIN+IV on motor performance, we can turn to research by Callow et al. (2017). This research theoretically proposed two probable mechanisms; firstly, that IVI and KIN may stimulate different independent areas of the brain, which may lead to a double-priming effect as a result of two separate areas being activated. The other possibility, they suggested a cumulative increase of brain activity in the (hMNS) particularly in the Brodmann Area 6 (BA6), is that this may have been caused by independent activations by IVI and KIN of the same brain area. Thus, the first suggestion regarded that more brain activity (i.e. perhaps suggesting a richer cognitive representation of the imaged performance) is the cause of enhanced the subsequent performance. While the second suggestion implies that an action execution may be associated with specific brain area that was activated during training (i.e., the brain area of functional equivalence).

Moreover, the current result demonstrated a significant increase in heart rate during the imagery practice of the hip abductors muscle task compared to resting HR. The increment of HR during imagery practice was consistent with HR elevation that was recorded after mental practice shown by Ranganathan et al. (2004) study. As previous reports indicated, if imagery training shares neural mechanisms with those responsible for motor programming, then brain activation during imagined action should be reflected, in some way, at the peripheral effectors level (Roth et al., 1996; Slimani et al., 2016). Imagery training could activate the Autonomic Nervous System (ANS) and peripheral effectors (Lang, 1979). The imagination of a physical task without any physical execution can change the cardiovascular system by increasing the systemic parameters (e.g. blood pressure, heart rate and respiration) following imagery practice, like it was shown in numerous studies (Beyer et al.,1990; Fusi et al., 2005; Jones and Johnson, 1980; Paccalin and Jeannerod, 2000; Wang and Morgan, 1992; Williamson et al., 2002;). Slimani et al. (2016) attempted to explain the mechanism of HR activity recorded during the imagery training according to the degree of imagined effort and mental imagery perspectives. However, they suggested that the underlying mechanisms for the cardiovascular effect during imagery training is not known, but it is possible that the central nervous system and the activation of the cortex caused an increase in sympathetic outflow and reciprocal inhibition of parasympathetic activity.

Together, the previous interpretations could contribute to the understanding of the effect of internal imagery practice "KIN+VI,” on subsequent muscle strength alterations. Hence, further empirical research investigating the role of combining visual imagery and kinaesthetic imagery modality with different strength tasks combined with neurological assessment techniques is warranted.

Study limitations and future research considerations

Despite the promising results of the current study, it has several limitations. The control group did not participate in any mental or physical exercise, and they only attended the assessment sessions at baseline and post-intervention test. Therefore, participants in the control group had less contact with the experimenter. This raises concerns of an experimenter-presence effect which may confound the results and we are therefore cautious to generalize the current results. This design was chosen because of time constraints and limited resources, to allow participants to engage in other activities not related to imagery practice. However, the no-practice control group design was performed according to the justification and methodology used in a previous similar study (Smith, Collins, & Holmes, 2003). They designed their methodology based on previous research that had been conducted by Driskell et al. (1994), which showed no significant differences in performance between control groups which performed a placebo task compared with no practice.

Another issue of this study is using self-report questionnaires (e.g., to rate the level of engagement of mental training during the practice and reporting the extent of remembering the imagery script), as participants may overestimate or underestimate the efficacy of the intervention.

This could be replaced by more objective measurements in further research studies. For example, electromyography (EMG) could be used to monitor muscle activity during imagery practice, which may help to indicate the underlying mechanisms of subsequent muscle strength improvement following imagery training. Thus, using EMG should be considered in further imagery intervention studies to avoid any misinterpretation of data. In addition, the healthy participants from Bangor's population, most of them young students, may have well developed physical attributes and the room for muscle strength improvements was therefore too small. Moreover, as there is a known difference in gender distribution across study groups, thus it would be suggested that future studies should consider matching groups for gender, e.g., through stratified randomisation.

Potential implications of current results for musculoskeletal physiotherapy practice.

The results of this study confirm the viability and potential effectiveness of simple imagery training techniques to improve the isometric strength of larger lower limb muscles. Thus, this result provides further support for the theoretical and practical justification of imagery practice in the field of physiotherapy and rehabilitation. It is a promising step towards integration and exploration of imagery training for muscle strength with patients who have a limited physical capacity (e.g., a neuro-musculoskeletal disorder), assuming the ability to engage in imagery is intact.

Hence, imagery practice may be applied to different rehabilitation contexts as a complementary or alternative approach to the traditional physiotherapy interventions. Specifically, the current study examined the role of imagery practice on hip abductor muscles which is one of the important components in walking and is important in rehabilitation programmes for lower limb musculoskeletal conditions. Therefore, targeting hip abductor muscles by using imagery practice might be a useful approach to be applied by physiotherapists when physical exercise is restricted (e.g., flare-up arthritis pain, post-operative protocol of total hip or knee replacement, post-operative protocol of anterior cruciate ligaments construction), or unavailable (e.g. first days following hip injury or surgery, immobilization period, gait training in neurological conditions).

In addition, for acute musculoskeletal injuries, most physiotherapists use a Rest, Ice, Compression, Elevation (RICE) protocol as traditional intervention, which can be effective. However, there is insufficient evidence available from randomized controlled trials to support the RICE approach, and it has been argued that the rest period should be replaced by adding an active therapeutic exercise in the early weeks of rehabilitation (Bleakley et al., 2007; van den Bekerom et al., 2012). Therefore, one of the limitations of the RICE protocol is that avoiding physical activity of the injured limb during the early weeks post-injury may delay the physical recovery by deterioration of strength. Consequently, one of the obvious possible clinical future applications of imagery practice in this regard is to incorporate it with RICE approaches in early stages of intervention protocols or to consider it as an alternative approach. Imagery training may facilitate healing by improving muscle strength (as suggested by the current study) or maintaining the muscle strength of an injured limb during the acute stage (as it has been shown to prevent muscle strength loss after short-term immobilization; Newsom et al., 2003).

Conclusion

This study provided promising results, indicating that larger lower limb muscle strength can be improved following two weeks of imagery training. This may have important implications for future physiotherapy research, and imagery practice might be considered as a feasible promising rehabilitative tool. The current study used a simple imagery training programme which has the potential to contribute to enhance the imagery ability. In addition, this study, to the best of our knowledge, is the first study on muscle strength that attempted to delineate kinaesthetic imagery from visual imagery during imagery training. The results of this aspect encourage the application of imagery training in a physiotherapy context with focus on the combination of kinaesthetic and visual imagery for patients with reduced ability to use active strength training.

Chapter 3: **Effectiveness of Imagery Training compared with Exercise Training on Hip Abductor Strength and Electromyography (EMG) Production in Healthy Adults**

Abstract

Purpose**:** Imagery training could be an important treatment for muscle function improvements in patients with limitations in exercise training as a result of pain or other adverse symptoms. However, recent studies have been restricted primarily to small muscle groups, using a wide variety of methodological approaches, and have reported contradictory outcomes. Moreover, a possible bilateral transfer effect in imagery training has not been examined in larger muscle groups. We therefore investigated the effectiveness of unilateral imagery training in comparison with exercise training on hip abductor muscles strength and electromyogram (EMG) amplitude. Additionally, both limbs were assessed to investigate bilateral transfer effects.

Methods*:* Healthy individuals (n=30) took part in an imagery or exercise training intervention for two weeks, with assessments conducted both before and after training. The participants, after randomization into an imagery and an exercise group, trained five times a week under supervision, with additional self-performed training on the weekends. The training consisted of performing or imagining five maximal isometric hip abductor contractions (one set), with the set repeated seven times. All measurements and training were performed with the participants lying on their side on a dynamometer table. The imagery script combined kinaesthetic and visual imagery (KIN+VI) for producing imagined maximal hip abduction contractions. The exercise group performed the same number of tasks, but they engaged in actual contractions. Maximal hip abduction isometric torque and EMG amplitudes were measured for the right and left limbs in both the pre- and post-training assessment points. Additionally, handgrip strength and right shoulder abduction (strength and EMG) were measured as a control measurement of motivation and generalized motor effects.

Results**:** Using a mixed model ANOVA (strength measures) and Wilcoxon tests (EMGs), data revealed a significant increase in hip abductors strength production in the imagery group on the trained right limb (~7%) (t (14)=-4.12, p=0.001). However, this was not reported for the exercise group. Additionally, left hip abduction strength (not used for training) did not show a main effect for strength; however, there was a significant interaction between group and time, revealing that the strength increased in the imagery group while it remained constant in the exercise group (F (1, 28)=11.25, p=0.002, η^2=0.29). EMG recordings supported the strength findings, showing significant elevation of EMG amplitudes after imagery training on the right and left sides (Z=-3.238, p=0.001; Z=-2.585, p=0.010) respectively, while the exercise training group did not show

any changes. Moreover, measures of handgrip strength and shoulder abduction showed no effects over time and no interactions in both groups.

Therefore, the experiments demonstrated that imagery training is a suitable method for the effective increase of functional parameters in larger limb muscles (strength and EMG). In addition, the enhancement in both sides (trained and untrained) revealed the induction of a bilateral transfer effect through imagery training. Exercise training did not show any increases in the measured parameters, omitting functional improvements. However, as the participants were healthy, it is possible that they would not be likely to see much improvement within the short study period. Imagery training was effective in increasing central motor command towards the muscles, and the effect seemed to be segmental (no increase in handgrip strength and shoulder abduction parameters) and affect both sides (trained and untrained).

Conclusion: The imagery training was effective in creating functional improvements in limb muscles and produced a bilateral transfer on strength and EMG measures.

Keywords: imagery, exercise, physiotherapy, motor imagery

Introduction

Improvement of muscle strength using traditional approaches is a cornerstone in physiotherapy practice. For example, exercise is one of the most common practices in routine physiotherapy intervention plans that aim to reduce the pain and optimize functional recovery in a wide range of musculoskeletal conditions (Calatayud et al.,2014; Kuhn, 2009; Verhagen et al.,2007; Barker et al.,2014; Bertozzi et al.,2013; Hanratty et al.,2012; Bennell, & Hinman, 2011). Exercise training can be applied with different modes and intensities to improve muscle strength. For example, a maximal and moderate intensity of voluntary isometric contraction training, carried out over a period of three weeks, can improve isometric strength gains (knee extension torque), while low intensity exercise did not show any strength improvement (Szeto, Strauss, De Domenico, & Lai, 1989). Additionally, unilateral 80% of maximal isometric training exercise undertaken for six weeks of knee extensors (quadriceps) showed significant improvement in the strength of the trained quadriceps (Weir, Housh, Weir, & Johnson, 1995).

In general, strength improvements could be a result of both morphological and neurological adaptations (Folland, & Williams, 2007); strength gains from voluntary contractions can be achieved by morphological changes (hypertrophy of muscle, increase muscle fibre diameter) which usually occur at the later stages of training. The strength gains at the early stages of training are based on neural adaptation (Yue, and Cole, 1992; Komi, 1986; Lebon, Collet, & Guillot, 2010).

However, the use of exercise is often limited if pain or other conditions impair its therapeutic application, e.g. after surgery and/or diseases (Krishnan, & Williams, 2011; Rainville, Hartigan, Jouve, & Martinez, 2004; Kitzman, Higginbotham, Cobb, Sheikh, & Sullivan, 1991; Lalande, Gusso, Hofman, & Baldi, 2008). Electrical stimulation has been used as an adjunct technique to overcome the limitations of exercise; however, this has not consistently been found to be successful (Coote, Hughes, Rainsford, Minogue, & Donnelly, 2015; Lepley, Wojtys, & Palmieri-Smith, 2015; Miyamoto, Kamada, Tamaki, & Moritani, 2016; Parissis et al., 2015).

Recently, increasing attention has been paid to the effects of imagery techniques on muscle strength and function. Significant improvements in muscle strength have been found following imagery training of various muscle groups (e.g. Ranganathan, Siemionow, Liu, Sahgal, & Yue, 2004; Reiser et al., 2011; Slimani, Tod, Chaabene, Miarka & Chamari, 2016). Notably, some studies examined the efficacy of imagery intervention compared with isometric contractions training on muscle strength gains. Sidaway & Trzaska (2005) trained ankle dorsiflexor muscles using either physical or mental (kinesthetic imagery) training. This was practiced performing maximal isometric contractions either physically or mentally for three sets of 10 repetitions, 3 times per week for 4 weeks. They found significant improvements (ankle dorsiflexor muscles strength) for the physical practice group (25.28%) as well as the mental practice group (17.13%), but not for a control group (-1.77%). Their findings did not show a significant difference between the physical and mental interventions on strength gains. Furthermore, Zijdewind, et al. (2003) examined the efficacy of imagery training compared with low intensity isometric contractions exercise on plantar-flexor muscles of the ankle over a seven-week intervention period. Results showed that imagery training was superior to low-intensity isometric training. These two studies demonstrated that both imagery and exercise could enhance isometric muscle strength, although each adopted different instructions in the imagery interventions.

A further benefit of imagery training, besides reducing the risk of pain, is related to the lack of induction of neuromuscular fatigue in contrast to physical exercise; adding imagery training to physical exercise training did not induce additional fatigue despite the repetitive activation of the corticospinal tracts (Rozand, Lebon, Papaxanthis, & Lepers, 2014). However, most of the imagery training studies investigated only small muscle groups (finger, forearm, ankle) (e.g., Ranganathan et al., 2004; Smith, Collins, & Holmes, 2003; Sidaway, & Trzaska, 2005; Yao, Ranganathan, Allexandre, Siemionow, & Yue, 2013; Yue, and Cole, 1992; Zijdewind, et al., 2003). Few imagery studies showing strength gains with larger muscle groups were identified; one study reported improvement of hip flexors by a 24% increment, following ten imagery sessions of approximately 15 minutes over two weeks of training (Shackell & Standing, 2007). However, the study was very simplistic in its technical approach, using very basic strength assessment protocols and measures (e.g. lifting weights).

Positive effects of imagery interventions on strength performance have been mostly associated with a shorter intervention period (3-6 weeks) rather than a longer intervention period (7-12 weeks) (Slimani, et al., 2016). Driskell, Copper, & Moran (1994) suggested that longer imagery training limits the efficacy of imagery intervention, and they recommended a duration of less than 20 minutes/session for effective imagery training.

The underlying mechanism of imagery training effects on muscle strength gains is believed to be neural adaptation; previous work reported a significant improvement in muscle strength that was associated with elevation in Movement-Related Cortical Potential (MRCP) over both the primary motor (M1) and supplementary motor cortices after internal imagery training (Ranganathan et al.,2004; Yao et al., 2013). It was suggested that imagery training strengthens the brain-to-muscle command and concurrently improves the motor unit recruitment and activation, leading to greater muscle output (Yao et al., 2013). However, the specific pathways and limitations of neural and muscular adaptions induced by imagery training are not well documented in the literature.

In addition to the effects of exercise training on the trained muscle group (ipsilateral training effect), training can also have effects on the contralateral untrained muscle group. The cross-training effect (also called the bilateral transfer, cross-education, or intermanual transfer), is an inter-limb phenomenon and was discovered by Scripture et al. in 1894 (Munn, Herbert, & Gandevia, 2004; Land, Liu, Cordova, Fang, Huang, & Yao, 2016; Lee, & Carroll, 2007). It has been extensively examined and defined as 'the transfer effect from the trained limb to the homologous contralateral untrained limb following unilateral training' (Land et al., 2016). It reportedly enhances performance outcomes (e.g. strength, skill execution and endurance) following a period of unilateral intervention (strength training, skill learning and endurance training) (e.g. Farthing, Borowsky, Chilibeck, Binsted & Sarty, 2007; Hortobágyi, Lambert, & Hill, 1997; Shima et al., 2002; Zhou, 2000).

The transfer effect can occur following various unilateral training methods, such as contraction training using physical voluntary exercise, electrical stimulation (Hortobágyi et al., 1997; Zhou, Oakman, & Davie, 2002), or mental practice training of finger muscles (Yue & Cole, 1992). In addition, the bilateral transfer effect might be influenced by specific sub-training methods; for example, Zhou (2000) found that training with eccentric contractions elicits a greater bilateral transfer effect than training with isometric or concentric contractions. In addition, the bilateral transfer effect can occur in the absence of a considerable muscle activity in the untrained muscle during the unilateral training (Hortobágyi et al., 1997; Evetovich et al., 2001; Devine, LeVeau, & Yack, 1981) and with no muscle hypertrophy (Ploutz, Tesch, Biro & Dudley, 1994; Narici, Roi, Landoni, Minetti, & Cerretelli, 1989).

The potential underlying mechanism of the bilateral transfer phenomenon seems more of a central adaptation rather than peripheral, as suggested by an investigation of the bilateral transfer on strength following unilateral exercise without detecting any hypertrophy (Farthing & Chilibeck., 2003; Farthing, Chilibeck, &, Binsted, 2005; Moritani, 1979). Further evidence that peripheral adaptation is improbable derives from studies that showed a bilateral training effect can occur (increased strength of untrained muscle group) even if the untrained muscle remained virtually quiescent during training, as measured by EMG (Hortobagyi et al., 1997; Evetovich et al., 2001; Ranganathan et al., 2004).

As mentioned, investigations on bilateral transfer of strength gains have been performed with varied approaches (e.g. exercise); however, studies related to imagery training are sparse (Farthing et al., 2007; Yue & Cole, 1992). Investigating the bilateral transfer effect with imagery training in muscle groups relevant to physiotherapy practice could provide important findings for the future application of imagery training to improve the efficacy of rehabilitation protocols (Ausenda, & Carnovali, 2011; Arora et al., 2011).

Moreover, whether the transfer effect is observed in homologous muscle groups in other segments (in particular, transfer from the leg muscle group to the homologous arm muscle group) has not been investigated. Thus, the specificity of effect is important in connection with other lines of evidence that support neural adaptation as the underlying mechanism of bilateral transfer effect, i.e. strength alterations only detected in the contralateral homologues muscle. If the mechanism mediating bilateral transfer is systemic in origin, then strength alterations may occur in the other muscle segments as well (Lee & Carroll, 2007). This could be particularly important for understanding the motor learning principles connected with imagery in comparison with exercise.

The current understanding of physiological responses to imagery training predicts specific response of the muscles involved in the movement, rather than a generalized arousal response (Cuthbert, Vrana, & Bradley, 1991; Zijdewind et al., 2003; Lang, 1979; 1985). Therefore, examining the specificity of imagery training on strength and EMG response in muscles might explain underlying mechanisms and physiological responses to imagery training.

Moreover, the efficacy of imagery training has not been established with larger muscle groups, with the exception of the findings of Shackell & Standing (2007), and no clear differential effects between imagery training compared with exercise training on bigger muscle groups (e.g. hip abductors) have been shown. Indeed, investigations into strength gains following imagery training have not been expanded to contralateral and homologous muscle groups of other segments.

Consequently, the first objective of this study was to examine the ipsilateral training effect of imagery training compared with exercise training on the trained hip abductors strength and electromyography amplitude (EMG) with short periods of intervention. For this, we used our formerly established imagery protocol (i.e. based on study one (chapter 2) findings. Hence, the current imagery training was used with the combined imagery protocol (KIN+VI) as it is showed superiority compared with other protocol, KIN alone) and compared this with two weeks of isometric exercise of the hip abductor muscles. The second objective was to explore whether bilateral transfer occurs in strength and EMG outcomes following unilateral imagery training, as it was not yet examined with hip abductors, which is important to identify the mechanism and physiological response with strength task following imagery intervention. The third objective was to investigate a possible transfer effect of imagery and exercise training to a homologous muscle group of a different body segment (deltoideus medius muscle). Fourthly, we examined the possible discrepancy in motivation between study groups which might influence potential strength gains. Thus, in the current study, motivation was investigated using subjective reports and a proxy-measure (handgrip strength) before and after administration of the assigned interventions. Finally, other possible covariates influencing the outcome parameters were assessed (imagery ability, intervention commitment and body characteristics).

Research questions

1. How do imagery and exercise practice differentially affect the muscle strength and muscle electrical activation (EMG) of the trained dominant lower limb muscles (hip abductor muscles) following a two-week training programme?
2. Do imagery and exercise practice for two weeks differentially affect the strength and muscle electrical activation of the homologous untrained muscles of the contralateral side (hip abductor muscles)?
3. Do imagery and exercise practice have a transfer effect on the muscle strength and muscle electrical activation of the upper limb (untrained deltoideus medius muscle) with homologue function (arm abduction) after lower limb training for two weeks?

Method

Participants

Thirty-three male participants (mean age ± SD: 25.50±3.99 years) were recruited from the North Wales population (Bangor University students and local residents of Bangor and surrounding towns). To be eligible for participation in the current study, potential participants had to be male, healthy, right-handed, and had no recent lower limb injuries or diseases. The target age range was between 18 and 60 years. Ethical approval was obtained from the ethics committee at the School of Sport, Health and Exercise Science at Bangor University. Participants were reimbursed for their time after completion of the study (£100 for all study groups). Written informed consent was given by all participants prior to the start of study participation.

Study Design and Experimental Groups

The current study used an experimental design with two arms. Participants were assigned to one of two study groups, either the *Imagery* group or the *Exercise* group, using random allocation (the principal researcher assigned participants to two groups based on a random number list generated using Excel). Both groups were identical on all study procedures except that the intervention approaches differed.

Intervention Protocols

The current study comprised two intervention protocols (*Imagery* and *Exercise*). Participants in the *Imagery* group received a mental practice protocol involving ‘imagery training’. Participants in the *Exercise* group received a physical practice protocol involving ‘isometric exercise training’. More details regarding the intervention procedure were given in the following sections.

The training protocol consisted of 10 supervised training sessions in the laboratory over a two-week period on all weekdays (Monday to Friday), with independent home practice at the weekends. Participants in both intervention groups performed either isometric exercise training or imagery training on the right hip abductors, lying on their left side with the right leg on top (Figure 3).

Exercise group.

Participants performed physical exercise training that involved maximal isometric contractions of the right hip abductors against a static dynamometer arm (Figure 3). EMG electrodes were connected to the right gluteus medius muscle during one of the training sessions (the 2nd session was selected to make sure all participants became familiar with their assigned intervention protocols) to determine muscle activations during the physical isometric exercise (Figure 5). All other training sessions were performed without EMG recordings, except for pre-study and post-study assessment sessions.

Each exercise training session lasted for 30 minutes and encompassed seven sets of isometric exercise training with two minutes of rest following each exercise set. The isometric exercise sets included performing five maximal physical isometric contractions of the right hip abductors against a static dynamometer arm that was fixed at 25˚ of hip abduction; this degree was used in the training protocol as it was used as a reference point during muscle strength assessment of hip abductors (Hislop, Avers, & Brown, 2013). Each isometric contraction was held for ~15 s followed by 15 s rest. The experimenter timed the exercises, telling participants when to start contraction and when to relax. A total of 35 maximal physical isometric contractions of the right hip abductors were performed during each session. Further descriptions of the physical practice protocol, specific instructions, and the structure of the physical practice protocol can be found in Appendix C-4.

Imagery group.

Participants performed an imagery-training task that included imagined maximal contractions of the right hip abductors. Participants were instructed to use a combination of KIN with VI modalities because the combined KIN+VI was found to be more effective in the first study of this thesis (chapter 2). The EMG electrodes were connected to the right gluteus medius muscle during only the second imagery session to check if there was any muscle activation (i.e. mental training engagement check).

The imagery training protocol involved 10 sessions over two weeks, Monday to Friday inclusive, with each session lasting for 30 minutes, encompassing seven sets of imagery training. The imagery training set included listening to an imagery audio script giving instructions, during which participants performed imagined maximal isometric contractions of the right hip abductors. The imagery script directed participants to mentally simulate the maximal isometric contractions exercise (cognitive imagery practice) and practice that by using the combined sensory modality (KIN+VI) without any visible physical execution of the task. For example, "See and feel yourself pushing your right leg against a dynamometer arm that fixes at 25˚ of hip abduction." After listening to the script, participants performed five imagined maximal isometric contractions of the right hip abductor muscles, drawing on an imagined scene of the physical task by using the combined modalities. Each imagined contraction was held for ~15 s, followed by 15 s of rest. The experimenter timed the imaginary contractions and relaxations during training by telling participants when to start and when to stop. A total of 35 imagined maximal isometric contractions of the right hip abductors were performed during each session. For more details regarding the mental practice protocol structure and specific instructions, see Appendix C-5.

Home training programme.

The home training protocol was mandatory for all participants in all study groups. A written intervention script, an audio version of the intervention script, a weekend diary log and a stopwatch were provided to each participant in both *Imagery* and *Exercise* groups to facilitate accomplishing the home training protocol. Participants were asked to perform two home training sessions on their own for each of two weekends to achieve four total weekend sessions over the study period. Each participant was asked to perform seven sets of either physical training or imagery training. Each set included five physical isometric contractions of the right hip abductors for the *Exercise* group or five imagined isometric contractions of the right hip abductors for the *Imagery* group, each held for ~15 s at 25˚ of hip abduction followed by 15 s of rest. The training protocols were identical to the lab-supervised protocol, except that the *Exercise* group participants were asked to perform an ‘unloaded’ exercise, only elevating and holding the leg, matching the pattern of the supervised exercise. Participants in both groups were asked to record the times they performed the sessions and to rate their level of motivation following each weekend session using the weekend diary log provided (see Appendix. B-5).

Procedure

Participants were invited to take part in the current study using various advertisement methods, including university email circulars, local advertisement boards, social media and personal invitations handed out in libraries. Prior to participation in the study, all potential participants read an information sheet, after which the experimenter asked if they wished to take part in the study and if they met our inclusion criteria. Each participant passed through the four phases of the study: the familiarization phase, the baseline assessment phase, the intervention phase and the post-intervention assessment phase (see Figure 1).

The familiarization phase started at the first session and involved having each participant complete three self-reported questionnaires: a physiology informed consent and medical questionnaire, the International physical activity questionnaire (IPAQ) (Craig et al., 2003) and a vividness of movement imagery questionnaire (VMIQ-2) (Roberts, Callow, Hardy, Markland & Bringer, 2008); further details regarding the questionnaires can be seen in the assessments sections below. In addition, the experimenter gathered demographic data about each participant that included body characteristics. At the end of this session, the experimenter briefly described to each participant the muscle strength measurements then performed practice trials of all assessments to familiarize the participant with the procedure before the baseline measurement phase.

Next, the baseline assessment phase comprised of one session, during which the experimenter examined the Maximal Isometric Torque (MIT) for different muscle groups, including bilateral hip abductors, right shoulder abductors and left-hand grip strength. Electromyography (EMG) was recorded for the bilateral gluteus medius and right deltoideus medius muscles on each participant. This was followed by the pre-intervention motivation and effort questions (See Appendix B-2).

As a precaution, participants were instructed to maintain their usual daily physical activity levels and not to take part in any non-routine resistance exercise programmes over the course of the study. At the end of this session, each participant was randomly allocated to one of two study groups (*Exercise* or *Imagery*). Participants were provided with brief information regarding each intervention type (explanations of how to perform the assigned intervention protocols; e.g. maximal physical isometric contractions or mental simulation of the maximal isometric contractions). Finally, this session concluded with producing an initial schedule for daily training visits for each participant.

The intervention phase lasted for two weeks. During the training programme, each participant attended 10 individual supervised sessions that each lasted for 30 minutes. These sessions were conducted in a quiet lab at the Physical Activity and Wellbeing centre (PAWB) at the School of Sport, Health and Exercise Science, Bangor University. At the first training session, each participant received a written copy of the training protocol that included specific instructions regarding the particular intervention training (i.e. *Imagery* or *Exercise*) they were participating in and received oral explanations and a practice trial demonstration of their particular intervention.

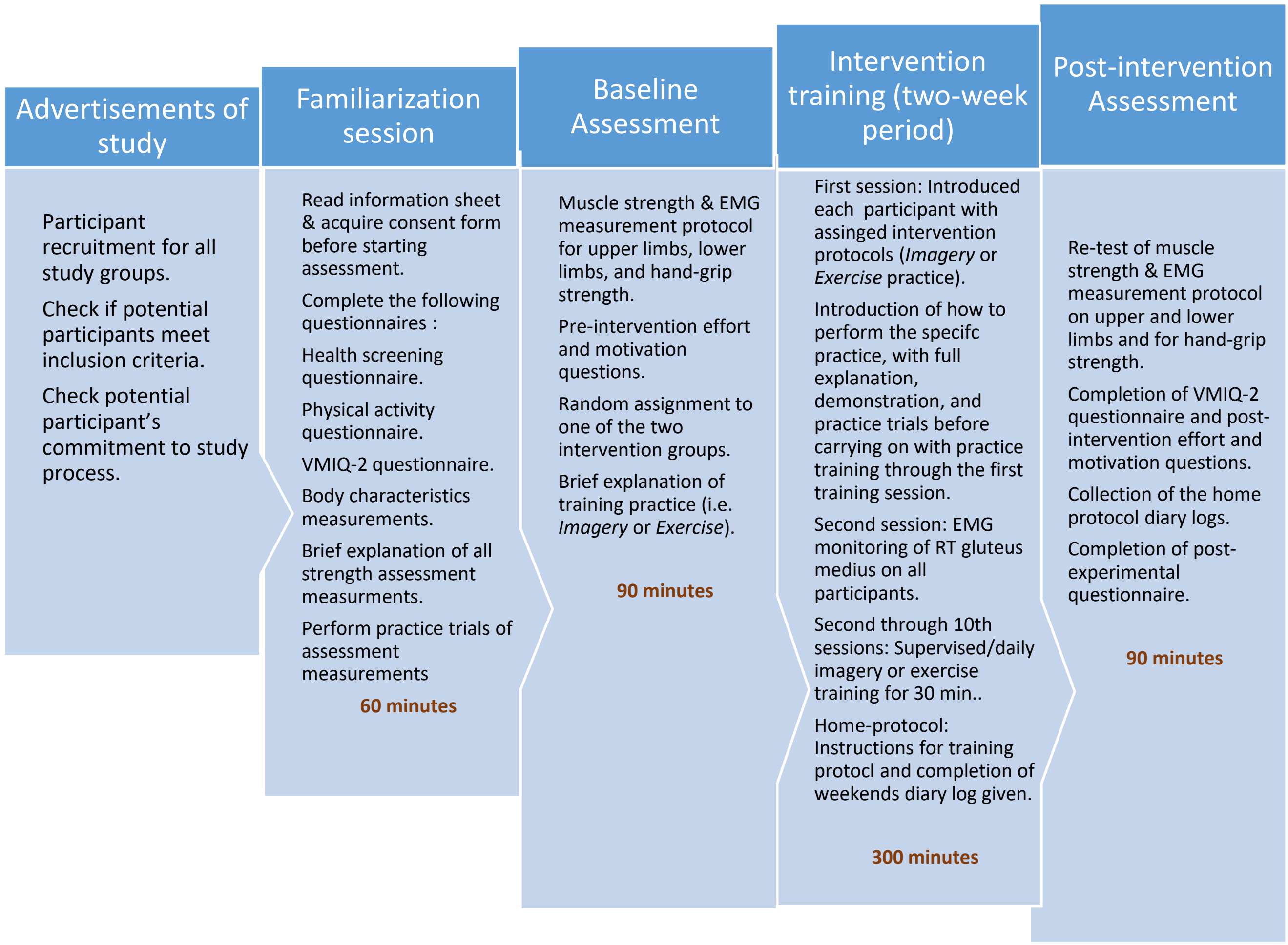
Participants in the *Exercise* group performed a couple of trials of physical isometric contractions against a static dynamometer arm following the experimenter’s guidance. For the *Imagery* group, the experimenter orally explained the imagery training technique, and then participants listened to an audio recording and performed a couple of imagery training trials as described above in the Intervention section. Once all participants understood the specific training protocol for their group, whether *Imagery* or *Exercise*, they then carried on the training protocol until the end of the first session under the experimenter’s supervision, as explained in the intervention section earlier.

Starting with the second session and continuing until the end of the training protocol segment of the study, each participant attended a daily imagery or exercise training session at a specific assigned time under the supervision and guidance of the experimenter (described in the intervention section). During the second intervention session, the experimenter monitored and recorded the EMG activity of the right hip abductor muscle (i.e. the gluteus medius). EMG monitoring was used to check if participants successfully engaged in their exercise or imagery practice. Participants of the *Imagery* group were corrected in their approach if they showed EMG activity during imagery practice.

In addition, as part of the training protocol, the home programme for each of the intervention groups was introduced at the end of the training session that preceded the first weekend of the intervention. All participants received an explanation of the protocol that they were asked to perform on weekends as described earlier.

All participants, who successfully completed the intervention protocol without missing any training sessions or reporting an injury that may have occurred during training, were asked to participate in the post-intervention assessment. This phase included a muscle strength and activation assessment using the same procedure used for the baseline assessment phase and completion of an imagery ability questionnaire, a post-intervention motivation and effort questionnaire and a post-experimental questionnaire. The total time required to complete the study was approximately 9 hours for each participant, divided across all study phases, as shown in Figure 1.

Figure 1: Study Phases



Assessments and Measurement

The assessment section of the current study comprised strength and activation measurements for handgrip, shoulder abductors and hip abductor muscles groups using direct objective assessments of strength and electrical muscle activity. Additionally, self-reported questionnaires related to physical activity, health status and imagery ability. Demographic data were also recorded, which encompassed body characteristics including age, gender, height, weight and dominant leg.

Muscle Strength Measurement

Experimental Procedure.

At pre-study and post-study assessment sessions, participants were asked to perform a three-minute warm-up on a cycle ergometer prior to muscle strength and activity assessments (figure 2).

After the warm-up cycling, participants were instructed on and prepared for the assessment tests that followed, as described below.

Bilateral Hip Abductor Muscles Strength Assessment.

Change in hip abductor muscles strength is the main outcome of this study. Hip abductor muscles strength was assessed for both sides on each participant in both the pre-study assessment and the post-study assessment phases, using the same procedures and protocols.

Instrument.

The Maximal Isometric Torque (MIT) of the hip abductor muscles on both sides was measured for each participant using a HUMAC dynamometer (HUMAC Cybex NORM 2004, Computer Sports Medicine Inc., Stoughton, MA, USA). Muscle strength data were analysed and processed using AcqKnowledge software (BIOPAC Systems Inc., Goleta, CA, USA) that interfaced with the HUMAC dynamometer. Prior to the assessment, all participants received information about the apparatus (i.e. safety precautions and positioning on the dynamometer), were familiarized with the strength test task and were asked to attempt trials (2-3 times) of the assessment protocol.

Participant positioning on the dynamometer followed the guidelines in the HUMAC dynamometer instruction manual (Papadopoulos, Noyes, Jones, Thom, & Stasinopoulos, 2014). Each participant lay on his non-tested side, facing away from the dynamometer. The tested leg was on top of the non-tested leg, with 0° flexion and external rotation of the hip joint. The non-tested leg had approximately 30° hip flexion and 30° knee flexion for more comfort and stability. The non-tested leg and trunk were also strapped to the dynamometer table for stability. The positions of the dynamometer table and the dynamometer arm were adjusted to obtain an accurate measurement of the maximal isometric torque of the hip abductor muscles (gluteus medius), see (Figure 3), using the following dynamometer settings: dynamometer orientation at 0°, dynamometer tilt at 0°, seat orientation at 0°, and seatback tilt fully reclined. The tested hip joint was fixed to examine hip abductors strength at 25° of hip abduction. The hip abduction angle of 25° was chosen because clinicians use this degree during manual muscle strength assessment in routine physical assessments (Hislop et al., 2013). The pads of the dynamometer arm were placed and stabilized by a strap on the distal, lateral portion of the thigh, just proximal to the patient's lateral femoral condyle. The length of the dynamometer arm was adjusted according to each participant's size. Finally, the dynamometer's rotation axis aligned with the midpoint of the line linking the posterior superior iliac spine and the greater trochanter (Correia, Ferreira, Aveiro, Pereira, & Driusso, 2013).

Assessment Protocol Procedure.

Each participant lay on one side of the body. For the pre-study assessment and the post-study assessment, side selection was randomized in a counter-balanced fashion, left or right side first, due to the need to measure both sides. Additionally, after the first set of assessments, participants completed a 3-minute cycling warm-up to avoid order effects and influences of hip abduction testing on the contralateral side. Therefore, the testing procedure proceeded in the following steps after this warm-up phase on a cycle ergometer, as defined above at the start of experimental procedure.

Each participant performed a trial of four submaximal contractions. After two contractions were performed, the exercise was interrupted by a one-minute rest. This was followed by 25% and 50% of maximal contraction in preparation for the maximal test, followed by two minutes of rest. Then, each participant performed the actual test, which included three maximal isometric contraction trials, with identical verbal encouragement given to all participants by the experimenter. Each maximal contraction was held for 5s, with a one-minute rest between each trial. The peak isometric hip abduction torque was recorded, and the highest of the three values was used for statistical analysis (Jan et al., 2004). The maximal isometric hip abduction torque was measured in newton-metres (N.m).

Figure 2: Photo of a volunteering participant (image used with permission) doing warm-up on a cycle ergometer

Figure 3: Participant's position for the maximal isometric contractions of the right hip abductors on HUMAC dynamometer (volunteering participant; image used with permission)

Shoulder Abductor Muscles Strength Assessment

Shoulder abductor muscles strength was assessed on the right side of each participant during the pre-study assessment and post-study assessment phases, using the same procedures and protocols. This was performed to assess any generalized effects and possible influences on homologue muscles of other segments.

Instrument.

A HUMAC dynamometer (HUMAC Cybex NORM 2004, Computer Sports Medicine Inc., Stoughton, MA, USA) was used to examine the maximal isometric torque of a shoulder abductor at 45˚ of abduction (Rahbek et al., 2017). Participant position in the dynamometer followed the guidelines published in the HUMAC dynamometer instruction manual. (Figure 4). Each participant was instructed to sit on the HUMAC chair that was attached to the dynamometer, with hip and knee at 90˚ flexion positions. Their back was fully supported in the chair by a lumbar pillow and chair belts and straps were used to ensure more comfort and stabilization. Participants' feet were supported and placed over the chair foot stand.

The dynamometer chair setting was modified to use the following specific settings: rotation scale of 80°, seat position up, back angle of 68° and the monorail was 32°. Additional set-up of the dynamometer and dynamometer arm were as follows: Dynamometer tilt of 30°, dynamometer height of 13° and dynamometer rotation of 10° (in green). The dynamometer handle was adjusted according to participant comfort and the length of the dynamometer arm was adjusted according to each participant's dimensions. The dynamometer's rotation axis was aligned parallel with the acromion process to allow matched movements of the right shoulder abductors and the dynamometer arm in the same direction (i.e. lateral abduction, side shoulder movement, moving the arm away from the side).

Assessment Protocol Procedure.

The protocol used to test maximal isometric torque of shoulder abductors (i.e. strength of deltoideus medius) was the same protocol described above for testing the MIT of the hip abductors, except the settings for the chair and dynamometer differed. The assessment here was only for the right side.

Participants were instructed to sit on the dynamometer chair and the dynamometer arm was positioned parallel to the lateral side of the participant's right shoulder. The participant held the dynamometer arm handle in their right hand and the movement of the dynamometer arm was aligned to be in the same direction as the shoulder abduction movement. The participant moved the dynamometer arm laterally away from their body (i.e. abduction movement) to become familiar with the movement. After that, the dynamometer arm was restricted to 45° of lateral abduction to enable participants to perform the maximal isometric contractions of shoulder abduction movement. Each participant was asked to complete four submaximal trials as explained above, followed by resting for two minutes.

Next, the participant was asked to perform the actual test, which consisted of three maximal isometric contraction trials against the static dynamometer hand of 45° of lateral abduction. Each contraction trial lasted for five seconds, followed by one minute of rest between trials, all of which were timed by the examiner. The peak isometric shoulder abduction torque was recorded and the highest of the three values was used for statistical analysis. The maximal isometric torque of shoulder abduction was measured in newton- metres (N.m).

Figure 4: Participant’s position for shoulder abductor muscles strength assessment (HUMAC dynamometer); (volunteering participant; image used with permission)

Handgrip Strength Assessment.

The handgrip strength (HGS) of the left hand was measured in the pre-study assessment and post-study assessment phases as a control measurement of motivation and generalized motor effects.

Instrument.

A Jamar Analogue Hand Dynamometer (Lafayette Instrument Company, Lafayette, IN, USA) was used to assess maximal handgrip strength in kilograms for the left hand (all participants in the study were right-handed). The apparatus was calibrated before starting handgrip testing.

Assessment Protocol Procedure.

The testing protocol was based on the recommendations from the systematic review conducted by Roberts et al. (2011). Therefore, the standardised positioning for each participant was as follows: participants were seated in an appropriate chair and shoulders were adducted and neutrally rotated, elbow flexed at 90°, forearm in a neutral position and wrist between 0° and 30° of dorsiflexion.

After one familiarization trial, participants were asked to perform three maximal trials; the mean of the three trials was calculated to be used in the statistical analysis.

Muscle Electrical-Activity Measurements (EMG)

The muscle activity was the secondary outcome in this study which was assessed by recording the EMG amplitude from the hip abductor muscles (gluteus medius) and the shoulder abductor muscles (deltoideus medius). Assessments of EMG of the bilateral gluteus medius and the right deltoideus medius were performed during the pre-study assessment and post-study assessment sessions using the same procedures and protocols.

EMG Assessment Procedures.

Skin preparation.

Prior to the assessment process, participants' skin was prepared by shaving off the hair, rubbing the skin with an abrasive gel, wiping with a paper tissue, cleaning with an alcohol swab and then allowing the alcohol to vaporise and dry before electrodes were placed on the skin. This skin preparation process was used to reduce skin impedance, which was then checked by using an ohmmeter (resistance meter), where the interelectrode resistance should be < 5 ohms (Kellis & Kouvelioti, 2009).

Electrode placements.

Two disposable surface Ag/AgCl electrodes (Neuroline 720 silver/silver chloride, Ambu, Ballerup, Denmark) were placed over the gluteus medius muscle and the deltoideus medius muscle in a bipolar configuration. The precise sites of electrode placements were specified according to the recommendations of the SENIAM project (Surface Electromyography for the Non-Invasive Assessment of Muscles), a concerted European action in the Biomedical Health and Research Program (BIOMED II) of the European Union (http://www.seniam.org/). Therefore, electrode placements for the gluteus medius muscle were at 50% on the line from the crista iliaca to the greater trochanter (Figure 5) and the electrode placement for the deltoideus medius (shoulder abductors) were on the area from the acromion to the lateral epicondyle of the elbow (Figure 6). The placement was meant to correspond to the greatest bulge of the examined muscle, and placement was directly over the muscle belly of the examined muscles. The surface electrodes centre-to-centre interelectrode distance was 20 mm. Surface electrodes were fixed over the target site with medical tape to prevent slippage during the examination. The ground electrode was placed around the wrist or on/around the ankle.

Instrument.

Raw EMG amplitude was obtained using a BIOPAC EMG System (BIOPAC Systems Inc., Goleta, CA, USA). The raw EMG signals were amplified with a band-width frequency ranging from 10 Hz to 500 Hz, then digitized online at a sampling frequency of 2 kHz and recorded by the BIOPAC system (MP150, BIOPAC Systems Inc., Goleta, CA, USA). The EMG amplitude output for this apparatus was recorded in millivolts (mV).

EMG Assessment Protocol.

The current protocol was based on the protocol used by Bolgla &Uhl (2005), which assessed gluteus medius muscle strength and activation at the same time. Surface EMG traces were collected simultaneously with the peak isometric torque assessments of the hip and shoulder abductors measurements on the HUMAC dynamometer. The raw EMG data of the bilateral gluteus medius and the right deltoideus medius muscle trials were obtained from EMG traces of three maximal isometric contraction trials. Each maximal contraction was held for 5s with one minute of rest between each trial. All participants received an equal amount of verbal encouragement during data collection. The average mean of the EMG’s Root Mean Square (RMS) that was associated with the highest peak force contraction was used in the statistical analysis. The mean RMS values were identified by simply taking an average between 0.5 sec before the peak force and 0.5 seconds after the peak force or using magnified vison tools of the software to identify the start and finish of RMS.

Figure 5: Volunteering participant (image used with permission) connected with electrodes for measurement of the electromyogram of the gluteus medius

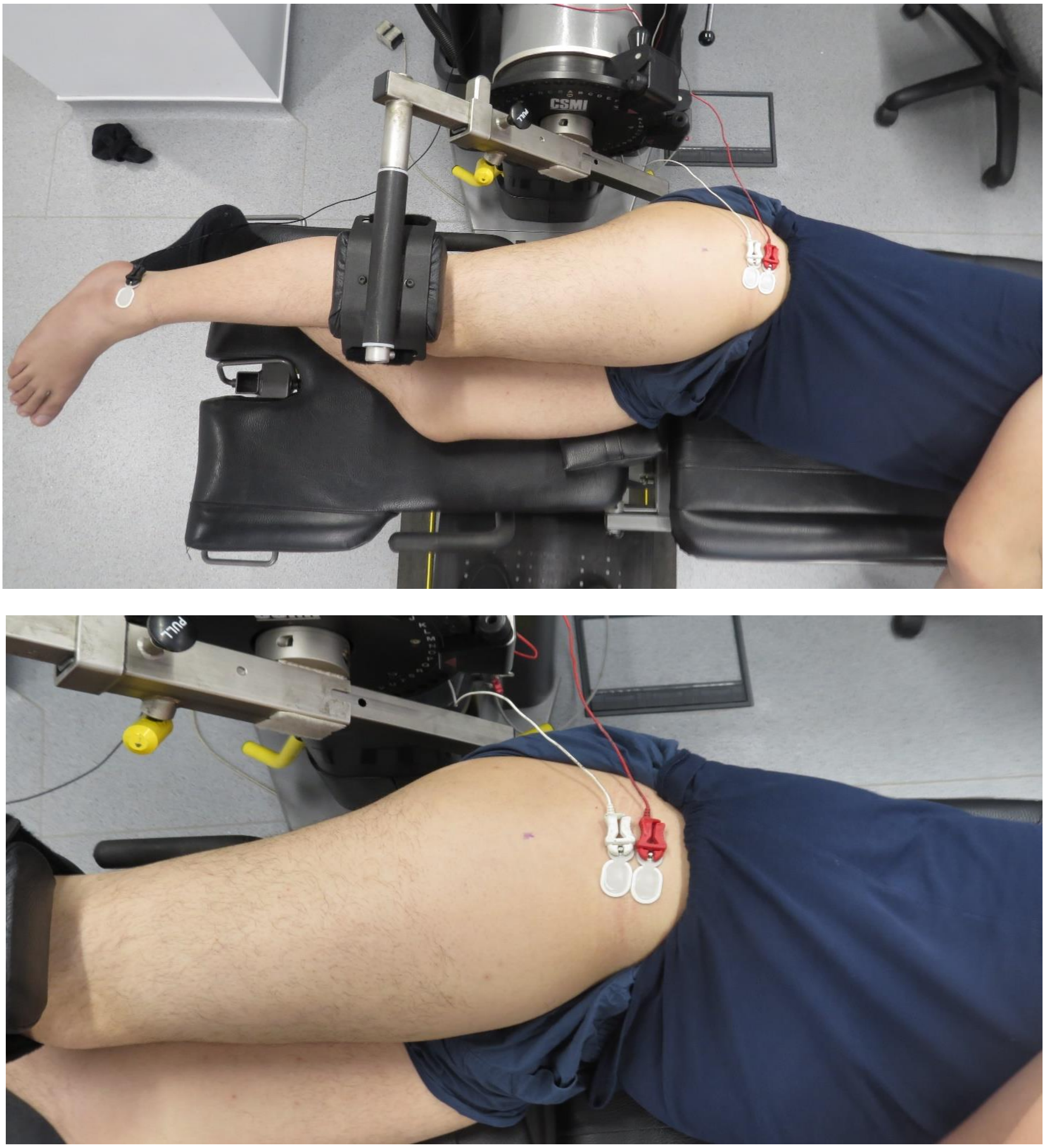
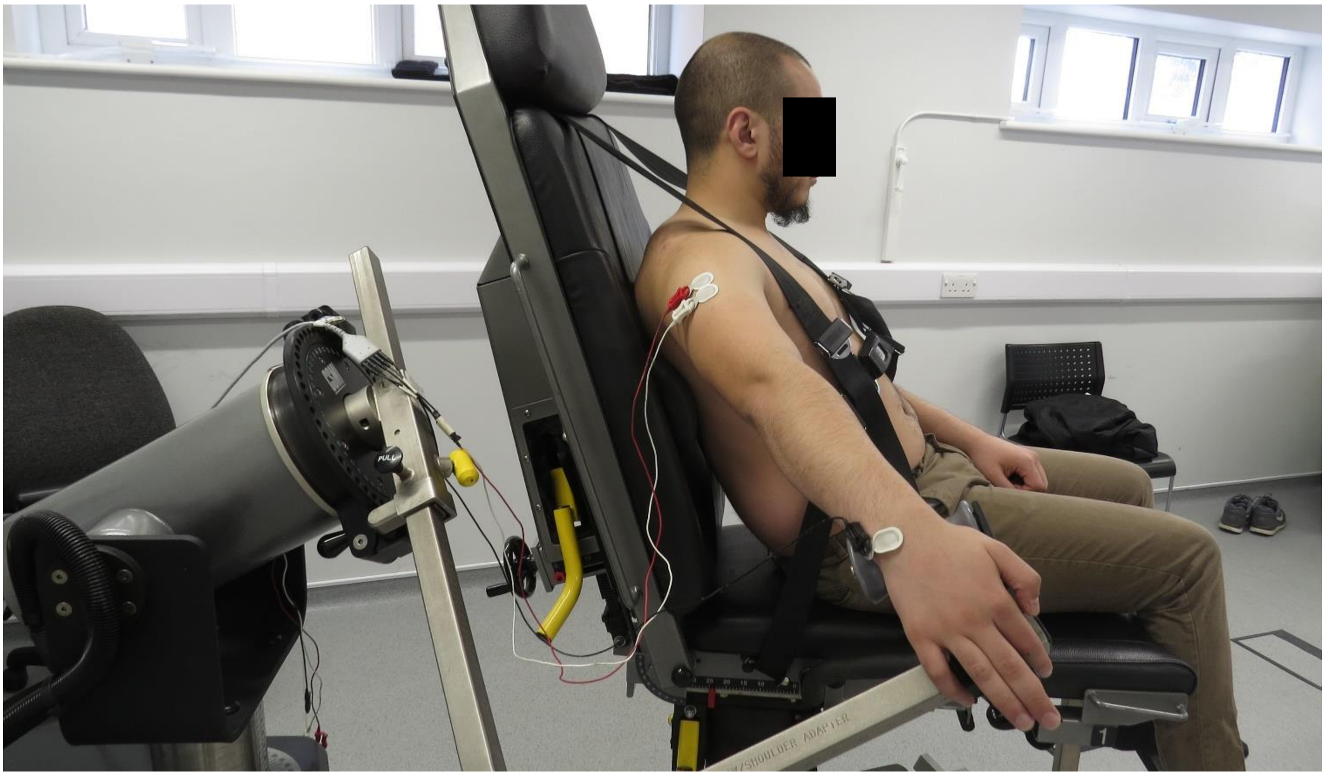


Figure 6: Volunteering participant (image used with permission) connected with electrodes for assessment of electromyogram of the deltoideus medius (shoulder abductors)



Muscle Activity EMG Monitor

The muscle activity EMG trace was monitored during one training session for all participants in all study groups.

Imagery training sessions.

The EMG traces were recorded across five imagined maximal contractions during the second set of the second session. This procedure was used to check if there was any visible muscle activity in an attempt to ensure that each participant performed the imagery training in the correct manner, without any muscular contraction. The EMG traces were not expected to reveal detectable activity and in cases where we found activity during imagery practice, participants were instructed to focus on the imagery practice and try to avoid any muscle contractions. This procedure had been applied in a previous study with imagined contraction training (see Yao et al., 2013).

Exercise training sessions.

The EMGs were recorded across five physical maximal isometric contractions during the second set of the second session. The average mean of RMS that was associated with the highest value of maximal contractions was used. This procedure was used to understand muscle strength activation during the physical training protocol.

Subjective Assessments

All self-reported questionnaires that have been administered in the current study are listed below with specific details.

Physiology Health Screening Questionnaire.

The physiology informed consent and medical questionnaire was completed during the pre-study assessment phase as a requirement of health and safety from the School of Sport, Health and Exercise Science. It is an essential requirement for reporting a participant's health, medication usage and ability to perform a maximal physical effort test. See Appendix B-1.

The International Physical Activity Questionnaire.

The IPAQ was completed during the pre-study assessment phase to report the current levels of physical activity for each participant. It is a validated, self-reported questionnaire, which reports an individual's physical activity level across five varied domains (i.e. job-related physical activity, transportation physical activity, housework, house maintenance, caring for family, recreation, sports, other leisure-time physical activity and time spent sitting) to assess the participant's general level of physical activity. For more information, (see www.ipaq.ki.se & Craig et al., 2003).

Imagery Ability Questionnaire.

The current study used the vividness movement imagery questionnaire (VMIQ-2) to evaluate an individual's imagery ability. It is a self-administered questionnaire that has been validated in healthy participants with acceptable psychometric properties (Robert et al., 2008). The VMIQ-2 was used to assess the participant's imagery ability with twelve movement tasks (e.g. running, walking, kicking a ball in the air). The vividness of the imagined movement task was assessed across three different imagery modalities and perspectives, with sub-scales that examine external visual imagery, internal visual imagery and kinaesthetic imagery. See Appendix. B-3.

Motivational and Effort Questionnaire.

A simple two-item Likert scale was used to evaluate participants' motivation and effort with regard to executing the tasks and training protocol. See Appendix B-2.

Post-Experimental Questionnaire.

This questionnaire was used to assess a participant's usage of imagery, type of imagery modalities that would be used during the training protocol and to gather subjective reports regarding levels of engagement in the imagery training. See Appendix B-6.

Weekend Diary Log.

Participants' commitment to the home programme was assessed using the weekend diary log data. It comprised adherence to performing the home training programme and ratings of motivation levels after performing the home training session. See Appendix. B-5.

Statistical Analysis

Baseline analysis across all study variables were completed using the independent samples *t*-test. Strength alteration was assessed using a mixed model repeated measure (2 x 2) Analysis of Variance (ANOVA). The independent variables were the study groups (*Imagery* or *Exercise*) and time (pre-training and post-training) and the dependent variable was muscle strength (Nm). Significant main effects or interactions were further analysed using paired-samples *t*-tests. EMG amplitude data (mV) were assessed using the Wilcoxon signed-rank test and a Mann-Whitney U test (as it not normally distributed).

All values are reported in means ± SD, except the EMG data, which are reported in median (50^{th}) plus percentiles (25^{th}, and 75^{th}) because they are not normally distributed. A significance level of $P < 0.05$ was used for all statistical comparisons. All statistical procedures were performed using Statistical Package for Social Sciences (IBM SPSS) version 22.0 (IBM Corp., Armonk, NY, USA).

Results

The following section reports the results for participants who successfully completed the two-week intervention programme in the *Imagery* or *Exercise* group.

Participants

Thirty-three participants were recruited and agreed to take part in this study. Data from 30 participants who completed all study procedures successfully were included in the statistical analysis. Three sets of data were excluded: one participant had an unstable medical condition and two others dropped out of the study due to time commitments.

The demographic data of all participants are listed in Table 1. Demographic and body characteristics showed no significant differences (t-test) between participants in the randomized groups as shown in Table 1.

Table 1. Demographic data of all participants across study groups

Parameter	***Exercise* (n = 15)**	***Imagery* (n = 15)**	**t-value**	***p* value**
Age (yrs)	26.53 ± 4.22	24.47 ± 3.58	1.445	0.16
Height (m)	176.57±4.56	177.00 ± 4.19	-0.271	0.79
Mass (kg)	77.39 ± 8.19	73.82 ± 12.21	0.939	0.36
BMI (kg/m2)	23.48 ± 3.16	23.55 ± 3.73	-0.061	0.95
Physical activity score	2.40 ± 0.51	2.47 ± 0.52	0.526	0.72

The categories of physical activity scores are 1 = low activity, 2 = moderate activity, 3 = high activity. BMI: Body Mass Index.

Baseline Comparison

All study outcomes at the baseline assessment are listed in Tables 2 and 3. The statistical comparison between study groups was performed using independent samples *t*-test for muscle strength outcomes and imagery (VMIQ-2 subscales) and a Mann-Whitney U test for EMG data, to investigate if there were any group differences between these variables prior to administration of the designated interventions. No significant differences were found between study groups for muscle strength in the various tested muscle groups, or imagery ability subscales at the baseline level, as shown in Table 2.

No significant difference was found between study groups on EMG amplitude for the right gluteus medius and the right deltoideus medius (shoulder abductors); however, results revealed a significant difference between study groups on EMG amplitude of left gluteus medius at baseline assessment with lower scores observed in the *Exercise* group, as shown in Table 3.

Table 2: Muscle strength and imagery ability subscales outcomes at baseline

Outcomes	*Exercise* (n = 15)	*Imagery* (n = 15)	t-value	*p*-value
MIT (Nm)				
R-GM	132.51 ± 19.19	135.62 ± 22.53	-0.407	0.687
L-GM	126.55 ± 17.75	127.92 ± 21.92	-0.189	0.851
R-DM	69.79 ± 10.50	64.84 ± 7.63	1.474	0.152
L-HGS (kg)	43.33 ± 7.10	43.78 ± 6.51	-0.179	0.859
VMIQ-2 Score				
EVI	33.00 ± 10.30	31.93 ± 8.73	0.306	0.762
IVI	26.87 ± 8.28	23.00 ± 6.95	1.385	0.177
KIN	23.13 ± 8.57	20.13 ± 4.81	1.183	0.247
TOTAL	83.00 ± 22.48	75.07 ± 14.66	1.145	0.262

MIT: Maximal isometric torque. **GM:** gluteus medius (hip abductor muscles). **DM:** deltoideus medius (shoulder abductor muscles)**. HGS:** handgrip strength**. kg**: Kilograms. **Nm:** newton*metre. **R:** Right side. **L:** Left side. **VMIQ-2:** Vividness of Movement Imagery Questionnaire-2. **Total**: Summation of all VMIQ-2 subscales scores. **EVI:** External visual imagery subscale. **IVI:** Internal visual imagery subscale. **KIN:** Kinaesthetic imagery subscale.

Table 3: EMG data of all tested muscle segments at baseline

Outcomes	*Exercise* (n = 15)			*Imagery* (n = 15)			Mann-Whitney U	*p*-value
EMG-Amp (mV)	**Percentiles**							
	25th	**50^{th} (Median)**	**75th**	**25th**	**50th (Median)**	**75th**		
R-GM	0.100	0.124	0.136	0.086	0.159	0.270	74.00	0.110
L-GM	0.067	0.109	0.126	0.095	0.178	0.267	56.00	0.019*
R-DM	0.401	0.433	0.666	0.389	0.542	0.823	91.00	0.373

EMG-Amp: Electromyography amplitude. **mV:** Millivolts**. R:** Right side. **L:** Left side. **GM:** gluteus medius (hip abductor muscles). **DM:** deltoideus medius (shoulder abductor muscles)**.** Data reported in median (50^{th}) plus percentiles (25^{th}, and 75^{th}). Median is reported instead of mean and standard deviations because of non-parametric data. *Significance level (p = < 0.05).

Main Analysis

Muscle Strength.

A mixed-design Analysis of Variance (ANOVA) model (Group × Time) was used to examine differential effects of the *Exercise* and *Imagery* interventions on muscle strength (trained right hip abductors, non-trained left hip abductors, non-trained left handgrip and non-trained right shoulder abductors) across time.

Right hip abductors strength (trained muscle group to test the ipsilateral training effect).

Strength outcomes of the right hip abductor muscles at pre- and post-assessments are listed in Table 4. There was a significant main effect of time, which displays a significant increase in muscle strength across time (F (1, 28) = 9.29, p = 0.005, η^2 = 0.25). In addition, results demonstrated a trend interaction between study groups and strength outcomes over time (F (1, 28) = 3.38, p = 0.08, and η^2 = 0.11), while the main effect of study groups was not significant, therefore, groups did not differ in strength alterations (F (1, 28) = 0.55, p = 0.46, η^2 = 0.019). As shown in Figure 7, both study groups (*Imagery* and *Exercise*) displayed positive strength alterations following the interventions.

The paired-samples *t*-test (i.e. within-group comparison) was used as a follow-up test. Results demonstrated participants in the *Exercise* group did not show any significant strength alterations of the right hip abductor muscles compared with the pre-assessment level, while participants in the *Imagery* group revealed significant strength alterations of right hip abductor muscles compared with the pre-assessment level, as shown in Table 4. The percentage of strength improvement from pre- to post-assessments in the *Imagery* group was 6.9%, while in the *Exercise* group was 1.7%.

Table 4: Right hip abductor muscles strength levels across both study groups at pre- and post-assessments

Study groups	**MIT (Nm)**		***t*-value**	***p*-value**
	Pre-GM	**Post-GM**		
***Exercise* (n = 15)**	132.51 ± 19.19	134.21 ± 17.71	-0.75	0.465
***Imagery* (n = 15)**	135.62 ± 25.53	142.48 ± 25.11	-4.12	0.001*

Data of paired sample t-test (within group comparison).   **MIT:** Maximal isometric torque. GM: gluteus medius (hip abductor muscles). **Nm:** Newton*meter. *, significant difference (P < 0.05) between pre and post assessment within each group.

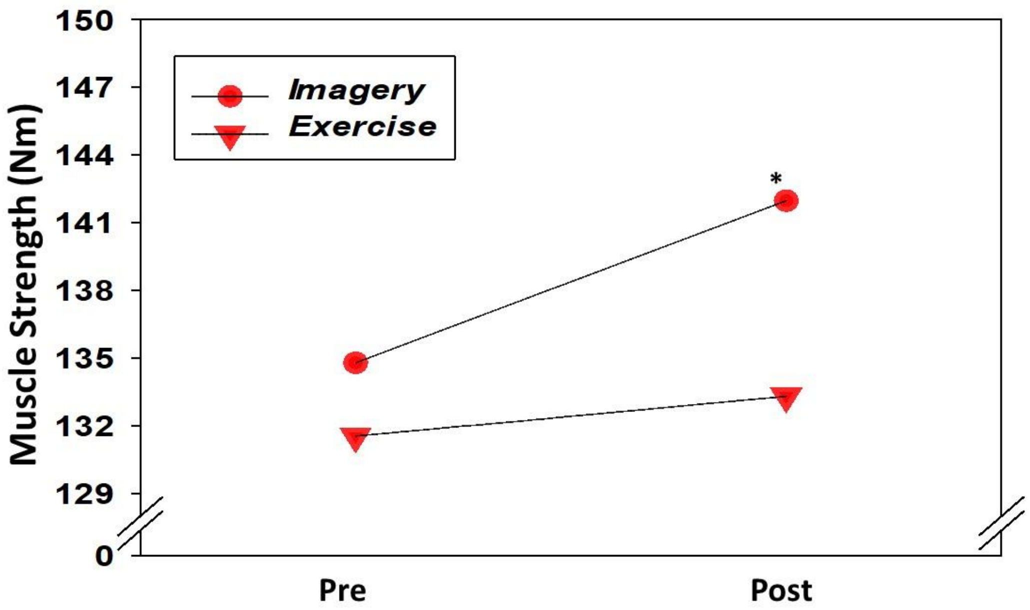


Figure 7: Right hip abductor muscles strength at pre- and post-intervention assessments. Estimated marginal means of right hip abductors strength at (1) pre- and (2) post-assessment points.

***Left hip abductors strength (untrained muscle group to test the transfer effect*).**

Strength outcomes of left hip abductor muscles at pre- and post-assessments are listed in Table 5. The mixed-model ANOVA showed significant interaction between study groups and strength outcomes over time (F (1, 28) = 11.25, p = 0.002, η^2= 0.29). In addition, results show a trend main effect of time, indicating an increase in strength across time (F (1, 28) = 3.19, p = 0.085, η^2= 0.10). The main effect of study groups was not significant (F (1, 28) = 1.01, p =0.32, η^2 = 0.035), therefore, groups did not differ in strength alterations. Figure 8 shows the positive improvement of muscle strength in the *Imagery* group, while there was a slight decline in muscle strength in the *Exercise* group over time. This shows that the two study groups responded differently to the intervention treatments in muscle strength over time (at two assessment points).

The paired-samples *t*-test (i.e. within-group comparison) was used as follow-up test. Results confirmed that participants in the *Exercise* group did not show any significant strength alterations of the left hip abductor muscles compared with the pre-assessment level, while participants in the *Imagery* group revealed significant strength alterations of left hip abductor muscles compared with the pre-assessment level, as shown in Table 5. The percentage of strength alterations from pre- to post-assessments in the *Imagery* group was ~8 %, while in the *Exercise* group was ~-2.7%.

Table 5: Left hip abductor muscles strength levels across both study groups at pre- and post-assessments

Study groups	MIT (Nm)		t-value	*p*-value
	Pre-GM	Post-GM		
***Exercise* (n = 15)**	126.55 ± 17.75	123.85 ± 13.38	1.31	0.211
***Imagery* (n = 15)**	127.92 ± 21.92	136.78 ± 25.31	-3.21	0.006*

Data of paired sample t-test (within group comparison). **MIT:** Maximal isometric torque. GM: gluteus medius (hip abductor muscles). **Nm:** Newton*meter. *, significant difference (P < 0.05) between pre and post assessment within each group.

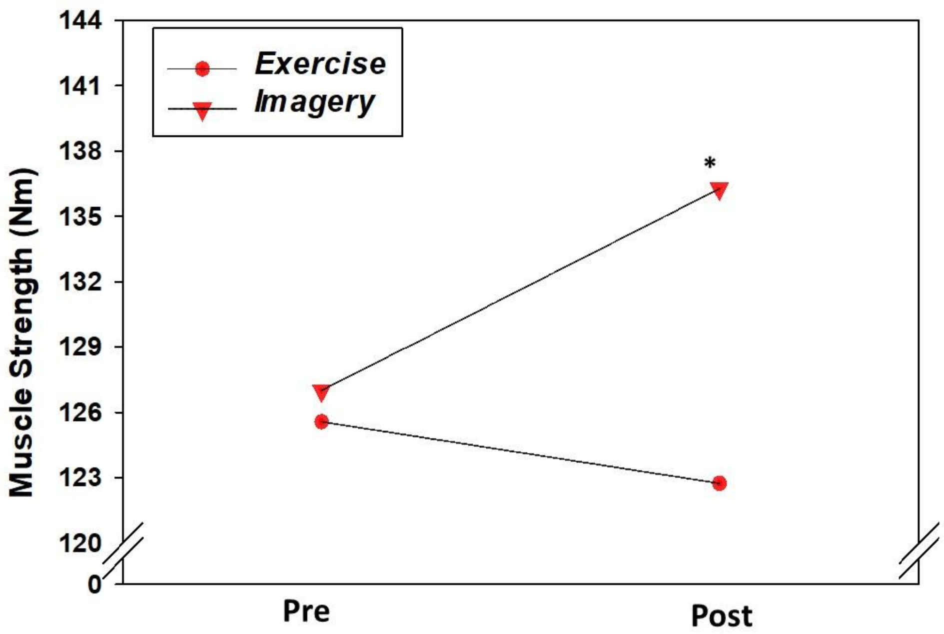


Figure 8: Left hip abductors strength at pre- and post-intervention assessments. Estimated marginal means of left hip abductors strength at (1) pre- and (2) post-assessment points.

Left hand grip strength.

Strength outcomes of left hand grip at pre- and post-assessments are listed in Table 6. A mixed-model ANOVA showed no significant interaction between study groups and strength outcomes over time (F (1, 28) = 2.31, p = 0.14, η^2 = 0.08). The main effect of time was not significant, which shows that there are no significant strength alterations across time (F (1, 28) = 0.96, p =

0.34, η^2 =0.03). In addition, the main effect of study groups was not significant, therefore, groups did not differ in strength alterations (F (1, 28) = 0.007, p = 0.94, η^2 = 0.00).

Table 6: Left hand grip strength levels across both study groups at pre- and post-assessments

Study groups	HGS(kg)		t-value	p-value
	Pre	**Post**		
***Exercise* (n = 15)**	43.33 ± 7.10	44.39 ± 6.80	-1.820	0.090
***Imagery* (n = 15)**	43.78 ± 6.51	43.55 ± 6.54	0.373	0.715

Data of paired sample t-test (within group comparison). HGS: hand grip strength, the maximum isometric strength of the left hand and forearm muscles. kg: Kilograms. *, significant difference (P < 0.05) between pre and post assessment within each group.

Right shoulder abductors strength.

Strength outcomes of right shoulder abductor muscles at pre- and post-assessments are listed in Table 7. A mixed-model ANOVA showed a trend interaction between study groups and strength outcomes over time (F (1, 28) = 3.47, p = 0.073, η^2 = 0.11). In addition, results showed a trend main effect of time, indicating a decrease in strength across time (F (1, 28) = 3.92, p = 0.08, η^2 = 0.11), while the main effect of study groups was not significant (F (1, 28) =0 .784, p = 0.38, η^2 = 0.027), therefore groups did not differ in strength alterations.

Table 7: Right shoulder abductor muscles strength levels across both study groups at pre- and post-assessments

Study groups	MIT (Nm)		t-value	p-value
	Pre-DM	**Post-DM**		
***Exercise* (n = 15)**	69.79 ± 10.50	65.63 ± 11.10	1.964	0.070
***Imagery* (n = 15)**	64.84 ± 6.51	63.86 ± 7.55	-0.030	0.976

Data of paired sample t-test (within group comparison). MIT**:** Maximal isometric torque. DM: deltoideus medius (shoulder abductor muscles). Nm: Newton*meter. *, significant difference (P < 0.05) between pre and post assessment within each group.

Additional analysis

The EMG data were used in a secondary analysis to further interpret the results in the strength data. EMG data were not normally distributed based on results of the normality test (Shapiro-Wilks test), we were also unable to transform the data to reach a normal distribution, and consequently, we used a non-parametric test (a Wilcoxon signed-rank test) to investigate the data.

Right gluteus medius (hip abductor muscles).

EMG data of right gluteus medius muscle at pre- and post-assessments are listed in Table 8. The Wilcoxon signed-rank test showed no significant difference in EMG amplitude (mV) of pre-and post-assessments in the *Exercise* group. However, in the *Imagery* group, there was a significant difference between pre- and post-assessments, showing an increase in EMG amplitude (mV) in this group.

Table 8: EMG data of right gluteus medius muscle at pre- and post-assessments

<table>
<tr><th colspan="2" rowspan="4"></th><th colspan="2">Exercise group (n = 15)</th><th colspan="2">Imagery group (n = 15)</th></tr>
<tr><th colspan="4">EMG-Amp (mV)</th></tr>
<tr><th colspan="2">R-GM</th><th colspan="2">R-GM</th></tr>
<tr><th>Pre</th><th>Post</th><th>Pre</th><th>Post</th></tr>
<tr><td colspan="2">Mean</td><td>0.122</td><td>0.144</td><td>0.182</td><td>0.234</td></tr>
<tr><td colspan="2">Std. Deviation</td><td>0.0357</td><td>0.068</td><td>0.095</td><td>0.125</td></tr>
<tr><td rowspan="3">Percentiles</td><td>25th</td><td>0.100</td><td>0.094</td><td>0.086</td><td>0.096</td></tr>
<tr><td>50th (Median)</td><td>0.124</td><td>0.135</td><td>0.159</td><td>0.195</td></tr>
<tr><td>75th</td><td>0.137</td><td>0.206</td><td>0.270</td><td>0.375</td></tr>
<tr><td colspan="2">Z</td><td colspan="2">-0.973</td><td colspan="2">-3.238</td></tr>
<tr><td colspan="2">P-value</td><td colspan="2">0.33</td><td colspan="2">0.001*</td></tr>
</table>

The Wilcoxon signed-rank (within group comparison). EMG-Amp: electromyography amplitude. mV: millivolts. R: right side. GM: gluteus medius (hip abductor muscles). *, significant difference (P < 0.05) between pre and post assessment within each group.

Left gluteus medius (hip abductor muscles).

EMG data of left gluteus medius muscle at pre- and post-assessments are listed in Table 9. The Wilcoxon signed-rank test showed no significant difference in EMG amplitude (mV) of pre-and post-assessments in the *Exercise* group. However, in the *Imagery* group, there was a significant difference between pre-post-assessments showing an increase in EMG amplitude (mV) in this group.

Table 9: EMG data of left gluteus medius muscle at pre- and post-assessments

		***Exercise* group (n = 15)**		***Imagery* group (n = 15)**	
		EMG-Amp (mV)			
		L-GM		**L-GM**	
		Pre	**Post**	**Pre**	**Post**
Mean		0.099	0.103	0.185	0.220
Std. Deviation		0.038	0.046	0.100	0.129
Percentiles	**25th**	0.067	0.059	0.095	0.109
	50th (Median)	0.109	0.093	0.178	0.209
	75th	0.126	0.151	0.267	0.349
Z		-0.596		-2.585	
P-value		0.551		0.010*	

The Wilcoxon signed-rank (within group comparison). EMG-Amp: electromyography amplitude. mV: millivolts. L: left side. GM: gluteus medius (hip abductor muscles). *, significant difference (P < 0.05) between pre and post assessment within each group.

Right deltoideus medius (shoulder abductor muscles).

EMG data of right deltoideus medius muscle at pre- and post-assessments are listed in Table 10. The Wilcoxon signed-rank test showed a significant difference between pre- and post-assessments in the *Exercise* group, showing a reduction in EMG amplitude (mV) in this group. However, in the *Imagery* group, there was no significant difference in EMG amplitude (mV) of pre-and post-assessments.

Table 10**:** EMG data of right deltoideus medius muscle at pre- and post-assessments

		***Exercise* group (n = 15)**		***Imagery* group (n = 15)**	
		EMG-Amp (mV)			
		R-DM		**R-DM**	
		Pre	**Post**	**Pre**	**Post**
Mean		0.501	0.419	0.608	0.630
Std. Deviation		0.149	0.118	0.366	0.351
Percentiles	**25th**	0.401	0.327	0.389	0.480
	50th (Median)	0.433	0.420	0.542	0.648
	75th	0.666	0.496	0.823	0.819
Z		-2.045		-0.057	
P-value		0.041*		0.955	

The Wilcoxon signed-rank (within group comparison). EMG-Amp: electromyography amplitude. mV: millivolts. R: right side. DM: deltoideus medius. *, significant difference ($P < 0.05$) between pre- and post-assessments within each group.

EMG recordings during imagery and exercise practice

For controlling any voluntary contractions during imagery practice, EMGs were recorded from trained hip abductors (right gluteus medius) during the second session in the imagery training group, as well as during isometric force production in the exercise group.

This EMG data was not normally distributed and could not be transformed to be normalized. Therefore, a non-parametric Mann-Whitney U test was used for comparison of EMGs between groups. Table 11 shows the outcomes, revealing a significant difference between *Imagery* and *Exercise* group on EMG amplitude; thus indicating participants in the exercise group performed voluntary muscle contractions during the training, while the imagery participants did not activate the muscles during imagery practice; the EMG is virtually silent.

Table 11: EMG data of right gluteus medius muscle during intervention training

Outcomes	*Exercise* (n = 15)			*Imagery* (n = 15)			Mann-Whitney U	*p*-value
EMG- Amp (mV)	**Percentiles**							
	25th	**50^{th} (Median)**	**75th**	**25th**	**50th (Median)**	**75th**		
R-GM	0.054	0.062	0.102	0.000	0.001	0.001	0.000	0.000*

EMG-Amp: Electromyography amplitude. **mV:** Millivolts**. R:** Right side. **L:** Left side. **GM:** gluteus medius (hip abductor muscles). **DM:** deltoideus medius (shoulder abductor muscles)**.** Data reported in median (50^{th}) plus percentiles (25^{th}, and 75^{th}). Median is reported instead of mean and standard deviations because of non-parametric data. *Significance level (*p* = < 0.05).

Imagery ability

Data of all VMIQ-2 sub-scales that measured the participants' imagery ability at pre- and post-assessments are listed in Table 12. A mixed-model ANOVA (Groups × Time) was used to examine if participants' imagery ability across time (the total VMIQ-2 score at pre- and post-assessments) was influenced by their assigned intervention training either *Imagery* or *Exercise*.

The mixed-model ANOVA showed no significant main effect of time *(F* (1, 28) =0.000, *P* = 0.991, η^2 = 0.000), therefore alterations of total VMIQ-2 was not significant over time. However, results revealed a significant main effect of study groups (*F* (1, 28) = 5.302, *P* =0.029, η^2 = 0.159), therefore, groups differed significantly in the total VMIQ-2 score alterations. In addition, the interaction between study groups and total VMIQ-2 score across time was significant (*F* (1, 28) = 4.516, *P* = 0.043, η^2 = 0.139). Figure 9 demonstrates the improvement of the total VMIQ-2 score (a lower VMIQ-2 score indicates an improvement of imagery ability) in the *Imagery* group, while the *Exercise* group did not show an improvement in the total VMIQ-2 score (a higher VMIQ-2 score indicates a decline in imagery ability), which suggested a difference in response in the imagery ability over time between study groups.

The follow up test (paired *t*-tests within group comparison) confirmed that participants in the *Imagery* group showed a significant improvement of total VMIQ-2 (imagery vividness) compared with pre-assessment level, while participants in the *Exercise* group did not show any significant improvement of imagery ability (total VMIQ-2) compared with pre-assessment level, as shown in Table 12. Specifically, the only sub-scale which showed a significant improvement was IVI in the imagery group, while the KIN sub-scale showed a decline in the exercise group after the training, as shown in Table 12. Consequently, the VIMQ-2 score changes could be attributed to the specific changes mentioned previously.

Additionally, correlation analysis between percentage improvement of VMIQ-2 sub-scales, muscle strength and EMG outcomes across study groups did not show any significant associations. However, a trend in association was found between the percentage of kinaesthetic subscale improvement with the percentage strength improvement of right hip abductors (r=0.49, p=0.066), and the percentage EMG amplitude improvement of right hip abductors (r=0.49, p=0.062) in the *Imagery* group only.

Table 12. VMIQ-2 subscales scored for all participants across study groups at pre- and post-assessments.

Parameter		***Imagery* group (n = 15)**				***Exercise* group (n=15)**			
VMIQ-2		**Pre**	**Post**	**t-value**	**p-value**	**Pre**	**Post**	**t-value**	**p-value**
SCORES	**EVI**	31.93 ± 8.73	30.47 ± 8.69	1.350	0.198	33.00 ± 10.30	32.67 ± 8.83	0.106	0.917
	IVI	23.00 ± 6.95	19.33 ± 5.29	2.558	0.023*	26.87 ± 8.28	29.93 ± 9.24	-1.396	0.184
	KIN	20.13 ± 4.81	19.07 ± 6.09	1.372	0.192	23.13 ± 8.57	26.67 ± 7.87	-2.164	0.048*
	Total	75.07± 14.66	68.87± 14.73	2.647	0.019*	83.00± 22.48	89.27 ±21.37	-1.165	0.263

Data of paired t-test (within group comparison). **VMIQ-2:** Vividness of Movement Imagery Questionnaire-2. **EVI:** External visual imagery subscale. **IVI:** Internal visual imagery subscale. **KIN:** Kinaesthetic imagery subscale. **Total**: The total score resulting from the summation of three VMIQ-2 subscales. *, significant difference (P < 0.05) between pre- and post-assessment within each group.

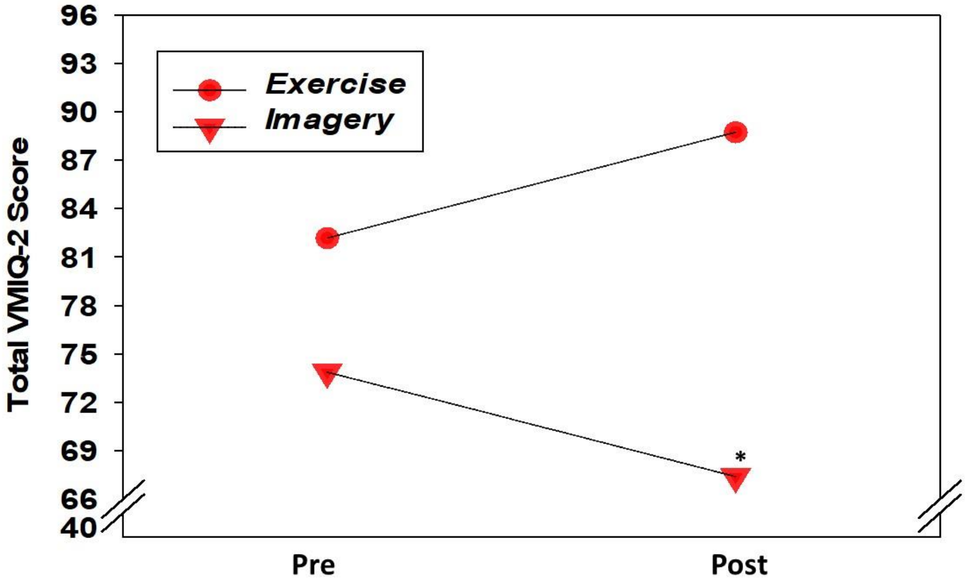


Figure 9: Pre- and post-intervention levels of the total VMIQ-2 score. Estimated marginal means of total VMIQ-2 (1) pre- and (2) post- intervention. Lower scores represent a better imagery ability.

Effort and motivation questions.

The level of motivation needed to complete the strength tasks and the level of effort involved while executing the task were assessed at pre- and post-assessments using two questions, which are explained in the Methods section. The levels of motivation and effort were included in this study to assess their contributions to subsequent strength gain following the intervention trainings, either *Imagery* or *Exercise*. The motivation variable scores and the effort variable scores across time with different study groups were assessed using a mixed-model ANOVA (Groups × Time).

Effort and motivation outcomes at pre- and post-assessments are listed in Table 13. The mixed-model ANOVA (motivation) showed no significant interaction between study groups and motivation score across time (F(1, 28) = 1.042, p = 0.316, η^2= 0.036), and the main effect of study groups was not significant, therefore, groups did not differ in motivation score alterations (F(1, 28) = 0.251, p = 0.62, η^2= 0.009). A trend main effect of time indicated an increase in motivation score across time F (1, 28) = 3.191, p = 0.085, η^2= 0.102).

The mixed-model ANOVA (effort) showed no significant interaction between study groups and effort score across time (F (1, 28) = 1.534, p = 0.226, η^2= 0.052). In addition, the main effect of time was not significant; therefore, alterations in the effort score was not significant over time (F (1, 28) = 2.377, p = 0.134, η^2= 0.078), and the main effect of study groups was not significant, therefore, groups did not differ in effort score alterations (F(1, 28) = 0.016, p = 0.900, η^2= 0.001).

Table 13: Effort and motivation data across both study groups at pre- and post-assessments

Study groups	Effort score (zero: *no* effort at all, to 130: *extreme* effort)		t-value	*p*-value
	Pre	Post		
***Exercise* (n = 15)**	105.50 ± 24.54	106.50 ± 16.47	-0.246	0.81
***Imagery* (n = 15)**	100.67 ± 19.26	109.83 ± 11.12	-1.764	0.10
	Motivation score (zero: not motivated at all, to 10: very highly motivated)			
	Pre	**Post**		
***Exercise* (n = 15)**	8.60±1.30	8.80±1.21	-0.899	0.38
***Imagery* (n = 15)**	8.13±1.60	8.87±1.06	-1.551	0.14

Data of paired sample t-test (within group comparison). *, significant difference ($P < 0.05$) between pre- and post-assessment within each group.

Compliance of home programme.

All participants in both study groups reported 100% compliance with the assigned home-protocol sessions in their weekend logs. The level of participants' motivation to perform the home-sessions (weekend sessions) successfully was assessed using a Likert scale (with 0 meaning "Not at all motivated" and 10 representing "Highly motivated").

The independent samples *t*-test showed a significant difference between study groups in the level of motivation to perform the assigned home-training sessions (t (28) = 4.422, p = 0.000), with higher motivation scores in the *Imagery* group, as shown in Table 14.

Additionally, correlation analysis showed a significant association between the average motivation score and the percentage alteration of hip abductors strength in the *Exercise* group (r=0.633, p=0.011), while no significant correlation was found in the *Imagery* group.

Table 14: Motivation data over weekend sessions

Study Groups	Motivation score	t-value	p-value
***Exercise* group (n = 15)**	6.38±1.53	-4.422	0.00*
***Imagery* group (n = 15)**	8.50±1.05		

Independent t-test (comparison between study groups). *Significance level (p = < 0.05).

Post-experiment questionnaire.

This questionnaire was administered only to the *Imagery* group.

Compliance with the imagery practice instructions.

All participants took part in all imagery sessions without missing any sessions (100% compliance). At the end of the study, participants were asked three questions to assess the intensity of using specific imagery modalities. Those data were used to assess participants' commitment to implement the use of specific imagery modalities, according to the study instructions.

Participants' usage of kinaesthetic imagery modality was rated with a Likert scale (0 representing "No kinaesthetic imagery use" and 10 representing "High kinaesthetic imagery use"). Results showed high usage of kinaesthetic imagery modality during imagery practice by all participants in the *Imagery* group, as shown in Table 15.

Participants' usage of visual imagery modality during imagery practice was rated with a Likert scale (0 representing "No visual imagery use" and 10 representing "High visual imagery use"). Results showed high usage of visual imagery modality during imagery training by all participants in the *Imagery* group, which is consistent with study instructions (Table 15).

Further questions were used to investigate which visual imagery perspective was adopted while using visual imagery, and this was rated on a Likert scale (0 representing "Completely internal perspective", 5 representing "Switched regularly", and 10 representing "Completely external perspective"). Results showed all participants in the *Imagery* group who used visual imagery tended to use an internal visual imagery perspective rather than using an external visual imagery perspective, or switching between perspectives, as shown in Table 15.

Table 15: Participants' usage level of imagery modalities and perspectives

Imagery group (n = 15)			
Mean ± SD	**Parameters**		
	KIN usage	**VI usage**	**VI Perspectives**
	8.60 ± 0.99	8.13 ± 0.83	1.80 ± 1. 61

KIN usage: Participants self-reported the intensity of using kinaesthetic imagery modality during the imagery training. **VI usage**: Participants self-reported the intensity of using visual imagery modality during the imagery training. **VI perspectives**: Participants reported the intensity of using different visual imagery perspectives; **IVI**: internal visual imagery or **EVI**: external visual imagery.

Further feedback regarding the imagery intervention.

Participants' feedback about their experience with the imagery intervention was assessed with three different questions (see Methods). The first question focused on their ability to memorize the imagery script, the second question addressed how strongly they believed in the efficacy of imagery training for strength changes and the third asked about how much the imagery prepared them for the strength task. Each question was rated on a Likert scale of 0-10, with 0 representing "Not at all" and 10 representing "Greatly".

Scores on the first question showed that participants could remember all components of the imagery script well [Mean ± SD, 8.40 ± 1.06].

Outcomes of the second question showed that participants had a strong belief in the imagery's efficacy on enhancing subsequent muscle strength [Mean ± SD, 7.00 ± 1.93]. In addition, correlation analysis showed a significant association of the former question scores with percentage of strength improvement of right hip abductors (r (15) = -0.56, p = 0.030).

Outcomes of the third question showed that participants felt that imagery practice could prepare them for the muscle strength task very well [Mean ± SD, 7.73 ± 1.22]. No correlation between subsequent strength improvement and strength alteration was found with this item.

Discussion

The current study was designed to explore the efficacy of imagery training compared with exercise training on bilateral hip abductors strength and EMG amplitude. Results revealed that imagery training could improve the strength of hip abductor muscles without any muscle activity during training. Additionally, our findings demonstrate the capability of imagery intervention to improve strength of homologous contralateral untrained hip abductor muscles, while other untrained muscle groups with homologous function in the upper body (shoulder abductors) did not show any strength alterations following imagery training. In addition, the current findings replicated the previous results (Chapter 2) that showed efficacy of imagery training to improve the imagery ability following a short period of imagery intervention.

Our data showed that exercise training did not significantly affect strength of the trained hip abductors. In addition, exercise training did not result in a transferred effect on the homologous contralateral untrained hip abductor muscles or the untrained muscle groups in upper body (shoulder abductors). Moreover, the exercise training group did not show any improvement in imagery ability following the intervention period.

Ipsilateral Training Effect

Muscle strength and EMG.

The *Imagery* group showed a significant strength improvement in the trained hip abductor muscles following a short period of imagery training (two weeks); the exercise training did not succeed in showing an incremental strength effect. The amount of strength gain of the trained hip abductors following the imagery training was (~7%), which is similar to the strength gain that we detected in the first study (~8%), using similar methodology and imagery training protocols (Chapter 2). Thus, the current result confirms the finding of the first study that imagery training can increase strength in this muscle group

The reported strength gains following the imagery intervention agree with previous studies. For example, Sidaway & Trzaska (2005) showed significant strength improvement of ankle dorsiflexor muscles following 4 weeks of imagery and exercise training (17.13% and 25.28), with no significant difference in strength alterations between the groups. Similarly, Zijdewind et al. (2003) found that imagery training improved torque productions of ankle plantar-flexor muscles; however, in agreement with our data, they found better gains with imagery than with low-intensity isometric training after 7 weeks of training. However, while all previous studies supported our current findings of strength gains following imagery training, they used longer training protocols (4-7 weeks) and trained smaller muscle groups. Additional support of the current strength gains following imagery was obtained from a study that targeted a larger muscle group, although the study design was very simplistic in measurements (weight machine); their result showed similar increase in strength between imagery and exercise groups (23.7% and 28.3%, respectively) (Shackell & Standing, 2007). In addition, strength improvements in trained muscle groups following a unilateral imagery-training programme in different settings and domains where reported by various other groups (e.g., Ranganathan et al., 2004; Smith et al., 2003; Yao et al., 2013; Yue & Cole, 1992).

The current study found no strength alteration in the trained hip abductors following an isometric exercise training protocol. However, using maximal isometric contractions in a training protocol effectively improved muscle strength following three to six weeks of training in previous studies (Szeto et al., 1989; Weir et al., 1995). The discrepancy between our results and former findings could be attributed to differences between our exercise protocol and their protocols, the duration of training; as the minimal isometric training period for reported strength improvements was three weeks, while our intervention was only two weeks. Thus, the period of isometric training might be too short to achieve subsequent strength improvements.

Moreover, training of the hip abductors with isometric maximal contractions was certainly new to the participants and most of participants in the *Exercise* group reported pain or discomfort during maximal contractions training sessions (expressed in interaction with individuals after the training sessions). Repetitive negative perceptions during training might have reduced their willingness to contract to the maximum; however, this suggestion is not supported in the data due to the lack of decline in force production at post-test.

Finally, participants' adherence to the home exercise training during weekend sessions might have influenced the strength gains. Our results showed participants in the *Exercise* group displayed less motivation to perform the weekend sessions than participants in the *Imagery* group; in addition, there was a positive correlation between motivation scores and strength improvements of trained hip abductor muscles in the *Exercise* group. Thus, motivation might have influenced outcome measures within the *Exercise* group through adherence to the new exercise programme and subsequent performance.

The strength gains following the imagery intervention training protocol were accompanied by EMG amplitude increases. Our EMG findings following imagery training are supported by

Ranganathan et al. (2004), who found a significant EMG amplitude improvement in the finger abductors (ABD group) and biceps brachii (ELB group) following imagery training for 12 weeks. This improvement was paralleled with the increases in the electroencephalogram-derived cortical potential and strength of each muscle group. Their results showed that an exercise training group improved the strength of finger abductors as well, but improvement of the EMG amplitude in finger abductor muscles did not reach significance. However, this could be explained by the relatively small sample size (five subjects) and large inter-subject variability, particularly for the EMG data.

Smith, Collins & Holmes (2003) examined the EMG and force parameters of the metacarpophalangeal joint of the right fifth digit at pre-and post four weeks of mental practice (kinesthetic imagery), exercise training and no practice (control group). Results showed that both imagery and exercise training groups improved the finger strength (by 53.36% and 23.27%, respectively), while the control group showed a decline in the muscle strength (-5.36%). In addition, following strength improvement, the EMG amplitude improved in the trained finger muscles in both imagery and exercise groups.

Further support for our EMG findings are found in a study that used mental training for 4 weeks, which showed strength improvement of the little finger abduction force by 22% accompanied by EMG amplitude increase in the finger abductor (Yue & Cole, 1992).

In summarising, previous studies support our findings that imagery training is effective for strength and EMG gains; however, the comparison with exercise shows variable outcomes.

Transfer Effect

Muscle strength and EMG.

To the best of our knowledge, the role of unilateral imagery training on bilateral transfer with strength outcomes received less attention across the imagery intervention literature, and it had not been examined with larger muscle groups. The current study demonstrates that the bilateral transfer effect can be induced on homologous contralateral untrained hip abductors; however, only by imagery training but not by our exercise intervention. Our results showed significant strength improvements of the homologues contralateral untrained hip abductor muscles following imagery training (~8%).

In agreement, an early study by Yue & Cole (1992) revealed the ability of unilateral imagery training to produce alterations in muscle strength from trained limb to untrained limb. Their results showed significant muscle strength improvement in the maximal abduction force of the right (untrained) fifth digit muscle following both unilateral imagery and voluntary contraction training (10% and 14%, respectively). Although this study targeted only a small muscle group (little finger), their results support our finding on efficacy of unilateral imagery training to produce a bilateral transfer with larger muscle group.

Farthing et al. (2007) examined the bilateral training effect following physical exercise compared with imagery training on strength outcomes. Their findings demonstrated that unilateral exercise training (6 weeks) was highly effective in increasing the strength of the ulnar deviation muscle in trained (45.3%; $P < 0.01$) and untrained (47.1%; $P < 0.01$) limbs. However, the strength of the ulnar deviation muscle did not increase after unilateral imagery training in either the trained or untrained arms. This finding contrasts with previous imagery interventions that showed strength gains as well as our results. Thus, the absence of bilateral transfer effect after imagery training in the study by Farthing et al. (2007) might be a consequence of general lack of efficacy of the protocol to induce strength gains in the trained muscles.

Owing to the limited evidence, we do not have a clear understanding regarding the bilateral transfer phenomenon following unilateral imagery training with muscle strength outcomes. Consequently, studies that examined the role of bilateral transfer learning of motor tasks by using imagery interventions might be used for further explanation of the bilateral transfer phenomenon. For example, the study by Amemiya, Ishizu, Ayabe & Kojima (2010) used a tapping sequence model (performance outcome) to evaluate the occurrence of inter-manual transfer (bilateral effect) after motor imagery and to compare the transfer effects with motor execution learning. In addition, the motor-related brain area activity was measured using Near-Infra-Red Spectroscopy (NIRS) to understand the relation between the transfer effect and neural activity during the learning phase. Results showed that the motor execution training improved the performance only for trained movements, while the imagery training improved the performance for both, trained movement and inter-manual transfer. Therefore, this study indicated the superiority of motor imagery training over motor execution training in the contralateral transfer of the tapping sequences task within a short learning period. The NIRS result showed that both types of learning methods activated the Supplementary Motor Area (SMA) and the pre-SMA area, both of which are important during motor learning. Furthermore, they suggested the difference between study groups could be attributed to the distinct neurological networks used in the training modalities, or perhaps due to the cognitive components involved in motor sequence acquisition, thus leading to different behavioural results.

Moreover, Land et al. (2016) further explored the superiority of imagery training effects on bilateral transfer compared with motor execution, by examining the influence of practice duration and task difficulty on the extent to which imagery training and physical training influenced bilateral transfer on a sequential key pressing task. The result showed that with an extended practice period, the physical practice became more effective than imagery in enhancing the performance on the trained hand. Further, this work suggested that motor imagery improved the bilateral learning in a sequential tapping task in the early stages of learning; however, with extended training, physical practice leads to larger influences on the transfer. This could help explain why our short intervention induced mainly strength and EMG enhancements in the imagery group but not in the exercise group.

In addition, although the transfer effect is well established following unilateral physical exercise contractions, some previous studies showed the transfer effect did not occur with strength outcomes following unilateral isometric exercise training (Szeto et al., 1989; Weir et al., 1995). This may indicate, in addition to the intervention duration, that the transfer effect may be specifically induced by certain contraction types/tasks but suppressed by others, such as isometric contractions in our study. Moreover, our study showed that a transfer effect is not inducible in on other untrained homologous muscle groups, such as shoulder abductors following either imagery or exercise training protocols, suggesting that the improvement is not generalized in terms of recruitment of motor function.

Imagery ability

The current study confirmed the previous findings of chapter 2, which looked at imagery ability (imagery vividness). Our current data revealed that a short period of imagery training (2 weeks) can be effective for improvement of imagery vividness (VMIQ-2 total score); this improvement specifically occurred in the internal visual imagery ability subscales. However, the exercise group did not show any improvement of imagery ability following our isometric exercise protocol; instead, some decline was observed following exercise training on the kinaesthetic imagery subscale.

Consistent with our findings, Rodgers, Hall & Buckolz (1991) found improvement in visual movement imagery ability following 16 weeks of imagery training compared with verbalization training. Another study (Williams, Cooley, & Cumming, 2013) used Layered Stimulus and Response Training (LSRT) with imagery practice (build the image up and make it as realistic and life-like as possible). Their results showed that LRST is an effective approach to facilitate visual and kinaesthetic motor imagery ability. However, they suggested that the kinaesthetic motor imagery ability requires more practice than visual motor imagery ability to be improved. Therefore, our results support previous findings that imagery ability can be modified and improved following imagery practice, as imagery ability has been described as a skill that individuals can continually develop with invested time and effort (Hall, 2001).

Potential mechanisms

The potential mechanism of strength gains in the trained limb.

EMG data during imagery training in the current study might be used to interpret and suggest an underlying mechanism for the strength gains in the trained hip abductors after imagery training. First, our EMG data during imagery training session remained almost quiescent compared with EMG amplitudes during maximal contractions (exercise session). This result was consistent with previous study results, showing that EMG signals from the major elbow flexor muscle monitored during imagery training sessions and the muscle activity remained well below 2% maximal contraction level (Yao et al., 2013). This absence of any EMG activity during imagery training might be considered as a support for a central mechanism of strength gains after imagery training that was not, due to low-level muscle activation and driven by neural adaptation in the periphery.

Some researchers required the absence of EMG activity as a precondition to execute a particular imagery task (Brody, Hatfield, Spalding, Frazer, & Caherty, 2000; Herbert et al., 1998; Naito et al., 2002; Yue& Cole, 1992). They considered the absence of any significant EMG activity during imagery training as proof that cerebral activation detected in their studies was not due to any muscular activation, therefore excluding any motor learning process based on afferent feedback from muscle sensors (Slimani et al., 2016; Ranganathan et al., 2004; Yao et al., 2013). In addition, previous experimental studies showed that strength gains in the trained limb following imagery training can be explained by central neural adaptation, with increased cortical potential and motor output observed (Ranganathan et al., 2004; Yao et al., 2013). They reported a significant improvement in elbow flexor strength after internal imagery training that followed, with elevation in Movement-Related Cortical Potential (MRCP) on scalp locations over both the primary motor (M1) and supplementary motor cortices, and suggested that imagery training augments cortical output, consequently driving the muscles to a higher activation level and increased strength.

Further support for a central mechanism which may be mainly driven by motor areas can be obtained from our motivation measures (subjective ratings and handgrip strength). Our results did not show any changes in motivation levels following imagery or exercise interventions. In addition, we did not find any associations between motivation measures and strength alterations for both groups, which suggests that the efficacy of imagery on strength gains was not a result of motivation to perform the motor tasks.

The potential mechanism of bilateral transfer effect.

In our study, the bilateral transfer effect was only observed following imagery training. Although the bilateral transfer is not well documented across the imagery intervention literature, numerous studies suggested that imagery practice stimulates similar areas of cortex to physical movements (Binkofski et al., 2000; Naito et al., 2002; Romero, Lacourse, Lawrence, Schandler, & Cohen, 2000). Based on an expected similarity in brain activation between imagery and physical exercise, we propose that some of the underlying mechanisms relevant for the bilateral transfer following exercise are also relevant for imagery training.

The potential underlying mechanisms of the bilateral transfer phenomenon that is responsible for strength improvement of the untrained limb has been broadly classified into central and peripheral adaptations (Lee, Gandevia & Carroll, 2009). Additionally, a neural mechanism has been supported by previous reports that have shown muscle strength improvements in the untrained limb being unaccompanied by muscle hypertrophy (Farthing & Chilibeck, 2003; Farthing, Chilibeck &, Binsted, 2005; Moritani, 1979). Evidence suggests that peripheral adaptation even on neural levels is improbable; the bilateral training effect was detected (increased strength) while the EMG in the untrained muscle was neglectable during contractions of the trained muscle (Hortobagyi et al., 1997; Evetovich et al., 2001; Ranganathan et al., 2004). However, this does not exclude the involvement of mechanisms on the spinal level.

Carroll, Herbert, Munn, Lee,& Gandevia (2006) explained the mechanisms of bilateral training effect by a central mechanism increasing the motor neuron output. They suggested two mechanisms in central adaptation; one involving a “spill over” to the motor control areas for the contralateral limb, and the other involving adaptations in the motor control areas for the trained limb that can be accessed by the untrained limb. Indeed, they suggested that the cortical, subcortical, and spinal levels are all potentially involved in the “transfer effects”, and none can be excluded based on the existing evidence.

With very similar reasoning, Ruddy & Carson (2013) postulated two possible central mechanisms. Firstly, they proposed that neural adaptations induced during unilateral exercise would spread to the opposite side of the body (cross-activation model). This model suggests, "During unilateral training, activation of the homologous motor network gives rise to bilateral adaptations that facilitate subsequent performance by the untrained limb" (Lee, Hinder, Gandevia & Carroll, 2010). Secondly, an alternative model suggests that the motor plan of a unilateral task is accessible by an attempt of reproducing the same task in the opposite side of the body and would therefore facilitate motor activation in the untrained limb (bilateral access model). The bilateral access model entails that "motor engrams" formed during unilateral practice, may subsequently be utilized bilaterally; that is, by the neural circuitry that constitutes the control centres for movements of *both* limbs (Ruddy & Carson, 2013). Thus, the bilateral access model has highlighted a possible role of the corpus callosum as a mean of information transfer from a single hemisphere in which the "motor engram" has been elaborated (Taylor & Heilman, 1980).

Carroll et al. (2006), however, reported presence of modifications in the synchronization of motor units and of neural conductivity during transfer effects in the untrained limb comparable to those detected in the trained limb. At sub-cortical and cortical levels, previous work confirms the presence of a neural interaction between the two hemi-spheres (Carroll et al., 2006; Farthing et al., 2011), consequently supporting the cross-activation/spill over model proposed by Carroll et al. (2006) and Ruddy & Carson (2013). Studies on the Mirror Neuron System (MNS) have revealed that simple visualization of a motor task is sufficient to provoke adaptations (Howatson et al., 2013; Zult et al., 2014). In addition, as previously mentioned, it appears that motor learning provokes cortical reorganizations (Carroll et al., 2006) and that unilateral training produces inter-hemispheric plasticity (Farthing & Zehr, 2014), thus supporting the bilateral access model.

Therefore, adaptations in the neuronal motor control circuits are suggested to be the primary cause for the bilateral transfer phenomenon, while the sites of neural adaptation (cortical, sub-cortical, or spinal pathways) are unclear (Carroll et al., 2006; Lee & Carroll, 2007).

The bilateral transfer effect in the current study did not occur in other muscle segments, i.e. no strength gains in the untrained muscle groups in upper limb segments (shoulder abductors) were found following either exercise or imagery training of the hip abductors. Hence, our results suggested that our imagery-training effects are specific to improving the trained hip abductors strength and that the effects only spilled over to the homologous contralateral untrained hip abductor muscles. If the mechanism mediating bilateral transfer would be more generalized in origin, then strength alterations should also be observed in other muscle segments (Lee & Carroll, 2007). Thus, our data support the neuronal mechanism of the bilateral transfer effect with strength gains following unilateral imagery training; however, the improvements are limited to the homologous muscle of the same segment. If imagery training would have enabled increased activation of a homologous function (deltoid muscle is functionally homologue to the hip abductors), then we would have seen an increase in strength in the deltoid muscle. Additionally, an even more basic activation or gating of the motor commands is excluded via non-detectable effects on the handgrip strength.

Study Limitations

The current study involved healthy participants who were physically active, which may leave little room for strength enhancement following imagery training. However, the hip abduction task was not regularly used in daily activity, which may have led to unpleasant perceptions making the maximal isometric hip abduction exercise more difficult, which could have influenced the subsequent strength gains in the exercise group. The current protocol was short and therefore it is not clear whether longer protocols would have led to strength gains in the exercise group; the superiority of imagery training over the exercise training on strength gains might be limited to short training protocols as discussed earlier (muscle strength & EMG) section.

The current study has several strengths, such as using EMG to understand the potential mechanisms of imagery training and using an exercise comparison group. In addition, a higher degree of control during the study procedure was used, such as allocating subjects randomly to study groups, randomizing the order of limbs during pre- and post-assessment points and cycling for 3 minutes following each strength assessment test to reduce familiarisation and learning effects. Additionally, both groups received identical protocol procedures with equal numbers of assessments and treatment sessions and the same level of encouragement and support.

Future implications

Physiotherapy application

The current findings have clinical implications with regard to optimizing physical recovery and enhancing training plans. For example, in the early stages of rehabilitation when the traditional therapeutic approach is restricted or limited by various factors (injury, surgery, acute pain or immobilisation), physiotherapists may consider applying imagery training to improve strength capacity and motor function with no negative side effects. In addition, imagery training could be used as an adjunct to traditional treatment in later stages of rehabilitation.

In relation to home training plans, our results showed promise in terms of using imagery training as a home-training tool, as most of the participants in the current study showed a high level of motivation to use imagery during weekend sessions to practice strength tasks. Thus, imagery training could be prescribed as a home-training tool, which could be used to practice strength tasks with less effort, space and with limited resources and time.

Additionally, evidence regarding the bilateral transfer of a motor skill might be considered as important factors for treatment of stroke patients. Findings of Ausenda& Carnovali (2011) showed a significant improvement of the motor skills in the paretic hand, following unilateral physical training of the non-paretic hand. Based on our finding and others, bilateral transfer might be considered as one of the important effects or goals in rehabilitation settings using imagery. Therefore, imagery training might be considered by physiotherapists who treat patients with unilateral impairments, such as following a stroke.

Furthermore, the current results showed positive effects of imagery training on imagery ability (vividness) following a short period of imagery training. Although the current study did not consider any inclusion criteria regarding imagery ability, most of the participants showed a good imagery ability. The current findings could inform future applications that include imagery training during pre-training sessions, to prepare patients with lower imagery ability prior to starting the imagery intervention protocol in order to maximize the benefits of imagery interventions.

Conclusion

This study showed that imagery training has clear effects on strength gains in trained and untrained homologous muscle groups without negative side effects. Imagery-based intervention are cost effective and easy to apply and may be appropriate for use with diverse medical conditions. Imagery could thus be used for a wide range of applications in physiotherapy and rehabilitation settings, and further research should investigate effects of imagery training in clinical populations.

Chapter 4: Translation and Cross-Cultural Adaptation of the Vividness Movement Imagery Questionnaire (VMIQ-2) to Classical Arabic Language: Validation Model Testing Using Bayesian Structural Equation Modelling

Abstract

Purpose: Imagery ability can influence the efficacy of imagery interventions across varied populations. The evaluation of imagery ability using validated questionnaires is well established across various fields, however, no Arabic copy of imagery ability questionnaires exist in the imagery literature. Therefore, the objective of this study was to translate and culturally adapt the Vividness of Movement Imagery Questionnaire-2 (VMIQ-2) to classical Arabic language and to examine the factorial validity of the translated version of the VMIQ-2 among healthy Arab-speaking participants who have lived either in the United Kingdom (UK) or in the Kingdom of Saudi Arabia (KSA). This work provides a basic research tool for imagery research in rehabilitation, sport psychology, and other domains in Arabic-speaking countries.

***Method*:** The process of translating the VMIQ-2 from an original English copy to a classical Arabic copy included the following stages: preparation, forward translation, reconciliation, back translation, back translation review, cognitive debriefing assessment, cognitive debriefing assessment review, proofreading, and reporting. Pilot tests: these were conducted with the Arabic copy (VMIQ-2-A) to review the cognitive debriefing and initial reliability of data gathered from participants in the UK and the KSA using the final translated questionnaire copy of VMIQ-2-A.

Advanced data analysis procedure: by using the Bayesian structural equation modelling (BSEM). A series of three BSEM analyses were conducted on the translated VMIQ-2 for the UK and Saudi Arabia samples separately. First, models with non-informative priors (i.e. freely estimated) for the major item loadings with no cross-loadings or residual correlations were assessed; second, models with informative approximately zero means and small variance cross-loadings were assessed; third, models with informative approximately zero means and small variances for both cross-loadings and residual correlations were assessed.

The prior variances for cross-loadings and residual correlations were specified at ±.01, which corresponds to standardised loadings and residual correlations of ±.20. In addition, for the KSA sample, each of the major factor loadings was set a priori as the value obtained for the corresponding loadings in the UK sample, with small variance priors of ±.01 to ensure that the major loadings were approximately invariant across the two samples.

Results**:** Factorial validity: the fit of the VMIQ-2A models for the UK and KSA samples showed a poor fit to the data in the restrictive independent clusters BSEM models, with zero cross- loadings and zero residual correlations and with informative small variance priors on the cross-loadings only. However, in both data samples, the model with informative small variance priors on the cross-loadings and residual correlations had an excellent fit to the data. For both samples, all major loadings were significant and acceptable by conventional criteria. In addition, for the VMIQ-2A with both samples, all cross-loadings and residual correlations fell within their pre-specified 95% limits of ±.10, indicating approximate invariance of the loadings with the VMIQ-2A across both samples.

Internal consistency: For both samples, acceptable reliabilities across all VMIQ-2A subscales were demonstrated. In addition, the relation among VMIQ-2A subscales for all samples showed moderate to strong positive correlations between the three imagery factors and the strongest relationship was found between kinaesthetic and internal visual imagery modalities across both samples, but none of the upper bounds of their 95% credibility intervals encompassed unity, indicating discriminant validity of these subscales with respect to each other.

Conclusions**:** The findings of this study provide initial support for the newly translated Arabic copy, VMIQ-2-A, with adequate psychometric properties.

Introduction

Imagery is a cognitive process that may play an important role in planning and executing action or movement (e.g. Nordin & Cumming, 2005; Robin et al., 2007; Short et al., 2002). Imagery can be practiced by using movement imagery training, called by different names across the literature (e.g., motor imagery, mental practice). Motor imagery (MI) is defined as the mental representation of action without any concomitant body movement (Guillot & Collet, 2008). It is typically a mental simulation of physical tasks without actual movement and is used to improve subsequent outcomes. Imagery practice has been used in various disciplines (e.g. rehabilitation, sport, and sport psychology) with different goals (e.g. motor skills learning, self-confidence and anxiety, motivation, strategies and problem-solving, locomotion retraining, motor performance, physical function, and neuropathic pain) with encouraging positive results (e.g. Dickstein & Deutsch, 2007; Guillot & Collet, 2008; Martin, Moritz, & Hall, 1999; Munzert & Lorey, 2013; Murphy, 1990).

Visual and kinaesthetic imagery activates various cerebral regions, including the supplementary motor area, the upper and lower parietal lobules, the primary motor cortex, the premotor cortex, the prefrontal areas, the inferior frontal gyrus, the superior temporal gyrus, the primary and secondary sensory cortex, the insula cortex, the cerebellum, and the basal ganglia (Jeannerod, 2001; Malouin, Belleville, Richards, Desrosiers, & Doyon, 2004). These areas directly and indirectly correspond with regions that participate in voluntary motor movement. Therefore, these areas might be specified as an important target with post-stroke patients in rehabilitation settings by using imagery practice (Sharma, Pomeroy, & Baron, 2006).

Gerardin et al. (2000) showed that imagining or physically executing a movement task causes relatively similar neural network activation at the cerebral level. Neurophysiological findings such as this have contributed to the development of post-stroke rehabilitation programmes that include integrating motor imagery during acute and subacute phases. The outcomes of these programmes indicate greater efficacy and superiority in terms of functional recovery when combined MI with traditional therapy compared to traditional interventions alone (e.g. Liu, Chan, Lee, & Hui-Chan, 2004; Page, Levine, & Leonard, 2007; Page, Levine, Sisto, & Johnston, 2001).

The recruitment of brain areas associated with imagery training is correlated with an individual's ability to imagine movements (Lorey et al., 2011) and can depend upon the way a task is imagined (i.e. visual or kinaesthetic) (Solodkin, Hlustik, Chen, & Small, 2004). Therefore, individuals with greater ability to mentally represent movements will activate more brain regions that connect with the motor system. This suggests that the inter-participant discrepancy in functional recovery following rehabilitation protocols could be moderated by imagery training.

Although evidence supports the effectiveness of imagery practice in both sport and rehabilitation programmes, the effectiveness of imagery interventions to augment performance might be influenced by the individual's imagery ability (Martin, Moritz, & Hall, 1999). Morris (1997, p.37) defined imagery ability as "an individual's capability of forming vivid, controllable images and retaining them for sufficient time to effect the desired imagery rehearsal".

Individuals' self-perceptions of imagery ability have been found to be quite varied among healthy participants (Atienza, Balaguer, & Garcia-Merita, 1994; Hall & Martin, 1997; Lorant & Gaillot, 2004). In practice settings, individuals could generate an image of a task and use imagery training, but their degree of imagery ability varied (Paivio, 1986). An intervention study that examined the moderating role of imagery ability between observational learning and gymnastic performance showed greater improvements in performance for a high imagery ability group compared with a low imagery ability group after observational learning (Lawrence, Callow, & Roberts, 2013).

In rehabilitation settings with stroke patients, the efficacy of mental training that uses motor imagery to improve limb loading is dependent on the ability to maintain and manipulate information in working memory (Malouin et al., 2004). Motor imagery ability may be impaired in patients with lesions in the superior regions of the parietal cortex (Sirigu et al., 1996). Similarly, Malouin, Richards, Durand and Doyon (2008) showed that stroke patients tend to display higher imagery scores when imagining movements with their unaffected side, with an overestimation of visual imagery for upper limb movements and overestimation of kinaesthetic imagery when imagining lower limb movements.

Furthermore, numerous studies suggest screening imagery ability prior to an imagery intervention (e.g. Callow & Hardy, 2005; Cumming & Ramsey, 2008; Guillot & Collet, 2008). As the impact of imagery intervention on various human functions can be affected by the variations in a person's imagery ability (e.g. Baddeley & Andrade, 2000; onzález, Campos, & Pérez, 1997; Isaac & Marks, 1994; Mantani, Okamoto, Shirao, Okada, & Yamawaki, 2005). Individuals with good imagery ability have been shown to perform better than individuals with poor imagery ability in motor performance (Goss, Hall, Buckolz, & Fishburn, 1986) and to be higher in self-efficacy (McKenzie & Howe, 1997).

Moreover, Malouin et al. (2004) suggested a mandatory screening of motor imagery ability and any cognitive problems for stroke patients. Therefore, assessing imagery ability prior to an experiment is important as it could maximise the potential benefits of imagery practice and ensure that all participants were able to imagine motor tasks appropriately prior to starting an imagery-training programme. Typically, individuals who were less able to demonstrate a minimum level of imagery ability were either excluded from the study or asked to attend a tailored pre-training programme designed to help them improve their imagery ability (e.g. Cumming, Olphin, & Law, 2007; Hardy & Callow, 1999).

Consequently, a participant's imagery ability needs to be assessed using a valid and reliable tool. Imagery ability can be assessed with various tools, but a subjective self-report or objective forms are usually used (Hall, 1998). An objective tool uses physiological parameters and behavioural responses (functional magnetic resonance imaging or functional MRI (fMRI), Electromyography (EMG), heart rate, skin conductance, electroencephalogram (EEG), and chronometry) that reflect a person's imagery ability and is based on the notion of functional equivalence (Amedi, Malach, & Pascual-Leone, 2005; Cremades & Pease, 2007; Cui, Jeter, Yang, Montague, & Eagleman, 2007; Decety, 1996; Marks & Isaac, 1995; Guillot & Collet, 2005a; Guillot, Collet, & Dittmar, 2004; Guillot et al., 2007; Lutz, 2003; Roure et al., 1999). Objective tools may not be appropriate in applied rehabilitation and sport settings, as they are time-consuming and expensive. Therefore, an inexpensive form (i.e. a self-report questionnaire) that has been validated in previous research is preferable in the current study.

A notable number of questionnaires, e.g. the Vividness of Movement Imagery Questionnaire (VMIQ), the Revised Movement Imagery Questionnaire (MIQ-R), and the Kinaesthetic and Visual Imagery Questionnaire (KVIQ) with acceptable psychometric properties have been validated in sport and rehabilitation domains (Hall & Martin, 1997; Isaac, Marks, & Russell, 1986; Malouin et al., 2007). These questionnaires were limited to evaluating a participant's ability to generate movement images using the visual and kinaesthetic modalities, however, without further separating the visual imagery into internal and external perspectives.

In addition, some of them are not self-administered questionnaires and need a demonstration of the questionnaire's tasks by the examiner before administering the questionnaire. Therefore, a self-administrated imagery ability questionnaire that delineates the kinaesthetic (KIN) and visual (VI) imagery separately and further separates visual imagery into internal visual (IVI) and external visual (EVI) perspectives was considered in this study.

Across the imagery literature, only two questionnaires distinguish between kinaesthetic and visual modalities and further separate visual imagery into external and internal perspectives. These questionnaires have been validated in the sport psychology domain to evaluate imagery ability in two forms (i.e. vividness and easiness) of movement task.

The first questionnaire is the Movement Imagery Questionnaire (MIQ-3), which was validated and extended by (Williams et al., 2012). The MIQ-3 measures the ease of imagery (it is composed of three subscales assessing external visual imagery, internal visual imagery, and kinaesthetic imagery) and needs a physical demonstration of its items (four basic movements: a knee lift, jump, arm movement, and waist bend) prior to administering the questionnaire to participants. An examiner then asks participants to imagine the action of the previously demonstrated movements and rate how difficult this is using a Likert scale ranging from 1 (very hard to see/feel) to 7 (very easy to see/feel), with a higher average score for a subscale representing a greater ease of imaging.

Physical execution of the movement required by the MIQ-3 procedure prior to imagining the movement, which may affect or confound the short-term memory of participants, who may simply retrieve their experience when they are asked to imagine the recent physical task. It may be worth using MIQ-3 when tightly controlling how movements are imagined or to eliminate inter-individual differences regarding the movement experience (i.e. imagined movements based on their own experience regarding the specific movement) and to prepare participants to readily retrieve the imagined experience of recent MIQ-3 movements. Furthermore, the physical execution of the questionnaire's tasks might not be possible in some conditions (e.g. injury, pain, or paralysis).

The second questionnaire was the Vividness of Movement Imagery Questionnaire (VMIQ-2; Roberts, Callow, Hardy, Markland, & Bringer 2008). The VMIQ-2 measures the vividness of imagery rather than the ease of imagery, which is an important characteristic of imagery ability (Callow & Hardy, 2005; Isaac, 1992; Start & Richardson, 1964). The VMIQ-2 does not include a physical demonstration of its items prior to administration, which makes it easier to administer with less supervision needed from the experimenter.

The VMIQ-2 comprises three subscales: external visual imagery, internal visual imagery, and kinaesthetic imagery rated against 12 movements for each subscale (36 items in total). Participants are instructed to rate the movement items first on the external visual imagery subscale, followed by internal visual imagery and kinaesthetic imagery. Examples of movement items are: walking, jumping off a high wall, throwing a stone into water, and riding a bike. Each image is rated on a 5-point Likert-type scale ranging from 1 (perfectly clear and as vivid as normal vision or feel of movement) to 5 (no image at all, you only 'know' that you are thinking of the skill).

The VMIQ-2 can be easily administered in a quiet room, can be completed individually or in groups, and does not require any preparation or space, all of which are ideal for clinics and research laboratories. The VMIQ-2 has been applied with a stroke patient population (Nobbe, Nilsen, & Gillen, 2012) as although it does not consider the participant's health condition (e.g. asking a patient with hemiparesis to imagine jumping sideways), the imagination of the tasks does not require using the paralysed or injured side if it is administered in a rehabilitation setting.

Williams et al. (2012) reported the existence of two questionnaires in the literature that assess different aspects of imagery ability using the following modality (EVI, IVI, KIN): the MIQ-3 and the VMIQ-2. They suggested that the MIQ-3 is better than the VMIQ-2 when assessing the ease of imagery or when there is a need to tightly control how movements are imagined and how recently participants have performed the movement. Furthermore, they stated that the VMIQ-2 is preferable to the MIQ-3 when the intention is to measure the vividness of imagining movement, when participants are unable to execute the physical movement of the MIQ-3, or if the space is too restricted to administer the MIQ-3.

As both vividness and easiness questionnaires have been used to evaluate imagery ability, we were not interested in further examination of the conceptual meaning of the two terms, but we were looking for the best applicable questionnaire that serves our short and long-term goals in research and in the applied rehabilitation field. We needed a questionnaire that is appropriate for use in future clinical settings (i.e. it can be applied with limited resources and space) and with different patient populations (e.g. injured or paralysed patients). In addition, it should evaluate the contemporary imagery modalities and perspectives (EVI, IVI, KIN).

Roberts et al. (2008) revised and modified the VIMQ-2 based on contemporary imagery modalities and perspective conceptualisations, then validated it using a confirmatory factor analysis (CFA) approach. They first used a single factor analysis on each dimension and then a three-factor correlated traits/correlated uniqueness (CTCU) analysis model with the maximum likelihood estimation. In a CTCU model, the traits are the factors (in this case the three imagery modalities) and the uniquenesses are the residuals of the 36 items (the variance in the items not explained by the factors).

A CTCU model was chosen because in the VMIQ-2, with the three modalities each being assessed with the same 12 movement items (e.g. kicking a stone), there was shared method variance. The CTCU model estimates covariances among residuals for variables that share a common method (Fan and Lance, 2017). Therefore, a CTCU model considers both the dimensional artefacts and random error by allowing correlation between traits (factors) while inferring the shared method effects from the correlated uniquenesses between each of the three imagery modality items that share the common method (Roberts et al., 2008).

The results of Roberts et al.'s (2008) first study revealed poor fit to the data with single factor CFAs, however, following the deletion of the problematic items, the three-factor CTCU analysis revealed an acceptable model fit. In the second study, the factorial validity of the VMIQ-2 was confirmed in a separate sample and the final study provided support for the concurrent and construct validity of the VMIQ-2. Altogether, the results provided preliminary support for the revised VMIQ-2 as a psychometrically valid questionnaire (Roberts et al., 2008).

Further support for the validity of the VIMQ-2 comes from a study on neural activation when engaged in the imagery modalities and perspectives of the VMIQ-2 (i.e. internal and external visual imagery and kinaesthetic imagery) (Jiang, Edwards, Mullins, & Callow, 2015). These were manipulated to study the brain activation areas underpinning these types of imagery using fMRI. The results showed that the imagery perspectives and modalities significantly activated both common areas of activation (in the right supplementary motor area: BA6) and dissociated areas of activation. Specifically, internal visual imagery activated the parietal lobe, external visual imagery displayed some temporal activation, and kinaesthetic imagery stimulated sub-cortical parts of the cerebellum. Therefore, Jiang et al. (2015) showed a delineation of VMIQ-2 imagery modalities and perspectives in certain brain activation areas, which was the first central evidence that showed the initial biological validity of the VMIQ-2.

The VMIQ-2 was adopted in this study to be translated into the Arabic language as there is currently no Arabic language version of the VMIQ-2 questionnaire. Therefore, the objective of this study is to translate and culturally adapt and examine the factorial validity of a classical Arabic language version of the VMIQ-2 with healthy Arab-speaking participants who have lived in either the UK or the KSA. This work aimed to provide a basic research tool for imagery research in rehabilitation, sport psychology, and other domains in Arabic-speaking countries. The translation were conducted using the classical Arabic language, which is the official language-dialect in the Arabic world.

Aims and Hypotheses

1) To translate and culturally adopt the VMIQ-2 to classical Arabic language.
2) To examine the factorial validity of a new Arabic VMIQ-2-A questionnaire with Arabic speakers in the UK using the BSEM method.
3) To examine the factorial validity of the new Arabic VMIQ-2-A questionnaire with Arabic speakers in the KSA using the BSEM method.

Methods

Translation process

The process of translating the VMIQ-2 from its original English to classical Arabic followed the guidelines developed by the Translation and Cultural Adaptation (TCA) group of the International Society for Pharmacoeconomics and Outcomes Research (ISPOR) (Wild et al., 2005). The translation process involved the following stages:

1. Preparation. Permission to translate the VMIQ-2 was obtained from the authors who developed the VMIQ-2 questionnaire. The VMIQ-2 was then revised to clarify the content of the questionnaire as much as possible for Arabic translators and a new target population (see Appendix D-2). The current revised English copy comprised three sections. First, explanations of imagery concepts and types of imagery modalities were added to the questionnaire's introduction section. These explanations included definitions of movement imagery (MI), modalities, and perspectives. Kinaesthetic imagery and visual imagery were defined and visual imagery was further divided into internal and external visual imagery. These explanations and definitions were derived from applied sport psychology literature (Callow & Roberts, 2012; Roberts et al., 2008; Williams et al., 2012) and were important for helping the new target population to understand the VMIQ-2 questionnaire as Arabic imagery studies have not yet been explored in the previous literature.

Second, an instruction sentence at the beginning of the questionnaire regarding the rating scale was altered. The modified sentence originally said, 'Think of each of the following acts that appear on the next page and classify the images according to the degree of clearness and vividness as shown on the RATING SCALE' and was altered to '*Imagine* each of the *movements* that appear on the next page and classify *your* images according to the degree of clearness and vividness as shown on the RATING SCALE *below*'. This modification was made to remind the participants of what to do in the next step and to simplify the instruction.

Third, minor grammatical revisions were made to simplify the VMIQ-2's sentences. These changes were also made to ensure that the use of capitalisation was consistent in the questionnaire. The authors of the VMIQ-2 reviewed the revised English copy and approved all the changes. They confirmed that the underlying meaning of the questionnaire was maintained.

2. Forward translation. The main goal of this stage was to translate the revised English version of the VMIQ-2 into classical Arabic language. This forward translation was performed by three independent translators who were native Arabic speakers, fluent in English, resided in Saudi Arabia, and were professional experts in English–Arabic forward and backward translations. All translators received translation guidelines (see Appendix D-1) prior to beginning the translation. The guidelines included avoiding a literal translation of the questionnaire and following the conceptual meaning of the questionnaire during the translation process. In addition, the translators could adapt questionnaire items if necessary to maintain the questionnaire’s relevance to the new target population. They could also contact the principal researcher at any time to discuss any potential problems during the translation process.

The primary in-country (Saudi Arabia) translator was a professional freelance translator who was contacted at different stages of the translation process. She had more than 12 years of translation experience, which included part-time jobs in healthcare institution management as an Arabic/English translator. She had completed numerous translation projects in various fields, including business, medicine, economics, politics, history, and security. The second translator was an academic lecturer at Northern Borders University (NBU). She worked in the university's Languages and Translation Department and was a professional translator with experience translating scientific essays, social journals, medical essays, poems, and short stories. The third translator was an academic lecturer at the University of Jeddah. She was also a freelance translator, with experience working as a translator and a proof-reader for Bookworm Translation, an agency in the UK, between September 2013 and December 2013. At the time of the study, she was in the process of translating several books from English to Arabic.

3. Reconciliation. This stage mainly comprised the reconciliation by a group of authors of the three translated Arabic copies of the VMIQ-2 into one copy. The author group's members were a first author (MA), a primary translator (NA), a native Arabic speaker who was fluent in English (TA), and a professional who specialised in physiotherapy and rehabilitation science. The reconciliation process comprised the following steps: first, read and check all three copies; second, agree on the best translated phrases in the three copies or produce new phrases if there are discrepancies between the translations; third, after a final agreement is reached, merge all selected phrases to produce a reconciled Arabic copy of the VMIQ-2 (i.e. to produce the first draft of the classical Arabic translation of VMIQ-2).

4. Back translation. This stage comprised the back translation of the reconciled Arabic copy of the VMIQ-2 into English. Three guidelines were followed: first, the translator was a new translator (a fourth translator) who was independent from the previous translators; second, the translator was not involved in the forward translation phase; third, the translator did not have any experience with the original English copy of the VMIQ-2.

The fourth translator was an English literature lecturer at the University of Anbar in Iraq who was fluent in English and a native Arabic speaker. He had lived in the UK since 2011 and was an expert in professional translation, a member of the Iraqi Translators Association, and had experience working as a part-time translator at the Anbar office for language and translation. At the time of the study, he was working towards a PhD in English Literature from Bangor University. He was also working in the International Student Department at the university to support Arab students.

5. Back translation review. This stage comprised a comparison of the back-translated English and original English copies of the VMIQ-2 conducted by the sub-author group (MA, AA, and AH). The main goal of this phase was to identify any differences in the conceptual meanings of the back translated and original copies. The authors did not find any major difference between the two copies. However, two minor changes were made to the reconciled Arabic VMIQ-2 copy. First, an answer to a question that asked participants to report which hand they used for an activity was rephrased. Participants could answer the question by circling one of two options: left or right. Second, item number six in the questionnaire was rephrased with 'jumping sideways' becoming 'jumping to one side' to ensure the meaning was not misconstrued as repeatedly jumping back and forth from side to side. At the end of this stage, a second Arabic draft of the VMIQ-2 was produced, which was used in the following translation step.

6. Cognitive debriefing assessment. This step was designed to test the participants' understanding of the second Arabic draft of the VMIQ-2. Specifically, the goal was to determine whether participants had the same understanding of the Arabic questionnaire as they had of the original English copy. The Arabic cognitive debriefing assessment questions copy (Appendix D-3) was produced by having (MA) and (TA) translate an English cognitive debriefing assessment questions copy (Appendix D-2) into classical Arabic. The Arabic cognitive debriefing questions was reviewed by the second author (AA) and the fourth translator and the assessment was then conducted.

The cognitive debriefing assessment comprised of completing the Arabic version of the VMIQ-2 questionnaire and answering the questions that were added after each section of the VMIQ-2 questionnaire to rate the clearness of the preceding sections. The participants then answered the cognitive debriefing interview questions, which included asking them to rephrase in their own words the imagery concepts, terms, and questions that were used in the test. This involved explaining whether they could imagine movement items in the questionnaire, and if they could, describing what they imagined during each specific movement of the questionnaire (Appendix D-3).

Wild et al. (2005) recommended performing a cognitive debriefing assessment with five to eight participants, so a sample of this size was used (see the pilot work subsection below). The sample was divided into two groups according to country and the participants then answered the assessment questions.

7. Cognitive debriefing assessment review. The goal of this phase was to assess the participants' understanding and the cultural relevance of all the Arabic VMIQ-2 items. To do this, the three authors reviewed the data collected during the cognitive debriefing stage, which comprised two sets: one from the UK participants and one from the KSA participants. The results of the sets can be seen in the pilot work sections below.

8. Proofreading. This stage comprised proofreading the second classical Arabic draft of the VMIQ-2 to ensure it was free of any errors (e.g. grammar, spelling, and context errors). The three authors (MA, TA, AA) performed independent reviews of the Arabic VMIQ-2 (see Appendix D-4 for the final Arabic version). The final classical Arabic version of the VMIQ-2 was named the VMIQ-2-A.

9. Reporting. A project manager (MA) wrote a report comprising notes, changes, and decisions regarding the translation process and the cultural adaptation, which can be used for similar projects. This report is available upon request.

Procedure

This section describes the procedure used to recruit participants from the UK and the KSA. Recruitment comprised two stages: participant recruitment for the cognitive debriefing assessment, then once the review of the cognitive debriefing assessment results indicated that the translated VMIQ-2-A was valid for Arabic populations in the UK and the KSA, recruitment proceeded for all other participants. The investigators invited any participant who was a native Arabic speaker from an Arabic country and who lived in either the UK or the KSA. Additionally, each participant had to be free from any physical or mental illness that could influence his or her participation.

Recruitment was done using posters and word of mouth, as well as emails and direct advertisements to Arabic societies and groups. All potential participants received an invitation letter, an information sheet, and an informed consent form. These documents were written in classical Arabic so they could be understood by all potential participants. If a participant satisfied the criteria and agreed to take part in the study, he or she was required to sign and return the informed consent form prior to participating in the study. The experiment took place in locations that were quiet and convenient for the participants, including community centres, houses, universities, and places of faith.

At each location, an investigator explained the study in detail to each participant. This explanation included how the participant could complete the VMIQ-2-A questionnaire and/or how the participant could answer and address extra questions for the cognitive debriefing assessment. The assessment was completed individually or with a group of no more than five participants. This was done under the supervision of the investigator, who answered any questions related to the study and/or the assessments. The investigator then checked all the participants' answers and wrote any necessary notes. Finally, the participants were thanked for their time and effort.

As per the UK Data Protection Act of 1998, the data for all participants were protected, and only the investigators could access the data for specific research purposes. Additionally, each participant's name was replaced by an identification number. In terms of preventing any effects regarding the order of the questionnaire subscales, different assessment versions with different questionnaire subscale orders (i.e. six versions, each with a different section order) were made and were randomly distributed to the participants. Moreover, participants who completed the questionnaire twice were given the same questionnaire order each time, one week apart.

Pilot Tests

Procedure

Pilot tests were conducted with the VMIQ-2-A to review the cognitive debriefing and the initial reliability of the data gathered from participants in the UK and the KSA. First, participants were asked to answer the VMIQ-2-A and cognitive debriefing assessment questions. Then, the data sets from these tests were reviewed and if their results suggested the VMIQ-2-A was understandable among Arabic speakers, the general recruitment of all participants started (i.e. they were asked to complete the VMIQ-2-A only) and their data for each country (UK and KSA) were examined and analysed for initial reliability. Specifically, the data sets were reviewed to determine whether the VMIQ-2-A was understood well and was appropriate for Arab cultures and to determine the preliminarily reliability and internal consistency of each data set.

Pilot test one (UK data)

All participants were native Arabic speakers who lived in the UK and were recruited using the method described above. The main goal was to later explore the characteristics of the UK data using two steps. First, reviewing the results of the cognitive debriefing test and second, evaluating the initial reliability by conducting two statistical analyses: a test-retest reliability analysis and an internal consistency analysis. The test-retest reliability analysis was conducted using scores for each scale (EVI, IVI, and KIN) on the assessment. Intraclass correlation coefficients (ICCs) were calculated for all subscales with a 95% confidence interval (CI) and a one-way random effect model in SPSS. The internal consistency analysis was conducted using Cronbach's alpha (α). An alpha was considered an indication of favourable coherence if it was greater than 0.70.

Results: UK data.

The cognitive assessment and general UK data sets were assessed for normality and were found to be normally distributed. The cognitive assessment sample comprised seven participants (3 female). The participants' ages ranged from 21 to 58 years old (21 to 35 for the females; 23 to 58 for the males). They were all native Arabic speakers from different Arabic countries and they all resided in the UK. The general UK sample comprised 169 participants (41 female) with a mean age of 34.41 years (SD = 8.18).

Cognitive debriefing assessment.

The VMIQ-2 was clear regarding its concepts and appropriate for the Arabic culture. All participants rated the questions in each section of the questionnaire as 'medium' to 'very easy' and no participants reported any difficulties understanding any words in the questionnaire. Moreover, all participants described all imagery terms accurately, except for one participant who confounded internal imagery with kinaesthetic imagery. There was only this one error in understanding imagery terms and it was not clear whether it was a misunderstanding of the term itself or of the questions in the VMIQ-2. Therefore, no changes were made to the questionnaire based on this error. In the last section of the assessment, all participants reported they could imagine all questionnaire items. They gave descriptions of how they imagined the questionnaire items and these descriptions matched the intended descriptions. Based on these results, the translated VMIQ-2 was considered acceptable as the final Arabic copy of the VMIQ-2-A for Arabic speakers who live in the UK.

Test-retest reliability.

The ICCs and 95% lower and upper CIs were reported for each subscale: EVI=.78 [.61, .87], IVI=.70 [.47, .83], and KIN=.61 [.33, .78], and the VMIQ-2-A total: .79 [.63, .88]. The reliability levels (ICCs) ranged from .61 to .79, indicating that the VMIQ-2-A questionnaire was reliable and had good reproducibility levels (Malouin et al., 2007).

Internal consistency.

Table 1 shows the Cronbach's α values for the VMIQ-2-A subscales (EVI, IVI, and KIN), which ranged from .88 to .90. The ranges indicated that the imagery subscales were internally consistent (i.e. there was high reliability across the VMIQ-2-A subscales) (see Field, 2013). In addition, Table 1 shows the lowest value of 'corrected item to total score correlation'. These values indicate the lowest correlations between the items within the subscales and the total scores of the subscales. As no correlations were lower than 0.3, all items of the subscales associated well with the total value of each subscale.

Finally, Table 1 shows the maximum 'Cronbach's α if item deleted' values. These values indicate whether the removal of any scale item would significantly improve the Cronbach α value of the questionnaire. The values were in the regions of the overall Cronbach's α value, which indicates that reliability was consistent across all the items within the scales.

Table 1. The internal consistency of VMIQ-2-A based on the UK data

	Cronbach's α	**Lowest 'corrected item to total score correlation' value**	**Highest 'Cronbach's α if item deleted' value**
EVI	.88	.53	.87
IVI	.88	.39	.88
KIN	.90	.53	.90

Pilot study two (KSA data)

All participants were native Arabic speakers who lived in the KSA. The participants were recruited using procedures similar to pilot test one. Moreover, the test was conducted and the results were analysed using the same method and analyses that were used for pilot test one.

Results: KSA data.

The cognitive assessment and general KSA data sets were assessed for normality and were found to be normally distributed. The sample for the cognitive assessment comprised 13 participants (seven female). The participants' ages ranged from 23 to 48 years old (23 to 41 for the females; 23 to 48 for the males). The general KSA sample comprised 178 participants (96 female) with a mean age of 26.73 years (SD = 7.5).

Cognitive debriefing assessment.

Most participants (77%) understood concepts related to MI. Eight percent had moderate difficulty and 15% had difficulty understanding some MI terms. In general, most participants understood all the imagery terms and only four women were confused about the different natures of IVI- and KIN-related terms. Therefore, the VMIQ-2 was easy to understand for the majority of the respondents, who accurately understood all key imagery concepts.

As a cognitive assessment was not conducted for the English VMIQ-2 using general native English speakers, it was not known whether the IVI- and KIN-related difficulties may occur with English speakers. For this reason, and because of the generally high levels of understanding among the participants, the VMIQ-2-A was considered an appropriate and culturally relevant translation for those residing in Arabic-speaking countries.

Test-retest reliability.

The ICCs and 95% lower and upper CIs were reported for each subscale: EVI=.87 [.74, .93], IVI=.83 [.67, .91], and KIN=.84 [.69, .92], and the VMIQ-2-A total: .87 [.75, .93]. The reliability levels (ICCs) ranged from 0.83 to 0.87, indicating that the VMIQ-2-A questionnaire was reliable and had good reproducibility levels (Malouin et al., 2007).

Internal consistency.

As mentioned previously, internal consistency of the data set was analysed by determining the Cronbach's α values, which ranged from .86 to .87 (see Table 2). The ranges indicated that the imagery subscales were internally consistent (i.e. there was high reliability across the VMIQ-2-A subscales) (see Field, 2013).

Table 2 shows the lowest 'corrected item to total score correlation' values for all subscales. As there were no values lower than 0.44, all subscale items correlated well with the total values of each subscales. In addition, Table 2 shows the highest 'Cronbach's α if item deleted' values. These values were in the region of the overall Cronbach's α values, which indicated that reliability was consistent across all the items within the scales.

Table 2. The internal consistency of VMIQ-2-A based on the KSA data

	Cronbach's α	Lowest 'corrected item to total score correlation' value	Highest 'Cronbach's α if item deleted' value
EVI	.86	.44	.85
IVI	.86	.48	.85
KIN	.87	.46	.87

Impression of pilot testing results

The results of the two pilot studies from the UK and the KSA revealed accurate and high understandings of the VMIQ-2-A (supported by cognitive debriefing assessment reviews). The results also indicated that the questionnaire was appropriate for the Arabic culture. Therefore, the VMIQ-2-A had been translated well. In addition, the results were promising in terms of the initial reliability of each data set. Specifically, the results of the statistical analyses (the test-retest reliability and Cronbach's α tests) were promising. Altogether, the current data supports the VMIQ-2-A's reliability and internal consistency showing preliminary support of UK & KSA data of Arabic VMIQ-2-A. Further studies should investigate the factorial validity of the questionnaire with an advanced analysis procedure.

Advanced data analysis procedure

The analytic strategy to assess factorial validity

As noted above, Roberts et al. (2008) confirmed the factorial validity of the VMIQ-2 via CFA and used the CTCU model with a maximum likelihood estimator (ML) of multi-trait-multi-method (MTMM) data. While the CTCU approach allows for correlations among the item residuals with the same method effects (e.g. between items with the same method, such as walking, running, etc.), it does not allow correlations between residuals for different method effects (e.g. between items referring to running and items referring to walking). In other words, it assumes that the effects of different methods are independent of each other.

Conway, Lievens, Scullen, and Lance (2004) suggested that if the assumption of uncorrelated method effects is not met, then biased estimates for trait variances and covariances will occur. Furthermore, evidence shows that the CTCU model often suffers from empirical estimation

(Conway, Lievens, Scullen, & Lance, 2004; Marsh & Bailey, 1991) and theoretical problems (Lance, Noble, & Scullen, 2002).

As a more general issue, although CFA with ML estimation is commonly used to assess the factorial validity of theoretically grounded multidimensional measures, it suffers from an inherent misspecification with more chances to reject a model with poor fit as it restricts the cross-loadings and residual correlations to exactly zero (Cole, Ciesla, & Steiger, 2007: Marsh, 2007). This independent clusters model (ICM) approach is parsimonious, but highly restrictive and considered less than optimal as it increases the likelihood of falsely rejecting a model because the factor structure in reality is more complex with many small cross-loadings and correlated residuals (Asparouhov & Muthén, 2009; Browne, 2001; Marsh et al., 2009).

Therefore, for the present study, the recently developed BSEM approach was adopted (Muthén & Asparouhov, 2012). BSEM is both strictly confirmatory in nature and less restrictive than ICM-CFA (Golay, Reverte, Rossier, Favez, & Lecerf, 2013; Muthén & Asparouhov, 2012). BSEM has recently been used to examine factorial validity in the sport and exercise psychology literature (e.g. Barnett et al., 2016; Gucciardi & Jackson, 2015; Gucciardi, Peeling, Ducker, & Dawson, 2016; Jackson, Gucciardi, & Dimmock, 2014; Markland & Niven, 2016; Stenling, Ivarsson, Johnson, & Lindwall, 2015).

The Bayesian statistical approach treats all parameters (e.g. in the case of measurement models, the factor loadings, cross-loadings and residuals) as variables with a mean and distribution of values, rather than as constants (as in the ML approach). This then allows the a priori specification of cross-loadings and residual correlations of approximately zero rather than exact zero means and with small variances to allow for small, substantively trivial deviations from zero.

The level of a researcher's (un)certainty about the specific parameter values can be reflected by the size of the a priori specified variances. Higher certainty can be reflected by using smaller prior variances and vice versa (Schoot et al., 2014). Therefore, the prior probability distributions are classified into three main categories: informative (precise parameter estimates specified a priori with small variances), weakly informative (precise parameter estimates with large variances), and non-informative (no a priori specification of the estimates or their variances). These reflect the varied degrees of the researcher's (un)certainty about the parameter value of interest (van de Schoot & Depaoli, 2014). Further advantages of BSEM compared to CFA models are that potential modifications with all the parameters can be estimated simultaneously with the information gained by small variance priors, that it can be used with highly skewed distributions, and that it can be performed with small sample sizes (Muthén & Asparouhov, 2012; Lee & Song, 2004).

For the present study, following common practice (e.g., Niven & Markland, 2016) a series of three BSEM analyses were conducted on the translated VMIQ-2 Arabic version, separately for UK and KSA samples. First, models with non-informative priors (i.e. freely estimated) for the major item loadings with no cross-loadings or residual correlations were assessed; second, models with informative approximately zero means and small variance cross-loadings were assessed; and third, models with informative approximately zero means and small variances for both cross-loadings and residual correlations were assessed.

Prior variances for cross-loadings and residual correlations were specified at ±.01, which corresponds to standardised loadings and residual correlations of ±.20. In addition, for the KSA sample, each of the major factor loadings was set a priori as the value obtained for the corresponding loading in the UK sample, with small variance priors of ±.01 in order to determine that the major loadings were approximately invariant across the two samples.

The potential scale reduction factor (PSR) was used to assess the convergence. If the final value of the PSR lies between 1.0 and 1.1, it provides evidence of convergence. The model fit was assessed in this study using posterior predictive checks that designate the degree of difference between the model generated and the observed data using the likelihood ratio X^2 test and its related posterior predictive p value (PPP). A PPP value of about .50 and a symmetrical 95% CIs for the variance between the observed and replicated X^2s centred around zero indicates a well-fitting model (Muthen & Asparouhov, 2012).

Internal consistency

Internal consistency of the VMIQ-2 subscales was assessed with the composite reliability coefficient (Fornell & Larcker, 1981).

Results

Factorial validity

Table 3 shows the fit of the VMIQ-2A models for the UK and KSA samples. Adequate convergence was achieved for the current models for both samples. The restrictive independent cluster BSEM models for both data sets with zero cross-loadings and zero residual correlations converged on a solution, but the PPP for the model indicated a poor fit to the data. The model fit was also unacceptable for the model with informative small variance priors on the cross-loadings only. However, in both data samples, the model with informative small variance priors on the cross-loadings and residual correlations had an excellent fit to the data, with PPPs above .5 and reasonably symmetrical 95% posterior predictive CIs centred around zero.

The items' standardised factor loadings with 95% CIs for both samples for the VMIQ-2A are shown in Table 4. For both samples, all major loadings were significant and acceptable by conventional criteria (e.g. >.4; Ford, MacCallum, and Tait, 1986). Furthermore, all cross-loadings and residual correlations (UK sample) were shrunk towards their zero prior means and were within their a priori variance limits of ± .10. For the KSA data, where the major loadings were specified based on those obtained from the UK data, all loadings fell within their a priori specified limits, indicating approximate invariance of the loadings. In addition, none of the cross-loadings nor the residual correlations escaped their a priori bounds.

Internal consistency

Table 5 shows the means, SDs, composite reliabilities (CR), and latent factor inter-correlations between the VMIQ-2A modalities across both samples with 95% credibility intervals [in brackets]. Results for both samples demonstrated acceptable reliabilities across all VMIQ-2A subscales. All VMIQ-2A subscale means were around the scale midpoint for all three imagery factors (EVI, IVI, KIN) for the UK sample, while in the KSA sample, the means of all subscales were a little below the midpoint. The relationships between the three imagery factors showed moderate to strong positive correlations for both samples, with the strongest relationship between the KIN and IVI modalities for both samples, but none of the upper bounds of their 95% credibility intervals encompassed unity, indicating discriminant validity of these subscales with respect to each other.

Table 3. BSEM fit and convergence

Model	**Difference between observed and replicated ×² 95% Cis**				
	No. free parameters	PPP	Lower 2.5%	Upper 2.5%	PSR
UK sample					
Non-informative	111	.00	1292.58	1467.96	1.00
Informative priors (cross-loadings)	183	.00	1174.73	1361.61	1.00
Informative priors (cross-loadings + residual correlations)	813	.79	-154.89	65.16	1.02
Saudi sample					
Non-informative	111	.00	889.92	1059.94	1.00
Informative priors (cross-loadings)	183	.00	856.42	1033.22	1.00
Informative priors (cross-loadings + residual correlations)	813	.76	-148.15	68.38	1.03

Note: PPP = posterior predictive p value; PSR = potential scale reduction

Table 4. VMIQ-2A standardised factor loadings with 95% credibility intervals in brackets

Item	External	Internal	Kinaesthetic
UK Sample			
Walking	.65 [.47,.79]	.62 [.43,.79]	.73 [.56,.89]
Running	.74 [.58,.86]	.62 [.43,.79]	.74 [.58,.87]
Kicking a stone	.57 [.39,.71]	.67 [.50,.82]	.65 [.47,.81]
Bending to pick up a coin	.65 [.50,.78]	.64 [.47,.80]	.68 [.51,.83]
Running up stairs	.75 [.61,.86]	.75 [.59,.89]	.70 [.54,.84]
Jumping sideways	.64 [.49,.77]	.70 [.54,.84]	.79 [.66,.91]
Throwing a stone into water	.67 [.52,.81]	.65 [.46,.80]	.67 [.51,.82]
Kicking a ball in the air	.69 [.53,.82]	.67 [.50,.83]	.72 [.56,.86]
Running downhill	.73 [.60,.85]	.68 [.51,.82]	.69 [.53,.83]
Riding a bike	.66 [.51,.79]	.63 [.45,.79]	.67 [.51,.81]
Swinging on a rope	.60 [.41,.74]	.63 [.44,.79]	.58 [.40,.74]
Jumping off a high wall	.61 [.45,.75]	.65 [.49,.79]	.61 [.43,.76]
Saudi sample			
Walking	.66 [.56,.76]	.60 [.48,.71]	.64 [.52,.75]
Running	.73 [.63,.82]	.70 [.59,.79]	.75 [.64,.85]
Kicking a stone	.56 [.44,.67]	.68 [.56,.79]	.70 [.59,.81]
Bending to pick up a coin	.61 [.50,.71]	.65 [.53,.76]	.70 [.60,.80]
Running up stairs	.73 [.63,.82]	.78 [.68,.88]	.70 [.59,.80]
Jumping sideways	.64 [.52,.73]	.63 [.51,.74]	.72 [.62,.82]
Throwing a stone into water	.66 [.55,.76]	.64 [.53,.75]	.64 [.52,.74]
Kicking a ball in the air	.64 [.49,.76]	.61 [.48,.73]	.65 [.54,.75]
Running downhill	.66 [.55,.76]	.60 [.49,.72]	.68 [.57,.78]
Riding a bike	.64 [.53,.74]	.61 [.50,.73]	.70 [.60,.80]
Swinging on a rope	.60 [.49,.70]	.57 [.45,.68]	.55 [.43,.67]
Jumping off a high wall	.58 [.46,.68]	.59 [.47,.70]	.55 [.43,.66]

Table 5. Means, SDs, CRs, and latent factor inter-correlations between VMIQ-2A modalities for both samples, and their 95% Credibility Intervals [in brackets]

	M	SD	CR	EVI	IVI	KIN
UK sample						
EVI	29.93	9.51	.91			
IVI	28.93	9.28	.90	.42 [.24,.58]*		
KIN	26.31	10.03	.92	.39 [.20,.56]*	.63 [.48,.74]*	
Saudi sample						
EVI	26.61	12.54	.89			
IVI	24.98	11.98	.89	.30 [.10,.47]*		
KIN	24.14	11.99	.91	.23 [.03,.41]*	.52 [.36,.65]*	

Discussion

The objective of the current study was to translate and culturally adopt the VMIQ-2 questionnaire to classical Arabic language to be used in Arabic countries. The factorial validity of the new Arabic VMIQ-2-A questionnaire among Arabic speakers in both samples (UK and KSA) was assessed using the BSEM analysis method. To the best of our knowledge, this is the first study that has translated an imagery ability questionnaire for use with the Arabic population and that uses the BSEM analysis for factorial analysis.

The use of BSEM analysis is becoming accepted as an innovative technique to check multidimensional models (Niven & Markland, 2016). Our study demonstrates the value of adopting the recently developed BSEM approach to assess the factorial validity of measurement instruments and our findings provide initial support for the psychometric properties of the translated VMIQ-2 for both samples.

Factorial validity of the VMIQ-2A

The VMIQ-2A produced poor fit models for both samples, as anticipated, when imposing the non-informative model and with models that imposed small variance priors on the cross-loadings alone. The advantage of the BSEM analysis model is that it allows the user to impose small variance priors on both cross-loadings and residual correlations. Therefore, this advantage was used in our samples and produced an excellent fit for the models for both samples, giving a more empirically and theoretically realistic model specification (in comparison to the non-informative priors and informative approximately zero means and small variance cross-loadings).

In addition, for the VMIQ-2A for both samples, all cross-loadings and residual correlations fell within their pre-specified 95% limits of ±.10 and indicated approximate invariance of the loadings with VMIQ-2A across both samples. In conclusion, the results of the BSEM analysis of the Arabic VMIQ-2A from both samples revealed that the VMIQ-2A has good factorial validity. The results also demonstrated that the level of internal reliability was good for the VMIQ-2 for both samples, which provides further evidence of the integrity of the measure.

Relationship among VMIQ-2A subscales

The imagery subscales (EVI, IVI and KIN) were positively intercorrelated, but this association was not to the level that they lacked discriminant validity with respect to each other. Furthermore, the kinaesthetic factor was more strongly correlated with the internal visual imagery factor than with the external visual imagery factor. This corresponds with previous findings in the literature. Roberts et al. (2008) validated the original English version of the VMIQ-2 with acceptable psychometric properties and found a significant correlation between KIN and IVI.

It has been argued that IVI and KIN occur together and are therefore better represented as a single factor labelled ‘motor imagery’ (e.g. Lotze & Halsband, 2006). Accordingly, Roberts et al. (2008) re-examined their data to explore whether, from a measurement perspective, having IVI and KIN as separate factors or as a single motor imagery factor was more factorially valid. Their results showed that IVI and KIN should be treated as separate modalities. A first assessment was done using a two-factor CTCU analysis that treated the IVI and KIN factors as separate and a second analysis simulated a one-factor model by fixing their correlation to 1.0. These further analyses confirmed that the two-factor model demonstrated a significantly better fit than the simulated one-factor model, indicating that despite their significant association, IVI and KIN should be considered as separate (cf. Glisky, Williams, & Kihlstrom, 1996).

Furthermore, Jiang et al. (2015) provided additional support for all three imagery factors of the VMIQ-2 (EVI, IVI, KIN) being delineated separately. They applied the VMIQ-2 in the study of the brain activation underpinning these types of imagery. Their results provided the first central evidence for the visual perspectives and modalities delineated in the VMIQ-2 and initial biological validity for the VMIQ-2.

Limitations and future directions

The strengths of this study are that it produced the first imagery ability assessment tool in the Arabic language and may support future imagery research with new target populations. In addition, the validation process of the current study used a novel analysis method (BSEM), which has only recently started to be used in sport and exercise psychology (Faull & Jones, 2017; Niven & Markland, 2016). Further research is required on the new Arabic VMIQ-2, specifically with imagery intervention studies.

In addition, the new Arabic imagery assessment tool can be investigated in relation to various imagery training methods and/or with various factors, such as participant type and different study settings. Additional studies further validating the new Arabic VMIQ-2 questionnaire may be required, especially in Arabic countries that do not use classical Arabic widely.

Lastly, although the VMIQ-2 was validated with healthy subjects, it could be applied in rehabilitation settings as it has been applied with a stroke patient population (Nobbe et al., 2012). The measure would be particularly appropriate for clinical settings as it can be easily administered or self-administered, can be completed individually or within groups, and does not require any preparation or space.

Conclusions

The findings of this study provide initial support for the newly translated Arabic VMIQ-2-A and with adequate psychometric properties. The measure was validated using BSEM as a novel method of analysis, which revealed the advantages of BSEM as a theoretically grounded, but empirically more realistic approach compared to the traditional restrictive independent clusters method. The results of this study provide the first version of an Arabic imagery ability questionnaire that places the measure at the disposal of Arabic-speaking researchers to use as a facilitating tool in future imagery studies in this population.

Chapter 5: General discussion

Summary

The objective of this thesis was to explore the viability of using imagery practice as a promising therapeutic tool for musculoskeletal rehabilitation. This chapter discusses and integrates all the main findings presented in this thesis.

Potential applications of imagery practice in musculoskeletal rehabilitation (chapter 1)

The first chapter in the thesis presented a literature review, which provided a brief overview of imagery practice in different applied fields (e.g. sport and neurorehabilitation); then, the review addressed imagery concepts and definitions, terminology, types and functions. The main reasons for using imagery interventions in the applied setting were summarised; in addition, the possibility of using imagery as an intervention tool for musculoskeletal rehabilitation was critically reviewed using studies that considered the efficacy of imagery interventions by assessing musculoskeletal system function (i.e. muscle strength). These studies, which involved healthy and/or patient populations, were selected for review if the efficacy of imagery interventions for varied muscle functional outcomes was tested directly.

The review chapter showed promising results regarding the use of imagery practice as a potential physiotherapeutic tool for varied applications and goals in connection with the musculoskeletal system. However, the current studies revealed that there is a need for adapting the current imagery protocols to specific applications/goals prior to their introduction to a clinical population. Indeed, most of the previous studies used inconsistent methodologies, intervention types and modalities, as well as targeting small muscle groups, making the replication of imagery interventions in the rehabilitation setting challenging. Based on the review in chapter 1, it is recommended that the evidence should be improved concerning the application of imagery practice for strength training, as strengthening muscles is one of the most important goals in musculoskeletal rehabilitation, including strengthening of larger muscle groups. Accordingly, the current thesis intended to improve the wealth of findings related to the efficacy of imagery training on strength outcomes using a consistent methodology. Based on this direction, the experimental part of this thesis was designed to achieve the following objectives: Firstly, to examine the efficacy of imagery practice on muscle strength with larger muscle groups (hip abductors) using two different imagery protocols. Secondly, following this, to use the more effective imagery protocol for a comparison of imagery with exercise training, assessing the strength and activation of muscles. In addition, the occurrence of a bilateral transfer effect on muscle strength was investigated to improve the mechanistic understanding of imagery effects on muscle strength and activation. Finally, the importance of the evaluation of individuals' imagery ability among the imagery intervention participants was addressed. A further part of this thesis built on the potential expansion of research activities using imagery to Arabic countries by translating and validating an Arabic version of the VIMQ-2 in Saudi Arabia.

Efficacy of imagery practice as an intervention tool

Efficacy of imagery training on hip abductor muscle strength (chapter 2).

The primary objective of this study was to investigate the effectiveness of cognitive imagery training (i.e. imagined performing the maximal contractions of the hip abduction task without overt contractions) on hip abductor muscle strength. A randomised control design was used, with the participants divided into two imagery groups, one using kinaesthetic imagery (KIN) alone and the other using a combination of the visual and kinaesthetic imagery modalities (KIN+VI), and a control group (no practice). The main results of chapter 2 revealed a significant interaction between the study groups and time. Although both imagery groups showed a trend toward muscle strength improvement compared with the baseline levels, the only group that reached a significant increase in muscle strength (approximately 8%) compared with the baseline was the KIN+VI group. Moreover, the KIN +VI group revealed significantly improved imagery ability, while there was no improvement in the KIN and control groups. These results are important for any potential implementation in physiotherapy, as most previous studies examined small muscle groups. Thus, ours is one of few studies supporting the efficacy of imagery training for improving strength in larger muscle groups (e.g. De Ruiter et al., 2012; Shackell & Standing, 2007).

Exploration of ipsilateral and bilateral training effects on muscle strength and EMG following imagery practice compared with exercise practice (chapter 3).

The first objective of this study was to examine the ipsilateral training effects of imagery training compared with exercise training on the trained hip abductor strength and electromyography (EMG) amplitude. For this, we used our formerly established imagery protocol (i.e. based on chapter 2's findings; hence, the current imagery training used the combined imagery protocol [KIN + VI], as this was found to be superior to the other protocol, KIN alone), and we compared this with 2 weeks of isometric exercise of the hip abductor muscles.

The second objective was to explore whether a bilateral transfer occurs in strength and EMG outcomes following unilateral imagery training, as this had not yet been examined with hip abductors, which is an important part of identifying possible mechanisms and physiological responses following imagery training. The third objective was to investigate a possible transfer effect of imagery and exercise training to a homologous muscle group of a different body segment (deltoideus medius muscle). Finally, we examined the possible influence of motivation between study groups on strength gains. The motivation was investigated using subjective reports and a proxy measure (handgrip strength) before and after administration of the assigned interventions.

Ipsilateral training effect/muscle strength and EMG.

The imagery group showed a significant strength improvement in the trained hip abductor muscles following a short period of imagery training (2 weeks), while the exercise training did not succeed in showing an incremental strength effect. The amount of strength gain of the trained hip abductors following the imagery training was (~7%), which is comparable to the strength gain that we detected in the first experimental study (~8%; chapter 2) using a similar methodology and imagery training protocol. Thus, both experimental studies demonstrated the efficacy of imagery practice on improving strength in larger muscle groups (hip abductors).

Bilateral transfer effect /muscle strength and EMG.

To the best of our knowledge, the role of unilateral imagery training on bilateral transfer with strength outcomes has received relatively little attention across the imagery intervention literature, and it has not been examined with larger muscle groups. The current study demonstrated that the bilateral transfer effect can be induced on homologous contralateral untrained hip abductor muscles; however, this was only accomplished by imagery training, and not by our exercise training protocol. Our results showed significant strength improvements of the homologous, contralateral, untrained hip abductor muscles following imagery training.

Home-training protocols

Participants' adherence to the home exercise training during weekend sessions may have been influenced by the training type. Our results showed that the participants in the *exercise* group displayed less motivation to perform the weekend sessions than participants in the *imagery* group did. Thus, the current study provides important information regarding the possibility of using imagery training as a proposed self-administered tool at home in the clinical population.

Compliance with home-based imagery intervention should rely strongly on participants' motivation, thereby influencing the subsequent strength results in interventions.

Imagery ability.

Our current data revealed that a short period of imagery training (2 weeks) can be effective in improving imagery vividness (VMIQ-2 total score); in this study, this improvement specifically occurred in the internal visual imagery ability subscales. However, the exercise group did not show any improvement in imagery vividness (VMIQ-2 total score) following our isometric exercise protocol, although some decline was observed following exercise training on the kinaesthetic imagery subscale. Thus, our result was consistent with the findings in chapter 2 on imagery ability (imagery vividness), which suggested a benefit from simple imagery training for imagery ability improvement; this may maximise the effects of imagery training.

Potential mechanisms.

The results from our experimental studies can contribute to a mechanistic interpretation of strength gained following imagery training. The second experimental study showed that EMG amplitudes from the trained limb recorded during imagery sessions were hardly detectable, and they were much smaller than the EMG data during the exercise training sessions. The absence of EMG activity during the imagery session indicated a central nervous system role rather than a more complex mechanism, with involvement of the peripheral parts of the reflex arch for strength gains following imagery training (Ranganathan et al., 2004; Slimani et al., 2016; Yao et al., 2013).

The current study contributes to the understanding of the underlying mechanism of the bilateral transfer effect. Our data showed the improvement of homologous untrained hip abductor muscles; however, we did not observe any improvement of muscle strength on untrained shoulder abductors or handgrip. These results suggested that the efficacy of imagery training was not due to general motivation or specific for the trained muscle group and homologous muscle group in the same segment. Lee & Carroll (2007) reported evidence that proposed cross education is a result of neural adaptation when the training effect specificity occurred (i.e. strength gain is only observed in the contralateral homologous muscle). If the mechanism mediating bilateral transfer were more generalised in origin (e.g. improved general motor command), then strength alterations should have been observed in other muscle segments as well (Lee & Carroll, 2007).

Establishing a first Arabic imagery evaluation tool (translation study, chapter 4)

As discussed above, imagery ability evaluation was considered an important measure when designing the imagery interventions. As there were initially no imagery ability questionnaires written in Arabic, the need to translate and validate an imagery assessment tool for future imagery research in Arabic-speaking countries was an important objective of this thesis. Consequently, the third study in this research included the translation of the VMIQ-2 into Arabic and subsequent validation of the tool.

The VMIQ-2 instrument was translated, culturally adapted and validated for Arabic native speakers. This questionnaire was chosen because it evaluates the imagery ability, delineating the imagery modality and perspectives in EVI, IVI and KIN, and it is a self-administered questionnaire, which is more suitable for application when resources are limited. The translation project comprised the following processes:

- Translating the VMIQ-2 from the original English to classical Arabic, which included many stages (preparation, forward translation, reconciliation, back translation, back translation review, cognitive debriefing assessment, cognitive debriefing assessment review, proofreading and reporting)
- Pilot assessment studies:
    - Cognitive debriefing assessment, assessment of understanding the initial VMIQ-2 Arabic version among Arabic speakers in two different countries (UK and KSA) and approval of the final Arabic version of the VMIQ-2;
    - Evaluation of the initial reliability of the final VMIQ-2 Arabic version among Arabic speakers from two different countries (UK and KSA); and
- Using an advanced analytical method, BSEM, to test the factorial validity of the VMIQ-2 Arabic version across both datasets (UK and KSA).

Altogether, the results of this project produced the first Arabic VMIQ-2 version, termed the VMIQ-2-A. The current results supported the initial validity of the VMIQ-2-A, with good psychometric properties.

Novelty of the current thesis

Previous work reported positive outcomes of imagery practice in neurological physical practice as a promising therapeutic strategy (Braun et al., 2006; Dickstein & Deutsch, 2007; 2001; Jackson et al., 2001; Johnson-Frey, 2004; Lotze & Halsband, 2006; Malouin & Richards, 2013; Mulder, 2007; Schuster, Butler, Andrews, Kischka, & Ettlin, 2012; Zimmermann-Schlatter et al., 2008). There is currently no review available that evaluated the comprehensive role of imagery practice in musculoskeletal conditions. Thus, the current thesis is one of the first works to evaluate the possibility of using imagery practice as an effective therapeutic tool in musculoskeletal physiotherapy practice that has included both a review of literature and experimental studies.

To the best of our knowledge, the current thesis is one of the first works examining the occurrence of a bilateral transfer phenomenon in a larger muscle group following imagery training. The results showed a significant strength improvement of the homologous, contralateral, untrained hip abductors (~8%) following 2 weeks of imagery training. A previous imagery training study on small muscles investigated the efficacy of imagery training regarding a bilateral transfer effect with strength outcomes; improvements of the untrained little finger muscle following unilateral imagery and physical training (10% and 14%, respectively) were reported (Yue & Cole, 1992). In addition, the current thesis confirmed the effectiveness of imagery practice for a larger muscle group (hip abductors), which are more important in rehabilitation settings.

Another novel feature of the thesis was the translation and validation of the VMIQ-2 into classical Arabic. An Arabic version of the imagery ability assessment questionnaire was formerly not available; thus, the new Arabic questionnaire could be used widely among Arabic speakers in Arabic countries.

Strengths and Limitations

This thesis has several strengths, including the following: First, it confirms the efficacy of imagery on a larger muscle group (hip abductors) in two separate experimental works using valid and reliable objective assessment tools (maximal isometric torque and EMG) and suitable experimental designs. Second, our thesis produced data that may contribute to understanding the underlying mechanisms of imagery efficacy on muscle strength (e.g. by examining the bilateral transfer effect phenomenon and recording EMGs during imagery sessions). Third, our thesis used a high level of control during the experimental work, such as allocating subjects randomly to study groups, randomising the order of limbs during the pre- and post-assessment points and cycling for

3 minutes following each strength assessment test to reduce familiarisation and learning effects. In addition, all study groups were exposed to identical protocol procedures, with equal numbers of assessments and treatment sessions and the same level of encouragement and support. Finally, our thesis translated and validated the first imagery ability questionnaire in the Arabic language (i.e. translated the VMIQ-2 to Arabic) using an advanced statistical method (BSEM).

Despite the promising results of the current thesis, it also has several limitations. Some of the limitations, like the lack of practice in the control group and using self-report questionnaires, for example, to rate the level of engagement in mental training during the imagery sessions in the first experimental study (chapter 2), were resolved in the second study (chapter 3) by using an exercise group instead of a no practice group and employing EMG during imagery training instead of self-report measurements for the imagery practice. An additional limitation in our thesis was that the studies involved only healthy participants who were physically active, which may leave little room for strength enhancement following imagery training. Moreover, the current protocol was short, and therefore, it is not clear whether longer protocols would have led to strength gains in the exercise group; the superiority of imagery training over the exercise training on strength gains may be limited to short training protocols.

Future research directions

This thesis adds important findings to the available data supporting the role of imagery as an intervention tool for musculoskeletal outcomes. In laboratory settings, future imagery research could investigate the efficacy of imagery interventions with varied dosages and intervention periods, examine the efficacy of imagery interventions after stopping training (short- and long-term effect studies) and compare imagery intervention with exercise training and other techniques used in physiotherapy (e.g. electrical stimulation). In addition, it is worth examining the feasibility of using imagery intervention in home-based interventions without supervising training sessions to check the efficacy of imagery as a self-management intervention protocol.

In clinical settings, future imagery research with clinical populations should develop the following features: the use of clear imagery scripts, including imagery type, sensory modality, goal of training, and function of imagery; definition of specific outcomes based on the imagery types that could be used in the imagery training protocol; and tailoring the imagery content based on patient ability and preference. In musculoskeletal rehabilitation settings, future research on musculoskeletal conditions needs to improve the features and efficacy of cognitive imagery training for muscle strength and other physical function outcomes. This should use clear imagery scripts with instructions describing the entire imagery intervention process. Furthermore, guided imagery and relaxation techniques should be implemented using relevant outcomes (e.g. pain and other psychological outcomes); guided imagery should be used separately from cognitive imagery training. In addition, creative delivery options should be used; this could involve employing new technology platforms that include the internet, telephone or pre-recorded compact discs (CDs); integrating the imagery intervention with new technology–based approaches like virtual reality or illusion mirrors; or combining the approach with other intervention methods, such as action observation. Moreover, objective measurements of mobility and physical function, like muscle strength, should be used. Finally, the feasibility and acceptability of imagery training in populations of interest need to be explored.

In Arabic countries, further validation of the new Arabic questionnaire (VMIQ-2-A) is needed, especially in Arabic countries that are affected by other languages. In addition, the future direction of imagery intervention research needs to be explored among Arabic speakers. Moreover, researchers can use our new Arabic imagery questionnaire as an assisting research tool in various research areas.

Directions in applied clinical practice

This thesis proposed the possibility of using imagery practice as a promising intervention tool in clinical settings for various medical conditions, with the aim of improving muscle strength and function. The concept of imagery practice should be introduced in hospitals and rehabilitation centres. Subsequently, we need to design workshops that enable physiotherapists to understand the imagery concept and learn about the multiple possible applications of imagery training. For example, physiotherapist should differentiate between cognitive imagery training, which involves mental rehearsal of the therapeutic exercise to improve the strength capacity, and pain management imagery, which involves images of pain dissipating or images that can help the patients cope with the pain associated with an injury. In addition, physiotherapy and rehabilitation practitioners should know that imagery training could be used either as an alternative to traditional physiotherapy intervention, at an early stage of rehabilitation when the patient is immobilised or unable to perform the physical contraction exercise, or as an adjunct to the traditional therapeutic exercise at the later stage of rehabilitation. The imagery intervention could be delivered in collaboration with nursing staff to maximise the benefit of imagery practice for patients who are admitted to the internal wards and willing to participate in low physical demanding exercise combined with tailored imagery practice.

Conclusion

The current thesis provided additional support for the role of imagery practice in improving muscle strength, especially with a larger muscle group (hip abductors), without any physical contractions and a short intervention duration (2 weeks). In addition, it demonstrated improvement in the imagery ability of participants following a simple imagery training protocol. The data from this study also offered additional support for the understanding of mechanisms behind the muscle strength gains following imagery practice. In addition, the occurrence of a bilateral transfer effect phenomenon with larger muscle groups after imagery training was shown for the first time. Finally, the first Arabic imagery ability evaluation tool (VMIQ-2-A) was validated using advanced statistical analysis (BSEM).

Our thesis results serve as support for future imagery research concerning various medical conditions, especially musculoskeletal conditions. We propose to inform practitioners in different physiotherapy and rehabilitation departments about the possibility of using imagery training as a potential therapeutic tool.

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Appendices

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Appendix A-1

Participant information sheet for Chapter 2 /Intervention group

Project Title
Effect of Motor Imagery on Muscle Strength of the Hip Abductor Muscles.

Invitation
You are being invited to take part in a research study on motor imagery practice and its influence on muscle strength in the School of Sport, Health, and Exercise Sciences (SSHES) at Bangor University. Before you decide whether you would like to participate, please take time to read the following information carefully and discuss it with the investigators. It is important for you to understand why the research is being conducted and what will be required of you should you agree to be involved. Please take your time in thinking about whether to participate. Feel free to ask questions regarding any points that you do not understand. This study has received ethical approval from the SSHES ethics committee.

What Will Happen
In this study we will investigate the efficacy of motor imagery practice on muscle strength. This study will involve measuring the strength of the hip abductor muscle twice, and completing 10 sessions of motor imagery training. Heart rate will be recorded during each session, and there will be some questionnaires to fill out regarding health issues and imagery ability.

All participants will perform maximal voluntary isometric contraction (MVIC). It will be measured by an isokinetic dynamometer by simply contracting your thigh as hard as you can when side lying in the dynamometer seat.

Time Commitment
Participants must be available daily for three weeks (excluding weekends).
Session 1: Introductory session & Muscle strength measurement with questionnaires (60 min).
Sessions 2-11 (i.e. 10 sessions): imagery training (30 min/session)
Session 12: Muscle strength measurement with filling Questionnaires (60 min).
Total time commitment: 7 hours.

All sessions will take place at Bangor University.

Participants' Rights
You may decide to stop being a part of the research study at any time without explanation. You have the right to have your questions about the procedures answered (unless answering these questions would interfere with the study's outcome; such questions can be answered after completion of the study). If you have any questions as a result of reading this information sheet, you should ask the researcher before the study begins.

Benefits and Risks
There are no known benefits or risks for you in this study. There is, however, the opportunity to know your strength level of the hip abductor muscle.

Cost, Reimbursement and Compensation
Your participation in this study is voluntary. Participants will receive £50 when participation has been completed. In addition participants have a chance to win a monetary prize of £50 when the entire study is completed. Participants also gain portfolio credit if needed.

Confidentiality/Anonymity
Only the experimenters will have access to your data. The data will be coded by participant number and will not be stored with any identifying information.

For Further Information
Dr. Amy Hayes, the supervisor of this study (a.hayes@bangor.ac.uk), and Majid Alenezi the experimenter (pep222@bangor.ac.uk /07472699663) will be glad to answer your questions about this study at any time.

If you would like to find out about the final results of this study, please contact one of the researchers.

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Appendix A-2

Participant information sheet for chapter 2 /control group

Project Title
Muscle Strength of the Hip Abductor Muscle.

Invitation

You are being invited to take part in a research study on motor imagery practice and its influence on muscle strength in the School of Sport, Health, and Exercise Sciences (SSHES) at Bangor University. Before you decide whether you would like to participate, please take time to read the following information carefully and discuss it with the investigators. It is important for you to understand why the research is being conducted and what will be required of you should you agree to be involved. Please take your time in thinking about whether to participate. Feel free to ask questions regarding any points that you do not understand. This study has received ethical approval from the SSHES ethics committee.

What Will Happen

This study will involve measuring the strength of the hip abductor muscle twice. Heart rate will be recorded before each session, and there will be some questionnaires to fill out regarding health issues and imagery ability.

All participants will perform maximal voluntary isometric contraction (MVIC). It will be measured by an isokinetic dynamometer by simply contracting your thigh as hard as you can when side lying in the dynamometer seat.

Time Commitment

Participants must be available for three weeks.
Session 1: Introductory session with questionnaires (30 min).
Session 2: Muscle strength measurement (30 min).
--Approximately 2 weeks break with no sessions--
Session 3: Muscle strength measurement (30 min).
Session 4: questionnaires (30 min)
Total time commitment: 2 hours.
All sessions will take place at Bangor University.

Participants' Rights

You may decide to stop being a part of the research study at any time without explanation. You have the right to have your questions about the procedures answered (unless answering these questions would interfere with the study's outcome; such questions can be answered after completion of the study). If you have any questions as a result of reading this information sheet, you should ask the researcher before the study begins.

Benefits and Risks

There are no known benefits or risks for you in this study. There is, however, the opportunity to know your strength level of the hip abductor muscle.

Cost, Reimbursement and Compensation

Your participation in this study is voluntary. Participants will receive £20 when participation has been completed. In addition, participants have a chance to win a monetary prize of £50 when the entire study is completed. Participants also gain portfolio credit if needed.

Confidentiality/Anonymity

Only the experimenters will have access to your data. The data will be coded by participant number and will not be stored with any identifying information.

For Further Information

Dr. Amy Hayes, the supervisor of this study (a.hayes@bangor.ac.uk), and Majid Alenezi the experimenter (pep222@bangor.ac.uk /07472699663) will be glad to answer your questions about this study at any time.

If you would like to find out about the final results of this stud, please contact one of the researchers.

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Appendix A-3
Participant information sheet for chapter 3

Project Title

Effectiveness of Imagery Compared with Exercise Training on Hip Abductor Strength and EMG Production in Healthy Adults study

Invitation

You are being invited to take part in a research study that examines the processes of learning of movements during performed exercises with voluntary activation of muscles (contractions) in comparison with imagined movements and contractions. Under normal conditions, when you train movements, both processes take place in an overlapping manner. However, we will separate those in our study to investigate what their effects are on various physiological parameters (here the activation of the muscle, measured with electromyography (EMG) and muscle strength (with a Dynamometer) on various locations in the body. This can be very useful to understand clinical conditions (stroke) and might help to develop training programmes for patients after hip replacement and other conditions. Here we will investigate hip muscles people use to elevate their leg sideways - hip abductors muscles. Additionally, for control reasons, we will further investigate a shoulder muscle (deltoid muscle) and forearm muscles. The measurement, training sessions and instruction of this study will take place at School of Sport, Health, and Exercise Sciences (SSHES) at normal site, Bangor University. Before you decide whether you would like to participate, please take time to read the following information carefully and discuss it with the investigators if you like. It is important for you to understand why the research is being conducted and what will be required of you should you agree to be involved. This document include information about the nature of study and expected benefit from taking a part on this study. Reading this information sheet will help you to decide if you would take a part or not on this study. Please take your time in thinking, and discussing that with your family about whether to participate or not. Feel free to ask researchers any questions regarding any points that you do not understand. If you agree to take part in this study, you will be asked to sign the consent form on the last page of this document. You will be given a copy of both the participant information sheet and the consent form.

What Will Happen

We will examine the processes of learning of movements during performed exercises with voluntary activation of muscles (contractions) in comparison with imagined movements and contractions. We will separate those in our study to investigate what their effects are on various physiological parameters (here the activation of the muscle, measured with electromyography (EMG) and muscle strength (with a Dynamometer) on various locations in the body. Here we will investigate hip muscles people use to elevate their leg sideways - hip abductors muscles. Additionally, for control reasons, we will further investigate a shoulder muscle (deltoid muscle) and forearm muscles. Participants will be randomly separate in two groups, one group which performs exercise training of the hip muscles over two weeks plus pre and post training assessments; the other group will be performing imagined exercises of the same type as the exercise group for two weeks plus pre and post assessments.

This study will involve familiarization into measurements and training as well the training sessions and pre- post-assessments. The pre-post assessments will involve measuring maximum muscle strength and activation of both sides of lower limb muscle groups (i.e. hip abductor muscles), and right upper limp muscle (i.e. lateral deltoid), and left hand grip strength by using specialized equipment that measures muscle force and nervous activation (i.e. Humac dynamometer, Biopac EMG). There will be some questionnaires to fill out regarding health screening, motivation and imagery ability, physical activity, plus training record. In addition the training programme involves completing 10 sessions of exercise or imagery practice training plus training on your own on the weekends. In addition, electrical activity of right hip abductor muscle will be monitor during second session of training sessions.

Time Commitment

Participants must be available daily for three weeks (excluding weekends).

Session 1:

- A familiarization session, it will involve the introduction of measurements and intervention practice and informed consent, and complete questionnaires (60 min).

Session 2:

- **Pre-test:** Muscle strength & activation measurement (90 min).

Sessions 3-12 (i.e. 10 sessions):

- Supervised imagery and physical practice training (30 min/session), unless the second session will involve EMG measurement (45 min).
- Home-exercise program

Session 13:

- **Post-test:** Muscle strength & activation measurement, and complete post-questionnaires (90 min).

Total time commitment: 9:15 hours.

- All sessions will take place at normal site, Bangor University.

What are the possible benefits of taking part?

There are no known immediate benefits, however, generally speaking, training of your hip abductor muscles with imagery or exercise may have positive effects on movement control. Additionally, the research will help to understand clinical conditions and to develop training programmes after injury.

What are the possible disadvantages and risks of taking part?

You will perform sets of maximal contractions of your hip muscles, forearm and shoulder muscles linked to a device called Dynamometer. The device measures the forces you develop with your muscles; the measure does not entail any risks beyond the usual feelings after muscle workouts. There might be slight muscle soreness depending on your usual activity level. The electromyography measures electrical currents produced by your muscles and does not add any electrical currents to your body. The electrodes are for detection reasons and will have some electrode gel applied which is normally without any skin irritation. If you have sensitive skin or you have allergies, please inform the experimenter. There are no additional known risks for participation in this study.

What if something goes wrong?

If you feel any unexpected alterations in your body which you might connect to the study, please contact us (see below) immediately, or in serious cases visit your GP or go to A&E. However, the study does not contain any components which likely produce any irritations or injuries.

Participants' Rights

You may decide to stop being a part of the research study at any time without explanation. You have the right to have your questions about the procedures answered (unless answering these questions would interfere with the study's outcome; such questions can be answered after completion of the study). If you have any questions as a result of reading this information sheet, you should ask the researcher before the study begins.

Who has reviewed this study?

This study was received an ethical review from by ethics committee at the school of sport, health, and exercise science at Bangor University.

Cost, Reimbursement and Compensation

Your participation in this study is voluntary. Participants will receive £100 when participation has been completed to compensate your time during participation

Confidentiality/Anonymity

Only the experimenters will have access to your data. The data will be coded by participant number and will not be stored with any identifying information.

For Further Information

Dr. Hans-Peter Kubis (pes203@bangor.ac.uk).

Majid Alenezi, PhD student (pep222@bangor.ac.uk) (07472699663).

Dr. Gavin Lawrence (g.p.lawrence@bangor.ac.uk).

All will be glad to answer your questions about this study at any time.

If you would like to find out about the results of this study, please contact Majid Alenezi.

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Appendix. A-4

Participant information sheet for chapter 4

Project Title

Translation and Cross-Cultural Adaptation of the Vividness Movement Imagery Questionnaire (VMIQ-2) to Classical Arabic Language: *Phase 2*

Invitation

You are being invited to take part in a study conducted by researchers in the School of Sport, Health, and Exercise Sciences (SSHES) at Bangor University. Before you decide whether you would like to participate, please take time to read the following information carefully and discuss it with the investigators. It is important for you to understand why the research is being conducted and what will be required of you should you agree to be involved. Please take your time in thinking about whether to participate. Feel free to ask questions regarding any points that you do not understand. This study has received ethical approval from the SSHES ethics committee.

What Will Happen

This study will involve completing a questionnaire. The questionnaire will ask you to imagine a number of movements, and to rate on a scale how clearly and vividly you can imagine each item. More instructions about the items and how to rate them will be provided before you complete the questionnaire.

Time Commitment and location

Approximately 30 minutes will be needed to complete the questionnaire.

If you are available, we would like you to complete the questionnaire a second time, in one week. Would you be willing to complete the questionnaire a second time? YES NO

The session will take place at Bangor University, or at another community building, or can be completed at your home.

Participants' Rights
You may decide to stop being a part of the research study at any time without explanation. You have the right to have your questions about the procedures answered. If you have any questions as a result of reading this information sheet, you should ask the researcher before the study begins.

Benefits and Risks
There are no known benefits or risks for you in this study.

Cost, Reimbursement and Compensation
Your participation in this study is voluntary. There is no cost, and you will not be compensated in any way for your participation.

Confidentiality/Anonymity
Only the researchers will have access to your data. The data will be coded by participant number and will not be stored with any identifying information. Your name will not be published in any way.

For Further Information

Majid Alenezi (PhD student; pep222@bangor.ac.uk /07472699663)

Dr. Amy Hayes (a.hayes@bangor.ac.uk)

Dr. Gavin Lawrence (g.p.lawrence@bangor.ac.uk)

Abdelbare Al Gamode (MSc student; elp2c1@bangor.ac.uk/ 07821801618)

They will be glad to answer your questions about this study at any time.

If you would like to find out about the final results of this stud, please contact one of the researchers.

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Appendix B-1

Physiology Informed Consent and Medical Questionnaire for chapter 2 & chapter 3.

Bangor University
SCHOOL OF SPORT, HEALTH AND EXERCISE SCIENCES

Name of Participant ……..…………………………………………………………..

Age ………………………

Are you in good health? ☐ YES ☐ NO

If no, please explain

How would you describe your present level of activity?
Tick intensity level and indicate approximate duration.

Vigorous		Moderate		Low intensity	

Duration (minutes)……………………………………………………………….

How often?

< Once per month		2-3 times per week	
Once per month		4-5 times per week	
Once per week		> 5 times per week	

Have you suffered from a serious illness or accident? ☐ YES ☐ NO
If yes, please give particulars:

Do you suffer from allergies? YES ☐ NO ☐
If yes, please give particulars:

Do you suffer, or have you ever suffered from:

	YES	NO		YES	NO
Asthma			Epilepsy		
Diabetes			High blood pressure		
Bronchitis					

Are you currently taking medication? ☐ YES ☐ NO

If yes, please give particulars:

Are you currently attending your GP for any condition or have you consulted your doctor in the last three months? YES NO ☐ ☐

If yes, please give particulars:

Have you, or are you presently taking part in any other laboratory experiment?
YES ☐ NO ☐

PLEASE READ THE FOLLOWING CAREFULLY

Persons will be considered unfit to do the experimental exercise task if they:

- have a fever, cough or cold, or suffer from fainting spells or dizziness;
- have suspended training due to a joint or muscle injury;
- have a known history of medical disorders, i.e. high blood pressure, heart or lung disease;
- have had hyper/hypothermia, heat exhaustion, or any other heat or cold disorder;
- have anaphylactic shock symptoms to needles, probes or other medical-type equipment;
- have chronic or acute symptoms of gastrointestinal bacterial infections (e.g. Dysentery, Salmonella);
- have a history of infectious diseases (e.g. HIV, Hepatitis B); and if appropriate to the study design, have a known history of rectal bleeding, anal fissures, haemorrhoids, or any other condition of the rectum.

PLEASE COMPLETE AND SIGN THE DECLARATION BELOW

DECLARATION

I agree that I have none of the above conditions and I hereby volunteer to be a participant in experiments/investigations during the period of …………………20……

My replies to the above questions are correct to the best of my belief and I understand that they will be treated with the strictest confidence. The experimenter has explained to my satisfaction the purpose of the experiment and possible risks involved.

I understand that I may withdraw from the experiment at any time and that I am under no obligation to give reasons for withdrawal or to attend again for experimentation.

Furthermore, if I am a student, I am aware that taking part or not taking part in this experiment, will neither be detrimental to, or further, my position as a student.

I undertake to obey the laboratory/study regulations and the instructions of the experimenter regarding safety, subject only to my right to withdraw declared above.

Signature *(participant)* ………………………………….. Date …………………..

Print name ……………………………………………………………………………….

Signature *(experimenter)* ………………………………. Date …………………..

Print name ……………………………………………………………………….…….

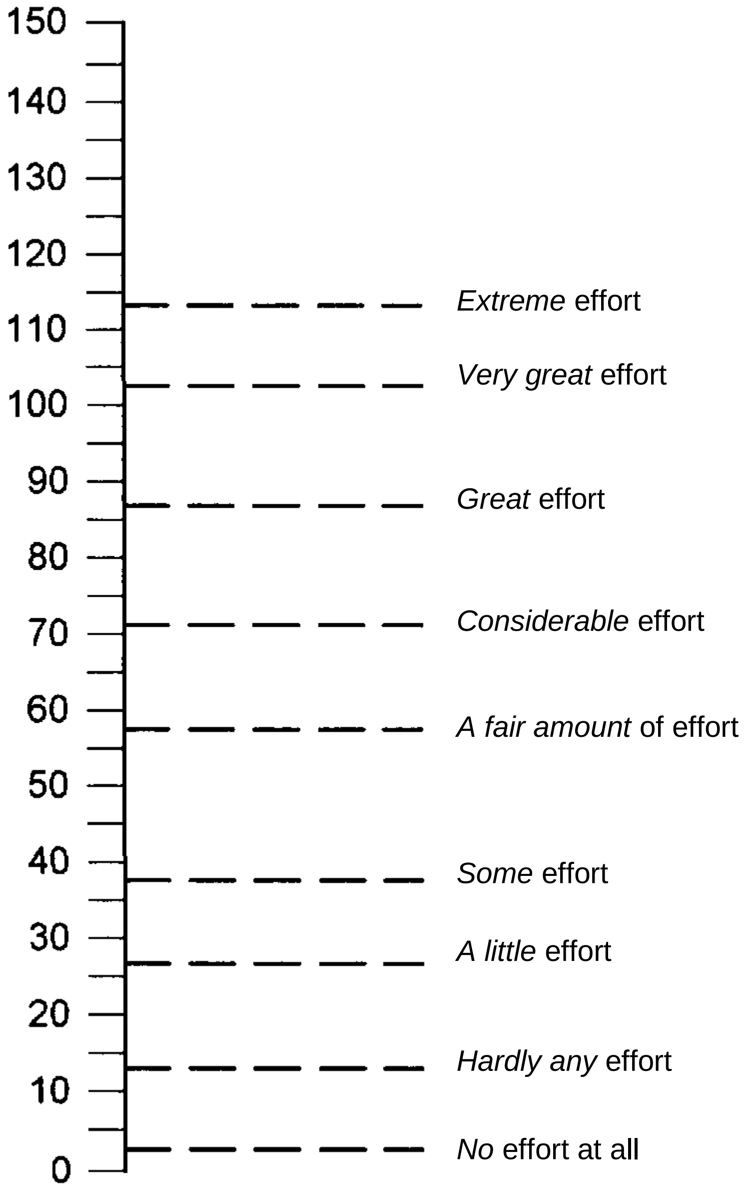
Appendix B-2

Motivational and Effort Questionnaire for chapter 2 & chapter 3.

How motivated were you to succeed in that task?

0	1	2	3	4	5	6	7	8	9	10
Not motivated at all										Very highly motivated

Please mark an **'X'** on the scale to indicate your level of **effort** during the previous task.


150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Extreme effort
Very great effort
Great effort
Considerable effort
A fair amount of effort
Some effort
A little effort
Hardly any effort
No effort at all

Appendix. B-3

Vividness of Movement Imagery Questionnaire-2 for chapter 2 & chapter 3.

Name: Age: Gender: Sport:

Level at which sport is played at (e.g., Recreational, Club, University, National, International, Professional)

Years spent participating in this sport competitively:

Movement imagery refers to the ability to imagine a movement. The aim of this questionnaire is to determine the vividness of your movement imagery. The items of the questionnaire are designed to bring certain images to your mind. You are asked to rate the vividness of each item by reference to the 5-point scale. After each item, circle the appropriate number in the boxes provided. The first column is for an image obtained watching yourself performing the movement from an external point of view (External Visual Imagery), and the second column is for an image obtained from an internal point of view, as if you were looking out through your own eyes whilst performing the movement (Internal Visual Imagery). The third column is for an image obtained by feeling yourself do the movement (Kinaesthetic imagery). Try to do each item separately, independently of how you may have done other items. Complete all items from an external visual perspective and then return to the beginning of the questionnaire and complete all of the items from an internal visual perspective, and finally return to the beginning of the questionnaire and complete the items while feeling the movement. The three ratings for a given item may not in all cases be the same. For all items please have your eyes CLOSED.

Think of each of the following acts that appear on the next page, and classify the images according to the degree of clearness and vividness as shown on the RATING SCALE.

RATING SCALE. The image aroused by each item might be:

Perfectly clear and as vivid (as normal vision or feel of movement)	……………	RATING 1
Clear and reasonably vivid	……………	RATING 2
Moderately clear and vivid	……………	RATING 3
Vague and dim	……………	RATING 4
No image at all, you only “know” that you are thinking of the skill.	……………	RATING 5

	Watching yourself performing the movement (External Visual Imagery)					Looking through your own eyes whilst performing the movement (Internal Visual Imagery)					Feeling yourself do the movement (Kinaesthetic Imagery)				
Item	Perfectly clear and vivid as normal vision	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the	Perfectly clear and vivid as normal vision	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the skill	Perfectly clear and vivid as normal feel of movement	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the skill
1.Walking	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
2.Running	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
3.Kicking a stone	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
4.Bending to pick up a coin	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
5.Running up stairs	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
6.Jumping sideways	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
7.Throwing a stone into water	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
8.Kicking a ball in the air	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
9.Running downhill	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

10.Riding a bike	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
11.Swinging on a rope	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
12.Jumping off a high wall	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5

Appendix B-4

Post Experimental Questionnaire Following Imagery Sessions for chapter 2

Participant number kivi-1_________________

Post Experimental Questionnaire Following Imagery Sessions

1. To what degree did you feel you used kinaesthetic imagery while performing the imagery task?

0	1	2	3	4	5	6	7	8	9	10

No kinaesthetic imagery use — High kinaesthetic imagery use

2. When performing the imagery task, how vivid was your kinaesthetic imagery? Please circle the appropriate number.

(1) Perfectly clear and vivid, as normal feel of the action
(2) Clear and reasonably vivid
(3) Moderately clear and vivid
(4) Vague and dim
(5) No image at all, you only know that you are thinking of the action

3. To what degree did you feel you used visual imagery while performing the imagery task?

0	1	2	3	4	5	6	7	8	9	10
No visual imagery use										High visual imagery use

4. Please indicate the form of visual imagery used when performing the imagery task:

0	1	2	3	4	5	6	7	8	9	10
Completely internal	Minimal switching			Switched regularly			Minimal switching to		Completely external	

perspective	to an external perspective		an internal perspective	perspective

5. When performing the imagery task, how vivid was your internal visual imagery? Please circle the appropriate number. **(If you did not use this perspective, please go to next question.)**

(1) Perfectly clear and vivid, as normal vision
(2) Clear and reasonably vivid
(3) Moderately clear and vivid
(4) Vague and dim
(5) No image at all, you only know that you are thinking of the action

6. When performing the imagery task, how vivid was your external visual imagery? Please circle the appropriate number. **(If you did not use this perspective, please go to next question.)**

(1) Perfectly clear and vivid as normal vision
(2) Clear and reasonably vivid
(3) Moderately clear and vivid
(4) Vague and dim
(5) No image at all, you only know that you are thinking of the action

7. When using kinaesthetic imagery with visual imagery, you may have used them at the same time, or one after the other. Please denote how often you used the following three possibilities by circling the most appropriate response:

Used kinaesthetic and visual imagery at the same time	*often*	*somewhat often*	*never*
Used kinaesthetic then visual imagery	*often*	*somewhat often*	*never*
Used visual then kinaesthetic imagery	*often*	*somewhat often*	*never*

8. How well do you think you were able to remember and include all components of the imagery script during the imagery task?

0	1	2	3	4	5	6	7	8	9	10

Not at all **Greatly**

9. To what extent do you think that the imagery instruction and training was effective in enhancing your muscle strength?

0	1	2	3	4	5	6	7	8	9	10

Not at all **Greatly**

10. To what extent did you feel that imagery practice prepared you for the muscle strength task?

0	1	2	3	4	5	6	7	8	9	10

Not at all **Greatly**

11. To what extent did you feel that imagery practice helped your motivation to perform well in the muscle strength task?

0	1	2	3	4	5	6	7	8	9	10

Not at all **Greatly**

12. How much effort did you put into performing the imagery task?

0	1	2	3	4	5	6	7	8	9	10

No effort **The most effort possible**

13. How motivated were you to perform the imagery task successfully?

0	1	2	3	4	5	6	7	8	9	10

Not at all motivated **Highly motived**

14. During the imagery sessions, how easy did you find it to image during the following time points? Please circle the appropriate response for each time point:

While listening to the recording

0	1	2	3	4	5	6	7	8	9	10
Easy to conduct imagery										Difficult to conduct imagery

After listening to the recording (during the 5 imaged 15 sec contractions)

0	1	2	3	4	5	6	7	8	9	10
Easy to conduct imagery										Difficult to conduct imagery

After reading the imagery script (during the 5 imaged 15 sec contractions)

0	1	2	3	4	5	6	7	8	9	10
Easy to conduct imagery										Difficult to conduct imagery

Post Experimental Questionnaire Following Muscle Test Sessions

1. How well do you think you performed on the muscle strength task?

0	1	2	3	4	5	6	7	8	9	10
Not at all well										**Very well**

2. To what extent did the presence of the experimenter increase your motivation to perform well on the muscle strength task?

0	1	2	3	4	5	6	7	8	9	10
Not at all									**Greatly**	

3. **<u>Other than during the imagery sessions</u>**, during the days between the two muscle tests did you ever think about how the muscle test felt? Please circle the response that best matches your experience.

Outside of the imagery sessions, I thought about how the muscle test felt:

(1) never
(2) less than once per day
(3) approximately once per day
(4) more than once per day

4. **<u>Other than during the imagery sessions</u>**, during the days between the two muscle tests did you ever use imagery of the muscle contraction to enhance your muscle strength? Please circle the response that best matches your experience.

Outside of the imagery sessions, I used imagery of the muscle contraction:

(1) never
(2) less than once per day
(3) approximately once per day
(4) more than once per day

If you did use imagery, please describe what sort of imagery you used:

5. **<u>During the first muscle test session</u>**, did you use imagery at all prior to the test to improve your performance? Circle one:

Yes No

If you did use imagery, please describe what sort of imagery you used:

6. **<u>During the second muscle test session</u>**, did you use imagery at all prior to the test to improve your performance? Circle one:

Yes No

If you did use imagery, please describe what sort of imagery you used:

7. During the period between the two muscle tests, did you conduct any resistance muscle strength training? Please circle one:

Yes No

If yes, please describe: (please specify any lower body or upper body exercise)

8. During the period between the two muscle tests, did you begin any other new exercise activity? Please circle one:

Yes No

If yes, please describe:

9. During the period between the two muscle tests, did you experience any injury or discomfort that might affect the test? Please circle one:

Yes No

If yes, please describe:

10. If you were to do this experiment again, please indicate your preference for how the imagery sessions could be arranged (circle the option you prefer).

Imagery sessions every weekday for 2 weeks

Imagery sessions 3 times per week for 4 weeks

Appendix. B-5

Weekend's diary log for chapter 3

Participants name:

<u>Please fill the questionnaire at the end of first and second home based session during weekends.</u>

Day & Dates	Time of starting the session	Time of ending the session	Motivation Scale	Notes
Saturday			How motivated were you to perform the **imagery/physical** practice protocol successfully? 0 1 2 3 4 5 6 7 8 9 10 **Not at all Motivated** **Highly Motivated**	
Sunday			How motivated were you to perform the **imagery/physical** practice protocol successfully? 0 1 2 3 4 5 6 7 8 9 10 **Not at all Motivated** **Highly Motivated**	
Saturday			How motivated were you to perform the **imagery/physical** practice protocol successfully? 0 1 2 3 4 5 6 7 8 9 10 **Not at all Motivated** **Highly Motivated**	
Sunday			How motivated were you to perform the **imagery/physical** practice protocol successfully? 0 1 2 3 4 5 6 7 8 9 10 **Not at all Motivated** **Highly Motivated**	

Appendix B-6

Post Experimental Questionnaire Following Imagery Sessions for chapter 3

<u>Post Experimental Questionnaire Following Imagery Sessions</u>

1. To what degree did you feel you used visual imagery while performing the imagery task?

0	1	2	3	4	5	6	7	8	9	10
No visual imagery use										High visual imagery use

2. Please indicate the form of visual imagery used when performing the imagery task:

0	1	2	3	4	5	6	7	8	9	10
Completely internal perspective	Minimal switching to an external perspective			Switched regularly			Minimal switching to an internal perspective		Completely external perspective	

3. When performing the imagery task, how vivid was your internal visual imagery? Please circle the appropriate number.

(6) Perfectly clear and vivid, as normal vision
(7) Clear and reasonably vivid
(8) Moderately clear and vivid
(9) Vague and dim
(10) No image at all, you only know that you are thinking of the action

4. If you sometimes used external visual perspective, how vivid was your external visual imagery during the imagery task? Please circle the appropriate number. **(If you did not use this perspective, please go to next question.)**

(6) Perfectly clear and vivid as normal vision
(7) Clear and reasonably vivid
(8) Moderately clear and vivid

(9) Vague and dim

(10) No image at all, you only know that you are thinking of the action

5. To what degree did you feel you used kinaesthetic imagery while performing the imagery task?

	0	1	2	3	4	5	6	7	8	9	10	
No kinaesthetic imagery use												High kinaesthetic imagery use

6. When performing the imagery task, how vivid was your kinaesthetic imagery? Please circle the appropriate number.

(1) Perfectly clear and vivid, as normal feel of the action
(2) Clear and reasonably vivid
(3) Moderately clear and vivid
(4) Vague and dim
(5) No image at all, you only know that you are thinking of the action

7. When using kinaesthetic imagery with visual imagery, you may have used them at the same time, or one after the other. Please denote how often you used the following three possibilities by circling the most appropriate response:

Used visual and kinaesthetic imagery at the same time	*often*	*somewhat often*	*never*
Used visual then kinaesthetic imagery	*often*	*somewhat often*	*never*
Used kinaesthetic then visual imagery	*often*	*somewhat often*	*never*

8. How well do you think you were able to remember and include all components of the imagery script during the imagery task?

	0	1	2	3	4	5	6	7	8	9	10
Not at all											**Greatly**

9. To what extent do you think that the imagery instruction and training was effective in enhancing your muscle strength?

	0	1	2	3	4	5	6	7	8	9	10
Not at all											**Greatly**

10. To what extent did you feel that imagery practice prepared you for the muscle strength task?

	0	1	2	3	4	5	6	7	8	9	10
Not at all											**Greatly**

11. To what extent did you feel that imagery practice helped your motivation to perform well in the muscle strength task?

	0	1	2	3	4	5	6	7	8	9	10
Not at all											**Greatly**

12. How much effort did you put into performing the imagery task?

	0	1	2	3	4	5	6	7	8	9	10
No effort											**The most effort possible**

13. How motivated were you to perform the imagery task successfully?

	0	1	2	3	4	5	6	7	8	9	10
Not at all motivated											**Highly motivated**

Post Experimental Questionnaire Following Muscle Test Sessions

1. How well do you think you performed on the muscle strength task?

	0	1	2	3	4	5	6	7	8	9	10
Not at all well											**Very well**

2. To what extend did the presence of the experimenter increase your motivation to perform well on the muscle strength task?

	0	1	2	3	4	5	6	7	8	9	10
Not at all										**Greatly**	

1. <u>**Other than during the imagery sessions**</u>, during the days between the two muscle tests did you ever think about how the muscle test felt? Please circle the response that best matches your experience.

Outside of the imagery sessions, I thought about how the muscle test felt:

(5) never
(6) less than once per day
(7) approximately once per day
(8) more than once per day

2. <u>**Other than during the imagery sessions**</u>, during the days between the two muscle tests did you ever use imagery of the muscle contraction to enhance your muscle strength? Please circle the response that best matches your experience.

Outside of the imagery sessions, I used imagery of the muscle contraction:

(5) never
(6) less than once per day
(7) approximately once per day
(8) more than once per day

If you did use imagery, please describe what sort of imagery you used:

3. **<u>During the first muscle test session</u>**, did you use imagery at all prior to the test to improve your performance? Circle one:

Yes No

If you did use imagery, please describe what sort of imagery you used:

4. **<u>During the second muscle test session</u>**, did you use imagery at all prior to the test to improve your performance? Circle one:

Yes No

If you did use imagery, please describe what sort of imagery you used:

5. During the period between the two muscle tests, did you conduct any resistance muscle strength training for lower limbs? Please circle one:

Yes No

If <u>yes</u>, please describe:

6. During the period between the two muscle tests, did you begin any other new exercise activity program? Please circle one:

Yes No

If <u>yes</u>, please describe:

7. During the period between the two muscle tests, did you experience any injury or discomfort that might affect the test? Please circle one:

Yes No

If <u>yes</u>, please describe:

Appendix C-1

Imagery script-KIN group for Chapter 2 only. Please note “close your eyes” is just on audiotape, and is omitted from the script assigned for reading.

Script for the Kinesthetic Only Imagery Group

FIRST IMAGERY PRACTICE OF THE SESSION

- Close your eyes.
- Take in a deep breath and prepare your mind to focus on the imagery practice.
- Now, imagine that you are lying on your side on the isokinetic machine. Think back to your own sensations you felt as you performed your maximal contraction of your thigh.
- Feel your top leg rise to meet the fixed dynamometer arm. Feel the cushion of the dynamometer touch the side of your thigh just laterally above the knee. Feel the muscles on the lateral side of your thigh, from your hip down to your knee, begin to tense up. Feel your thigh pushing against the fixed dynamometer arm.
- Now, feel the pad of the dynamometer arm pressing harder and harder into the lateral portion of the thigh. In other words, try to retrieve your feeling of the same position, muscle contractions, and action that you experienced when your hip abductor was measured by the isokinetic machine.
- Feel your muscles contract more and more for 15 seconds. <reader pauses for 15 seconds>
- Now, feel your thigh muscles begin to relax. Feel the cushion of the dynamometer pressing against your thigh less and less, and bring your leg back to the neutral position.

<participant gets a break for 15 seconds>

SUBSEQUENT IMAGERY PRACTICES OF THE SESSION

- Again, feel your top leg rise to meet the fixed dynamometer arm.
- Feel the pad of the dynamometer arm pressing harder and harder into the lateral portion of the thigh.
- Feel your muscles contract more and more for 15 seconds. <reader pauses for 15 seconds>
- Now, feel your thigh muscles begin to relax and bring your leg back to the neutral position.

<participant gets a break for 15 seconds; continue with brief instructions until 30 min complete>

Appendix C-2

Imagery script-KIN+VI group (first order) for chapter 2 & chapter 3

FIRST IMAGERY PRACTICE OF THE SESSION

- Close your eyes.
- Take in a deep breath and prepare your mind to focus on the imagery practice.
- Now, imagine that you are lying on your side on the isokinetic machine. Think back to your own visual image and the sensations you felt as you performed your maximal contraction of your thigh.
- See and feel your top leg rise to meet the fixed dynamometer arm. See and feel the cushion of the dynamometer touch the side of your thigh just laterally above the knee. See and feel the muscles on the lateral side of your thigh, from your hip down to your knee, begin to tense up. See and feel your thigh pushing against the fixed dynamometer arm.
- Now, see and feel the pad of the dynamometer arm pressing harder and harder into the lateral portion of the thigh. In other words, try to retrieve your visualization and feeling of the same position, muscle contractions, and action that you experienced when your hip abductor was measured by the isokinetic machine.
- See and feel your muscles contract more and more for 15 seconds. <reader pauses for 15 seconds>
- Now, see and feel your thigh muscles begin to relax. See and feel the cushion of the dynamometer pressing against your thigh less and less, and bring your leg back to the neutral position.

<participant gets a break for 15 seconds>

SUBSEQUENT IMAGERY PRACTICES OF THE SESSION

- Again, see and feel your top leg rise to meet the fixed dynamometer arm.
- See and feel the pad of the dynamometer arm pressing harder and harder into the lateral portion of the thigh.
- See and feel your muscles contract more and more for 15 seconds. <reader pauses for 15 seconds>
- Now, see and feel your thigh muscles begin to relax and bring your leg back to the neutral position.

<participant gets a break for 15 seconds; continue with brief instructions until 30 min complete>

Appendix C-3

The training protocol for chapter 2

Mental Training Practice Protocol

In this session you will participate in the mental training practice.

You will be seated in a relaxed position, and you will wear a heart rate monitor watch.

The mental training practice will be structured in the following way:

- First you will hear a recording of the mental imagery script. The recording will describe what you should be imaging as you practice the imaginary contractions. As you listen to the recording, please do the imagery along with the recording.
    - Please note: the recording makes reference to the *lateral* side of the thigh; this is the side of the thigh that is facing the ceiling when you are lying on your side.
- Next you will perform one imagery trial just to be familiar with mental practice program.
- Then you will perform 5 imaginary contractions, each for ~15 s followed by 15s rest. The experimenter will time you and will tell you when to start and finish.
- Next you will read the script, to refresh your memory. You do not have to perform imagery while you read.
- Then you will conduct 5 imaginary contractions, each for ~15 s followed by 15s rest. The experimenter will time you and will tell you when to start and finish.
- The script recording will be played again. As you listen to the recording, please do the imagery along with the recording.
- Then perform 5 imaginary contractions each for ~15 s followed by 15s rest. The experimenter will time you and will tell you when to start and finish.
- 1 minute rest.
- The mental practice procedure would be repeated again as above.

Summary of the session:

Listen to recording; conduct the imagery as you listen 1 practice with conducting the imagery 5 imagined contractions for 15 seconds each (timed by the experimenter.)
Read the imagery script to refresh your memory (you do not need to image) 5 imagined contractions for 15 seconds each (timed by the experimenter.)
Listen to recording; conduct the imagery as you listen 5 imagined contractions for 15 seconds each (timed by the experimenter.)

One minute break

Read the imagery script to refresh your memory (you do not need to image) 5 imagined contractions for 15 seconds each (timed by the experimenter.)
Listen to recording; conduct the imagery as you listen 5 imagined contractions for 15 seconds each (timed by the experimenter.)
Read the imagery script to refresh your memory (you do not need to image) 5 imagined contractions for 15 seconds each (timed by the experimenter.)
Listen to recording; conduct the imagery as you listen 5 imagined contractions for 15 seconds each (timed by the experimenter.)

End of session

Appendix C-4

The exercise training for chapter 3

This protocol describes the physical training practice.

The participant will receive an explanation and demonstration of the physical practice. The demonstration will enable the participant to perform the exercise in a standardized manner under experimenter's control, as well as at home. The following instruction will be delivered to the participant by the researcher for this practice:

- Participants will be instructed to lie down on their left side on the dynamometer table, and their right leg will be in the top position. This will enable them to prepare themselves for physical practice of right hip abduction.
- Participants of the exercise group have had a full explanation of the physical exercise practice, and one session of max isometric contractions as part of the pre-test assessments (earlier visit) and to secure that participants can perform physical practice with the protocol below.

The physical training practice will be structured in the following way:

- You will be positioned on the dynamometer table and connected to equipment, as it has been for the pre-test assessment. You are going to perform maximal isometric exercises. The right leg will be elevated towards the dynamometer arm to perform the maximal isometric hip abduction exercise at the correct angle.
- Then you will be instructed to perform the maximal physical contraction of right hip abduction movement by the following verbal instruction; **please note:** in the home sessions you will be asked to perform the exercise without additional loading, just elevate the leg and hold it at the 25 degree position matching the pattern of supervised exercise.
- **Starting position:** Lie on your left side, with your head supported, and both knees straight and feet together. Elevate your leg until you feel the solid resistance of the dynamometer arm – this is at 25˚ of hip abduction.
- **Action:** Keep your leg in the former position 25˚of hip abduction, and then slowly push your right leg in abduction direction against the dynamometer lever as much as you can (MAXIMAL FORCE!). Keep pushing the dynamometer arm as much you can for 15 seconds (timed by the experimenter).
- Then slowly relax your hip muscles and move your leg down into starting position (legs on top of each other with feet together.
- **Key points:** Ensure your pelvis does not rotate backward during the lift.

- The participants will perform the physical exercise practice of maximal isometric contractions of hip abduction with the pattern below. EMG electrodes will be connected to the right gluteus medius muscle during the second training sessions to understanding the muscle activation during the physical exercise. The other sessions will be without EMG recordings except pre and post assessments.

- The training protocol involves 10 daily sessions over two weeks. Each session lasts 30 minutes, including 7 sets of physical exercise training practice. Each set includes performing five maximal physical isometric contractions of hip abduction movement each held for ~15 s against dynamometer arm that fixed at 25˚of hip abduction followed by 15s rest. The experimenter will time the contraction and relaxation exercises, telling when to start and finish. Consequently, participants will perform seven sets of physical exercise training during each session, and each set followed by maximal 2 minutes rest. A total of 35 maximal physical isometric contractions of hip abduction will be performed during each session.
- Home-protocol: participants will perform one home session each day on the weekends and record the motivation on a diary sheet; they will perform 7 sets of physical training practice and each set includes performing five isometric contractions of hip abduction movement each held for ~15 s at 25˚of hip abduction followed by 15s rest. The only difference between the home and lab sessions is that participants will be asked to perform unloaded exercise, just elevating and holding the leg matching the pattern of supervised exercise. The participants will be provided with a stopwatch for performing the exercise at home.

Overview of the session:

1st set of contractions 1 practice with conducting under experimenter guidance 5 physical isometric contractions for 15 seconds each (timed by the experimenter.) **Rest** up to 2 minutes
2nd set 5 physical isometric contractions for 15 seconds each (timed by the experimenter.) **Rest** up to 2 minutes
3rd set 5 physical isometric contractions for 15 seconds each (timed by the experimenter.) **Rest** up to 2 minutes
4th set 5 physical isometric contractions for 15 seconds each (timed by the experimenter.) **Rest** up to 2 minutes
5th set 5 physical isometric contractions for 15 seconds each (timed by the experimenter.) **Rest** up to 2 minutes
6th set 5 physical isometric contractions for 15 seconds each (timed by the experimenter.) **Rest** up to 2 minutes

7th set

5 physical isometric contractions for 15 seconds each (timed by the experimenter.)

Rest up to 2 minutes --

End of session

Appendix C-5
Imagery training protocol for chapter 3

This protocol describes the imagery training practice.

The participants will receive an explanation and demonstration of the imagery practice. The demonstration will enable the participant to perform the imagery practice in a standardized manner under experimenter's control, as well as at home. The following instruction will be delivered to the participant by the researcher for the practice:

- Participants will be instructed to lie down on their left side on the dynamometer table, and their right leg will be on top of the left with feet together, legs stretched out. This will enable them to prepare for the imagery practice of right hip abduction.
- Participants of the imagery group have had a full explanation of the physical exercise practice, and one session of maximal isometric contractions as part of the pre-test assessments (earlier visit) and to secure that participants can perform imagery practice with the protocol below.

The imagery training practice will be structured in the following way:

- You will be positioned on the dynamometer table and connected to equipment, as it has been for the pre-test assessment performing maximal isometric exercises. The right leg will be on the top of the left leg, feet together. However, it will be rested without any hip abduction to enable you to perform the imagined isometric hip abduction exercises from this position without any actual physical contractions.
- Then you will hear a recording of the mental imagery script. The recording will describe exactly what you should imagine as the practice is being performed for the imagined contractions. You will be asked to listen to the recording and to perform imagined isometric contractions of hip abduction movements along with the audio recording. The audio recording will instruct you to use combined kinaesthetic and visual imagery training of hip abduction without actual contraction of the muscle. **Please note:** the recording refers to the lateral side of the thigh; this is the side of the right leg that is facing the ceiling when you lying on your left side.

The following part is the imagery script that will be delivered by the audio recording.

- ***<u>Close your eyes.</u>***
    - Take in a deep breath and prepare your mind to focus on the imagery practice.
    - Now, imagine while you lying on your side on the isokinetic machine, think back to the sensations you felt and your own visual image as you performed your maximal contraction of your thigh muscle.

- Feel and see your top leg rise to meet the fixed dynamometer arm. Feel and see the cushion of the dynamometer touch the side of your thigh just laterally above the knee. Feel and see the muscles on the lateral side of your thigh, from your hip down to your knee, begin to tense up. Feel and see your thigh pushing against the fixed dynamometer arm.
    - Now, feel and see the pad of the dynamometer arm pressing harder and harder into the lateral portion of the thigh. In other words, try to retrieve your feeling and visualization of the same position, muscle contractions, and action that you experienced when your hip abductor was measured by the isokinetic machine.
    - Feel and see your muscles contract more and more for 15 seconds. <reader pauses for 15 seconds>
    - Now, feel and see your thigh muscles begin to relax. Feel and see the cushion of the dynamometer pressing against your thigh less and less, and bring your leg back to the neutral position.
- <participant gets a break for 15 seconds>

- Next, participants will perform a further imagery practice of maximal imagined contraction of hip abduction. The EMG electrodes will be connected to the right gluteus medius muscle during one of imagery sessions (session 2) and on pre- and post-assessment visits for understanding muscle activation during the various conditions.
- The training protocol involved 10 daily sessions over two weeks, each session lasts 30 minutes, including 7 sets of imagery training practice and each set includes listening to imagery script instruction while performing the imagined isometric contractions as explained above. In each set five maximal imagined isometric contractions of hip abduction muscles for a duration for ~15 s will be performed, followed by 15s rest. The experimenter will time those and will tell participants when to start and finish. Therefore, participants during each session will perform 7 sets of imaginary training. A total of 35 maximal imagined isometric contractions of hip abduction will be performed during each session.
- Home-protocol: participants will perform one home session on each day of the weekends and record the motivation on a diary sheet. They will perform 7 sets of imagery training practice and each set includes performing five maximal imagined isometric contractions of hip abduction movement each for ~15 s followed by 15s rest. The only difference in the home sessions is that participants will be asked to listen to the audio imagery script themselves and to perform imagery practice. In addition, they need to record the imagery sessions they have performed on the weekends on a diary sheet.

Summary of the session:

Listen to recording; conduct the imagery as you listen
1 practice with conducting the imagery
5 imagined contractions for 15 seconds each (timed by the experimenter.)

Listen to recording; conduct the imagery as you listen 5 imagined contractions for 15 seconds each (timed by the experimenter.)
Listen to recording; conduct the imagery as you listen 5 imagined contractions for 15 seconds each (timed by the experimenter.)
Listen to recording; conduct the imagery as you listen 5 imagined contractions for 15 seconds each (timed by the experimenter.)
Listen to recording; conduct the imagery as you listen 5 imagined contractions for 15 seconds each (timed by the experimenter.)
Listen to recording; conduct the imagery as you listen 5 imagined contractions for 15 seconds each (timed by the experimenter.)
Listen to recording; conduct the imagery as you listen 5 imagined contractions for 15 seconds each (timed by the experimenter.)

End of session

Appendix D-1

Guidelines for the Translators of VMIQ-2 –Chapter 4

1- Guidelines to be given to the Forward Translators of VMIQ-2

Please review the following 6 guidance points for translating the questionnaire.

1. Each translator should work independently until his/her translation is complete.
2. The intention is that the translation will **capture the conceptual meaning of the questions rather than being a literal translation.** Translators should always aim at the conceptual equivalent of a word or phrase, not a word-for-word translation. They should consider the definition of the original term and attempt to translate it in the most relevant way.

Below we explain some of the basic concepts underlying the questionnaire to be translated, so that the conceptual meaning of the questionnaire is as clear as possible to the translators:

Movement imagery: Movement imagery refers to the ability to imagine a movement. In this questionnaire three types of movement imagery will be considered. These are external visual imagery, internal visual imagery and kinaesthetic imagery.

Visual perspective: This is a concept that is important for understanding the two types of visual imagery (external and internal). Visual perspective refers to the fact that objects and events in the world can be viewed from different directions in space. A person's actions can be perceived from the direction of the actor's own eyes or first person perspective (internal perspective). A person can also *imagine* perceiving

one's own actions from the perspective of an outside observer or third person perspective (external perspective).
External visual imagery (EVI): External visual imagery is defined as generating an image by watching yourself from an outside point of view. It is the scene you would see if looking at yourself performing the movement from a third person perspective.
Internal visual imagery (IVI): Internal visual imagery is defined as generating an image from an inside point of view or first person perspective. It is the scene you would see if looking through your own eyes while performing the movement.
Kinaesthetic imagery (KIN): Kinaesthetic imagery is defined as feeling yourself do the movement. It is the feelings and sensations you would experience if performing the movement. It includes feeling the contractions of your muscles or the sensations experienced when parts of your body touch one another or an object.
Vividness: this is used in the ordinary sense of the word. For example, vivid images could be strong, intense, high contrast.
Clearness: this is used in the ordinary sense of the word. For example, clear images could be easy to perceive, sharp.
3. The overall aim of translation is to produce a new language version, which is both conceptually equivalent with the original version (as explained above in point 2), **and relevant to the new target culture.** Terminology or questionnaire items that are not relevant to the target culture may be adapted, if necessary, to be relevant to the target culture.
4. The translators should produce **classical Arabic** translations that will be **easily understood by adults in the general population**. Translators should avoid the use of any jargon, technical terms that cannot be understood clearly, colloquialisms, idioms, or vernacular terms that cannot be understood by common people in everyday life.
5. Translators should strive to be simple, clear and concise in formulating a question. Fewer words are better. Long sentences with many clauses should be avoided.
6. Translators should consider issues of gender and age applicability and avoid any terms that might be considered offensive to the target population.
These recommendations are compiled from:
□□The World Health Organization (WHO) Guidelines (http://www.who.int/substance_abuse/research_tools/translation/en/)
□□The ISPOR (*International Society for Pharmacoeconomics and Outcomes Research)* Task Force for Translation and Cultural Adaptation (Wild, D., Grove, A., Martin, M., Eremenco, S., McElroy, S., Verjee-Lorenz, A., & Erikson, P. (2005). Principles of good practice for the translation and cultural adaptation process for patient-reported outcomes (PRO) measures: Report of the ISPOR Task Force for Translation and Cultural Adaptation. *Value in Health, 8*(2), 94-104.)

2- Guidelines to be given to the Back Translators of VMIQ-2
Please review the following 4 guidance points for translating the questionnaire.
1. Each translator should work independently until his/her translation is complete.
2. The intention is that the translation will be **a literal translation of the questionnaire.**
3. The translators should produce English translations that will be **easily understood by adults in the general population**. Translators should avoid the use of any jargon, technical terms that cannot be understood clearly, colloquialisms, idioms, or vernacular terms that cannot be understood by common people in everyday life.

4. Translators should strive to be simple, clear and concise in formulating a question. Fewer words are better. Long sentences with many clauses should be avoided.

These recommendations are compiled from:

□□The World Health Organization (WHO) Guidelines (http://www.who.int/substance_abuse/research_tools/translation/en/)

□□The ISPOR (*International Society for Pharmacoeconomics and Outcomes Research)* Task Force for Translation and Cultural Adaptation (Wild, D., Grove, A., Martin, M., Eremenco, S., McElroy, S., Verjee-Lorenz, A., & Erikson, P. (2005). Principles of good practice for the translation and cultural adaptation process for patient-reported outcomes (PRO) measures: Report of the ISPOR Task Force for Translation and Cultural Adaptation. *Value in Health*, *8*(2), 94-104.)

Appendix D-2

VIMQ-2 questionnaire with simple modification combined with English and versions of the cognitive debriefing questionnaire-Chapter 4

Introduction to Movement Imagery

Movement imagery refers to the ability to imagine a movement. In this questionnaire three types of movement imagery will be considered. These are external visual imagery, internal visual imagery and kinaesthetic imagery. These are explained below.

External visual imagery is defined as generating an image by watching yourself from an outside point of view. It is the scene you would see if looking at yourself performing the movement from a third person perspective.

Internal visual imagery is defined as generating an image from an inside point of view or first person perspective. It is the scene you would see if looking through your own eyes while performing the movement.

Kinaesthetic imagery is defined as feeling yourself do the movement. It is the feelings and sensations you would experience if performing the movement. It includes feeling the contractions of your muscles or the sensations experienced when parts of your body touch one another or an object.

Please rate how easy this section was to understand:

1	2	3	4	5
Easy		Medium		Difficult

Please note any words that you found difficult to understand: ____

Vividness of Movement Imagery Questionnaire-2

Name: **Age:** **Handedness:**

Gender: **What sports do you play (if any):**

Level at which sport is played at (e.g., Recreational, Club, University, National, International, Professional):

Years spent participating in this sport competitively:

Movement imagery refers to the ability to imagine a movement. The aim of this questionnaire is to determine the vividness of your movement imagery. The items of the questionnaire are designed to bring certain images to your mind. You are asked to rate the vividness of each item by reference to the 5-point scale. After each item, circle the appropriate number in the boxes provided. The first column is for an image obtained watching yourself from an external point of view (external visual imagery), and the second column is for an image obtained from an internal point of view, as if you were looking through your own eyes (internal visual imagery). The third column is for an image obtained by feeling yourself do the movement (kinaesthetic imagery). Try to do each item separately, independently of how you may have done other items. Complete all items using an external visual perspective and then return to the beginning of the questionnaire and complete all of the items using an internal visual perspective, and finally return to the beginning of the questionnaire and complete the items using kinaesthetic imagery (while feeling the movement.) The three ratings for a given item may not be the same in all cases. For all items please have your eyes CLOSED.

Imagine each of the movements that appear on the next page, and classify your images according to the degree of clearness and vividness as shown on the RATING SCALE below.

RATING SCALE. The image aroused by each item might be:

Perfectly clear and as vivid (as normal vision or feel of movement)	……………	RATING 1
Clear and reasonably vivid	……………	RATING 2
Moderately clear and vivid	……………	RATING 3
Vague and dim	……………	RATING 4
No image at all, you only “know” that you	……………	RATING 5

are thinking of the skill.

Please rate how easy this section was to understand:

1	2	3	4	5
Easy		Medium		Difficult

Please note any words that you found difficult to understand: ____

	Watching yourself do it (External Visual Imagery)						Looking through your own eyes (Internal Visual Imagery)						Feeling yourself do it (Kinaesthetic Imagery)				
Item	Perfectly clear and vivid as normal vision	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the skill		Perfectly clear and vivid as normal vision	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the skill		Perfectly clear and vivid as normal feel of movement	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the skill
1.Walking	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
2.Running	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
3.Kicking a stone	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
4.Bending to pick up a key	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5

5.Running up stairs	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
6.Jumping sideways	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
7.Throwing a stone into water	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
8.Kicking a ball in the air	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
9.Running downhill	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
10.Riding a bike	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
11.Swinging on a rope	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
12.Jumping off a high wall	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5

Please rate how easy this section was to understand:

1	2	3	4	5
Easy		Medium		Difficult

Please note any words that you found difficult to understand: ____

1. Please indicate on this scale if you have a preference for using a particular visual imagery perspective (internal or external; if you have no preference then circle 5):

0	1	2	3	4	5	6	7	8	9	10
Strong preference internal			Moderate preference internal		No preference		Moderate preference external			Strong preference external

2. Please indicate on the following questions the extent to which you "switched" between visual imagery perspectives (internal and external), when completing the two visual columns of the questionnaire:

a) When completing the *watching yourself do it* (external visual imagery) column, what perspective did you use?

0	1	2	3	4	5	6	7	8	9	10
Completely internal perspective		Minimal switching to an external perspective			Switched regularly			Minimal switching to an internal perspective		Completely external perspective

b) When completing the *looking through your own eyes* (internal visual imagery) column, what perspective did you use?

0	1	2	3	4	5	6	7	8	9	10
Completely internal perspective		Minimal switching to an external perspective			Switched regularly			Minimal switching to an internal perspective		Completely external perspective

3. When completing the two visual imagery columns of the questionnaire please specify if you used kinaesthetic imagery at the same time as the designated visual imagery perspective:

External visual imagery

0	1	2	3	4	5	6	7	8	9	10
No kinaesthetic imagery use										High kinaesthetic imagery use

Internal visual imagery

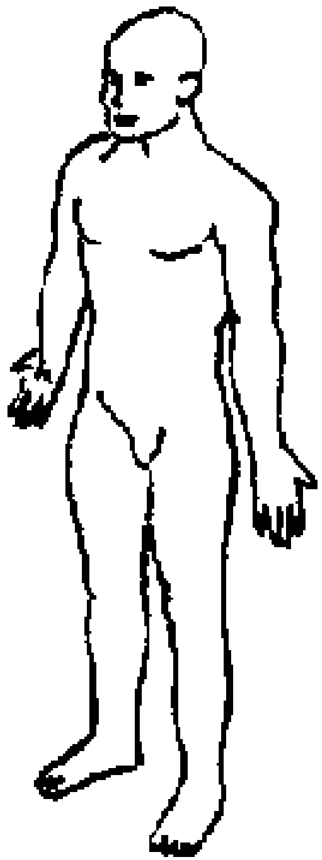
0	1	2	3	4	5	6	7	8	9	10
No kinaesthetic imagery use										High kinaesthetic imagery use

4. If you used kinaesthetic imagery at the same time as the designated visual perspective please denote (Using the numbers 3 = most often, 1 = least often) the order in which visual and kinaesthetic imagery were used

External visual imagery	Internal visual imagery
Visual and kinaesthetic imagery at the same time _______	Visual and kinaesthetic imagery at the same time _______

Visual then kinaesthetic imagery ______ Kinaesthetic then visual imagery ______	Visual then kinaesthetic imagery ______ Kinaesthetic then visual imagery ______

5. On <u>one</u> of the diagrams below, please draw an arrow and provide a short explanation to illustrate where you imaged from most of the time, when completing the external visual imagery column of the questionnaire.



Please rate how easy this section was to understand:

1	2	3	4	5
Easy		Medium		Difficult

Please note any words that you found difficult to understand: ____

Post-questionnaire interview:

Section 1. Introduction. **Follow-up on anything they did not understand.**
Section 2. Instructions. **Follow-up on anything they did not understand.**
Section 3. Imagery vividness questions.
1) **Follow up on anything they did not understand.**
2) Find out more about their understanding and experience of the imagery concepts and the 12 items:
"Next I would like to ask you about a few of the terms that are used in the questionnaire. I wonder if you could just explain, in your own words, what you understood the meaning of these terms to be."
Movement imagery. How would you describe movement imagery in your own words?
Did you feel that it was difficult to understand what was meant by "movement imagery"?
External visual imagery. How would you describe external visual imagery in your own words?
Did you feel that it was difficult to understand what was meant by "external visual imagery"?
Internal visual imagery. How would you describe internal visual imagery in your own words?
Did you feel that it was difficult to understand what was meant by "internal visual imagery"?

Kinaesthetic imagery. How would you describe kinaesthetic imagery in your own words?
Did you feel that it was difficult to understand what was meant by "kinaesthetic imagery"?
Vividness of imagery. How would you describe “vividness of imagery” in your own words?
Did you feel that it was difficult to understand what was meant by "vividness"?

"Now I will ask you about the 12 actions that you were asked to imagine."

1. Walking. Were you able to imagine it? _______________
Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?
2. Running. Were you able to imagine it? _______________
Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?
3. Kicking a stone. Were you able to imagine it? _______________
Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?
4. Bending to pick up a key. Were you able to imagine it? _______________
Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?
5. Running up stairs. Were you able to imagine it? _______________
Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?
6. Jumping sideways. Were you able to imagine it? _______________
Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?

7. Throwing a stone into water. Were you able to imagine it? _______________
Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?
8. Kicking a ball in the air. Were you able to imagine it? _______________
Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?
9. Running downhill. Were you able to imagine it? _______________
Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?
10. Riding a bike. Were you able to imagine it? _______________
Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?
11. Swinging on a rope. Were you able to imagine it? _______________

Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?
12. Jumping off a high wall. Were you able to imagine it? _______________
Describe what you imagined:
How did you decide, in the questionnaire, how vivid the image was?

Section 4. Imagery preference questions.
"One of the questions asked if you have a preference for using a particular visual imagery perspective (internal or external)."
How easy was it to decide which you preferred? _____________
Which did you prefer? _____________________
General question:
"Was there anything in the questionnaire that you found offensive?

Appendix D-3

Arabic versions of the cognitive debriefing questionnaire-Chapter 4

المقابلة مع المشاركين بعد الانتهاء من الإجابة على الاستبيان

الجزء الأول: المقدمة: مراجعة أي شيء غير مفهوم في هذا الجزء من الاستبيان مع اقتراح بديل عن الكلمات الغير مفهومه.

الجزء الثاني: التعليمات والارشادات: مراجعة أي شيء غير مفهوم في هذا الجزء من الاستبيان مع اقتراح بديل عن الكلمات الغير مفهومه.

الجزء الثالث: الأسئلة المتعلقة بقوة وحيوية الصورة.

1) مراجعة أي شيء غير مفهوم في هذا الجزء من الاستبيان مع اقتراح بديل عن الكلمات الغير مفهومه.

2) معرفة المزيد عن استيعاب المشاركين وتجربتهم وخبراتهم المتعلقة بالتصور الحركي لمختلف الحركات المشمولة بالاثني عشر فقرة في الاستبيان: **في الفقرات التالية سيتم سؤالك عن بعض المصطلحات المستخدمة في الاستبيان. والتي تكون كالتالي هل تستطيع شرح ماذا فهمت من معاني هذه المصطلحات وماذا يجب ان تكون وذلك (باستخدام كلماتك و تعبيرك الخاص)** .

التصور الحركي: كيف تصف التصور الحركي (باستخدام كلماتك و تعبيرك الخاص)؟

هل تشعر انه من الصعب فهم ما هو المقصود بالتصور الحركي؟

<u>التصور البصري الخارجي:</u> كيف تصف التصور البصري الخارجي (باستخدام كلماتك وتعبيرك الخاص)

هل تشعر انه من الصعب فهم ما هو المقصود بالتصور البصري الخارجي؟

<u>التصور البصري الداخلي:</u> كيف تصف التصور البصري الداخلي (باستخدام كلماتك و تعبيرك الخاص) ؟

هل تشعر انه من الصعب فهم ما هو المقصود بالتصور البصري الداخلي؟

<u>التصور الحركي الحسي:</u> كيف تصف التصور الحركي الحسي (باستخدام كلماتك و تعبيرك الخاص)؟

هل تشعر انه من الصعب فهم ما هو المقصود بالتصور الحركي الحسي؟

قوة وحيوية التصور الحركي: كيف تصف قوة وحيوية التصور الحركي (باستخدام كلماتك و تعبيرك الخاص)؟

هل تشعر انه من الصعب فهم ما هو المقصود بقوة وحيوية التصور الحركي ؟

في الجزء التالي سوف نقوم بسؤالك عن الاثني عشر حركة التي طلب منك ان تقوم بتخيلها في الجدول السابق بالاستبيان؟

1. المشي: هل كنت قادراً على تخيّل ذلك؟

الرجاء وصف ماذا تخيّلت ________________________________

- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة بالمشي؟

2. الركض: هل كنت قادراً على تخيّل ذلك؟

الرجاء وصف ماذا تخيّلت ________________________________

- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة بالركض؟

3. ركل حجرة: هل كنت قادراً على تخيّل ذلك؟

- الرجاء وصف ماذا تخيّلت ________________________________
- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة بركل حجرة؟

4. الانحناء لالتقاط مفتاح: هل كنت قادراً على تخيّل ذلك؟

الرجاء وصف ماذا تخيّلت ________________________________

- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة بالانحناء لالتقاط مفتاح؟

5. الركض صعوداً على الدرج: هل كنت قادراً على تخيّل ذلك؟

الرجاء وصف ماذا تخيّلت ________________________________

- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة بالركض صعوداً على الدرج؟

6. القفز الى أحد الجانبين: هل كنت قادراً على تخيّل ذلك؟

الرجاء وصف ماذا تخيّلت ________________________________

- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة بالقفز الى أحد الجانبين؟

7. رمي حجر في الماء: هل كنت قادراً على تخيّل ذلك؟
الرجاء وصف ماذا تخيّلت ________________________________

- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة برمي حجر في الماء؟

8. ركل كرة في الهواء: هل كنت قادراً على تخيّل ذلك؟

- الرجاء وصف ماذا تخيّلت ________________________________
- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة بركل كرة في الهواء؟

9. الركض نزولاً من منحدر: هل كنت قادراً على تخيّل ذلك؟
الرجاء وصف ماذا تخيّلت ________________________________

- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة بالركض نزولاً من منحدر ؟

10. ركوب دراجة: هل كنت قادراً على تخيّل ذلك؟
الرجاء وصف ماذا تخيّلت ________________________________

- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة بركوب دراجة؟

11. التأرجح على حبل: هل كنت قادراً على تخيّل ذلك؟
الرجاء وصف ماذا تخيّلت ________________________________

- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة بالتأرجح على حبل؟

12. القفز من حائط عالي: هل كنت قادراً على تخيّل ذلك؟
الرجاء وصف ماذا تخيّلت ________________________________

- كيف حددت في الاستبيان مدى قوة وحيوية الصورة الخاصة بالقفز من حائط عالي؟

الجزء الرابع. الأسئلة الخاصة بتفضيلات التصور الحركي

1) مراجعة أي شيء غير مفهوم في هذا الجزء من الاستبيان مع اقتراح بديل عن الكلمات الغير مفهومه.

2) في أحد الأسئلة في هذا الاستبيان تم سؤالك عما إذا كان لديك أي تفضيلات في استخدام نوع محدد من التصور البصري سواء كان داخلي او خارجي.

كيف كانت سهولة تحديد أي تصور بصري تفضّل؟

أي منظور فضلت الخارجي ام الداخلي؟

سؤال عام: هل كان في الاستبيان أي شيء فيه تهجم او إساءة؟

لكم تحياتي وبارك الله فيكم

Appendix D-4

The final Arabic version of the VMIQ-2-A –Chapter 4

مقدمة عن التصور الحركي

التصور الحركي يشير الى القدرة على تخيل حركة ما. في هذا الاستبيان سيتم التطرق لثلاثة أنواع من التصور الحركي وهي: التصور البصري الخارجي، التصور البصري الداخلي والتصور الحركي الحسي وسيتم شرحها كالتالي:

يعرف **التصور البصري الخارجي** بأنه تكوين صورة من خلال مشاهدتك لنفسك من منظور خارجي. وهو المشهد الذي ستراه حين تنظر لنفسك وأنت تؤدي الحركة من منظور شخص ثالث.

كما يعرف **التصور البصري الداخلي** بأنه تكوين صورة من منظور داخلي أو من خلال منظور الشخص المتحرك نفسه. وهو المشهد الذي ستراه حين تنظر لنفسك من خلال عينيك وأنت تؤدي الحركة.

أما **التصور الحركي الحسي** فيعرف بالشعور بنفسك وأنت تؤدي الحركة. وهي المشاعر والاحاسيس التي تشعر بها عندما تؤدي الحركة وتتضمن الشعور بإنقباضات عضلاتك أو الاحاسيس التي تشعر بها عندما تتلامس أجزاء جسمك مع بعضها البعض أو عند ملامستها للأشياء.

استبيان مدى قوة وحيوية التصور الحركي (2)

الاسم:		**العمر:**		**اليد التي تستخدمها**	**أيسر/أيمن**
الجنس:		**ماهي الرياضة التي تمارسها (ان وجدت):**			
المستوى الذي تمارس فيه الرياضة (على سبيل المثال: ترفيهي، ملتحق بنادي رياضي، جامعي، وطني، دولي، احترافي):					
عدد السنوات التي قضيتها في ممارسه هذه الرياضة على مستوى تنافسي:					

التصور الحركي يشير إلى القدرة على تخيل حركة ما. الهدف من هذا الاستبيان هو تحديد مدى قوة وحيوية التصور الحركي لديك. فقرات هذا الاستبيان صممت لاستحضار صور معينه في ذهنك. سيُطلب منك تقييم مدى قوة وحيوية تصورك لكل فقرة على مقياس مكون من خمس درجات. وذلك بوضع دائرة على الرقم المناسب بعد كل فقرة في الجدول ادناه.

العمود الأول مخصص للصورة المُستحضرة من خلال مشاهدة نفسك من منظور خارجي (**التصور البصري الخارجي**)، والعمود الثاني مخصص للصورة الُمستحضرة من منظور داخلي، كما لو كنت تنظر لنفسك من خلال عينيك (**التصور البصري الداخلي**)، أما العمود الثالث فهو مخصص للصورة الُمستحضرة من خلال الشعور بنفسك وانت تؤدي الحركة (**التصور الحركي الحسي**).

حاول أن تُجيب على كل فقرة على حدة، وبشكل مستقل عن كيفية اجابتك في الفقرات الأخرى. أكمل كافة الفقرات باستخدام المنظور البصري الخارجي. ومن ثم عُد الى بداية الاستبيان وأكمل كافة الفقرات باستخدام المنظور البصري الداخلي. وأخيراً عُد إلى بداية الاستبيان وأكمل كافة الفقرات باستخدام التصور الحركي الحسي (من خلال الشعور بالحركة). التقييمات الثلاث لأي فقرة ما قد لا تكون متشابه في جميع الأحوال. الرجاء إغماض عينيك عند الإجابة على جميع الفقرات.

قم بتخيل كل حركة مُدرجة في الصفحة التالية، وصنف صورك وفق درجة وضوحها وحيويتها كما هو مبين في **مقياس التقييم** التالي:

مقياس التقييم: الصورة المُستحضرة بواسطة كل فقرة قد تكون :

واضحة تماماً وحيّة (كالرؤية و الشعور الطبيعي بالحركة) .... التقييم 1

واضحة وحيّة بشكل معقول .... التقييم 2

واضحة وحيّة بشكل متوسط .... التقييم 3

غامضة وخافته .... التقييم 4

لا توجد صورة على الاطلاق , انت فقط "تعرف" أنك تفكر بالمهارة .... التقييم 5

الفقرة	مشاهدة نفسك وانت تقوم بالحركة (التصور البصري الخارجي)					النظر من خلال عينيك (التصور البصري الداخلي)					الشعور بنفسك وانت تقوم بالحركة (التصور الحركي الحسي)				
	واضحة تماماً وحيّة (كالرؤية و الشعور الطبيعي بالحركة)	واضحة وحيّة بشكل معقول	واضحة وحيّة بشكل متوسط	غامضة وخافته	لا توجد صورة على الاطلاق , انت فقط "تعرف" أنك تفكر بالمهارة	واضحة تماماً وحيّة (كالرؤية و الشعور الطبيعي بالحركة)	واضحة وحيّة بشكل معقول	واضحة وحيّة بشكل متوسط	غامضة وخافته	لا توجد صورة على الاطلاق , انت فقط "تعرف" أنك تفكر بالمهارة	واضحة تماماً وحيّة (كالرؤية و الشعور الطبيعي بالحركة)	واضحة وحيوية بشكل معقول	واضحة وحيّة بشكل متوسط	غامضة وخافته	لا توجد صورة على الاطلاق , انت فقط "تعرف" أنك تفكر بالمهارة
1. المشي	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
2. الركض	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
3. ركل حجرة	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
4. الانحناء لالتقاط مفتاح	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
5. الركض صعوداً على الدرج	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
6. القفز إلى أحد الجانبين	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
7. رمي حجر في الماء	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
8. ركل كرة في الهواء.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
9. الركض نزولاً من منحدر	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
10. ركوب دراجة	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
11. التأرجح على حبل	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
12. القفز من حائط عالي.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

1. **الرجاء الإشارة على هذا المقياس اذا كان لديك تفضيل في استخدام تصور بصري معين (داخلي او خارجي ،إذا لم يكن لديك أي تفضيل فضع دائرة على رقم خمسة):**

0	1	2	3	4	5	6	7	8	9	10
تفضيل قوي للداخلي			تفضيل متوسط للداخلي		لا تفضيل		تفضيل متوسط للخارجي			تفضيل قوي للخارجي

2. **الرجاء الإشارة على الأسئلة التالية عن مدى "التحول" بين المنظورين البصريين (داخلي وخارجي) لديك عند تعبئة العمودين الأول والثاني في الاستبيان:**

أ. عندما أكملت العمود المتعلق بـمشاهدة نفسك وانت تقوم بالحركة (التصور البصري الخارجي)، حدد ما هو المنظور الذي استخدمته؟

0	1	2	3	4	5	6	7	8	9	10
من منظور داخلي بحت		تحول بسيط للمنظور الخارجي			تحول بشكل منتظم			تحول بسيط للمنظور الداخلي		من منظور خارجي بحت

ب. عندما أكملت العمود المتعلق بالنظر من خلال عينيك (التصور البصري الداخلي) حدد ما هو المنظور الذي استخدمته؟

0	1	2	3	4	5	6	7	8	9	10

من منظور داخلي بحت	تحول بسيط للمنظور الخارجي	تحول بشكل منتظم	تحول بسيط للمنظور الداخلي	من منظور خارجي بحت

3. عندما أكملت عمودي التصور البصري من الاستبيان , الرجاء تحديد ما إذا كنت قد استخدمت التصور الحركي الحسي في نفس الوقت المخصص للتصور البصري:

التصور البصري الخارجي:

0	1	2	3	4	5	6	7	8	9	10
عدم استخدام التصور الحركي الحسي										استخدام عالي للتصور الحركي الحسي

التصور البصري الداخلي:

0	1	2	3	4	5	6	7	8	9	10
عدم استخدام التصور الحركي الحسي										استخدام عالي للتصور الحركي الحسي

4. إذا كنت قد استخدمت التصور الحركي الحسي في نفس الوقت المخصص للتصور البصري الرجاء الإشارة (باستخدام الأرقام حيث الرقم 3= غالباً و1= نادراً) الى ترتيب استخدام التصور البصري مع التصور الحركي الحسي:

التصور البصري الخارجي		**التصور البصري الداخلي**	
التصور البصري والحسي في نفس الوقت	_______	التصور البصري والحسي في نفس الوقت	_______
التصور البصري ثم الحسي	_______	التصور البصري ثم الحسي	_______
التصور الحسي ثم البصري	_______	التصور الحسي ثم البصري	_______

5. على <u>أحد</u> الرسمتين ادناه، الرجاء رسم سهم وقدم شرحاً موجزاً لتوضيح المكان الذي قمت بالتصور منه في الأغلب عندما قمت بتعبئة العمود الخاص بالتصور البصري الخارجي في الاستبيان.