Effect of Aging on the Planning and Execution of Sit-to-Stand Movement

by

Kanokwan Srisupornkornkool

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Summary

Whole-body coordination such as in sit-to-stand (STS) movements is an important activity of independent daily living that is affected by decreased muscular strength and postural control due to ageing and also as a result of neurological diseases such as stroke. Recent research has taken an interest in using motor imagery for rehabilitation and training because it has many features in common with movement execution without some of the practical difficulties of repeated physical practice. Imagery tends to be more effective when it takes a first person perspective and focuses on kinesthetic aspects of movement. On the contrary, research in exercise science shows that movement execution is more fluent when attention is focused on body-external perceptual consequences of movement. How ageing affects this difference in the impact of attentional focus is not well understood. This thesis examines the effects of body-external (visual) and body-internal (muscular or somatosensory) attentional focus on STS movement execution and imagery in healthy young and older adults.

The thesis reports four experiments comparing execution and imagery performance in young and older adults. Experiment 1 was designed to clarify the impact of attentional focus on motor performance and imagery in young and older adults. Experiment 2 examined the impact of changing the level of effort (by manipulating the starting seat height) on the effects of attentional focus. Experiment 3 measured the impact of unimanually balancing a load in the hand on the role of attentional focus in physical and imagined STS movements. Experiment 4 studied the role of attentional focus in a training protocol employing motor imagery practice. Postural transition duration and transition stability during physical trials, self-reported movement times during physical and imagined trials, and ground reaction force and vividness of imagery during imagined trials were recorded.

The results show that focusing attention on muscular effort not only benefitted older people's motor performance, but also increased both the level and task-linked modulation of inadvertent force production during imagery (Experiment 1). Increasing the level of effort (by lowering seat height) resulted in better modulation of movement time as a function of effort level when older adults focused attention internally (Experiment 2). When a secondary task of holding a fluid container upright was added, external attentional focus benefitted both age groups (Experiment 3), indicating that the effects of attentional focus are task-linked. There was also a numerical indication that focusing attention on muscular load during motor imagery-based practice may be more effective in older adults (Experiment 4). These results suggest that kinesthetic imagery may be particularly consonant with the more internally focused motor control that benefits older people. Thus, training or rehabilitation protocols using kinesthetic imagery may serve more effectively as a form of practice for this age group by activating neural pathways similarly to their motor execution. On the other hand, young people consistently performed better under external attentional focus, and even modulated their force production during imagery better when externally focused. The focus on musculoskeletal dynamics that kinesthetic imagery requires may therefore correspond less closely to motor planning and control processes in this age group. Thus, pathways by which kinesthetic imagery can serve as practice are likely to be more indirect than for older people. These findings provide fundamental knowledge for further clinical research on patients who suffer disability in STS movements.

Abbreviations

ABC	Activities-specific Balance Confidence
ADL	Activities of daily living
AP	Anteroposterior component of ground reaction force
BBS	Berg Balance Sclae
CNV	Contingent negative variation
CoM	Centre of Mass
CoP	Centre of pressure
EMG	Electromyography
fMRI	functional Magnetic Resonance Imaging
KVIQ	Kinesthetic and Visual Imagery Questionnaire
MI	Motor imagery
MIQ	Movement Imagery Questionnaire
MIQ-R	Movement Imagery Questionnaire-Revised
ML	Mediolateral component of ground reaction force
MP	Mental practice
MT	Movement time
PD	Parkinson disease
PET	Positron Emission Tomography
RMS	Root mean square
ROM	Range of motion
RT	Reaction time
SCI	Spinal cord injury
STS	Sit-to-stand
TBI	Traumatic brain injury
TMS	Transcranial Magnetic Stimulation
TUG	Time Up and Go

Chapter 1: Introduction

1.1. Sit-to-stand movement

1.1.1. Definition of sit-to-stand movement

Sit-to-stand (STS) movements can be considered a fundamental motor skill, a common motor activity with a specific pattern that involves different body parts, namely the head, the trunk, the arms and the legs, for transitioning from a sitting to a standing position. The nature of STS movements is dynamic and destabilizing because of a rapid change of the body from a stable seat position to a small base of support and a higher centre of mass (CoM) position (Nevitt, Cummings, & Hudes, 1991). Precisely defining standard STS movements seems to be difficult because people have unique and distinctive movement styles. Thus, the definition of STS can depend on the aim of the study in question. For example, Roebroeck, Doorenbosch, Harlaar, Jacobs, and Lankhorst (1994) defined the STS movement as moving the body’s CoM upward from a sitting position to a standing position without losing balance. Vander Linden, Brunt, and McCulloch (1994) stated that the STS movement was a transitional movement to the upright posture requiring movement of the CoM from a stable position to a less stable position over extended lower extremities.

Several daily activities are performed from a standing position because this posture is not only vital for proper functioning of many organs, but also helps to maintain proper bone loading and prevent excessive bone demineralization (Leo, 1985; Krebs, Ragnarsson, & Tuckman, 1983; Lukert, 1982). The ability to perform STS movements is a fundamental ability to achieve normal activities of daily living and also a prerequisite of locomotion (walking) activity. Moreover, the unassisted STS movement is an essential skill that determines the functional level of a person

(Ragnarsson et al., 1981; Igaroski & Black, 1985; Paulus, Straube, & Brandt, 1984; Kerr, White, Barr, & Mollan, 1994; Lee, Wong, Tang, Cheng, & Ling, 1997; Mathiyakom, McNitt-Gray, Requejo, & Costa, 2005; Janssen, Bussmann, & Stam, 2002; Etnyre & Thomas, 2007). Therefore, an understanding of the standing up in healthy individuals provides fundamental knowledge about how the task is organized and enables identification of abnormal STS movements when it occurs.

1.1.2. Biomechanics of sit-to-stand movement

The STS movement is a discrete task beginning from a seated position and then transitioning to a standing position. Giving a standardized description of human biomechanics is difficult because people do not only have individual and distinctive movement styles, but also tend not to repeat movements in exactly the same way (Etnyre & Thomas, 2007). Moreover, numerous studies have used varying methods to explain biomechanics of STS movements. The majority of studies have utilized kinematic (e.g., using videotape recordings, electrogoniometers and accelerometers) and kinetic (mainly using force platform) measurement analysis to identify the structure of STS movements. The effective analysis of STS events is generally described in two ways: either flexion and extension phases, or momentum, torque and velocity event changes. These events have often served as the major variables of most studies on STS movements (see Etnyre & Thomas, 2007 for a review).

To clarify STS movements, the events were subdivided into four phases, including a flexion-momentum, a momentum-transfer, an extension and a stabilization phases. The flexion-momentum phase starts with initiation of movement and ends just before lifting the buttocks from the seat. This phase is called an onset of movement (which is the onset of change in vertical force). The momentum-transfer phase (seat-off) starts with lifting the buttocks and ends with achieving maximal ankle dorsiflexion. The extension phase begins after achieving maximal ankle dorsiflexion and ends when one stops hip, leg and trunk extension. The stabilization phase begins after achieving the hip extension and ends when all motion is completed (Schenkman, Berger, Riley, Mann, & Hodge, 1990; Shepherd & Gentilel, 1994).

This description emphasized the movement of body segments during the performance of flexion and extension movements more than momentum changes. However, events of STS movements should be unequivocal for any performance. Riley, Schenkman, Mann, and Hodge (1991) divided STS events into three phases in terms of momentum, including an initial, a transitional and an extension phases. The initial phase is to generate upper body momentum. The transitional phase starts when momentum from upper body movement is transferred to the total body, as the momentum of body's CoM changes from forward to vertical. The extension phase takes place during the vertical ascent of the body. In addition, STS events are often divided into seat off, beginning of movement and end of movement phases. The seat off event is a transitional point, changing from a stable to unstable base of support. There are different definitions of transitional point, depending on the objectives of studies, such as the time at peak horizontal force (Doorenbosch, Harlaar, Roebroeck, & Lankhorst, 1994; Gross, Stevenson, Charette, Apyka, & Marcus, 1998), peak vertical force (Kaya, Kerbs, & Riley, 1998), initial vertical force (Riley et al., 1991; Schenkman et al., 1990) and a point of the thigh's separation from the seat (Kotake, Dohi, Kajiwara, Sumi, Koyama, & Miura, 1993; Moxley Scarborough, Kerbs, & Harris, 1999; Tully, Fitoohabadi, & Galea, 2005; Vander et al., 1994). The beginning of movement has also varied among studies, such as initial fore-aft momentum

(Kralj, Jaeger, & Minih, 1990) or initiation of trunk flexion displacement or momentum (see Etnyre & Thomas, 2007 for a review). Although the end of movement is difficult to describe because there is postural sway during quiet standing, this event is simply defined as a point of fully standing up. Moreover, the end of movement is described, by monitoring displacement, velocity or momentum in horizontal direction, as related to minimal movement of the head, the spine, the shoulders or the hips (see Etnyre & Thomas, 2007 at follow review).

Although there is a wide range of studies involving analysis of STS movements, it seems that there is no consensus on a standardized method for analyzing STS events because of the diversity of movements between and within individuals, relating to influential factors on the movement such as unique pattern of movement, constrained conditions of studies' purpose, and varied strategies during performing STS movements. Studying STS movements also requires knowledge of the potential factors influencing how the movement is performed. Thus, it is necessary to conduct further research on STS movements.

1.1.3. Determinants of sit-to stand movement

STS movements are common physical tasks that are frequently used (ranging between 45-65 times a day in independently living people) to change to locomotor or other functional activities (Bohannon et al., 2008; Dall & Kerr, 2010). A clearly understanding of the features of STS movements requires a basic knowledge of determinants that influence how the movement is performed. Generally, the determinants are often divided into two domains–constraint-related and participant-related.

1.1.3.1 Constraint-related

In studies of STS movements, positional constraints are commonly divided to chair-related and strategy-related.

Chair-related:

The literature indicates that a chair has an influence on the ability to perform STS movements (Janssen et al., 2002). Chair-related determinants, such as the height of a chair, type of a chair and use of a backrest, have been observed, however, most studies have focused on the height of a chair (e.g., Schenkman, Riley, & Pieper, 1996; Arborelius, Wretenberg, & Lindberg, 1992; Hughes & Schenkman, 1996; Hughes, Weiner, Schenkman, Long, & Studenski, 1994; Hughes, Myers, & Schenkman, 1996; Itakazu, Uemura, Aoki, & Takatsu, 1998; Kawagoe, Tajima, & Chosa, 2000; Munro, Steele, Bashford, Ryan, & Britten, 1998; Munton, Ellis, & Wright, 1984; Rodosky, Andriacchi, & Andersson, 1989; Su, Lai, & Hong, 1998; Weiner, Long, Hughes, Chandler, & Studenski, 1993), whereas a few studies have tried to clarify the influence of a type of chair that is designed for making STS movements easy (e.g. Munro et al., 1998; Burdett, Habasevich, Pisciotta, & Simon, 1985; Wheeler, Woodward, Ucovich, Perry, & Walker, 1985; Bashford, Steele, Munro, Westcott, & Jones, 1994; Ellis, Seedhom, Amis, Dowson, & Wright, 1979). For example, Ellis et al. (1979) claimed that the knee moment and joint loading force decreased during STS movements when using a motorised chair that assists the postural transition. Similarly, use of an ejector chair (a type of motorized chair) has been reported to assist the STS transfer (Bashford et al., 1994; Munro et al., 1998). Surprisingly, there are no experimental studies concerned with the influence of a backrest on STS performance. Previous studies have only used a chair with a backrest in order to standardize the STS movement starting position (e.g., Munro et al., 1998; Hughes et al., 1994; Weiner et al., 1993).

Evidence suggests that changing the height of a seat affects the maximal moment needed at the knee and the hip (e.g., Hughes & Schenkman, 1996; Rodosky et al., 1989; Su et al., 1998; Arborelius et al., 1992; Schenkman et al., 1996; Riley et al., 1991). These findings suggest that using a higher chair leads to a decrease in moments and joint loading forces acting at the knee level (up to 60%) and at the hip level (up to 50%), whereas using a lower chair increases the need for momentum generation and more repositioning of the feet. Hughes et al. (1994) described the repositioning of the feet as a movement strategy to lower moments used for STS movements. They called this a "stabilization strategy". Although comparison of results among studies is difficult because of differences in study design and reference points of seat height, the findings could be summarized by noting that an unsuitable chair height changes biomechanical demands or alters strategies of STS movements. This is due to the imposed biomechanical demand due to different foot, trunk, or arm positioning. Despite reports in the literature that chairs should be of adequate height, and have sufficient space under the seat (Kawagoe et al., 2000), people usually need to engage in this task from different chair heights that typically vary from 30.5-45.7 cm (Weiner et al., 1993). It is a challenge to understand how individuals accommodate to these changing conditions.

Strategy-related:

Despite the absence of a standardized method for studying STS movements, previous studies have often analysed STS movements while restricting sitting position before initiation of standing up and constraining movements to control variability among individuals. There are several strategy-related determinants that have been studied in order to gain insight into the influence of the determinants on STS movements, such as foot position, speed of movement, use of the arms, and attention. Firstly, the position of the foot is one of the common parameters that is frequently controlled before starting the STS movement in experimental studies. Abundant evidence supports the fact that different foot placements can influence the strategy of STS movements. For example, some studies have reported a shorter movement time of the pre-extension phase, and lower maximum extension moment at the hip, with the feet placed posterior than in neutral or anterior position (e.g., Shepherd & Koh, 1996; Kawagoe et al., 2000; Khemlani, Carr, & Crosbie, 1999; Raina, Stevermer, & Gillette, 2005; Gillett & Stevermer, 2012). Previous studies have also reported less the head movement and lower ground reaction forces when the lower leg is in the preferred position while performing STS movements (Stevens, Bojsen-Moller, & Soames, 1989). These findings provide information on how to choose suitable foot placement to help decrease force requirements for people with weakness or disability.

Secondly, speed of movement is generally known as having an influence on the strategy of movement. Many studies did not allow participants to stand up at their self-selected speed; speed of movement was sometimes controlled by synchronization of movement with a metronome (e.g., Roebroeck et al., 1994; Pai, Naughton, Chang, & Roger, 1994; Pai & Rogers, 1990). For instance, some experiments constrained movement by regulating the speed of movement during rising, demonstrating that rising speed increases moments of the hip flexion, the knee extension and the ankle dorsiflexion (Pai & Roger, 1991) and decreases the momentum-transfer phase (Vander Linden et al., 1994; Hanke, Pai, & Roger, 1995).

However, the constrained speed condition is not the usual way to perform STS movements.

Thirdly, based on the literature, use of the arm while performing STS movements appears to influence performance. Carr (1992) reported that arm position has an influence on the position of the body's CoM. The CoM moves forward at the end of the STS movement with the arm point the arm pointed forward, whereas restricting the arm leads to a different pattern of angular displacement. More than half of previous research did not allow participants to use the arm during STS movements; participants were instructed to perform the movements with their arms by the side, on the lap, crossed on the chest or placed on armrests (e.g., Alexander, Schultz, & Warwick, 1991; Etnyre & Thomas, 2007; Gillette, Stevermer, & Hall, 2012). Some studies reported that use of the arm during STS movements is very common among older adults and even among young people (Durward, 1994; Wheeler et al., 1985). Moreover, several previous studies showed that the hip and the knee extension moment and joint loading force were decreased when using a chair arm-rest support (Gillette et al., 2012; Burdett et al., 1985; Arborelius et al., 1992; Seedhom & Terayama, 1976; Bahrami, Riener, Jabedar-Maralani, & Schmidt, 2000; Schultz, Alexander, & Ashton-Miller, 1992). Accordingly, Etnyre and Thomas (2007), for example, reported that using an armrest while performing STS movements produced less average force and had longer time to vertical peak force than three conditions (with the arm free, the hand on the knee and the arm crossed), but there was no significant difference between the arm-use conditions in STS times. However, to our knowledge, there are no experimental studies to clarify the impact of functional arm motion during STS movements, particularly standing up while holding an object in the hand, which is a common activity in daily life.

Finally, it is generally known that attention to movement is able to modulate motor responses. For instance, directing attention away from cued movements is able to shorten reaction time (e.g., Wulf, McNevin, & Shea, 2001) and increase frequency of movement adjustments (e.g., McNevin, Shea, & Wulf, 2003). Previous research did not directly emphasise the effect of focus of attention on STS performance. Usually, they only provided verbal instructions to keep the movement correct, and inhibit habitual postural adjustments. For example, Gillette et al. (2012) used different verbal commands to correct the movement while using different movement strategies, including momentum, stabilization and vertical strategies. The results showed that the knee extension moment increased with the vertical strategy. Stevens et al. (1989) compared the effects of guidance to inhibit head and neck postural adjustment on STS movements. Their finding showed that there was significant decrease in the head movement in the guided movement. It also found that ground reaction force and electromyography (EMG) activity were decreased with the guided movement.

Surprisingly, little experimental research has addressed the influence of attending to the movement on the performance of STS movements. The strategy for STS movements can differ considerably with the participant’s attention to the movement under specific instructions. For example, Yamada and Demura (2005) found that the peak value of the ground reaction force was higher and movement time (MT) was faster under the assigned-speed condition (i.e., stand up as fast as possible) than in the self-paced condition (stand up without any speed instructions). In another study, Sato, Mizuma, Kawate, Kasai, and Wada (2012) asked participants to perform STS movements while paying attention to their bilateral symmetry. They found that approximately 50% of STS movements were asymmetric, despite participants remaining aware of the need for bilateral symmetry during STS movements. It can be seen from these examples that instructions were not precisely detailed and oriented towards directing attention to the STS movement. Therefore, it is worth knowing how beneficial focus instructions are to the performance of STS movements before attempting to utilize them in enhancing the STS skill.

Indeed people have to perform STS movements under widely different circumstances, particularly under different seat height conditions and different body positions (e.g., depending on how the hands are used). There are no reports of the effects of changing seat height or simultaneously using the hands under different attentional instructions during STS performance. Thus, to understand the STS movement skill, it is necessary to explore the ability to perform STS movements while coping with different constraint conditions, and use that information to interpret the performance. In the last section of the introduction, the implications of attention to movement are discussed again.

1.1.3.2 Participant-related

The ability to perform STS movements is essential for activities of daily living, especially in older people, because this transitional movement is among the most challenging co-ordinations of daily life. When rising from a chair, the lower extremities, the lower body joints and the leg muscles have to be used to transfer the body up from a seated position (Eriksrud & Bohannon, 2003; O’Meaea & Smith, 2006). Thus, the transitional movements require significant muscular strength and postural control. STS movements register high moments of as much as 4.7 times body weight across joints in the lower limbs (Khemlani et al., 1999), which can pose problems for older people with reduced strength (e.g., Hughes et al., 1996). The movements also pose a significant balancing challenge because of the rapid upward shift of the body’s CoM to a position of reduced stability (Roebroeck et al., 1994; Vander Linden et al., 1994).

STS movements among different populations have been described in several previous studies. Older people and those with disabilities have particular difficulty in performing transitional movements. Age-related differences appear to be important during transitional movements because it is widely accepted that aging and a decline in numerous physical performance measures are linked. Some investigators have claimed that strategies of the STS task were slightly different between healthy young and older adults (e.g., Ikeda, Schenkman, & Riley, 1991; Pai et al., 1994). According to Feland, Hager, and Merrill’s study (2005), rising power decreases with increasing age, whereas weight transfer time and centre of gravity sway remain similar regardless of age. However, much STS research have been carried out on deconditioned older people, because older people often have functional limitations, leading to difficulty in achieving extension of the hips, the legs and the trunk, and they move more slowly (due to decreased trunk flexion angular velocity). For example, Papa and Cappozzo (2000) reported that their elder group showed a trend to flex the trunk more before the seat-off phase, resulting in bringing the CoM closer to the base of support and gaining a higher momentum. Older people also rotated the body forward after the seat-off phase, bringing the CoM over the base of support and then standing up. However, maximal speed during STS movements was lower in older people than young adults. In addition, a study by Mourey, Pozzo, Rouhier-Marcer, and Didier (1998), suggested that older participants spent more time completing the sitting down movement and adjustment of velocity appeared in the final part of the movement before reaching a chair.

Evidence suggests that the difference in physical movement outcomes between young and either older adults or disabled people may the result of changes in any of three areas of movement control, including execution, control and planning systems (Blevins, Hecker, Bigler, Boland, & Hayes, 1994; Johnson et al., 1994; Lewis & Shaw, 1997; Ketcham & Stelmach, 2001; Butler, Lord, Rogers, & Fitzpatrick, 2008). For example, the mechanical properties of muscles and tendons, the effectiveness of sensory systems (e.g., visual, proprioceptive and vestibular) and the selection of joint trajectories to perform a task (planning system) deteriorate with age. Because older adults have often experienced a change in the mechanical properties of muscles and tendons (execution system), such as a decrease in muscle strength, a decrease in the rate of force production and an increase in tendon stiffness, there are two important strategies adopted during STS movements in older adults, including a momentum-transfer strategy and a stabilization strategy (Riley et al., 1991; Hughes et al., 1994; Schultz et al., 1992). The momentum-transfer strategy is characterized by a movement of the upper part of the body to generate momentum. The stabilization strategy is characterized by the placement of the CoM closer to base of support before the seat-off. Hughes et al. (1994) reported that older people often use the stability strategy during STS movements.

Because of deterioration in the ability to perform the basic transitional movements in older adults, impaired functioning and mobility in activities of daily living normally occurs (Guralnik et al., 1994; Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995). As a result of functional limitations, older people’s STS performance should differ from young people if determinants change (Ikeda et al., 1991; Hughes et al., 1994; Pai et al., 1994; Schenkman et al., 1996). For example, Schenkman et al. (1996) reported that the body segments’ maximum extension angular velocities were changed in older adults at the lower chair height. The authors also suggested that older adults have to change their performance when they face more demanding tasks. Likewise, Mazza, Benvenuti, Bimbi, and Stanhope (2004) claimed that functional abilities and difficulty of the task have an influence on the effectiveness of the ability to stand up from a chair. The results showed that participants in the middle functional ability group had to swing their arm during STS movements at the lower seat height, whereas participants in the least functional group were not able to stand up at all at the lowest height of seat. In addition to changing the arm-use determinant, Leung and Chang (2009) investigated three posture-transfer strategies (no support, chair-arm, and cane) during STS movements in older people. They found that the no-support strategy had the smallest value of hip-compressed angle during STS movements, whereas there was no significant difference between chair-arm and cane-use strategies. Subsequently, the trunk flexion when using no support was greater than when using other strategies, suggesting that these two strategies may be seen as adaptive mechanisms to decrease the risk of anterior disequilibrium in older adults. People need to accomplish STS movements under widely varying circumstances in daily life, including different surfaces, different seat heights, different chair configurations and different body positions (e.g., where the feet are during the task, whether the arms are used). Each of these conditions should be evaluated especially regarding age-related differences before interactions of all constraints on STS movements are fully appreciated.

1.1.4. Improvement on sit-to-stand movement

During STS movements, significant leg muscle strength and a wide range of joint motion are involved, which presents a considerable challenge to dynamic equilibrium constraints (Riley et al., 1991). Decreased lower extremities muscle strength is associated with a diminished ability to perform functional activities (Brill, Maccera, Davis, Blair, & Gordon, 2000; Lauretani et al., 2003; Purser, Pieper, Poole, & Morey, 2003; Salem, Wang, Young, Marion, & Grendale, 2000; Adams, Gandevia, & Skuse, 1990; Canning, Ada, & O'Dwyer, 1987) and a higher risk of falling during movements (Blevins et al., 1994; Johnson et al., 1994; Lewis & Shaw, 1997; Guralnik et al., 1994; Guralnik et al., 1995; Cheng et al., 1998). Thus, this motor act is a good indicator of mobility and frailty of older people (Shumway-Cook, Brauer, & Woollacott, 2000; Studenski et al., 2003). It is also often included in assessment and rehabilitation programs for people who present the inability to perform this basic skill, due to impaired functioning and mobility in activities of daily living (ADL).

The question of how to help these populations change position from sitting to standing more easily and safely should be considered. Fortunately, the ability to achieve STS movements is possible to develop with sufficient training. Physical practice and MI training are current issues for improvement in functioning and mobility in activities of daily living (ADL).

1.1.4.1. Physical practice

Muscular strength and postural control are essential to perform STS movements independently. If the lower limb strength is reduced by weakness or sedentary life style, balance and postural control will decline, with the consequence that STS movements become difficult to carry out (Alexander et al., 1995; Doherty, 2003; Frontera et al., 2000; Alexander et al., 1991; Gross et al., 1998). Research suggests that the ability to achieve STS movements can be improved with adequately optimal physical training programmes, even in older people (DiPietro, 1996; Schot, Knutzen, Poole, & Mrotek, 2003). Considerable effort has been focused on how to improve muscular strength and postural control in order to achieve STS movements more effectively. Numerous studies have shown positive effects of resistance training or exercise intervention to enhance motor performance, including muscle strength, balance, muscle mass, flexibility and aerobic capacity (e.g., Keysor & Jette, 2001; Singh, 2002; Seynnes et al., 2004; Schlicht, Camaione, & Owen, 2001). As a result of gains in strength and balance, improvement in independent performance of STS movements can be achieved. Although resistance training is safe and effective for improving performance, it requires close supervision, especially during provision of high-intensity resistance training. One solution for reducing the level of supervision would be to lower intensities of the exercise programme. Moreover, evidence suggests that strength training alone does not appear to improve STS performance (Schlicht et al., 2001).

Using a task-specific function to provide a low-intensity resistance exercise has been little attended. Repeating the STS movement may be sufficient to improve lower limb muscle strength and then improve STS performance because by repeating the STS movement, one can gain the quadriceps strength required to generate the knee extension to stand up (Hughes et al., 1996). Some evidence indicates the effectiveness of task-specific training on STS performance. For instance, Rosie and Taylor (2007) compared six weeks of repeated STS exercise with a progressive-resistance knee extension exercise using ankle weights. They found that functional abilities measured by the Berg Balance Scale (BBS) in the repeated sit-to-stand exercise group showed more improvement than in the other group. Canning et al. (2003) investigated the effect of intensive task-specific training for four weeks on STS performance in people who have had traumatic brain injury

(TBI). The study showed that training of STS and step-up combined with usual rehabilitation programme resulted in an improvement in STS performance, probably because of increases in lower limb muscle strength and endurance, and increases in inter-segmental co-ordination. Furthermore, Mak and Hui-Chan (2008) stated that peak horizontal velocity during STS movements increased more after two weeks of task-specific training than conventional exercise training in people who suffered from Parkinson's disease (PD), and after four weeks of task-specific training, peak horizontal and vertical velocity increased and movement time decreased when compared with conventional exercise training. It appears that task-specific training is better than conventional or resistance exercise training in improving STS performance in older adults and disable patients.

1.1.4.2. Motor imagery (MI) practice

The majority of studies of STS movements have focused on four major applications, including chair design, analysis of normal and abnormal STS movements, biomechanical modeling and intervention method (Aissaoui & Dansereau, 1999). Surprisingly, although there have been a range of studies on potential interventions for enhancing STS performance, to our knowledge, only a few studies have investigated the effectiveness of MI practice on the STS task. Imagined movement represents a covert access to motor representations, and then overt and covert movements facilitate a common network of cortical areas (e.g., Bonnet, Decety, Requin, & Jeannerod, 1997; Clark, Tremblay, & Ste-Marie, 2004). It has been demonstrated that MI alone is able to affect movement execution and MI training can induce a reactivation of the neural networks involved in the representation of action (e.g., Page, 2001; Decety et al., 1994; Jackson, Lafleur, Malouin, Richards, & Doyon, 2001; Lotze & Cohen, 2006; Lotze & Halsband, 2006). Moreover, MI is practical to provide and low in cost and time, so this may be used in rehabilitation as an alternative or additional technique combined with other techniques, such as physical practice. The present study expects that MI may be able to improve the STS skill. It is likely to be successful if researchers and clinicians understand how healthy people accommodate to MI practice prior to applying this knowledge to people who have had impairments and functional limitations.

To date, MI has been used either as a way of accessing higher-level control of complex body movements, or as an alternative to physical practice in clinical settings. It seems to be valuable to clarify the impact of factors that influence how the movement is performed during motor imagery. Particularly, the effects of such determinants of performance as seat height or concurrent use of an arm, while performing STS movements under different types of attentional focus need to be established. Although the use of motor imagery is a rapidly growing area of focus in motor rehabilitation (Dijkerman, Ietswaart, & Johnston, 2010; Oh, J. S. Kim, S. Y. Kim, Yoo, & Jeon, 2010; Skoura, Papaxanthis, Vinter, & Pozzo, 2005), to the best of our knowledge, differences due to changes in performance determinants (e.g., such as seat height or concurrent use of an arm), especially under different focus of attention, and in different age groups, has not been considered. Studying these effects will provide valuable practical information about the conditions under which MI practice might be effective.

Therefore, in the next section, motor imagery and motor imagery practice will be defined and the effects of various factors that influence MI will be examined. Then, evidence of brain activation during MI and brain reorganization following MI training will be reviewed. Finally, evidence supporting the potential of MI for improving motor performance in healthy individuals and retraining motor tasks involving upper and lower extremities in people with disability will be discussed.

1.2. Motor imagery

1.2.1. Definition of motor imagery

Imagery has been considered as a means of accessing motor networks and restoring motor function without executing actions (Gabbard & Cacola, 2009). Imagery is defined as a complex cognitive process that refers to the creation or recreation of experience in the mind using perception and sensory representations, including auditory, olfactory, gustatory, tactile, visual and kinesthetic sensations (Dickstein & Deutsch 2007; Jackson et al., 2001). When imagery is of human movements, it is called motor imagery.

Motor imagery (MI) is the ability to imagine performing movement (without any overt movement) using a cognitive organization that requires memory and spatial attention. It is self-generated using sensory and perception processes, enabling the reactivation of specific motor actions within working memory (Guillot & Collet, 2005; Solodkin, Hlustik, Chen, & Small, 2004; Annett, 1995; Kosslyn, Ganis, & Thompson, 2001; Jeannerod, 1995; Decety & Grezes, 1999). Thus, three major components of neural processing are required for MI– sensory-perceptual, memory and motor mechanisms–such that persons engaged in imagery are consciously aware of it and are able to report the contents of the imagined acts (Murphy & Jowdy, 1992).

1.2.2. Factor influencing motor imagery

In the context of rehabilitation in general, research on motor imagery has not only considered the effects of motor impairment severity (Kwakkel, Kollen, Van Der Grond, & Prevo, 2003), and time since impairment (Liu, Chan, Lee, & Hui-Chan, 2004; Mueller, Butefisch, Seitz, & Homberg, 2007), but also imagery ability (Malouin, Richards, Durand, & Doyon, 2008), cognitive deficits (Malouin, Belleville, Richards, Desrosiers, & Doyon, 2004), and imagery characteristics such as first or third-person perspective (Jackson, Meltzoff, & Decety, 2006), and visual or kinesthetic imagery modality (Dickstein & Deutsch, 2007). Therefore, studies involving MI should be concerned with the factors that influence MI, such as imagery perspective, imagery modality, and imagery ability.

1.2.2.1. Imagery perspective

Imaging of motor actions requires the ability to form internal representations of specific motor activity. Movement representation can be categorized as having external (third-person) perspective or internal (first-person) perspective (Mahoney & Avener, 1977; Callow & Hardy 2004; Malouin, Richards, Jackson, & Doyon, 2010; Dijkerman et al., 2010; Jackson et al., 2001; Bakker, de Lange, Stevens, Toni, & Bloem, 2007; Solodkin et al., 2004). External perspective corresponds to imagining another person's movement and implies only visual representation of the motor task, whereas internal perspective engages imagination of one's own movement and can involve both visual and kinesthetic representation of the imagined movement (Malouin et al., 2010; Malouin & Richards, 2010).

One issue in MI practice is the selection of perspective. There is evidence showing that the effectiveness of using MI appears to be influenced by imagery perspective (Dijkerman et al., 2010). Several studies have claimed that performance on motor tasks were improved by first-person MI training (Page, 2000; Page, Levine, Sisto, & Johnston, 2001 a; Page, Levine, & Leonard, 2007; Crosbie, McDonough, Gilmore, & Wiggam, 2004; Dijkerman, Letswaart, Johnston, & MacWalter, 2004; Muller et al., 2007). Moreover, evidence from behavioural, neurophysiological and neuroimaging studies suggests that MI using first-person perspective engages the motor system more than MI using third- person perspective (Jackson et al., 2006; Jackson et al., 2001; Bakker et al., 2008; Guillot et al., 2008; Fourkas, Avenanti, Urgesi, & Aglioti, 2006; de Lange, Helmich, & Toni, 2006; Guillot et al., 2009; Stinear, Byblow, Steyvers, Levin, & Swinnen, 2006; Vargas et al., 2004). These findings suggest that the internal, first-person perspective shares more physiological characteristics with movement execution.

1.2.2.2. Imagery modality

There can be two modalities of mental representation in imagined action–kinesthetic or visual (Deiber et al., 1998; Ruby & Decety, 2001). Kinesthetic imagery corresponds to the intense sensation of kinesthetic representation of the action from inside the person. A key difference between kinesthetic and visual imagery is that kinesthetic imagery involves imaging one’s own movement, whereas visual imagery is associated with spatial coordination of a movement in the environment, which could be one’s own or another person’s movement (Stevens, 2005). Evidence from functional brain imaging studies suggest that visual and kinesthetic MI promote different but overlapping neural networks (Guillot et al., 2009). Visual MI activates occipital and the superior parietal area, whereas kinesthetic MI promotes motor-related areas and the inferior parietal area.

MI practice always involves maintenance and manipulation of visual and kinesthetic information in memory (Malouin et al., 2004), but evidence from psychology and sport science suggests that the modality used in MI can depend on the type of task and the stage of learning (Fery, 2003). Fery (2003) suggested that at the early stages of learning, visual MI is more suited to the task as it focuses on the form of the movement. However, movement timing and coordination are better learned by kinesthetic MI. Moreover, Rodrigues et al. (2003) suggested that visual MI is more effective than kinesthetic MI in improving stance stability and learning open motor skills, but kinesthetic MI is more effective for learning closed motor skills (Hall, Buckolz, & Fishburne, 1992). So, a challenge in using MI is to ascertain that people are using the imagery modality that best facilitates activation of the targeted neural networks. Consequently, a key consideration during MI is the instructions that direct attention to different aspects of the task. Focus of attention instruction will be discussed in the last section. We consider imagery ability next.

1.2.2.3. Imagery ability

Because MI requires the representation of an action within working memory (Decety & Grezes, 1999), the effectiveness of MI can be modified by the ability to form internal representation of motor acts (Dickstein & Deutsch, 2007; Malouin & Richards, 2010). Before using MI, MI ability could be determined in order to obtain optimum benefits from MI practice. MI ability is difficult to assess, however, and there are three main approaches used in clinical settings: mental rotation, mental chronometry and questionnaires. Mental rotation is a sort of inner motor simulation; it is used to measure the accuracy of motor representations (Johnson, 2000; Johnson, Sprehn, & Saykin, 2002). Mental chronometry is the comparison of movement times while performing imagined and physical motor tasks; it is used to determine temporal organization of imagined actions (Decety & Boisson, 1990; Malouin, Richards, Desrosiers, & Doyon, 2004; Sirigu et al., 1995; Sirigu et al., 1996; Stinear, Fleming, Barber, & By-blow, 2007). Finally, questionnaires are commonly used to clarify details of the images and the intensity of the sensations (vividness) perceived during imagined movement.

MI ability is usually evaluated by individual responses to ordinal rating scales. Although there are several assessment tools for determining the ability to engage in MI, two are most commonly used: the Movement Imagery Questionnaire (MIQ) (Hall, Pongrac, & Buckloz, 1985) and the Kinesthetic and Visual Imagery Questionnaire (KVIQ) (Malouin et al., 2007). It has been shown that MIQ is useful for examining the imagery ability of healthy people, while KVIQ was developed for assessing imagery ability (vividness of MI from a first-person perspective) in people with disabilities. KVIQ consists of ten visual and ten kinesthetic imagery items addressing different body parts (e.g., the head, the shoulders, the trunk, and the upper and lower extremities). It has five point scales to rate the clarity of the image (visual subscale) and the intensity of the sensations (kinesthetic subscale) (Malouin et al., 2007). However, KVIQ has not been of much help when used with healthy people (Malouin, Richards, Durand, & Doyon, 2008).

MIQ was developed for use in motor learning and control research (Hall et al., 1985; Goss, Hall, Buckolz, & Fishburne, 1986) and then has been extensively used in sport research (Rodgers, Hall, & Buckolz, 1991; Gregg, Hall, & Nederhof, 2005). It has been shown to have high reliability and validity. MIQ is composed of nine visual and nine kinesthetic imagery items involving the arm, the leg and the whole body movement. Each item requires four steps, including the starting position, movement description, the imagined movement, and rating the ease or difficulty of the imagining movement on a seven-point scale (7= very ease to picture/feel, 1= very difficult to picture/feel). MIQ was revised by Hall and Martin (1997) in order to be feasible to use for a wide range of people, as is the case for the Movement Imagery Questionnaire-Revised (MIQ-R). MIQ-R consists of four visual and four kinesthetic items (see Appendix 2), which are completed in the same manner as MIQ. It has been found that MIQ-R is a useful substitution for MIQ when used in non-athletes.

Because of the subjective nature of self-reported ratings, the validity of MI questionnaires has been questioned. However, several studies have examined the relationship between the imagery ability scale and brain activation patterns (Alkadhi et al., 2005; Cramer, Orr, Cohen, & Lacourse, 2007; Hotz-Boendermaker et al., 2008) or motor cortex excitability (Lotze, Scheler, Tan, Braun, & Birbaumer, 2003; Lotze, Flor, Grodd, Larbig, & Birbaumer, 2001; Fourkas, Bonavolonta, Avenanti, & Aglioti, 2008). These studies have shown a strong relationship between imagery vividness scores and either brain activation patterns or motor cortex excitability during MI, suggesting that imagery questionnaire scores can be good indicators of the ability to generate strong activation of motor areas in the brain. The present study was interested in imagery performance and training in healthy people, so it attempted to determine the ability to generate clear imagery of movements. MIQ-R was used for examining imagery ability as baseline individual information.

1.2.3. Brain areas involved in motor imagery

It is generally known that an action has an overt stage and a covert stage. Every overtly executed action implies the existence of a covert stage while a covert action need not have an overt stage. The covert stage is a representation of the action that consists of the purpose of the action, the information needed to practice it, and the possible outcomes. This stage includes not only self-intending action that will become eventually executed action, but also imagined action and recognizing tools (Jeannerod, 2001). A clear understanding of MI comes from behavioural studies as well as neurophysiological and neuroimaging studies (e.g., measured by Positron Emission Tomography (PET), functional Magnetic Resonance Imaging (fMRI), Transcranial Magnetic Stimulation (TMS)) examining the similarities between overt and covert motor activities.

The process of imagining body movements is so similar to the act of performing them that imagined actions are thought to be simulations of their physical counterparts (Jeannerod, 2006; Jackson et al., 2001). Evidence for this comes from behavioural studies showing that imagined actions adhere to the same temporal regularities that are observed in corresponding physical actions, such as temporal scaling of movement duration to distance (e.g., Papaxanthis, Schiepatti, Gdentili, & Pozzo, 2002; Sirigu et al., 1996), the speed-accuracy tradeoff expressed in Fitts' law (e.g., Decety & Jeannerod, 1996; Stevens, 2004), adherence to biomechanical constraints (e.g., Frak, Paulignan, & Jeannerod, 2001; Johnson, 2000), and the same pattern of simulated effort (e.g., Cerritelli, Maruff, Wilson, & Currie, 2000). Likewise, neurophysiological evidence supports a unitary mechanism for action representation and execution (e.g., Bonnet et al., 1997; Clark et al., 2004), and brain imaging also points to common loci of cortical activation between motor imagery and execution (de Lange, Hagoort, & Toni, 2005; Grèzes & Deecety, 2001; Orr, Lacourse, Cohen, & Cramer, 2008; Miyai et al., 2001; Malouin, Richards, Jackson, Dumas, & Doyon, 2003; Bakker et al., 2008; Iseki, Hanakawa, Shinozaki, Nankaku, & Fukuyama, 2008; Ouchi, Okada, Yoshiwa, Nobezawa, & Futatsubashi, 1999; Wagner et al., 2008; Jahn et al., 2004; Szameitat, Shen, & Sterr, 2007) and similar the excitability of the corticomotor pathway, in term of temporal and spatial characteristics between motor imagery and actual movements (Hashimoto & Rothwell, 2003). These studies suggest that the similarities of cortical network activation between imagined and real movements apply to simple or complex body movements (e.g., locomotor skills and transitional movement). In addition, the literature indicates that corticospinal effects of more complex limb or body MI movement could be predicted from corticospinal effects of a simple MI task involving the same muscle (Bakker et al., 2008).

As a result of the above, it has been suggested that the benefits of MI training should be linked to the activation of neural networks that are comparable to those activated during physical execution. There is some evidence that MI training induces the use of brain organization that represents functional movement (Page, 2001; Decety et al., 1994; Jackson et al., 2001), and also activates the same neuromuscular structures as physical practice (Ito, 1993). Moreover, it has been found that MI training is able to induce changes in brain activation patterns (brain reorganization) (e.g., Lotze & Cohen, 2006; Lotze & Halsband, 2006). Sacco et al. (2006), for instance, reported that people who mentally rehearsed sequences of leg movements showed a decrease in the visuospatial activation in the posterior cortex, suggesting that MI training was able to decrease the role of visual imagery processes in favor of motor-kinesthetic processes. Accordingly, Jackson, Lafleur, Malouin, Richards, and Doyon (2003) illustrated that brain reorganization was found in the medial aspect of the orbitofrontal cortex (increase) and cerebellum (decrease) after intense MI training of a sequence of foot movements for 5 days, supporting that MI training was able to improve motor skills by acting on motor preparation and planning (Pascual-

Leone et al., 1995). In addition, recent brain imaging research has strongly suggested that using MI training can enhance motor learning. In Lafleur et al. (2002), for example, early and late phases of learning of a sequence of foot movements showed a similar pattern of changes in neuronal activity during physical and MI training.

Also, MI may not generate overt movements, but it has been shown to produce specific, patterned, and level-attenuated EMG activity in the involved muscles (e.g., Guillot et al., 2007; Lebon, Rouffet, Collet, & Guillot, 2008). The absence of movement execution during imagery despite the many similarities between imagined and physical movements (and the common patterns of cortical activation, including in the primary motor cortex) is thought to be the result of an inhibition mechanism that acts downstream of the motor cortex, possibly at the brain stem or spinal level (Jeannerod, 2006), and potentially arising in the posterior cerebellum (Lotze et al., 1999), or descending from the premotor cortex in parallel with corticospinal excitation (Prut & Fetz, 1999). EMG activity occurring during MI might originate from an incomplete motor command inhibition (Jeannerod, 1994), leading to tiny muscular contractions (Bonnet et al., 1997). Moreover, the content of the MI has been found to be reflected in the magnitude of EMG activity. That is, internal imagery showed higher muscular excitation than external imagery (Harris & Robinson, 1986; Bakker, Boschker, & Chung, 1996).

1.2.4. Implication of motor imagery

Mental practice (MP) refers to the systematic application of imagery techniques for improving output (Dickstein, Dunsky, & Marcovitz, 2004). Thus, MP is a voluntary training or rehearsal while a person performs a task, whereas motor imagery (MI) practice refers to the mental rehearsal of specific motor imagery content in the absence of overt physical movement for the purpose of improving physical execution (Richardson, 1967; Nilsen, Gillen, & Gordon, 2010; Decety & Grezes, 1999; Malouin et al., 2004; Braun, Beurskens, Borm, Schack, & Wade, 2006; Jackson et al., 2001). The terms of mental practice and motor imagery practice are often used interchangeably (Dickstein & Deutsch, 2007).

Although the general consensus is that MI training is not more beneficial than physical training, it is often found to be superior to no practice at all (Driskell, Cooper, & Moran, 1994; Feltz & Landers, 1983). However, many studies (as mentioned above) have shown that MI training was able to induce brain reorganizations that were responsible for functional improvement, because the same neuromuscular structures that were promoted during physical movement were also facilitated during MI. Based on this, many studies have supported the potential use of MI to produce an effective improvement in motor performance and learning. Moreover, MI training has been suggested to have great benefits in term of being easy to conduct and low in cost and time (Dickstein & Deutsch, 2007; Page et al., 2007), so this may be used in rehabilitation as a new or additional technique combined with other techniques. However, strategies and guidelines for the use of MI to promote relearning of motor activities and improve motor performance are under development; the optimal conditions for this have to be considered.

1.2.4.1. Designing imagery protocols:

Practising action without making noticeable movement, as is the case with MI training, could be used to replicate the pattern and timing of a physical skill. Not only the images of movement must be correct, but the intensity and timing of mental representation used in rehearsal also must match the physical skill in order to lead to improvement in performance (Rushall & Lippman, 1998). Thus, studies on MI practice have to be concerned with MI content, type of instructions, intensity, and duration of training (Schuster et al., 2011). Because of the similarities of neural operation and behavioural features between physical and imagined movements, the same rules and concepts that underline the formulation of physical practice should apply to imagery practice as well.

Studies that have investigated the effect of MI training on motor performance vary widely regarding MI content, intensity and duration, resulting in difficulty in comparing the result of MI training on performance across those studies. For instance, some programmes of MI training in gait rehabilitation consisted of 15 to 20 minute sessions, 3 times a week for 6 weeks without physical intervention, resulting in improvement in gait performance and balance (Dunsky, Dickstein, Marcovitz, Lavy, & Deutsch, 2008). Sacco et al. (2006), for another example, reported that MI training (15 minutes a day for 5 days) with physical practice induced a change in brain activity. Based on a meta-analysis of controlled studies of MI practice, the duration of MI training tended to be shorter than that of physical practice. It is recommended that training for healthy people should be limited to 20 minutes because there is a negative relationship between the effects and increased practice duration (Driskell et al., 1994). For individuals with difficulty in performing a motor task, training duration might be even shorter, with example protocols reporting training times of about15 minutes for patients after stroke (e.g., Dunsky, Dickstein, Ariav, Deutsch, & Marcovitz, 2006; Dunsky et al., 2008). Accordingly, evidence from a systematic literature review has suggested that, for beneficial effects, the mean MI intervention should last 34 days with MI practice on average three times a week for 17 minutes, although there is no consensus on successful design characteristics for MI training (Schuster et al., 2011). One should bear in mind that these protocols were created by individual researchers or clinicians for specific groups of participants under particular study conditions. Determining what forms of MI practice are appropriate for particular purposes and activities is helpful in developing specific guidelines for implementing MI practice.

Because MI focuses on movement, it plays an important role in sport psychology and rehabilitation medicine. In order to facilitate imagery practice, however, some established facts should be considered. Type of instructions is an essential parameter to develop optimized MI programmes. There are two main types of focus instructions, external (mainly visual) and internal (mainly kinesthetic) imagery. During practice, it has been recommended that the instructions of MI exercises should be detailed and oriented towards directing the individual to focus on either external or internal aspects of the task. Both focus instructions have been used in numerous studies. Despite most studies reporting that MI practice was performed from internal perspective with kinesthetic mode (see in Schuster et al., 2011), there is no consensus on standard instructions for focusing attention in MI programmes. For example, Dunsky et al. (2008) used MI training to facilitate movement of the affected lower limb and improve posture by focusing on a specific problem, such as paying attention during training to the time of application of propulsive force or put emphasis on the loading of the affected limb during standing and walking. Other examples include instructions to focus on both visual and kinesthetic components, including looking at the displacement of the limb (e.g., see the top of the feet, see the foot movement, see the knee flex, etc.) and re-creating the sensations associated with the task (e.g., feeling the push-off, feeling the foot movement, feeling the knee flex, and etc). It has been suggested that these focus instructions should be introduced gradually and progress according to the ability and needs of individuals (see Hall, Schmidt, Durand, & Buckolz, 1994; Jackson, Doyon, Richards, & Malouin, 2004; Dickstein et al., 2004).

Although the effectiveness of MI and focus instructions on sit-to-stand movements has tended to not be investigated, Skoura et al. (2005) provided detailed instructions to focus on the imagined stand-sit-stand task. Participants were asked to feel themselves performing the stand-sit-stand (actual and imagined movement) rather than see themselves performing it. Their results showed that participants presented dissimilarities in the duration of the stand-sit-stand task. More work is needed to clarify the potential of attentional instruction to affect STS performance. Comparisons of the benefits of different focus instructions on STS movement and imagery have not been established. This is the main point of the present study. This issue will be discussed again in the last section.

1.2.4.2. Evidence supporting the effect of motor imagery:

The effect of MI practice on motor performance is well established in the healthy population (e.g., Fansler, Poff, & Shepard, 1985; Hamel & Lajoie, 2005; Baston, Feltman, McBride, & Waring**,** 2006; Beauchet et al., 2010), particularly in older people, as a means of developing performance skills. It has also been found to promote motor learning and maintain the performance level of athletes (e.g., Feltz & Landers 1983; Hinshaw, 1991; Driskell et al., 1994; Boschker, Bakker, & Rietberg, 2000; Gould & Bamajian, 1997; Blair, Hall, & Leyshon, 1993; Yue & Cole, 1992). Although, motor imagery was initially utilized to enhance the performance of athletes, to date, motor imagery training has been widely generalized to improving performance in a variety of disciplines, in both sport psychology and rehabilitation.

MI started being used in rehabilitation in the late 1980s and early 1990s. During the last decade, MI practice has been used in a variety of patients in rehabilitation settings, such as in patients with stroke, Parkinson disease, and spinal cord injury (e.g., Page, 2000; Page, Levine, Sisto, & Johnston, 2001 b; Yoo, Park, & Chung, 2002; Dickstein et al., 2004; Dunsky et al., 2006; Dunsky et al., 2008; Jackson et al., 2004; Tamir, Dickstein, & Huberman, 2007; Cramer et al., 2007).

Healthy populations:

MI training has been used to enhance the performance in healthy people and athletes. MI is frequently used to promote the performance of athletes in competition as well as in rehabilitation in order to facilitate an athlete's return to sport (Salmon, Hall, & Haslam, 1994; Brewer & Helledy 1998; Fox, 2004; Annett, 1994; Hardey & Fazey, 1990). The benefits of MI have also been demonstrated, for example, in increasing speed (e.g., Boschker et al., 2000; Gould & Bamajian, 1997; Blair et al., 1993), muscle force (e.g., Yue & Cole, 1992), movement execution (e.g., Yaguez et al., 1998; Blair et al., 1993), electromyographic (EMG) activity in involved muscles (e.g., Boschker et al., 2000; Harris & Robinson, 1986), and improving performance in highly skilled athletes (e.g., Grouios, Mousikou, Hatzinikolaou, Semaglou, & Kabitsis, 1997; see Taktek, 2004).

Numerous studies of healthy people have found that enhancement of performance, such as increased strength of selected muscle groups (e.g., Sidaway & Trzaska, 2005; Zijdewind, Toering, Bessem, Van Der Laan, & Diercks, 2003), improved speed in arm pointing (e.g., Gentili, Papaxanthis, & Pozzo, 2006), increased range of motion (ROM) of the hip joint (e.g., Williams, Odley, & Callaghan, 2004), and improved postural control in older adults (e.g., Fansler et al., 1985; Hamel & Lajoie, 2005), as a result of MI training. On the other hand, Batson et al. (2006) found that balance in older adults did not improve after MI training combined with physical practice, and a net trend towards a decrease in balance confidence was observed. The finding suggested that decline in balance might imply increased body awareness and real-life awareness of functional deficits. Moreover, interpretation of the effects of MI training on balance should be considered, because many factors may have affected performance, such as personal factors (e.g., mood, motivation, personal distractions, sickness and level of hunger or fatigue) and environmental factors (e.g., noise and weather). Furthermore, it is believed that age-related differences affect the performance of MI. This is in agreement with the finding of Jarus and Ratzons (2000). Their study showed that an arm coordination task in older adults was slower than young adults after MI training, whereas older adults and children in the mental-physical group made fewer errors than their physical group counterparts. This suggested that children and older adults benefited more from the combination of MI and physical practice than did young adults. It supported the suggestion that MI performance was still intact in old age, despite age-related changes. However, the full potential of MI in young and older adults has not yet been sufficiently investigated, as there have been a relatively small number of MI investigations in these age groups, and the diversity of protocols in the available studies makes it difficult to draw conclusions. An overview of studies that have used motor imagery training to improve performance in healthy people is provided in Table 1-1 in Appendix 1.

MI is typically used in practice to improve motor skill performance in healthy people and athletes, so only few studies have focused on MI as a way of studying higher-level, top-down control of complex body movements (e.g., gait, balance and transitional movement). Mental chronometry is a technique used to measure the time course of higher-level control of action. Studies using this technique have usually focused on hand and arm movements, showing, for example, that approximately the same amount of time is used to write and imagine writing a short sentence, or that both physical and imagined movements conform to Fitts'law (Decety & Michel, 1989; Parsons, 1987, 1994; Maruff et al., 1999; Skoura et al., 2005; Choudhury, Charaman, Bird, & Blakemore, 2007). The characteristics of imagery of complex body movements are not entirely clear, although there is some evidence that both physical and imagined walking conform to Fitt's law (e.g., Decety, 1991; Decety & Jeannerod, 1995; Stevens, 2005). Recently, it has been found that there is a close temporal correspondence between physical and imagined gait in healthy young adults (Bakker et al., 2007; Courtine, Papaxanthis, Gentili, & Pozzo, 2004). Similarly, Skoura et al. (2005) reported that the duration of overt and covert walking was similar in healthy young and older adults. Although these finding confirmed that internally simulated movement can be isochronous to overt movement of different body segments including the arm, the hand or the whole body, this does not guarantee that physically performed and imagined movements are identical in the two age groups, or that the same temporal structure or the same motor rules operate for other complex body movements (e.g., transitional movements) in both age groups. For instance, Beauchet et al. (2010) stated that older adults' Time Up and Go (TUG) performance was slower than young adults, and imagined TUG performance was faster than actual TUG performance. This finding supported that MI performance was also still intact in old age and imagined TUG could be clinically feasible in older adults. An overview of studies that have used motor imagery as a means of investigating higher-level control of complex body movements in healthy people is given in Table 1-2 in Appendix 1.

Patients:

As MI can be a clinically feasible, cost-effective complement to therapy, it has emerged as a promising technique to improve motor skills in rehabilitation. In recent years, MI training has been applied to a variety of patients, mainly with neuromuscular conditions (e.g., stroke, spinal cord injury, and Parkinson disease) in order to retrain motor function, decrease negative outcomes of restricted mobility, improve motor recovery and enhance the performance (e.g., Crosbie et al., 2004; see Braun et al., 2006; see Sharma, Pomeroy, & Baron 2006; Dickstein & Deutsch, 2007). Although most studies in MI have focused on training the upper extremities in people with disability (e.g., Page, 2000; Page et al., 2001 b; Yoo et al., 2001; Page et al., 2007; Steenbergen, Craje, Nilsson, & Gordon, 2009), evidence supporting the potential of MI for retraining gait and other tasks involving coordination of the lower extremities is now emerging (e.g., Dickstein et al., 2004; Dunsky et al., 2006; Dunsky et al., 2008; Jackson et al., 2004; Tamir et al., 2007). These studies suggest that MI is effective for retraining the upper and lower extremities in people with disability. An overview of studies that have used motor imagery training to improve the performance of upper and lower extremities is given in Table 1-3 and 1-4 in Appendix 1.

The effectiveness of MI in retraining upper extremities:

Evidence from neurophysiological studies suggests that imagining making hand movements can lead to activation of several brain areas in which greater activity was observed after the recovery of hand function (Decety et al., 1994; Jackson et al., 2001). This suggests that imagining hand movements was able to facilitate the redistribution of brain activity that accompanies recovery of hand function. It is unclear whether the potential of MI training is specific to the trained task or a more general motor skills improvement. On one hand, some studies showed a non-specific effect of MI–imaging moving one digit also activated another digit as well (Fadiga et al., 1999; Stinear, Fleming, & Byblow, 2006). On the other hand, other studies have shown a one-to-one relationship between imagined and performed movements (Rossini, Rossi, Pasqualetti, & Tecchio, 1999; Li, 2007). Craje, van def Graaf, Lem, Geurts, and Steenbergen (2010) investigated whether MI training affects the trained hand exclusively or both hand. The results showed that hand function improved after MI training in the trained hand only. The study also found specific effects of MI training for simple tasks (e.g., reaching and grasping), but not for complex tasks (e.g., fine dexterity). This suggests that MI specificity is dependent on the complexity of the hand function task measured. However, it can be confirmed from the literature that the beneficial effects of MI training are not only found after training of relatively simple movements, namely the finger sequence movements (Mueller et al., 2007), wrist movements (Stevens & Phillips Stoykov, 2003), grasping a cup (Crosbie et al., 2004), reaching to grasp (Guttman, Burstin, Brown, Bril, & Dickstein, 2012), improve line tracing (Yoo et al., 2001), or motor training tasks and pegboard (Dijkerman et al., 2004), but also after training of complex tasks of daily life, such as household tasks (e.g., putting clothes on a hanger) or community tasks (e.g., using the telephone) (Liu et al., 2004).

MI training has not only been proven to be beneficial by itself, but has also been proven to be helpful as an addition to physical training. Many studies have shown the added value of MI training mixed with physical training for improvement in upper extremity functions during rehabilitation. More evidence of this comes from Page and colleagues' studies. Their initial pilot study showed improvements in upper limb function after combined physiotherapy and MI training in stroke patients (Page, 2000). A further study with a large sample showed that patients who practiced arm movements via occupational therapy combined with MI improved more than those who had occupational therapy alone (Page et al., 2001 a). Likewise, combined programmes of physiotherapy and MI were able to decrease impairment and increase arm function (Page et al., 2001 b; Page, Levine, & Leonard, 2005; Page, Levine, & Hall, 2007; Page et al., 2007). In addition, positive effects of MI training combined with physical practice has also been found in other studies, including improvement in manual motor tasks (Dijkerman et al., 2004; Butler & Page, 2006; Gaggioli, Meneghini, Morganti, Alcaniz, & Riva, 2006; Simmons, Sharma, Baron, & Pomeroy, 2008), and in reaching and range of motion (ROM) of the elbow and the shoulder (Hewett, Ford, Levine, & Page, 2007). Although using MI in conjunction with physical practice is a potentially valuable technique for enhancing performance, MI training can independently improve motor performance and produce similar cortical plastic change, providing a useful alternative when physical training is not possible.

The effectiveness of MI in retraining lower extremities:

MI practice can benefit locomotion, coordination of the lower extremities, and body movement tasks through safe and self-training in disabled people. Although a few studies have investigated the effects of MI on motor tasks of the lower extremities, the potential use of MI practice for optimizing the relearning of such activities has been gradually revealed in exploratory studies and case reports with small sample sizes. For instance, Dickstein et al. (2004) have developed a programme for MI training in people with stroke. These authors investigated the effects of MI training on locomotor skills in a case report, and found that gait performance was improved by MI training programme. Later, in 2006, they used this programme extensively at home in 4 case studies, and found improvements in locomotor performance. The benefit of MI training on gait performance in people who have had stroke was confirmed and extended by Dunsky et al. (2008). They reported that home-based MI training induced an increase in gait performance, such as walking speed, stride length, cadence, single-support time of the affected limb, and reduced double-support time. Another study examined the effects of MI training on lower extremity function in hemiplegic patients by looking at the effect of MI training on the foot movement sequence task (Jackson et al., 2004). It found that the combination of MI and physical training improved response time rather than physical practice alone. However, it was also found that MI training alone helped the retention of performance. Thus, MI training can play an important role in the retention of newly acquired abilities.

Besides using MI training in patients with stroke, MI training has been extended to patients with other neurological conditions, including Parkinson disease (PD) and spinal cord injury (SCI). Recently, for example, it was reported that bradykinesia in patients with PD could be decreased by practicing MI combined with physical intervention over a 12 week period, leading to faster performance during the TUG task, and improved ADL and movement sequence performance (Tamir et al., 2007). For patients with SCI, MI training has not been reported to directly affect motor performance. Cramer et al. (2007), for instance, examined the effects of imagined movements of the tongue and the foot in patients with SCI compared with healthy people. They found improvements in behavioural outcome (e.g., maximum rate of tapping) of nonparalyzed muscles, and also found activation of cortical networks in congruence with imagery of specific movements. This finding suggests that the brain’s motor functions could be modulated independently of voluntary motor control and peripheral feedback, and MI training might have a value for post-SCI deficits.

Beneficial effects of MI training are not only found in studies involving locomotor skills, but also in coordinating the lower limbs or in transitional movements. However, only a few studies have considered the effects of MI on motor tasks of the lower extremities related to transitional functions (e.g., sit-to-stand and stand-to-sit movement). To date, six studies have investigated the potential use of MI training. Malouin, Richards, Doyon, Desrosiers, and Belleville (2004) examined the effect of MI practice combined with a small amount of physical practice on the amount of loading on the affected leg during STS movements. The findings showed that the loading on the affected side during rising from a chair and sitting down improved after a training session and the improvements were retained 24 hours and 3 weeks later, indicating that some learning had occurred. Moreover, their pilot study found that a small amount of physical practice alone did not produce gains in the loading of the affected limb during either rising from a chair or sitting down (Malouin, Richards, Durand, & Doyon, 2009). Oh et al. (2010) examined the effect of MI training on the symmetrical use of the knee extensors during rising from a chair and sitting down in post-stroke hemeparesis. The results showed that EMG activation ratio increased and onset time for the knee extensors decreased during either sit-to-stand or stand-to-sit movements, suggesting that MI training had a positive effect on the symmetrical use of the knee extensors during transitional movements. In another example, Guttman et al. (2012) explored the effects of motor imagery practice on STS performance in post-stroke hemeparesis. They reported that STS duration decreased after imagining the STS training, whereas weight distribution between the legs was not affected by the intervention. These results supported the potential use of MI training in improving STS performance, and suggested that MI training was beneficial either by itself or in addition to physical training.

Surprisingly, although MI training can benefit transitional (e.g., STS) skills, only one study, to best of our knowledge, has explored MI as a way of accessing the higher-level of control of STS movements in healthy adults (Skoura et al., 2005). This study demonstrated that the ability to generate MI did not differ between young and older participants. They also found that participants presented dissimilarities in the duration of the stand-sit-stand task, between MI and actual durations, because both young and older adults actually execute the sit-to-stand phase faster than the stand-to-sit phase. Consequently, the duration was underestimated while imagining the whole movement. However, this finding suggested that normal aging did not affect the ability to internally simulate motor actions. Further studies are needed to clarify the ability of MI to be a way of accessing the higher-level of control of STS movements. A summary of studies using motor imagery training to improve STS performance is in Table 1-5 in Appendix 1.

Despite the fact that STS movements are one of the essential movements of daily activity in healthy people, and the importance of the need to improve performance in disabled patients, MI as an approach to learning motor skills related to coordinated lower limb and body movements (e.g., the STS) has received relatively less attention. Although the positive effects on transitional movements have been described in previous clinical studies, the role of MI training in the extent of gain reported is difficult to determine because of small sample sizes, and the lack of uniform control over the amount of MI and physical training. The large variability in training protocols is a limitation in determining the real potential of MI training. Importantly, attentional focus on various aspects of the process is not generally controlled and examined. Therefore, there is need of further investigations.

In summary, although MI plays an important role in improving motor performance and a number of studies have shown the benefits of MI training in healthy or in-patients populations, generalizations are difficult to make, because of different study designs with respect to participant characteristics, intervention protocols and outcome measures. Interventions used varied among studies in terms of how MI was facilitated (e.g., audiotape, written instruction, picture), the imagery perspective used (e.g., internal vs. external), the tasks practiced, and the duration and intensity of the session. Moreover, most studies are case studies or exploratory studies. Randomized control trials with large sample sizes are still needed to confirm and generalize the positive findings. The optimum protocol and the specificity and sensitivity of outcome measures need to be established. Furthermore, interpretations of the benefits of MI training should exercise caution because a change in performance could be due to more physical movement during the training period, personal factors and other environmental factors. Controlling for these factors during MI training is essential to validating the contributions of MI training.

Another important question in the design of MI protocols is the focus of attention that is induced by task instructions. It is important to provide imagery instructions with proper details to ensure that participants imagine the task in the correct manner. It would be of interest to clarify the impact of attentional focus instructions on the imagery of STS performance. Moreover, it is important to determine the factors that influence how the STS movement is performed during MI under different attentional foci. The next section reviews what is known about the effects of attentional focus on movement planning and execution.

1.3. Attention to movement

Several variables that affect the performance and learning of motor skills have been considered in the motor learning literature, such as the frequency and volume of practice given to the performer (e.g., Salmoni, Schmidt, & Walter, 1984; Schmidt, 1991; Schuster et al., 2011), the organization of practice (e.g., Magil & Hall, 1990; Shapiro & Schmidt, 1982), the provision of physical guidance (e.g., Winstein, Pohl, & Lewthwaite, 1994) and body-internal versus body-external attentional focus (e.g., Wulf, 2007).

1.3.1. Definition of Attention

Attention has been a general issue of interest in psychology and motor behaviour research. There are two important features of attention. One is a limited capacity for processing information to handle information from the environment. Another feature of attention is its selectivity. Attention can be also classified into separate functions, such as selective, sustained, divided and alternating. Selective attention enables filtering of stimulus information and suppression of distracters, and is commonly referred to as concentration. Sustained attention refers to the ability to maintain attention to one task over a period of time. Divided attention refers to the ability to carry out more than one task at the same time. Alternating attention refers to rapid shifting of attention from one task to another (James, 1890; Lezak, 1995; Rogers, 2006).

1.3.2. Focus of attention and motor performance

To focus attention is to prioritize processing of specific information during the production of action (Schmidt & Wrisberg, 2000; Perkins-Ceccato, Passmore, & Lee, 2003). It is recognized as a potentially influential factor in determining performance. Generally, not only motor performance, but also the learning process appears to be affected by what is focused while practicing a skill. Attentional focus during task performance can be induced by instructions, and can be broadly on body-external or body-internal processes. (Wulf, 2007). Instructions for complex motor tasks may refer to the coordination of body movements, such as the order, form and timing of required limb motions (Wulf, 2007). Such instructions can induce a body-internal focus of attention. However, recent evidence suggests that instructions directing attention to body movements might not be effective in guiding skilled actions, because they are more likely to encourage a conscious effort to remember or control the pattern of movement, which obstructs automaticity of motor planning and execution (Wulf, 2007). Many studies (e.g., Gallwey, 1982; Garfield & Bennett, 1985; Singer, 1985, 1988; Singer & Suwanthada, 1986) have observed that best motor performance occurs when performers are not thinking about their action, but performing the skill more automatically. Focusing attention on body-external aspects of the coordination, such as its perceptual consequences, leads to better performance. One explanation for the benefits of body-external attentional focus is the constrained action hypothesis (Wulf & Prinz, 2001; Shea, Wulf, Whitacre, & Park, 2001; Zachry, Wulf, Mercer, & Bezodis, 2005). This suggests that focusing attention on the body itself promotes conscious control, which constrains the motor system by interfering with automatic regulation of coordination. In contrast, a body-external focus of attention promotes a more automatic mode of motor control and allows actions to naturally self-organise (i.e., use unconscious, fast and reflexive processes to control movement). This view has been supported by observations of differences in movement accuracy (e.g., Zachry et al., 2005), attentional load (e.g., Wulf et al., 2001), movement frequency characteristics (e.g., McNevin & Wulf, 2002), and EMG activity (e.g., Vance, Wulf, Töllner, McNevin, & Mercer, 2004; Zachry et al., 2005), suggesting more accurate, automatized and energy-efficient action under external attentional focus. Moreover, many studies have shown that the advantages of body-external focus increase as the distance of the external effect from the body increases (Wulf, Hoess, & Prinz, 1998; Wulf, Lauterbach, & Toole, 1999; Maddox, Wulf, & Wright, 1999; Park, Shea, McNevin, & Wulf, 2000; McNevin et al., 2003; McKay & Wulf, 2012; Malek, Mohammad, Mehrab, & Hossein, 2012).

1.3.3. Internal versus external attentional focus during performance and learning

Several studies over the past ten years have illustrated that focus of attention has an essential influence on either the performance or learning of a variety of motor skills (see Table 1-6 in Appendix 1). Traditionally, body-related focus instructions were commonly used in the practice of motor skills, particularly in rehabilitation (e.g., physiotherapy). People learning a motor skill would receive instructions related to their own body movement, or correction of their movement pattern during performance. Canning (2005), for example, investigated the effect of directing attention to gait performance while carrying a tray of glasses in people with Parkinson disease (PD). The study found that participants walked faster and longer strides when focusing on walking (internal focus) compared with focusing on the tray and glasses (external focus) and control condition. However, the instructions in this study were ambiguous because maintaining big steps while walking or balancing the tray and glasses could be executed under either external (e.g., focus on distance covered / stride targets on the floor or tray surface / objects on the tray) or internal attentional focus (e.g., on the coordination of body segments while walking or on the hand while holding the tray). Another example is a study by Perkins-Ceccato et al. (2003) that found a benefit of internal focus (on the form of the golf swing and on adjusting the force of the swing depending on distance of the shot) in novices, as compared to external focus instruction (focus on hitting the ball as close to the target as possible). However, the instructions referred to different aspects of the task, and there were no references to the body in internal focus instructions.

In contrast to the findings above, there is considerable evidence showing that performance can be disrupted when paying attention on one's own movement. For example, Singer, Lidor, and Cauraugh (1993) found that performance after practice in a new skill of a ball-throwing was more effective when the learner performed the task without consciously attending to the body's movement pattern. This agrees with the results of Wulf and Weigelt (1997, Experiment 1). Performers were instructed to try to exert force on a platform. The results showed that performance under those instructions reduced during practice and in a transfer test compared to control group (no such instructions). These findings concerned the learning of new skills, but there is also evidence of detrimental effects of directing attention to body movements in well-learned motor skills. Baumeister and Steinhilber (1984), for example, demonstrated that the execution of overlearned skills could be disrupted if conscious attention to the performer's body movement was increased. The detrimental effect of self-attention on one's own performance of well-learned skills was also supported by

Wulf & Weigelt (1997, Experiment 2). They reported that performance after extended practice on a ski-simulator task significantly decreased when performers paid conscious attention to their own body movement. Thus, appears that directing attention to internal body movement not only disrupt the execution of automatic skills but can also degrade the effect of learning.

If internal, body-related instructions negatively affect the performance and learning, how can task instructions direct attention so as to not disrupt efficient motor planning and execution? The literature suggests that focus instructions related to the effects of movement on the environment (external focus), would be more effective for the performance and learning. For a variety of complex motor skills, such as in golf (Wulf et al., 1999; Wulf & Su, 2007; Bell & Hardy, 2009; Perkins-Ceccato et al., 2003), tennis (Maddox et al., 1999), throwing (Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002; Zachry et al., 2005; Lowen, 2010), dart throwing (Marchant, Clough, & Crawshaw, 2007; Lohse, Sherwood, & Healy, 2010; McKay & Wulf, 2012), badminton (Malek et al., 2012), or valleyball and football (Wulf, McConnel, Gartner, & Schwarz, 2002; Zachry, 2005), body-external attentional focus results in better performance and learning. For instance, Wulf et al. (1999) examined the advantage of external focus on the learning of a sport skill under field-like conditions. One group was asked to focus on the swing of their arms (internal focus), while another group was provided external focus instructions–focusing on the pendulum-like motion of the club. The results showed that external focus enhanced the accuracy of the shot in both practice and retention. Maddox et al. (1999) also found a benefit of external focus instruction for the learning of a tennis skill (backhand stroke cross-court). Learners were asked to focus on the trajectory of the ball and its landing point (external focus) as opposed to focusing on the back swing and the racket-ball contact point (internal focus). Their results supported that external focus produced greater accuracy than internal focus. Zachry et al. (2005) asked participants to perform free throws while focusing either on wrist motion (internal focus) or the rim of the basket (external focus). The findings showed that accuracy was markedly higher when focusing externally rather than internally. These studies demonstrated the generalizability of the advantages of attention to the effects of movement, rather than to the movement itself, in the acquisition and retention of motor skills.

Besides studies in complex motor skills, the advantages of adopting external focus of attention have also been found for the performance and learning of balance skills (Wulf et al., 1998; Wulf, Shea, & Park, 2001; Wulf et al., 2001; McNevin & Wulf, 2002; McNevin et al., 2003; Wulf, Weigelt, Poulter, & McNevin, 2003; Wulf, Mercer, McNevin, & Guadagnoli, 2004; Shea & Wulf, 1999; Wulf, Tollner, & Shea, 2007; Jackson & Holmes, 2011). For instance, Wulf et al. (1998) examined the effects of different types of focus instructions on slalom-type movements on a ski-simulator. Participants practiced the task on two consecutive days and then performed a retention test on Day 3. The results showed that external focus instruction (focus on the wheels of the platform located directly under the feet) was more effective than either internal focus (focus on the feet) or no focus instructions. Moreover, the authors replicated the differential effects of external versus internal focus with a different task (balancing on a moving platform). The results were consistent with the previous study in external focus instruction (directing attention to two markers attached to the balance platform in front of the feet) was more beneficial for learning that internal focus instruction (directing attention to the feet). This result was supported by Wulf et al. (2001), who explored the effects of individual differences in attentional preference. Learners were given the option of either external or internal focus of attention, and asked to find out which type of attentional focus improved performance. Participants chose external focus more than internal focus, reporting that focus on markers attached to the board in front of the feet (external focus) showed superior balance performance. Accordingly, Wulf et al. (2001) found short probe reaction time (RT) for performing a balance task with external focus (on markers on the platform) as compared to internal focus (on the feet). Moreover, McNevin et al. (2003) showed consistently higher mean power frequency values with external focus (on markers) as compared to internal focus (the feet). The automaticity resulting from external focus also seems to make performance more resistant to skill failure under pressure (Ong, Bowcock, & Hodges, 2010). These studies provide consistent evidences that external focus of attention to the effects of movement improves effectiveness of motor performance and learning and the benefits appear to be general in nature.

The focus of attention not only influences movement effectiveness, such as accuracy and balance, but also movement efficiency, as measured by muscle activity (EMG), maximum force production, or movement speed (Wulf, 2013). Several studies have begun to clarify how the nervous system operates when performing under different attentional focus conditions (external vs. internal). Vance et al. (2004), Marchant, Greig, Scott, and Clough (2006), Marchant, Greig, and Scott (2008) examined the effects of attentional focus on muscle activity during a biceps curl task. Their results illustrated that EMG activity was lower in external focus of attention (on the movement of the curl bar) than internal focus (on the arms) condition, although the movement outcome was identical under both conditions. This indicated that external focus of attention was more efficient. Moreover, the results also showed that EMG activity in external focus condition was not only decreased in the biceps muscles, but also in the triceps muscles compared to internal focus and control conditions, suggesting that movement efficiency was increased not only through a more effective recruitment of the agonist muscles, but also through the antagonist muscles. Similar spreading effects were seen in other studies as well (Zachry et al., 2005; Wulf, Dufek, Lozano, & Pettigrew, 2010). Interestingly, a possible association between muscular activity and movement accuracy was demonstrated by a few studies. Zachry et al. (2005) reported that EMG activity in both the biceps and triceps brachii were reduced under external focus (on basket) compared to internal focus (on wrist motion). That is, external focus of attention not only increased movement efficiency (reduced in muscle activity), but also reduced noise in the motor system.

Importantly, reduced muscular activity is associated not only with greater accuracy, but also with the production of greater maximal force. Maximum force production requires optimal muscle fiber recruitment as well as optimal activation of the agonist and antagonist muscles. Evidence supporting the production of maximum force with external focus was found in different muscle activities, such as bicep curls (Marchant, Greig, & Scott, 2009), jumping (Wulf, Zachry, Granados, & Dufek, 2007; Wulf et al., 2010; Wulf & Dufek, 2009; Wulf et al., 2010), standing long-jump (Porter, Ostrowski, Nolan, & Wu, 2010; Wu, Porter, & Brown, 2012), or discus-throwing (Zarghami, Saemi, & Fathi, 2012). In a study by Marchant et al. (2009), for instance, the influence of force production and muscle activity during isokinetic elbow flexions was investigated. The findings suggest that peak joint torque increased and EMG activity decreased when focusing on the crank bar while performing the bicep curls, as compared to internal focus on the arm muscles. In line with these findings, a series of studies by Wulf (e.g., Wulf & Dufek, 2009; Wulf et al., 2010) found that greater jump height was achieved through greater force production when external focus was adopted relative to lower EMG activity in various the leg muscles. These results confirm the benefits of external focus of attention for enhancing maximum force production.

Due to the increased movement efficiency and automaticity associated with external focus, movement speed has been found to be improved as well. How changing attentional focus is able to improve movement speed comes from studies of movement time while performing reaching tasks (e.g., Fasoli, Trombly, Tickle-Degnen, & Verfaellie, 2002), longer-duration tasks (e.g., Porter, Nolan, Ostrowski, & Wulf, 2010), dribbling (Jackson, Ashford, & Norsworthy, 2006), or swimming (e.g., Freudenheim, Wulf, Madureira, U.C. Correa, & S. C. P. Correa, 2010; Stoate & Wulf, 2011). For example, Porter et al. (2010) determined the effect of directing attention externally on an agility performance. The results showed a decrease in the time taken to complete an agility task with focusing externally. Also, in a study by Freudenheim et al. (2010), shorter swimming time was recorded when participants were asked to focus externally on pushing the water back relative to internal focus.

Although, the differential effects of external versus internal focus of attention have been studied more extensively in young adults, these have also been found in skill learning by healthy older adults (Chiviacowski, Wulf, & Wally, 2010) and patient populations (Laufer, Rotem-Lehrer, Ronen, Khayutin, & Rozenberg, 2007; Rotem-Lehrer & Laufer, 2007; Porter & Anton, 2011; Chiviacowsky, Wulf, & Avila, 2012; Landers, Wulf, Wallmann, & Guadagnoli, 2005; Wulf, Landers, Lewthwaite & Tolner, 2009). For example, Landers et al. (2005), examined the effect of focus instructions on postural stability in patients with PD. They found that postural stability was improved when patients were given external focus instructions (focus on rectangles under the feet) as opposed to either internal (focus on the feet) or no focus instructions on a more challenging task with a swaying support surface. This study was replicated by Wulf et al. (2009). They explored the generalizability of the attentional focus effect to postural stability in older adults with PD. The results showed that external focus of attention increased postural stability more than either internal focus or control conditions. There was also no difference between internal and no focus of attention. Moreover, Fasoli et al. (2002) clarified the impact of attentional focus on reaching performance in stroke patients. The results showed better performance (shorter movement times and greater peak velocities) if given external rather than internal focus instructions. These converging lines of evidence supported the notion that external focus helped patients who had a disability to preplan the movement and use more automatic control processes. Consequently, these finding could have potentially important implications for focus instructions given in rehabilitation.

In summary, the benefits of external focus of attention during the performance and learning appear to be clear and consistent, and therefore generalizable across motor activities, populations, and measure outcomes reflecting movement effectiveness (e.g., accuracy and balance) and movement efficiency (e.g., EMG, force production and speed). Even though the attentional focus effect is now well established; and has implications for several practice settings (e.g., sport, physiotherapy and occupational therapy), some questions remain. How should the use of focus of attention be translated into practice and rehabilitation setting, when the typical focus-instructions used in clinical or rehabilitation settings are related to the patient’s body movements? A few studies have investigated the effects of focus of attention on the coordination of whole-body tasks, but most of them have emphasized locomotor movements. Hardly any studies have examined the effects of changing attentional focus on transitional activities (e.g., the sit-to-stand movement). It is a valuable to determine whether a similar pattern of results would be found for tasks that require whole body movements. More importantly, there are a variety of disparate techniques that share a goal of improving performance, such as relaxation, self-efficacy statements, attentional focus and imagery. A performance improvement may derive not only from focus of attention, but also from other factors. It is an interesting question, therefore, whether attentional focus instructions have broader implications for other motor-cognitive phenomena, for example studies involving motor imagery?

1.3.4. Attentional focus and motor imagery

Typically, human movement requires little conscious effort even when changing pattern. An individual does not think about the exact motions of body parts but instead focuses on other important things. The automatic control of movements is critical to daily activities and an implicit process in which movements become more effective and efficient (Schmidt & Wrisberg, 2000; Malone & Bastian, 2010), because the automatic processing is not attention demanding and parallel in nature, with various operations occurring together, as opposed to the controlled processing (Schmidt & Lee, 1999). A movement is performed automatically until faced with a novel situation or injury, where thinking about the movement will be required. Specifically, during rehabilitation, thinking about the movement pattern is emphasized, following the idea that encouraging the conscious control of movements will assist in learning automatic tasks, and improve movement effectiveness and efficiency.

When does a movement require attention, what parts of the movement are involved, and what type of attention should be applied? Previous work showed that attention to movements could be beneficial in the early stages of learning a novel motor skill by making learners aware of the movement (Todorov, Shadmehr, & Bizzi, 1997; Wulf & Prinz, 2001). After continued practice, the action becomes automatic, and little or no attention and effort is required to control the action. Beyond this point, thinking about the movement interferes with performance. Most recent evidence from newer approaches suggests that the relative effectiveness of non-awareness of the movement for enhancing the performance and learning has been seen in both novice and expert performers (e.g., Singer et al., 1993; Singer, Lidor, & Cauraugh, 1994; Wulf, 2007). More importantly, it appears to consistently show that directing attention to the effects of movements on the environment is more beneficial than directing attention to movements. The benefits of external focus have been found across a range of motor tasks (e.g., complex motor skills, balance, locomotor) and populations (e.g., children, young adults, elder, patients). However, some everyday whole-body coordinations, such as STS movements, have not been explored in this respect.

On the other hand, thinking about a movement during motor imagery (MI) represents conscious access to the contents of the intention of the movement, which is usually performed unconsciously during movement preparation. Conscious MI and unconscious motor preparation (noted at the cortical level and at the neuromuscular level of facilitation or inhibition of spinal reflexes) appear to share common mechanisms and are functionally equivalent (Jeannerod, 1994, 1995; Jackson et al., 2001; Annett, 1995). That is, such a process may well be of value in motor performance and learning improvements. This begs the question of how to drive MI in terms of focus of attention. Prior evidence suggests that internally driven images that promote movement awareness would be preferable (Jackson et al., 2001). Movement awareness is associated with knowledge of the physical response and defines the kinematics and kinetics involved. Evidence from behavioural and neuroimaging studies supports an advantage for kinesthetic (imaging of one's own movement: internal imegery) imagery for enhancement in motor performance and learning rather than external imagery (associated with spatial coordination of a movement in the environment; mainly visual).

In the two lines of research compared above, the performance and learning have been enhanced by directing attention to the effects of movements on the environment (external focus), whereas MI research has shown positive effects of imaging one's own movement (internal imagery) on motor performance and learning (see Table 1-1).The beneficial effects of attentional focus on the performance and learning have been observed largely in the context of performing physical motor tasks. The effects of attentional focus on MI are less clear.

Table 1-1: Demonstrates similarity and dissimilarity aspects between attentional focus and motor imagery.

Similarity	
Attentional focus	Motor imagery
-Internal focus: pay directing attention to the one own movement	-Internal imagery: imagine one' own movement from the inside
-External focus: pay attention to the effect of movement on the environment	-External imagery: imagine movement associated with spatial coordination of a movement in the environment
Dissimilarity	
Attentional focus	Motor imagery
Internal focus appears to be less effective to enhance the performance and learning than external focus	Internal imagery seems to be more effective to improve the performance and learning than external imagery, although, to date, there is no consensus on standard instruction focus

In conclusion, the beneficial effects of external relative to internal focus to attention in wide variety of motor skills among young and older adults as well as patients with physical disability may have implications for the use of motor imagery in learning or rehabilitation. Further research is required in this area. It would be interesting to examine how differential effects of attentional focus interact with motor imagery. There are still some questions about the benefits of motor imagery under different attentional foci. How do different foci of attention affect motor imagery? Does changing focus of attention during imagery have the potential to improve either motor performance or learning? Are there age-related differences in the effects of attention focus during imagery? The effects of attentional focus on the performance and imagery of STS movements have not been studied, although there are a few pieces of research on MI of STS movements. How can attentional focus be used to enhance STS performance or imagery?

1.4. The Present Work

Sit-to-stand movement (STS) is a familiar activity that is frequently performed in daily life. The ability to perform STS movements is fundamental to normal activities of daily living and also a prerequisite of locomotion (walking) activity. Moreover, an unassisted STS movement is an essential skill that determines the functional level of a person, especially in older people who have had general deterioration in the ability to perform effortful movements. STS movements are a good indicator of mobility and frailty in older adults, and therefore often targeted in rehabilitation programmes.

The majority of studies in STS movements have focused on four major applications, including chair design, analysis of normal and abnormal STS movements, biomechanical modelling and intervention method. To our knowledge, only a few studies have investigated the potential of motor imagery (MI) during STS tasks, either as a way of accessing higher-level planning of complex body movements or to develop intervention procedures for enhancing performance and learning. In fact, MI is practical to provide and low in cost and time, so this technique should be valuable to use in rehabilitation as an alternative or additional technique combined with other techniques, such as physical practice. There is evidence suggesting that kinesthetic (internal) imagery (focusing on one's own movement) is more effective in activating motor pathways than imagery focused on body-external aspects (such as spatial coordination of movement in the environment). However, how these results relate to the case of STS movements is not known. The effects of directing attention to body-internal or body-external aspects of movement coordination on imagery or execution need to be examined.

Focus of attention is a common variable used in either motor learning research or rehabilitation in order to improve motor performance and learning. Based on work in exercise science, two types of attentional focus are of particular interest – external focus (directed to the effects of movement in the environment) and internal focus (directed to the articulation of the movement itself). In studies of motor performance, it has been found that directing attention to the effects of movements on the environment (external focus of attention) results in greater fluency than directing attention to the movements (internal focus of attention).

MI approaches have been used in clinical or rehabilitation settings with the intention of improving effectiveness and efficiency of training, but the effects of attentional focus have been studied mostly in the context of executing motor skills. It is of interest whether focusing attention on movement articulation (body-internal focus) or away from the body and to the perceptual effects of movements in the environment (body-external focus) during MI and motor execution differ systematically in the context of STS movements, and whether any such differences are sensitive to the process of ageing.

To clarify the impact of attentional focus on motor imagery and performance, this study directly compared the effects of external versus internal focus on physical and imagined instances of STS movements. Knee extensor function and weight bearing on the feet are known to be essential factors in determining performance in STS tasks. Thus, we asked participants to focus their attention on the load on their thighs, or the pressure under their feet, as variants of body-internal focus during imagined and physical STS movements. In the case of body-external focus, we asked participants to fixate a visual target on the wall (at eye-level when standing), and focus on the change in viewpoint relative to the target. We measured how these conditions affected the self-reported movement times and the ground reaction forces during imagined STS movements. We also measured the self-reported and actual movement times of physical STS movements, and the smoothness or stability of the physical movements under these internal and external focus conditions.

Older people are known to accrue deficits in motor planning, control and execution that increase reliance on visual information to guide movements as proprioceptive control deteriorates with decreasing muscular strength. This suggests that young and older participants may respond differently to changes in attentional focus from body-internal (proprioceptive) to body-external (visual) aspects of coordination. However, the direction of any such difference is unclear. Older people may benefit from external (visual) focus, or from focusing on proprioceptive information (if deliberately directing attention counteracts the deficits they have in utilizing this type of information).

This study also examined two further aspects of STS performance that have practical importance and also theoretical significance. The first aspect concerned the height of the seat from which STS movements are made. A variety of seat heights can be found in various settings, such as in houses, offices and even in hospitals, and changing this parameter is known to alter the biomechanical demands of STS movements and also the strategies employed in executing them. In particular, standing up from a lower seat height (especially lower than knee height) adds significantly to the required muscular effort, which may amplify the differences in performance (and maybe also imagery) between young and older adults. The second aspect concerns manual activity concurrent with STS movement (e.g., standing up with a drinks cup or food plate balanced in one hand). This is effectively a divided attention task, something that is known to challenge older people to a greater extent. The effects of deliberately targeting attention to internal or external aspects of coordination on these task situations are not well understood, and what any age-related differences occur during execution and imagery are useful to study.

Finally, this study also began to test the effects of internal versus external attentional focus on a motor-imagery based learning protocol. During STS movements, the weight of the body tends to be supported to a greater extent by the dominant leg, such that the force distribution is laterally asymmetrical. Although this strategy may be adaptive in healthy individuals, unilateral strength loss due to brain trauma can induce task conditions whereby altering the symmetry of force application can become a training goal. In the final experiment of this study, we implemented a learning protocol using motor imagery training, and asked participants to try to make their STS movement more symmetrical. We were interested in the effects of attentional focus and ageing on the effectiveness of training in this task.

In summary, the present study began with a comparison the effectiveness of body-internal or external attentional focus during physical and imagined STS movements in healthy young and older adults. It then examined the effects of changing seat height (i.e., level of effort) and manual secondary task (i.e., divided attention). Finally, it tested whether imagery-based STS training might be affected by the attentional focus manipulation.

1.5. Overview of the following chapters

1.5.1. Chapter 2

Chapter 2 describes the common methodology used to generate, record and analyse the data for all experiments.

1.5.2. Chapter 3

To clarify the impact of attentional focus on motor imagery and performance, we directly compared the effects of external versus internal focus on physical and imagined instances of STS movements in young adults, as compared to older adults. We tested how focusing on the change in viewpoint relative to the environment (external focus) or the change in muscular load on the thighs, or cutaneous pressure under the feet (both internal focus), affected the self-reported movement times and the ground reaction forces of imagined STS movements. We also measured the self-reported, actual movement times, and the smoothness or stability (which we measured as the path length of the center of pressure during standing up) of the physical movements under these internal and external focus conditions. After the practice and test trials of each imagery condition, we also collected a rudimentary subjective measure of how vividly the participants felt they had managed to imagine the STS movements.

1.5.3. Chapter 4

In the second experiment, we manipulated the seat height from which participants made sit-to-stand movements (setting it to 100% or 80% of participants' lower leg length). We introduced this manipulation of effort in order to amplify differences in timing between task conditions and age groups. We tested how focusing on the change in viewpoint relative to the environment (external focus) or the change in muscular load on the thighs (internal focus), affected the self-reported movement times and the ground reaction forces of imagined STS movements. We also measured the self-reported and postural transition duration and stability during physical STS movements under the internal and external focus conditions.

1.5.4. Chapter 5

In the third experiment, we tested the impact of adding the manual task of holding a container filled with fluid in either hand and performing or imagining STS movements under external and internal attentional focus conditions. The participants' task was to attempt standing up without spilling the fluid from the container. Thus, in effect, their task requirement now had an explicit component relating the body (or parts of it) to the environment. Again, we tested how focusing on the change in viewpoint relative to the environment (external focus) or the change in muscular load on the thighs (internal focus), affected the self-reported movement times and the ground reaction forces of imagined STS movements. We also measured the self-reported and postural transition duration and stability during physical STS movements under the internal and external focus conditions.

1.5.5. Chapter 6

In the fourth experiment, we carried out a preliminary study of how (or whether) attentional focus may influence the effectiveness of motor imagery training. During imagery training, participants' task was to try to make their movement as laterally symmetrical as possible. We tested visual (external), muscular and somatosensory (internal) attentional focus during imagery training, and measured postural transition duration and stability and lateral symmetry of ground reaction force during physical movements, both before and after the set of training sessions.

1.5.6 Chapter 7

In this concluding chapter, we provide a summary of our experimental results and discuss its possible implications for understanding the role of attention in motor imagery and for applications to clinical settings.

Chapter 2: Common Methodology

2.1. Introduction

This chapter describes the common methodology used to generate, record and analyse the data. Participant details, together with a specific experimental design, are presented with each experiment in the respective chapter.

2.2. Method

2.2.1. Apparatus

The experimental setup (Figure 2-1: A) consisted of a height-adjustable chair placed adjacent to an AMTIAccusway force platform (Watertown, MA) driven by AMTI's Balance Clinic software. Sequencing of experimental trials and recording of self-reported movement time data at millisecond resolution was controlled by an E-Prime script (PST: Sharpsburg, PA)

2.2.2. Experimental procedures

The experiment was conducted in a quiet room within a laboratory suite. Participants were instructed to come dressed in comfortable clothing, and asked to take their seat on a vertically adjustable chair set to the height of their lower leg (Figure 2-1: A). Participants' feet rested on the force platform with heels approximately 10 cm apart. Participants' ankles were positioned with ~10° of dorsiflexion and knees with ~100 - 105° of flexion using a handheld goniometer. The position of the feet on the force platform was then marked with tape. Participants' thighs were positioned with the edge of the chair at two-thirds of their thigh length. This position was marked with tape on the thighs and on the seat behind the buttocks. Participants were asked to keep their arms by the sides of their bodies.

Before each trial, the position of the trunk, the legs, and the feet, were checked and corrected if necessary.

Each participant performed the physical and imagined STS movements under three focus conditions – visual-external (focus on a fixation point on the wall), muscular-internal (focus on the load on thigh muscles), and somatosensory-internal (focus on the pressure under feet).The order in which participants encountered the focus conditions was counterbalanced. In each focus condition, participants first performed the physical movement (3 recorded trials) followed by the corresponding imagined movement (3 recorded trials), with 1 - 2 minutes of rest in between. Each set of 3 recorded trials was preceded by 2 practice trials. In conditions involving imagined movement, participants were asked to provide a vividness judgment after the practice trials and then again after the experimental trials to record a subjective impression of the strength of STS imagery.They indicate on a 5-point scale (see in Appendix 2) how vividly they felt they had been able to imagine the movement. At the beginning of each trial, participants were instructed to sit comfortably with their backs straight, and look forward at the fixation point on the wall, which was placed level with the participants' eyes when standing on the force platform. Participants held a computer mouse in their right hand (to provide self-report of movement completion, see below), and then followed trial-specific instructions (see the details of specific instruction for each experiment in Appendix 3).

In each trial, the participant awaited a pre-recorded auditory "Ready … Go" signal played by the E-prime software, and then performed a physical or imagined STS movement. In the visual-external focus condition, their instruction was to stand up (or imagine standing up) at their natural speed while keeping their eyes on the fixation target, and focusing on the way their viewpoint's position changed relative to the fixation point. The fixation target was always positioned at the participants' standing eye-height. In the muscular-internal focus condition, they were told "As you stand up (or imagine standing up), focus your attention on how the weight of your body feels in your thighs," and in the somatosensory-internal focus condition, they were told to focus their attention on how "the pressure of your body weight feels under your feet." They were also asked to press the left button of the handheld mouse when they felt they had completed the STS movement and were "standing comfortably and steadily" (or imagining doing so, according to the experimental condition) and then stay standing steadily until hearing the experimenter said DONE. Participants were then asked to sit down, relax, and prepare for the next trial.

2.3. Measures, Design and Data Analysis

During the physical STS movement trials, participants' center of pressure (CoP) was recorded by the force platform following the arrangement shown in Figure 2-1: B. From the start of each trial, as marked by the offset of the auditory GO signal, CoP data were acquired for 10 s at a sampling rate of 50 Hz. Participants were instructed to start their STS movement when they heard the GO signal, and keep standing steadily until instructed to break stance (which occurred 10 s later). Both the mediolateral (ML) and anteroposterior (AP) components of the CoP time series were collected and analysed. In Experiments 1 (Chapter 3), 2 (Chapter 4) and 3 (Chapter 5), we report the AP data only, as the STS movements were orientated in the AP direction, and analysis of ML data showed a very similar pattern to the reported AP data. In Experiment 4 (Chapter 6), we additionally present data for ML components because the task instructions asked participants to try to maximize the lateral symmetry of the sit-to-stand action.

To isolate the period of transition between sitting and standing steadily, the CoP time series was smoothed (moving average, 100 ms window), and then searched from the beginning in the positive time direction for an absolute velocity exceeding 4 cm/s to determine the start of the STS movement, and from the end in the negative time direction for a absolute velocity exceeding 1.2 cm/s to determine the end of movement. The start parameter value of 4 cm/s was chosen as it consistently signaled, in a large sample of collected data, the start of the large backward shift of AP CoP that accompanies the transfer of weight on to the feet (see Figure 2-1: C). The end parameter of 1.2 cm/s was chosen as the velocity fluctuations associated with the steady standing state rarely exceeded this level. Figure 2-1: C shows representative times series from a young (light grey) and an older participant (dark grey) marked with the STS start and end points picked by this algorithm. The start and end points enclosed the postural transition duration for a given trial, and the RMS displacement of the CoP during the postural transition, or the transitional CoP path length, served as a measure of stability–the shorter the CoP path length, the smoother and more stable the postural transition. Note that the postural transition interval isolated by the above method included not only the period of movement between sitting and standing stances, but also an initial period of CoP instability after the participant achieved standing posture. It was expected that participants might not be aware of this latter period of CoP fluctuation, and therefore self-report transition durations may be shorter than those identified from CoP data. The duration of postural transition and transitional CoP path length in physical movement trials were analysed using a mixed ANOVA with age (young, old) and gender (male, female) as between subjects factors, and attentional focus (visual, muscular, somatosensory) as the within subject factor.

Self-reported movement time in physical and imagined trials was analysed using a mixed ANOVA with age (young, old) and gender (male, female) as between subjects factors, and movement condition (physical, imagined) and attentional focus (visual, muscular, somatosensory) as within subject factors. Vividness of imagery was analysed using a mixed ANOVA with age, gender, attentional focus and time of judgement (after practice, after data recording) as factors.

During the imagined movement trials, where the instruction was to not make any movements, the force platform recorded the anteroposterior, mediolateral and vertical components of the ground reaction force. For each trial, the range of recorded force was extracted and analyzed as an indicator of the level of muscular activity. The Figure 2-2 shows representative samples of the AP component of force change during imagined movement trials in a young (light grey) and an older participant (dark grey). As in the case of postural transition duration and transition stability, we have reported the results of the AP component, but analysis of the ML component showed the same pattern of results. Ground reaction force data for the imagined movement trials were analysed using a mixed ANOVA with age (young, old) and gender (male, female) as between subjects factors, and attentional focus (visual, muscular, somatosensory) as the within subject factor. In Experiments 1-3 (Chapters 2-5), we present data for the AP component of ground reaction force. In Experiment 4 (Chapter 6), we present data for the lateral range of ground reaction force only because the task instructions asked participants to try to maximize the lateral symmetry of the sit-to-stand action.

For all ANOVA tests, significance value was set to $p < .05$, and post hoc means comparisons were performed using unpaired (between subjects effects) or paired (within subjects effects) t-tests. Significance levels are shown in figures as

*** $p < .001$, ** $p < .01$, or * $p < .05$, and error bars always indicate standard error of the mean. Significant three-way interactions were further analysed as sets of two-way ANOVAs. Partial eta (η_p^2) was used to measure effect size.

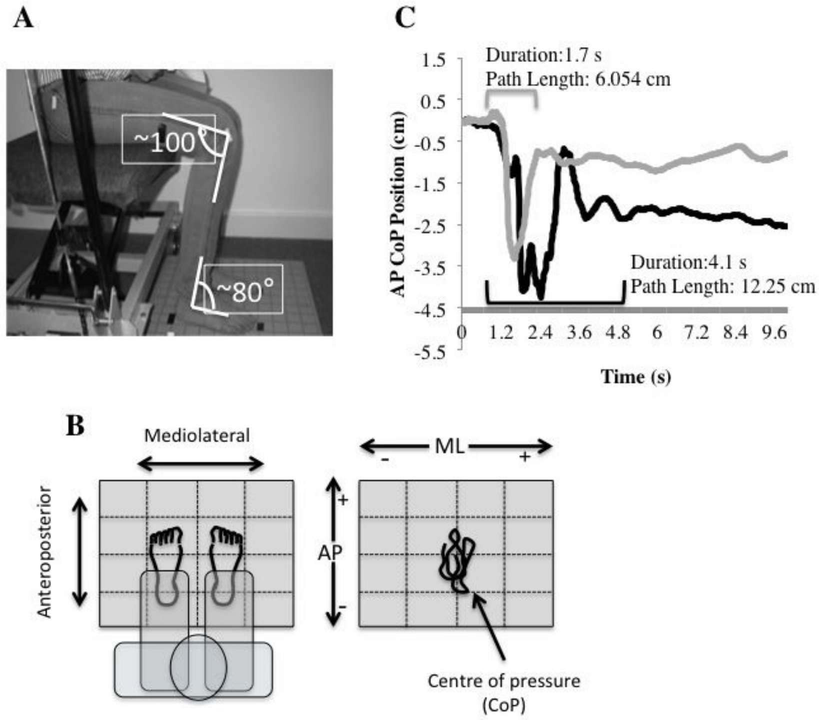


Figure 2-1: Experimental setup and measurement conventions. A. Participants' sitting position at the start of each STS movement. B. Schematic representation of the conventions used in recording CoP data from the force platform. C. Sample data of a young (light grey) and an older (dark grey) adult, showing the postural transition durations identified by the analysis algorithm.

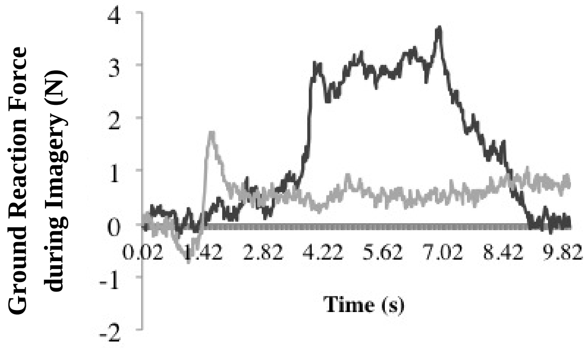


Figure 2-2: Sample data of the AP component of ground reaction force from a young (light grey) and an older (dark grey) adults during imagined movement.

2.4. Further experiments

2.4.1. Experiment 2

In Experiment 2, the impact of changing seat height and attentional focus on motor imagery and performance was examined. We directly compared the effects of external versus internal focus on physical and imagined instances of STS movements under two seat height levels in young adults, as compared to older adults. Common methodology for Experiment 2 was as described in this chapter, but experiment-specific methods, including seat height settings are presented in Chapter 4.

2.4.2. Experiment 3

In Experiment 3, the impact of unimanually balancing a load on the role played by attentional focus was measured in physical and imagined STS movements. We directly compared the effect of external versus internal focus on physical and imagined instances of STS movements while holding a filled cup of fluid in the hand. Common methodology for Experiment 3 was described in this chapter, but experiment-specific details are presented in Chapter 5.

2.4.3. Experiment 4

In Experiment 4, the effectiveness of MI training and attentional focus on STS performance was studied. We directly compared the effects of external versus internal focus on physical STS movements at the beginning and the end of a two-week training period. Common methodology for Experiment 4 was again as described in this chapter, but details of the training protocol and testing procedure are separately presented in Chapter 6.

Chapter 3: Experiment 1

Attentional focus during physical and imagined standing up affects young and older adults in divergent ways

3.1. Introduction

Healthy adults leading active, independent working lives are estimated to stand up from sitting position 45 - 65 times a day, and people in sedentary indoor occupations do so more frequently than those in outdoor active occupations (Bohannon et al., 2008; Dall & Kerr, 2010). Sit-to-stand (STS) movements are among the most challenging coordinations of daily life because of the significant demands they place on both muscular strength and postural control. STS movements register high moments of as much as 4.7 times body weight across joints in the lower limbs (Khemlani et al., 1999), which can pose problems for older people with reduced strength (e.g., Hughes et al., 1996). The movements also pose a significant balancing challenge because of the rapid upward shift of the body's center of mass to a position of reduced stability (Roebroeck et al., 1994; Vander Linden et al., 1994). Deterioration in STS ability in older people is associated with higher risk of disability (Guralnik et al., 1995), falling (Nevitt et al., 1991), hospitalization (Penninx et al., 2000), and nursing home admission (Guralnik et al., 1994). The STS movement is also a good indicator of mobility and frailty in older adults, and several age-related neurological (e.g., stroke: D. M. Cameron, Bohannon, Garrett, Owen, & D. A. Cameron, 2003; Parkinson's disease: Inkster, Eng, MacIntyre, & Stoessl, 2003) and orthopedic (e.g., arthritis: Newcomer, Krug, & Mahowald, 1993; hip fracture: Zimmerman et al., 2006) conditions can also result in STS impairment. These are often targeted for improvement through rehabilitation programmes, so it is worth finding practical techniques that can help in changing position from sitting to standing more easily and safely.

A rapidly growing area of focus in this regard, and in motor rehabilitation more generally (Dijkerman et al., 2010), is on developing methods that target the process of motor planning, and thereby reduce emphasis on repeated execution of effortful, and potentially unsafe, whole-body movements such as STS (see, for example, Oh et al., 2010; Skoura et al., 2005).These methods employ motor imagery in place of some physical practice because the process of imagining body movements can be so similar to the act of performing them that imagined actions can be considered simulations of their physical counterparts (Jeannerod, 2006). Imagined actions show many behavioural similarities to physical ones, such as temporal scaling of movement duration to distance (e.g., Papaxanthis et al., 2002; Sirigu et al., 1996), patterns of effort (e.g., Cerritelli et al., 2000), speed-accuracy tradeoffs (e.g., Decety & Jeannerod, 1996; Stevens, 2004), and adherence to biomechanical constraints (e.g., Fraket al., 2001; Johnson, 2000). Likewise, neurophysiological evidence supports a unitary mechanism for action representation and execution (Bonnet et al., 1997; Clark et al., 2004), and brain imaging suggests common loci of cortical activation between motor imagery and execution (de Lange et al., 2005; Grèzes & Decety, 2001; Orr et al., 2008). Importantly, these similarities reach beyond central processes. For example, motor imagery can also modulate corticospinal excitation (Stinear et al., 2006) and generate EMG activity in involved muscles (Guillot et al., 2007; Lebon et al., 2008). These commonalities, especially the peripheral effects, imply that there are neurophysiological pathways by which imagery-based mental practice may elicit performance benefits in a similar way to physical practice (for a review, see Guillot, Lebon, & Collett, 2010). However, to our knowledge, only a few studies have investigated the potential of MI during the STS task (e.g., Skoura et al., 2005).

Research on imagery-based rehabilitation techniques has not only considered the effects of motor impairment severity (Kwakkel et al., 2003), time since impairment (Liu et al., 2004; Muller et al., 2007), but also imagery ability (Malouin et al., 2008), cognitive deficits (Malouin et al., 2004), imagery characteristics such as first or third-person perspective (Jackson et al., 2006), and, importantly, visual or kinesthetic imagery modality (Dickstein & Deutsch, 2007). Whereas kinesthetic imagery necessarily focuses attention on body-internal aspects of motor coordination, visual imagery can focus on body-external, goal-related aspects of the movement. Despite a lot of evidence supporting the advantages of kinesthetic (internal) imagery (focusing on one's own movement) for enhancing motor performance and learning, compared to visual (external) imagery (associated with spatial coordination of a movement in environment), there are many differences in study designs, particularly with respect to optimum protocol, specificity and sensitivity of outcome measures, and the quality of imgery. It is believed, however, that the quality of imagery can be enhanced via specific focus instructions, making the simulation more real. It has been recommended that the focus instructions should be detailed, and should direct the individual to focus attention to an external or internal aspect of the task.

For a variety of motor skills, such as balancing (McNevin & Wulf, 2002; Shea & Wulf, 1999), jumping (Wulf et al., 2010), or throwing (Zachry et al., 2005), body-external attentional focus has been found to result in better performance. This difference has been studied extensively in young adults, but it has also been found in skill learning by healthy older adults (Chiviacowski et al., 2010) and balancing in patients with Parkinson's disease (Landers et al., 2005). According to the constrained action hypothesis (Zachry et al., 2005), the reason for this difference is that body-internal attentional focus results in constraints on the motor system that disrupt automatic control. This view has been supported by observations of differences in movement accuracy (Zachry et al., 2005), attentional load (Wulf et al., 2001), movement frequency characteristics (McNevin & Wulf, 2002), and EMG activity (Vance et al., 2004; Zachry et al., 2005), suggesting more accurate, automatized and energy-efficient action under external attentional focus. However, this external-focus benefit in motor performance contrasts with results from motor imagery research that show greater involvement of kinesthetic imagery in whole body movements (Golomer, Bouillette, Mertz, & Keller, 2008; Sacco et al., 2006), greater facilitation of corticospinal excitation during kinesthetic imagery (Stinear, 2010), greater benefit from kinesthetic mental practice in tasks emphasizing timing or bimanual coordination (Féry, 2003), and even significant modulation of motor contingent negative variation (CNV) in patients with Parkinson's disease following kinesthetic but not visual motor imagery (Lim et al., 2006).

It appears that, during the performance or learning of physical motor skills, directing attention to the environmental effects of movements (external focus of attention) is more beneficial than attending to the movements themselves (internal focus; e.g., Wulf, 2007). This distinction between body-internal and body-external focus has important implications for motor learning and performance (Wulf, 2007) that have not been considered in research using motor imagery. It is worth investigating whether focusing attention on body movements (internal focus) during motor imagery can be effective, or whether performance and learning improve if attention is focused away from the body movement, and to the effects those movements have on the environment (external focus). There have been no studies of what should be the target focusing on the body movement. It is generally known that the knee extensor function and weight bearing on the feet are essential components of performance in the STS task. Thus, we asked participants to focus on the muscular load due to the knee extension (muscular-internal focus), and on the pressure felt under the feet (somatosensory-internal focus) in the internal focus conditions. In the visual-external focus condition, we asked participants to focus on a fixation point on the wall (placed at standing eye-height). To clarify the impact of attentional focus on motor imagery and performance, we directly compared the effects of external versus two internal focus conditions on physical and imagined instances of STS movements.

The Present Research

In the present study, we sought to clarify whether attentional focus can affect STS performance, and, for reasons outlined in the following section, whether any such effects are age-dependent. Specifically, we targeted three aspects of motor performance. First, we wanted to observe how external versus internal attentional focus affects execution parameters such as movement time (MT) and stability. We did this by testing how focusing on the change in viewpoint relative to the environment (external focus) or the change in muscular load on the thighs, or cutaneous pressure under the feet (both internal focus) affected the MT of physical STS movements. We also measured the smoothness or stability of the movements (which we measured as the path length of the body’s center of pressure while standing up).

Second, we were interested in the effects of attentional focus particularly on central motor planning processes. Whereas motor imagery primarily (but not exclusively, see below) evokes central motor planning processes, movement execution can additionally involve significant peripheral feedback incorporation. To test whether internal versus external attentional focus affects these two processes differently, we recorded and compared the (self-reported) MT of imagined and physically executed STS movements.

Third, we were interested in the fact that, even though motor imagery does not generate overt movement, it has been shown to produce specific, patterned, but level-attenuated EMG activity in the involved muscles (e.g., Guillot et al., 2007; Lebon et al., 2008). Since this property may be an important element of the effectiveness of motor imagery as a rehabilitation technique, we tested whether imagined STS movements result in muscular activity, and also whether the level of such activity differs as a function of attentional focus. We did this by measuring changes in force transmission to the ground while imagining STS movements (which we measured as the anteroposterior components of the ground reaction force, as described in Chapter 2).

Effects of Aging

We expected attentional focus to differentially affect motor planning and execution in young and older adults for three reasons that correspond to our three measurement goals outline above. First, older people are known to accrue deficits in motor planning (Ketcham & Stelmach, 2001) that increase reliance on visual information to guide movements (Haaland, Harrington, & Grice, 1993) as proprioceptive control deteriorates with decreasing muscular strength (Butler et al., 2008). This suggests that young and older participants may respond differently to changes in attentional focus from body-internal (proprioceptive) to body-external (visual) aspects of coordination. However, the direction of any such difference is unclear. Based on existing data on the benefits of external focus in motor performance, and considering in addition the increased reliance on visual guidance in old age, older participants may be expected to receive greater benefit from an external attentional focus. On the other hand, focusing attention on proprioceptive information may counteract the relative disadvantage older participants have in utilizing it. In this respect, we expected age-related differences to appear in parameters of physical STS movements.

Second, task-level action planning and effector-level movement control are often considered modular elements of goal-directed action (e.g., Saltzman & Kelso, 1987; Wolpert & Kawato, 1998), and it has been suggested that the coupling between these processes deteriorates with ageing such that direct attentional focus on effector control may mitigate against older people’s reduced ability to translate behavioural goals into actions (Haaland et al., 1993; Skoura et al., 2005; Trewartha, Endo, Li, & Penhune, 2009). This suggests that older people’s movement planning and performance are more likely to benefit from an internal focus of attention. It also suggests that, relative to the young, older people’s imagery and execution performance may not be as closely coupled. We therefore expected age-related differences in the correspondence between planning and execution to appear in self-reported movement times.

Third, we expected young and older people to differ in the extent to which they generated peripheral activation during motor imagery. The absence of movement execution during imagery, despite the many similarities between imagined and physical movements (and the common patterns of cortical activation, including in the primary motor cortex), is thought to be the result of an inhibitory mechanism that acts downstream of the motor cortex, possibly at the brain stem or spinal level (Jeannerod, 2006), and potentially arising in the posterior cerebellum (Lotze et al., 1999), or descending from premotor cortex in parallel with corticospinal excitation (Prut & Fetz, 1999). Importantly, aging is a well-known source of deficits in inhibitory mechanisms in general (Maylor, Schlaghecken, & Watson, 2005), and also in low-level motor control in particular (Schlaghecken, Birak, & Maylor, 2011, 2012). Whether these inhibitory deficits extend to motor imagery is not clear, but there are indications in the literature that older adults may not inhibit neuromuscular activity during motor imagery as effectively as young adults, especially if, as in the present study, the task involves a balancing component (Paizis, Personnier, Pozzo, & Papaxanthis, 2008). We expected, therefore, that older participants would transfer greater force to the ground during imagined STS movements, but how or whether any such difference might interact with attentional focus remained to be seen.

3.2. Method

The common aspects of the method (given in Chapter 2) were used, but with the following differences.

3.2.1. Participants

Fifty three healthy young adults (18 - 30 yrs) and 34 older adults (60 - 80 yrs) took part in the study, receiving course credit and payment for their participation. Young adults (Male: N = 25, M_{age} 21.24 $\pm$ 3.84yrs, M_{weight} 71.18 $\pm$ 10.19 kg, M_{height} 176.88 $\pm$ 7.50 cm; Female: N = 28, M_{age} 20 $\pm$ 2.88 yrs, M_{weight} 58.86 $\pm$ 8.93 kg, M_{height} 166.57 $\pm$ 6.42 cm) were recruited from the local university student population, and older adults (Male: N = 16, M_{age} 70.94 ± 5.40yrs, M_{weight} 74.19 ± 9.10 kg, M_{height} 175.50 ± 6.44 cm; Female: N = 18, M_{age} 69.94 ± 4.61 yrs, M_{weight} 68.94 ± 8.69 kg, M_{height} 164.11 ± 8.59cm) came from a community-based volunteer panel maintained by the research group. All participants were screened for unimpaired ability to stand up several times per session from a sitting position and had no significant medical history or current problem affecting balance or everyday motor function (questionnaire form in Appendix 2). Three young adults (2 males, 1 female) and 4 older adults (2 males and 2 females) reported having had a past medical condition affecting balance. Three young adults (2 males and 1 female) and 8 older adults (3 males and 5 females) had past experience of loss of balance, falling or weakness in the legs, and 1 (male) young adult reported taking medication with possible effects on balance.

Potential volunteers were given advance information regarding general task requirements and they had the opportunity to seek clarification before choosing to participate. All participants gave written informed consent (see an example of the consent form in Appendix 4) before taking part. The study received ethical approval from the Humanities and Social Sciences Research Ethics Committee (HSSREC) of the University of Warwick.

3.2.2. Experimental procedures

Participants performed the physical and imagined STS movements under three focus conditions – visual-external (focus on a fixation point on the wall), muscular-internal (focus on the load on thigh muscles), and somatosensory-internal (focus on the pressure under feet). Participants were randomly assigned to trial-order groups; 1) external (visual)-internal (muscular)-internal (somatosensory), and 2) external (visual)-internal (somatosensory)-internal (muscular). The experimental session consisted of one 45-minute visit to the laboratory. The summary protocol is shown in figure 3-1.

In each focus condition, participants first performed the physical movement (3 recorded trials) followed by the corresponding imagined movement (3 recorded trials), with 1 - 2 minutes of rest in between. Each set of 3 recorded trials of physical movement was preceded by 2 practice trials of physical movement. Each set of 3 recorded trials of imagined movement was preceded by 3 practice trials of imagined movement followed by 2 practice trials of physical movement. This ensured that participants had fresh memory of physically performing the movement when they started the recorded imagined movement trials.

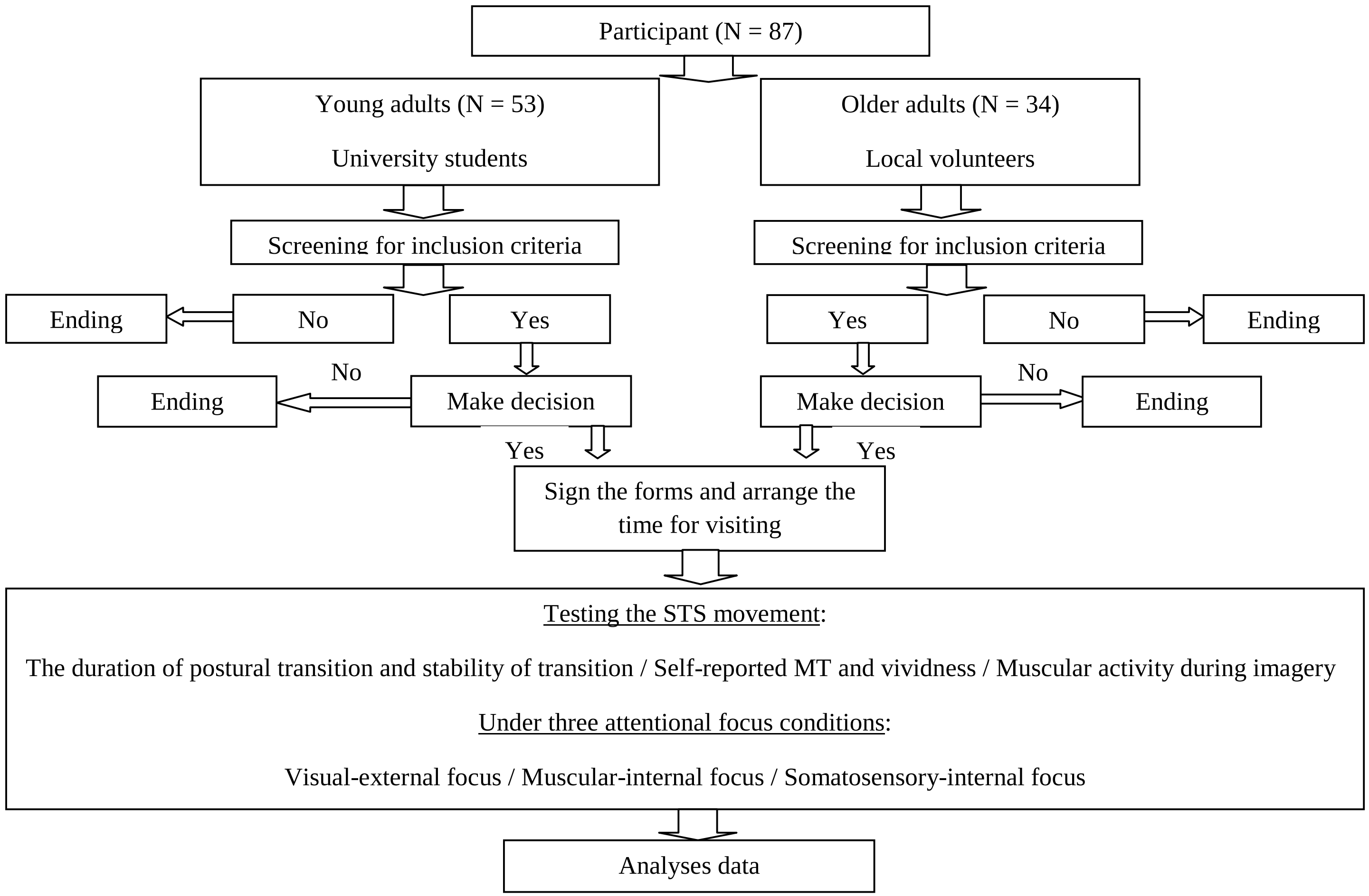


Figure 3-1: The summary protocol of Experiment 1

3.3. Results and Discussion

3.3.1. Duration of postural transition and stability of transition

The main effect of age on the duration of postural transition was significant (*F* (1, 83) = 18.88, *p*< .001, $\eta_p{}^2$= .19; the transition was longer in older participants) (Figure 3-2). The interaction between attentional focus and age was marginally significant (*F* (2, 166) = 2.66, *p* = .073, $\eta_p{}^2$ = .03); whereas young participants' transition duration was shorter in the visual-external condition than in either internal focus conditions (both *p* < .05), older participants' transition duration did not change with attentional focus (Figure 3-3). As expected, the duration of postural transition extracted from CoP data tended to be longer than those self-reported by the participants (Figure 3-3 and 3-6).

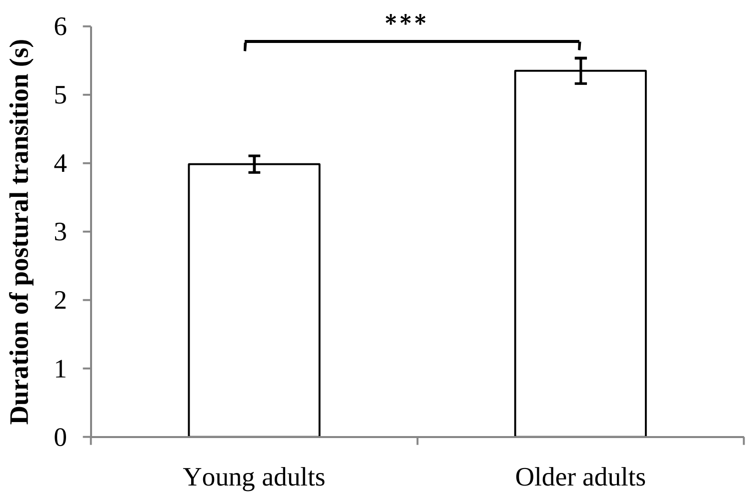


Figure 3-2: Effect of age on the duration of postural transition of young and older adults.

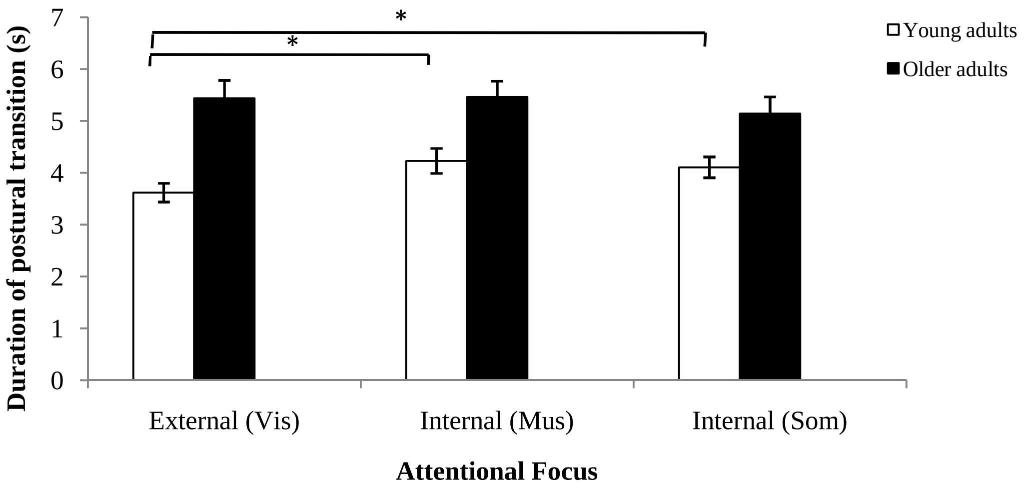


Figure 3-3: Effect of attentional focus and age on the duration of postural transition of young and older adults.

The stability of postural transition, as measured by the anteroposterior CoP path length during the transition interval, was greater in young than older participants (F (1, 83) = 37.37, $p < .001$, $\eta_p^2 = .31$) (Figure 3-4). The interaction between age and attentional focus was also significant (F (2, 166) = 5.98, $p < .01$, $\eta_p^2 = .07$). Young participants' CoP path length was shorter (i.e., transition stability was greater) in the visual-external focus condition than in the internal-muscular ($p <$ .01) and internal-somatosensory ($p < .05$) focus conditions. Older participants, however, were more stable in the internal-muscular focus condition than in the visual-external condition ($p < .05$). Their stability in the internal-somatosensory condition was numerically in between the other two focus conditions, but not significantly different from either (Figure 3-5).

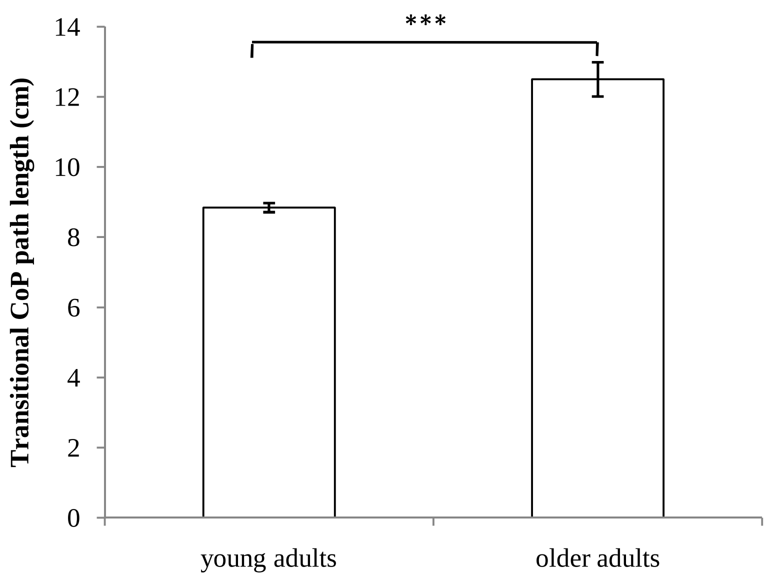


Figure 3-4: Effect of age on the stability of transition of young and older adults.

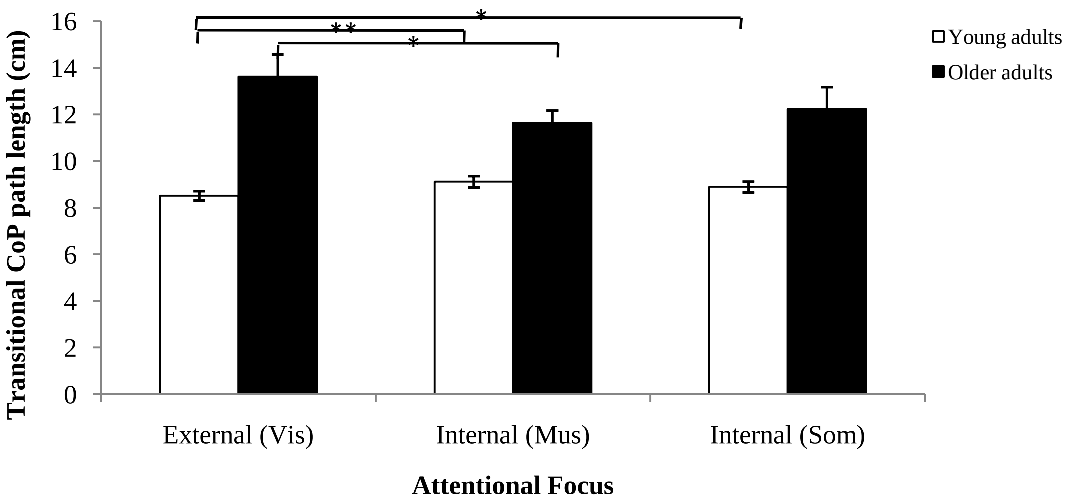


Figure 3-5: Effect of attentional focus and age on the stability of transition of young and older adults.

Unsurprisingly, older participants' postural transition was longer and less stable than young participants, which could be either due to differences in the pattern of force production or differences in body weight across the age groups. The corresponding interactions between age and attentional focus revealed an important difference between the age groups. Young participants' postural transition was more time-efficient and stable in the external focus condition. The results of young participants showed better performance under external attentional focus, consistent with Wulf and colleagues' results. Conversely, older participants' postural transition duration did not differ across attentional focus conditions, and their transition stability was actually significantly greater in the internal-muscular focus condition than in the external focus condition (with the same numerical tendency for the somatosensory internal focus condition). It might be noted that CoP path would be longer if the postural transition duration is longer assuming the same level of CoP fluctuation (see Figure 2-1: C). Older participants' shorter CoP path length under internal-muscular focus relative to external-visual focus was observed despite no corresponding difference in transition duration, which clearly implicates reduced CoP fluctuation. This divergence of results suggests that, unlike young people, older people may benefit in their motor performance from a body-internal, especially muscular, attentional focus. However, their mental motor-chronometry during imagery does not reflect this age effect.

3.3.2. Self-reported movement times and vividness of imagery

There was a significant main effect of attentional focus (F (2, 166) = 14.00, $p < .001$, $\eta_p^2 = .26$; see Figure 3-6) on self-reported movement time. Movement time in the visual-external focus condition was shorter than in the muscular-internal and somatosensory-internal conditions ($p < .001$). Young and older participants did not differ, and there were no other significant effects on self-reported movement time.

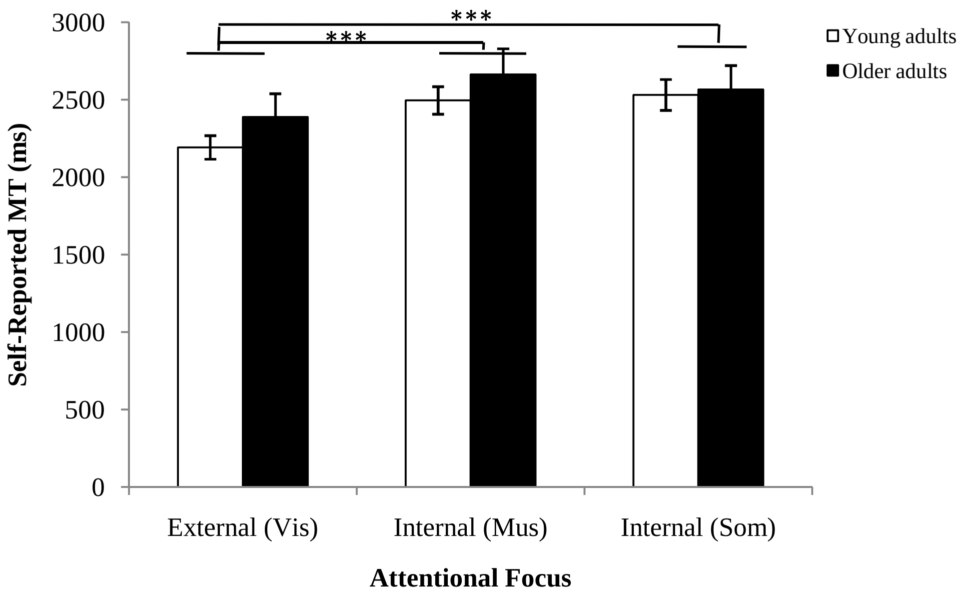


Figure 3-6: Effect of attentional focus on self-reported movement times of young and older adults (across physical and imagined movements). Young and older adults' movement times did not differ.

The main effect of time of judgement on vividness of imagery was significant (F (1, 83) = 5.77, p < .05, η_p^2 = .06; vividness of imagery increased by the end of the session, see Figure 3-7), as was the interaction between time of judgement and attentional focus (F (2, 166) = 4.41, p < .05, η_p^2 = .05); vividness increased during the session in the visual-external focus condition, but not in either internal focus condition (p < .01) (Figure 3-8). The interaction between time of judgement, age and gender was also significant (F (1, 83) = 9.31, p < .05, η_p^2 = .10). This interaction was further analysed as two 2(age) x 2(gender) ANOVAs, one each for vividness judgements at the end of practice and the end of session. There were no significant effects at the end of practice. At the end of session, there was a significant interaction between age and gender (F (1, 257) = 14.53, p <.001, η_p^2 = .05);

vividness increased during the session among older females ($p < .01$) and young male ($p < .05$; see Figure 3-9).

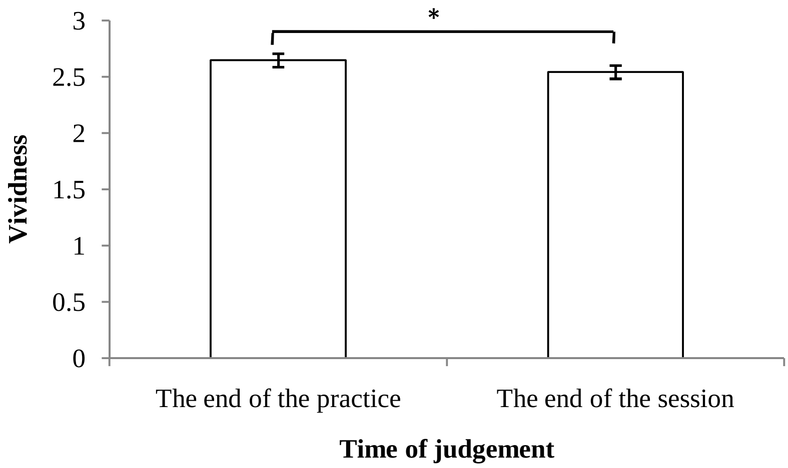


Figure 3-7: Effect of time judgement on vividness.

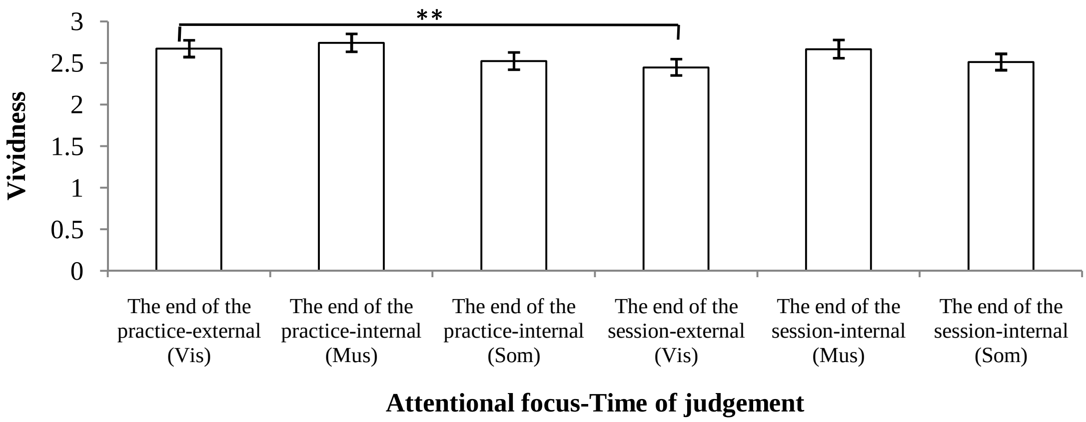


Figure 3-8: Effect of attentional focus and time judgement on vividness.

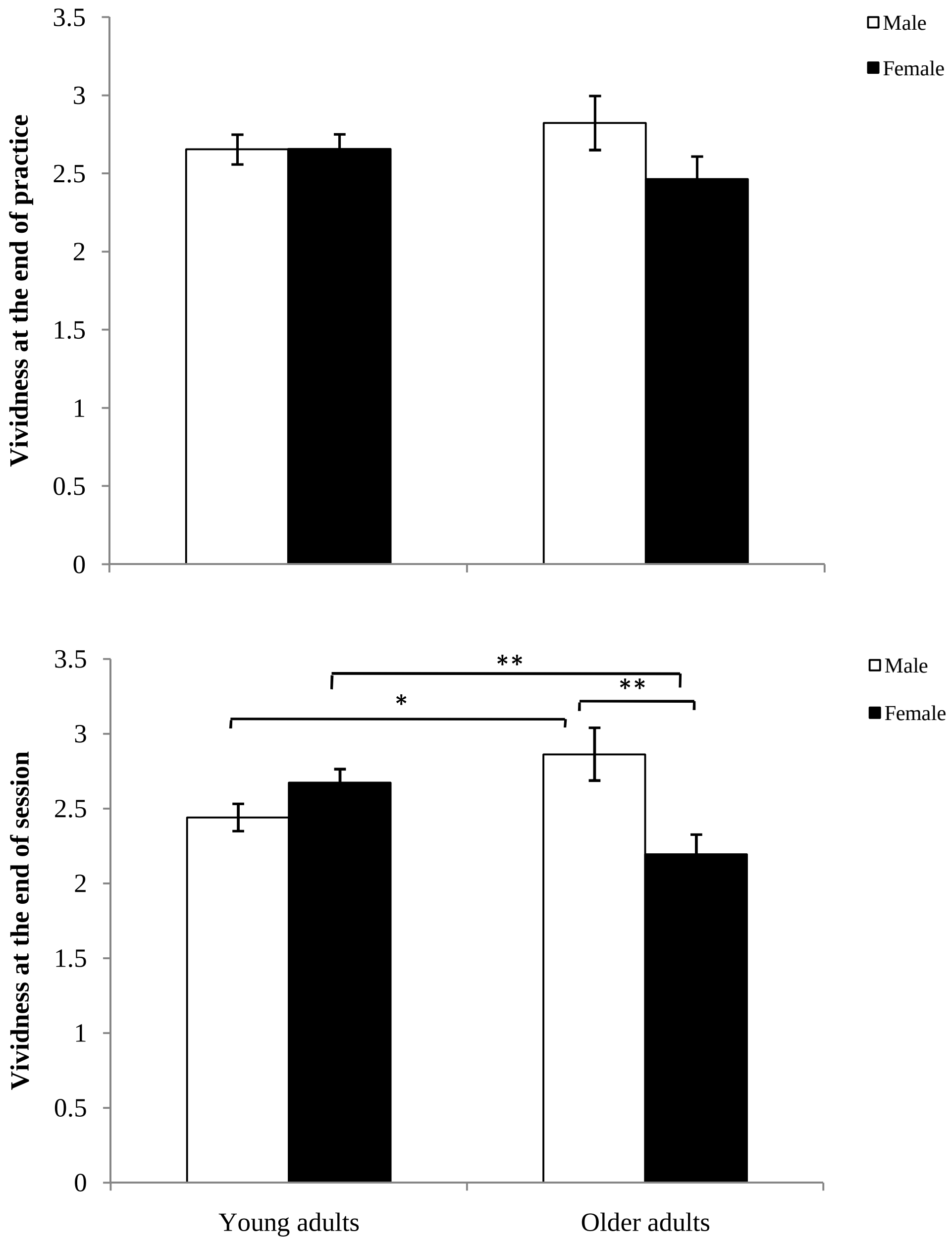


Figure 3-9: Effect of age and gender on vividness at the end of practice (top panel) and at the end of session (bottom panel).

Self-reported movement times did not differ between physical and imagined STS movements or between young and older adults. The main effect of attentional focus suggests that participants felt their executed and imagined movements to be more time-efficient in the external rather than either internal focus condition. For young adults, this impression is consistent with the timing and stability of their actual postural transitions. For older adults, it is not, which highlights a reduced correspondence between their motor planning and execution.

The vividness judgements indicate an improvement in the self-reported clarity of imagery between the ends of the practice and data recording periods, but this difference was only significant in the external focus condition, and was shown only by older females and young males. The implications of the interaction with gender are unclear, but it is worth noting that the range of vividness judgements across conditions was very small (condition means ranged 2.03 - 2.94 around an overall mean of 2.4 on the 5-point scale), which is consistent with observations of poor correspondence between subjective impressions of imagery and its physiological correlates (Guillot et al., 2010). As vividness judgements had such narrow range of response, and no clear relationship with task conditions or performance was found, we do not report it in subsequent experiments.

3.3.3. Muscular activation during imagined STS movements

The main effect of age on the range of ground reaction force along the AP direction was significant (F (1, 83) = 4.60, p < .05, η_p^2 = .05; force range was greater for older participants (Figure 3-10). The main effect of attentional focus was also significant (F (2, 166) = 8.44, p < .001, η_p^2 = .09) (Figure 3-11). Ground reaction force was greater in the two internal focus conditions (p < .01). The main effect of gender (F (1, 83) = 3.64, p = .06, η_p^2 = .04) and the interaction between age and gender (F (1, 83) = 3.31, p = .07, η_p^2 = .04) were marginally significant; older males had a greater force range than older females (p < .05), but young males and females did not differ.

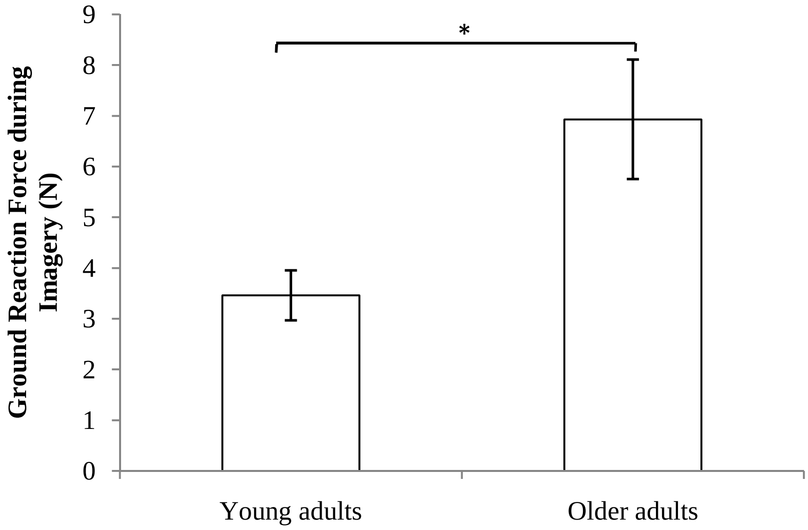


Figure 3-10: Effect of age on the ground reaction force of young and older adults.

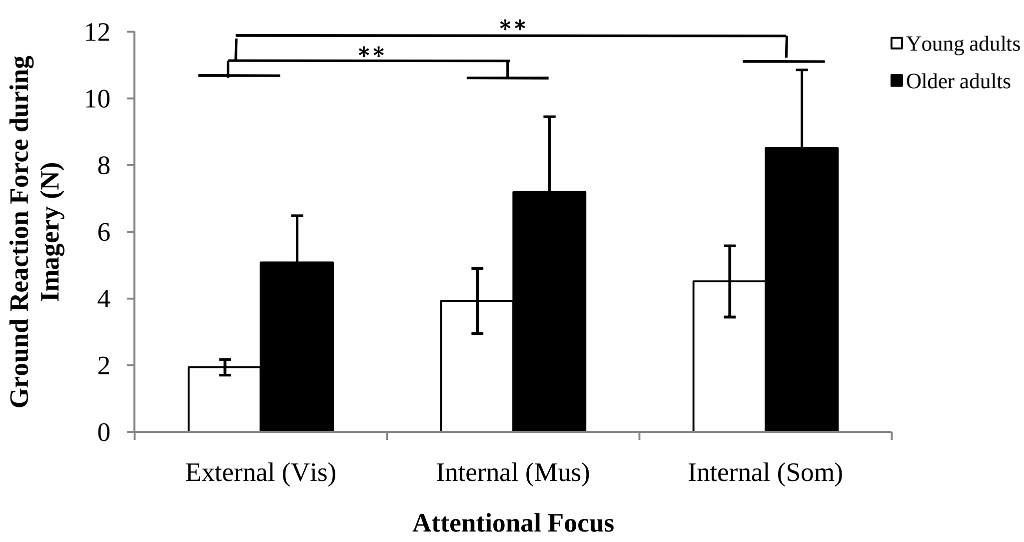


Figure 3-11: Effect of attentional focus on the ground reaction force of young and older adults.

Thus, despite instructions to imagine, but not execute, the STS movements, both young and older participants transmitted a small amount of force to the ground (i.e., generated muscular activation) along the direction of imagined STS movements (the range of 2 - 8 N observed was very small relative to the 706 N exerted by a standing adult weighing 72 kg). The level of force, hence muscular activity, was greater in older participants and during internally focused kinesthetic imagery. Greater muscular activation during imagery in older people may be the result of deficits in motor inhibition, as suggested earlier. Alternatively, it may reflect attempts to amplify afferent signals from the motor periphery (which are known to contribute to the level of imagery-related brain activation - e.g., de Lange et al., 2006) to mitigate against age-related decline in the ability to generate and control motor intentions (Skoura et al., 2005). Greater muscular activation observed during both the kinesthetic imagery conditions is consistent with previous work contrasting corticospinal excitation during visual and kinesthetic imagery (Stinear et al., 2006). Whereas the instructions used in that study only ensured a first-person perspective in the kinesthetic, but not the visual imagery condition (Guillot et al., 2010), the present study enforced a strict first-person perspective in both the externally focused visual, and internally focused kinesthetic imagery conditions. This result supports Stinear et al's assertion that the kinesthetic modality generates motor imagery that most closely mirrors the neurophysiology of motor performance.

It might be noted that older participants in this study weighed more than young ones (and there were differences between genders as well), and therefore would have needed greater force production in thigh muscles to successfully transition to standing posture. The greater force production during imagery by older adults may well reflect this difference in body weight. However, it should be noted that the measure of force range used here (and in subsequent experiments) factored out the resting weight of the lower body on the force plate (see Figure 2-2) and only considered the change in force transmitted to the ground during imagery. Thus, older participants' greater force production during imagery does constitute a failure of inhibition, but its higher level may reflect their estimation of the amount of force that would be needed if the movement were to be executed. Thus, greater force production by older participants may not simply reflect reduced levels of inhibition. Rather, it might at least partially reflect the expected level of force production required for the execution of the imagined movement.

3.4. Conclusion

In the present study, duration of postural transition, stability of transition, self-reported movement time, and muscular activity of imagined and executed motor actions in young and older adults were explored under different foci of attention. The findings mainly showed three potential impacts of attentional focus on the planning and execution of STS movements. Firstly, young participants' movement was faster, and their stability greater, under visual-external attentional focus. Older participants' speed did not differ as a function of attentional focus, but their stability during postural transition was greater under muscular-internal focus. Secondly, both young and older participants self-reported a quicker postural transition in the visual-external focus condition. Finally, older participants generated more force than young participants, and both age groups transmitted more force under the internal focus conditions.

To sum up, consistent with Wulf and colleagues' results (see Wulf, 2007), young participants' postural transition duration and transition stability, and their self-reported (physical and imagined) movement times, were convergent in showing better performance under body-external attentional focus. Older participants had the same self-reported movement time pattern, suggesting similar motor planning to young adults, but their movement execution benefited more from a body-internal focus on muscular load. Although the literature on training protocols utilizing motor imagery records the benefits of first-person kinesthetic imagery, the age-related difference in the impact of attentional focus observed here has not been previously appreciated, and should be systematically explored. This divergence of older participants' performance also points to age-related changes in the coupling between task-level action planning and effector-level motor control (often considered modular elements of goal-directed action, for example, in Wolpert & Kawato (1998) or Saltzman & Kelso (1987)), whereby direct attentional focus on the latter may mitigate against reduced ability to translate behavioural goals into motor plans and effector control (Haaland et al., 1993; Skoura et al., 2005; Trewartha et al., 2009).

The level of force transmitted to the ground during motor imagery was greater in older participants (which could be due to weight differences) and greater in both age groups during kinesthetic imagery. As discussed earlier, these differences may point to changes in the application of inhibition during imagery (Jeannerod, 1994; Bonnet et al., 1997; Maylor, Schlaghecken, & Watson, 2005; Schlaghecken, Birak, & Maylor, 2011, 2012), or possibly in the level of peripheral activity generated to aid imagery (e.g., de Lange et al., 2006). The present data cannot distinguish between these possibilities, but neurophysiological measurements targeted at these age and attentional focus linked differences could clarify the nature of associated changes in the motor imagery process. From a rehabilitation viewpoint, a greater tendency to generate muscular activity during kinesthetic imagery may prove beneficial as a form of exercise, regardless of the precise mechanism involved.

Chapter 4: Experiment 2

Seat height affects STS movements performed under internal and external attentional focus

4.1. Introduction

In Chapter 3 (Experiment 1) young and older adults' STS performance diverged as a function of focus of attention. Whereas young participants' STS movements consistently showed better performance (i.e., postural duration, postural stability and self-reproted MT) under external attentional focus, older participants' postural transition had greater stability (i.e., shorter CoP path length) when attention was focused internally on the load on the thigh muscles, but the duration of their postural transition did not show focus-based differences. There was also a discrepancy between older participants' self-reported and actual movement time, which may be due to reduced correspondence between motor planning and effector control, as previously suggested, but it is not clear why the benefit from internal-muscular focus was apparent in the stability but not the speed of postural transition. If attentional focus on muscular effort is indeed beneficial for older people, movements planned or executed with such focus should also be more time-efficient.

In the present experiment, we attempted to draw out temporal differences in the planning and execution of STS movements by introducing a manipulation of muscular effort. Previous studies suggested that physical and imagined movement times tend to be longer when movements involve greater effort, such as when the involved limbs carry additional load (e.g., Gentili, Cahouet, Ballay, & Papaxanthis, 2004; Papaxanthis et al., 2002). There is also evidence that older people modulate movement speed as a function of effort to a greater extent than young people (e.g., Dean, Kuo, & Alexander, 2004). We expected, therefore, that manipulating effort would increase the likelihood of detecting any time-efficiency differences that might occur as a function of attentional focus. We manipulated effort by asking participants to perform physical and imagined STS movements from seats placed at two different heights, at 100% (as in Experiment 1) or 80% of their lower leg length.

In our first experiment, the starting position was the seat on a vertically adjustable chair that was set to the height of participants' lower leg. However, in everyday life, people have to perform STS movements under widely different seat height circumstances. A variety of seat heights is in use in settings such as as houses, offices and hospitals (Weiner et al., 1993). Several studies show that seat height has an influence on the performance of STS movements (Arborelius et al., 1992; Hughes et al., 1994; Hughes et al., 1996; Hughes & Schenkman, 1996; Schenkman et al., 1996; Kawagoe et al., 2000); a change in seat height leads to altered biomechanical demands or strategy of STS movements. As a result of this, standing up from an unsuitable seat may be identified as a problem for older people, due to their reduced muscle strength (Khemlani et al., 1999) and postural control (Roebroeck et al., 1994; Vander Linden et al., 1994), and lead to functional limitations in older adults (Guralnik et al., 1994; Guralnik et al., 1995). It is important to clarify the impact of this determinant of STS performance in order to provide a basis for how the task is organized, to interpret results, or to develop programmes targeting STS coordination.

Although changing seat height is known to have performance implications, especially with respect to age-related differences, how seat height interacts with attentional focus has not been studied. By adding a lowered seat height condition in this experiment, we expected to amplify differential effects of attentional focus. Based on the results of Experiment 1, we predicted that, in older people, focusing on muscular effort would result in a greater difference between seat height conditions in both the timing (i.e., transitional duration and self-reported MT) and stability of postural transition. We also expected to observe seat height-related changes to the force transmitted to the ground (during imagined movements) as a function of attentional focus. In particular, we expected older participants to activate leg muscles more strongly in the lower seat-height condition, and to a greater extent under internal attentional focus.

4.2. Method

The common aspects of the method (given in Chapter 2) were used, but with the following differences.

4.2.1. Participants

Twenty four healthy young adults (18 - 30 yrs) and 24 older adults (60 - 80 yrs) took part in the study, receiving course credit and payment for their participation. Young adults (Male: N = 12, M_{age} 21.25 $\pm$ 0.91 yrs, M_{weight} 66.00 $\pm$ 2.48 kg, M_{height} 173.83 $\pm$ 2.31 cm; Female: N = 12, M_{age} 18.17 $\pm$ 0.11 yrs, M_{weight} 56.5 $\pm$ 2.5 kg, M_{height} 161.58 $\pm$ 1.95 cm) were recruited from the University of Warwick student population, and older adults (Male: N = 12, M_{age} 71.67 $\pm$ 1.26 yrs, M_{weight} 77.75 $\pm$ 3.02 kg, M_{height} 175.83 $\pm$ 1.19 cm; Female: N = 12, M_{age} 69.17 $\pm$ 0.80 yrs, M_{weight} 66.42 $\pm$ 2.98 kg, M_{height} 161.67 $\pm$ 2.14 cm) came from a community-based volunteer panel maintained by the research group. All participants were screened for unimpaired ability to stand up several times per session from a sitting position and had no significant medical history or current problem affecting balance or everyday motor function (see a questionnaire form in Appendix 2). One (male) young adult and 7 older adults (4 male, 3 female) reported having had a past medical condition affecting balance. Four older adults (female) had past experience of loss of balance, falling or weakness in the legs. Participant screening, consent procedures, and ethical approval were the same as in Experiment 1.

4.2.2. Experimental procedures

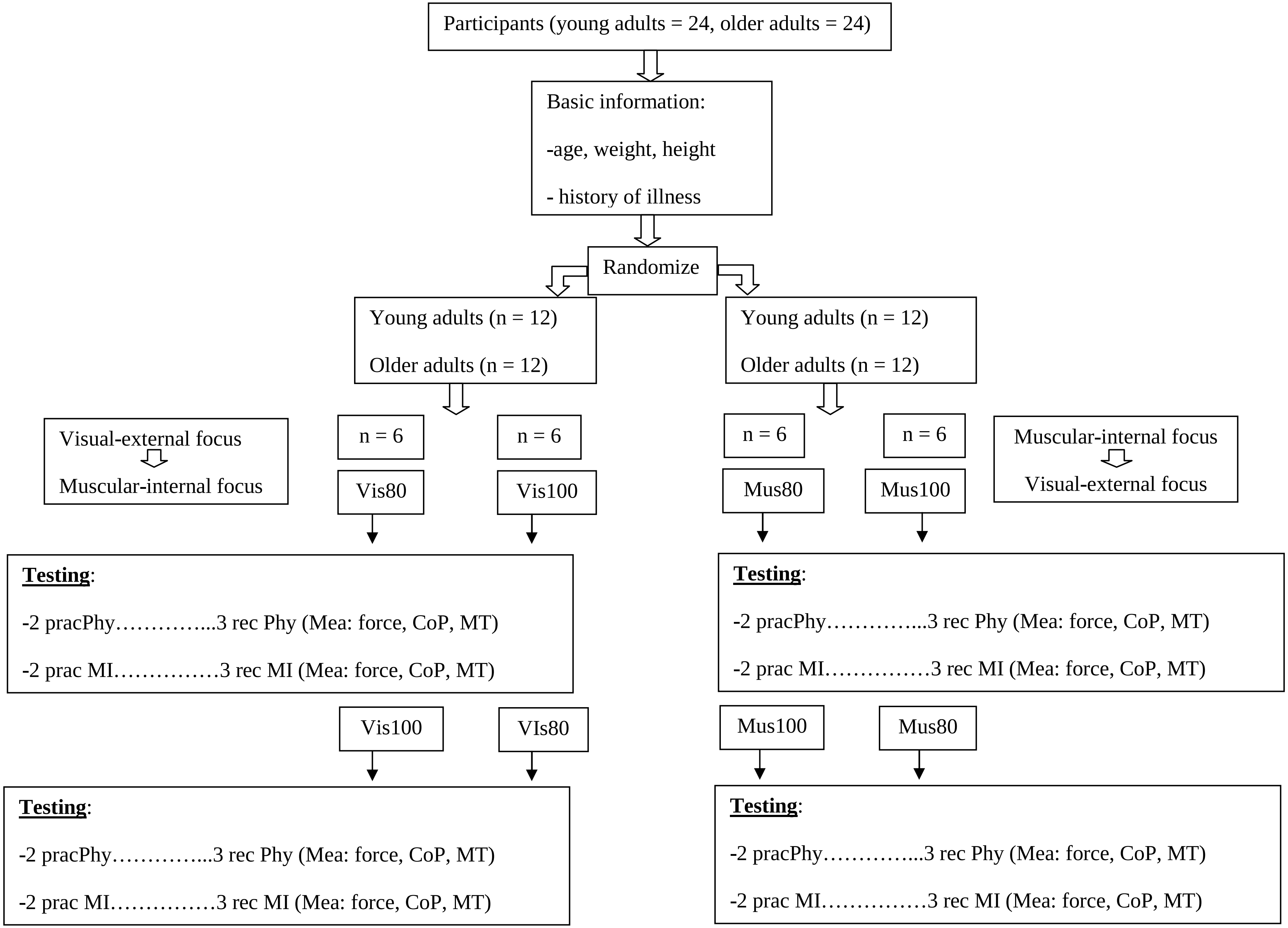
The experimental setup (Figure 2-1: A) was identical to Experiment 1 except that seat height was set to either 100% or 80% of the participant's lower leg length (henceforth, H100 and H80). Participants' feet rested on the force platform with heels approximately 10 cm apart, and their ankles were also positioned with ~10° of dorsiflexion using a handheld goniometer. Participants performed the physical and imagined STS movements with the seat set of two different heights (80% and 100% of the lower leg length) under two focus conditions – visual-external (focus on a fixation point on the wall) and muscular-internal (focus on the load on thigh muscles). Participants were randomly assigned to trial-order groups; 1) the visual-external and muscular-internal, and 2) the muscular-internal and visual-external. Participants were also counterbalanced into two different orders of each set; 1) 80%-100% of the lower leg length, 2) 100%-80% of the lower leg length. The whole testing lasted for an hour's visit to the laboratory. The summary protocol is in figure 4-1.

4.2.3. Measures, Design and Data Analysis

Measures and data analysis procedures were identical to Experiment 1. The duration of postural transition and transitional CoP path length in physical movement trials were analyzed using a mixed ANOVA with age (young, old) and gender (male, female) as between subjects factors, and attentional focus (visual-external, muscular-internal) and seat height (80% and 100% of the lower leg length) as the within subject factor.

Self-reported movement time in physical and imagined trials was analyzed using a mixed ANOVA with age (young, old) and gender (male, female) as between subjects, and movement condition (physical, imagined), attentional focus (visual-external, muscular-internal) and seat height (80% and 100% of the lower leg length) as within subject factors.

Ground reaction force data for the imagined movement trials were analyzed using a mixed ANOVA with age (young, old) and gender (male, female) as between subjects factors, and attentional focus (visual-external, muscular-internal) and seat height (80% and 100% of the lower leg length) as the within subject factor.


Participants (young adults = 24, older adults = 24)
Basic information:
-age, weight, height
- history of illness
Randomize
Young adults (n = 12)
Older adults (n = 12)
Young adults (n = 12)
Older adults (n = 12)
Visual-external focus
Muscular-internal focus
n = 6
n = 6
Vis80
Vis100
n = 6
n = 6
Mus80
Mus100
Muscular-internal focus
Visual-external focus
Testing:
-2 pracPhy…………...3 rec Phy (Mea: force, CoP, MT)
-2 prac MI……………3 rec MI (Mea: force, CoP, MT)
Testing:
-2 pracPhy…………...3 rec Phy (Mea: force, CoP, MT)
-2 prac MI……………3 rec MI (Mea: force, CoP, MT)
Vis100
VIs80
Mus100
Mus80
Testing:
-2 pracPhy…………...3 rec Phy (Mea: force, CoP, MT)
-2 prac MI……………3 rec MI (Mea: force, CoP, MT)
Testing:
-2 pracPhy…………...3 rec Phy (Mea: force, CoP, MT)
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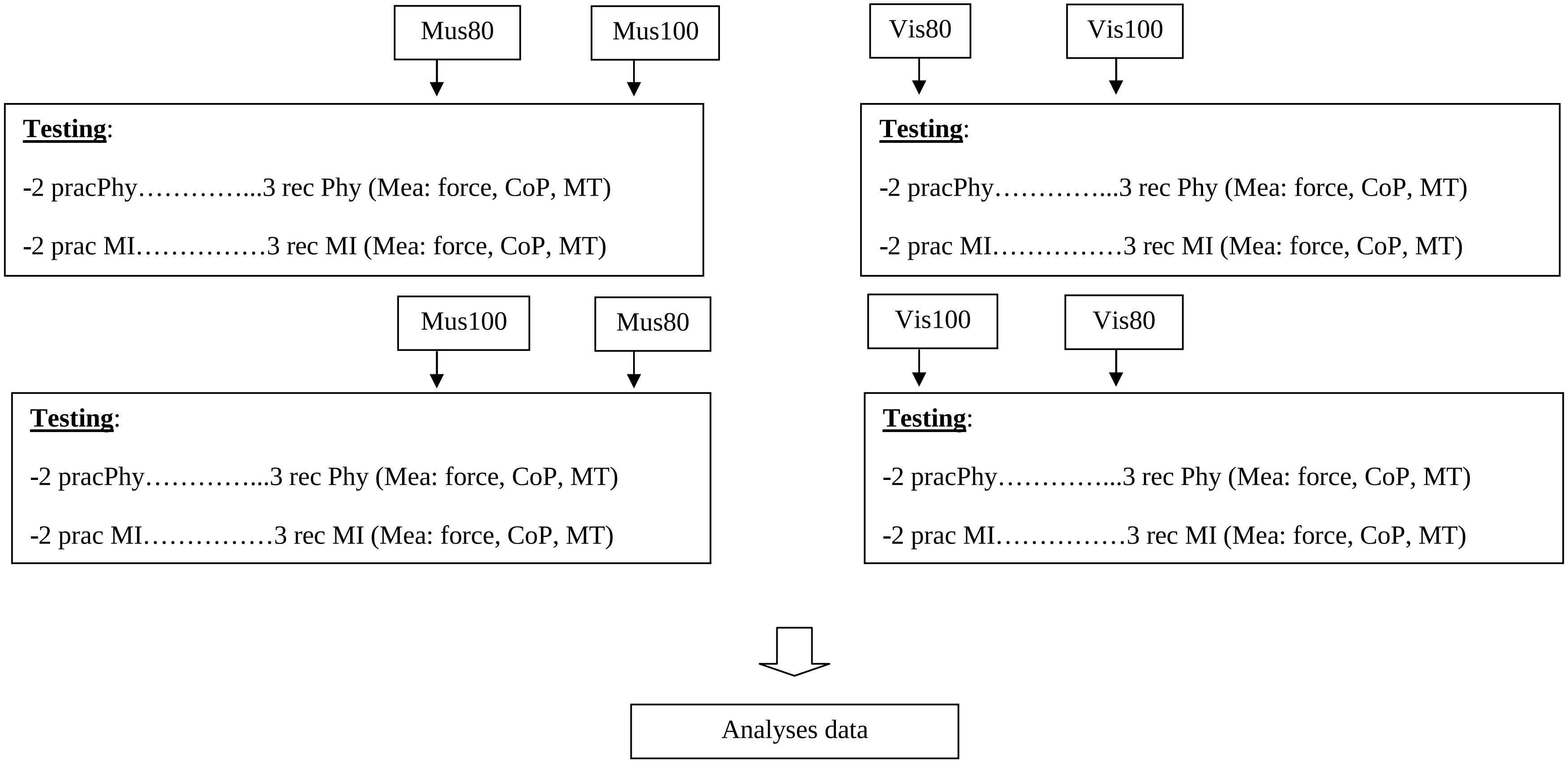


Figure 4-1: The summary protocol of Experiment 2

4.3. Results and Discussion

4.3.1. Duration of postural transition and stability of transition

The main effect of age on the duration of postural transition was significant (*F* (1, 44) = 25.29, $p < .001$, $\eta_p^2 = .36$; the transition was longer in older participants) (Figure 4-2). The interaction between attentional focus, seat height and age was significant (*F* (1, 44) = 6.24, $p < .05$, $\eta_p^2 = .12$). This interaction was further analysed as two 2(Age) x 2(Seat Height) ANOVAs (Figure 4-3), one each for the external (visual) and internal (muscular) focus conditions. In the external focus condition, there was only a significant main effect of age (*F* (1, 46) = 21.44, $p < .001$, $\eta_p^2 = .32$; older participants' transition duration was longer for both seat heights, $p < .001$). In the internal (muscular) focus condition, there was also a main effect of age (*F* (1, 46) = 24.94, $p < .001$, $\eta_p^2 = .35$); the transition was longer in older participants. The interaction between seat height and age was also significant (*F* (1, 46) = 12.53, $p < .001$, $\eta_p^2 = .21$; older participants' transition duration was shorter with standard seat height (H100) than with low seat (H80) conditions ($p < .01$).

Further, the interaction between seat height and age were marginally significant, *F* (1, 44) = 3.44, $p = .07$, $\eta_p^2 = .07$); whereas older participants' transition duration while performing STS from the lower seat height was longer than from the standard seat height ($p < .01$), young participants' transitional duration did not change with seat height conditions (Figure 4-4).

The interaction between seat height, age and gender was also significant (*F* (1, 44) = 5.22, $p < .05$, $\eta_p^2 = .11$). This interaction was further analysed as two

2(Age) x 2(Seat Height) ANOVAs, one each for male and female participants. There was a significant main effect of age for males (F (1, 46) = 29.02, p < .001, η_p^2 =.37), and for females (F (1, 46) = 19.01, p < .001, η_p^2 =.29); the transition was longer in older participants. The main effect of seat height on the duration of postural transition was significant for females (F (1, 46) = 5.91, p < .05, η_p^2 =.01); transition duration while performing STS from the lower seat height was longer than from the standard seat height. The interaction between seat height and age was also significant for females (F (1, 46) = 10.30, p < .01, η_p^2 = .18); whereas older females' transition duration while performing STS from the lower seat height was longer than from the standard seat height (p < .001), young participants' transitional duration did not change with seat height conditions (Figure 4-5). As expected, the duration of postural transition extracted from CoP data tended to be longer than those self-reported by the participants.

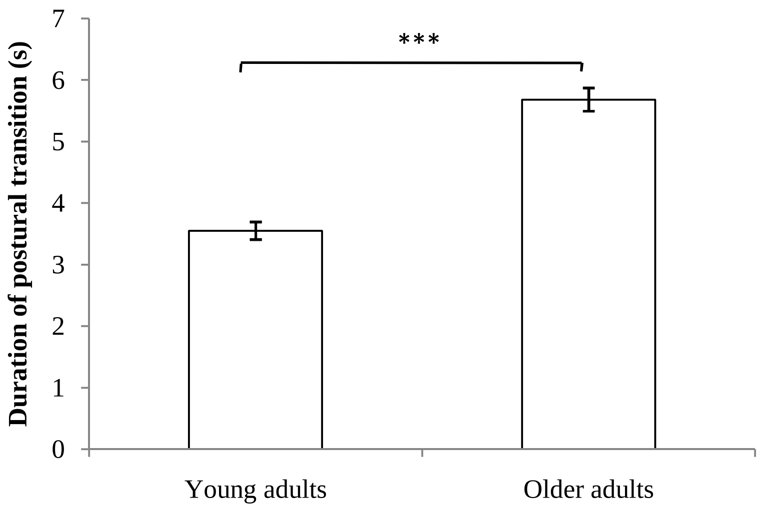


Figure 4-2: Effect of age on the duration of postural transition of young and older adults.

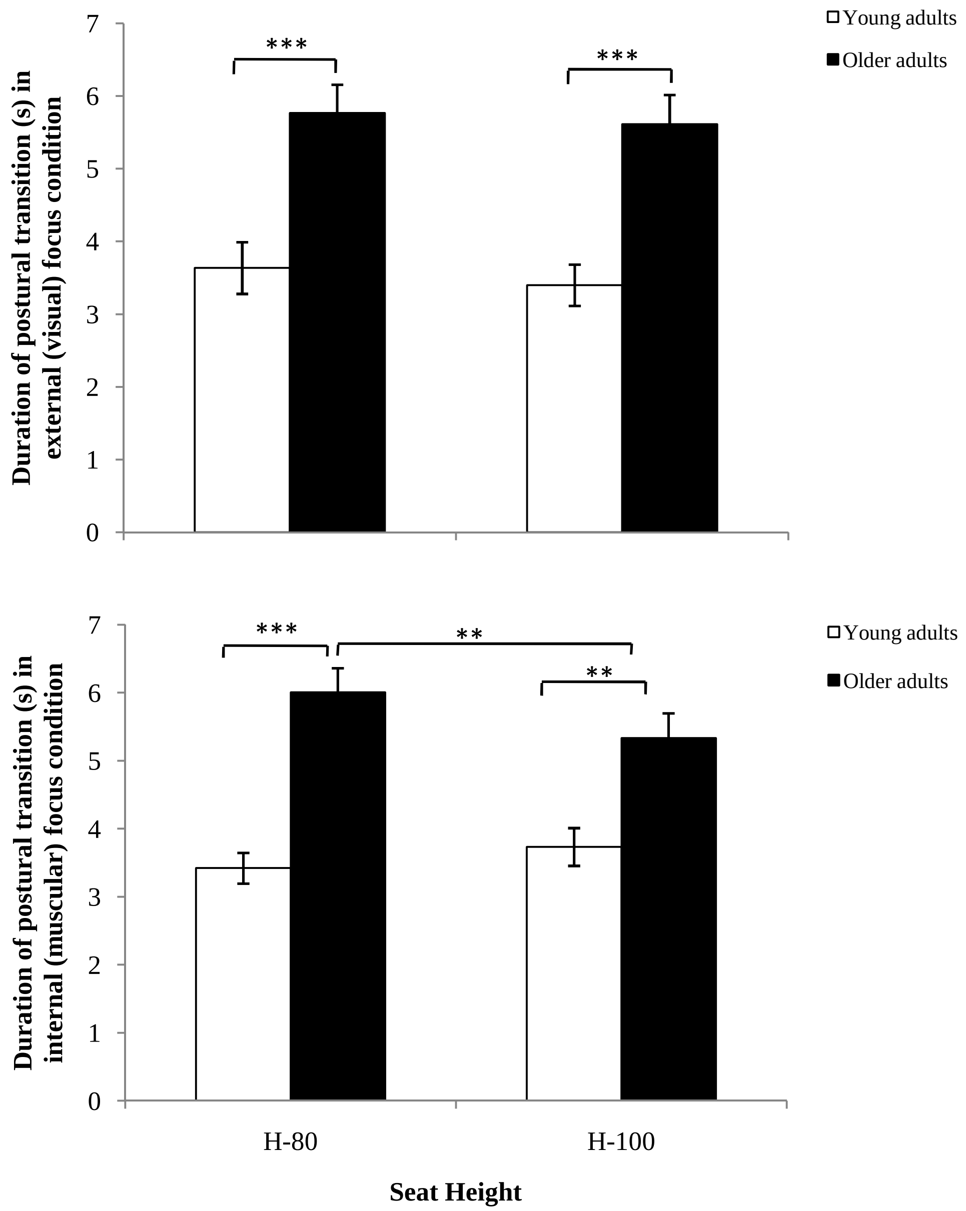


Figure 4-3: Effect of seat height and age on the duration of postural transition in external (visual) focus condition (top panel) and internal (muscular) focus condition (bottom panel).

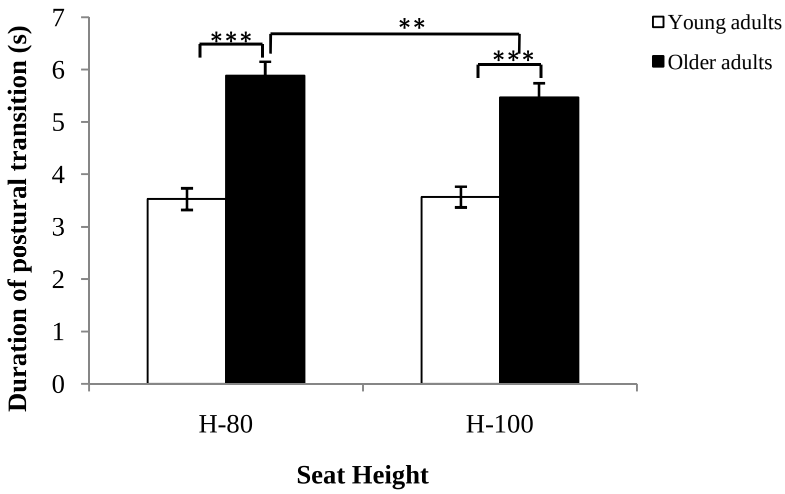


Figure 4-4: Effect of seat height and age on the duration of postural transition of young and older adults.

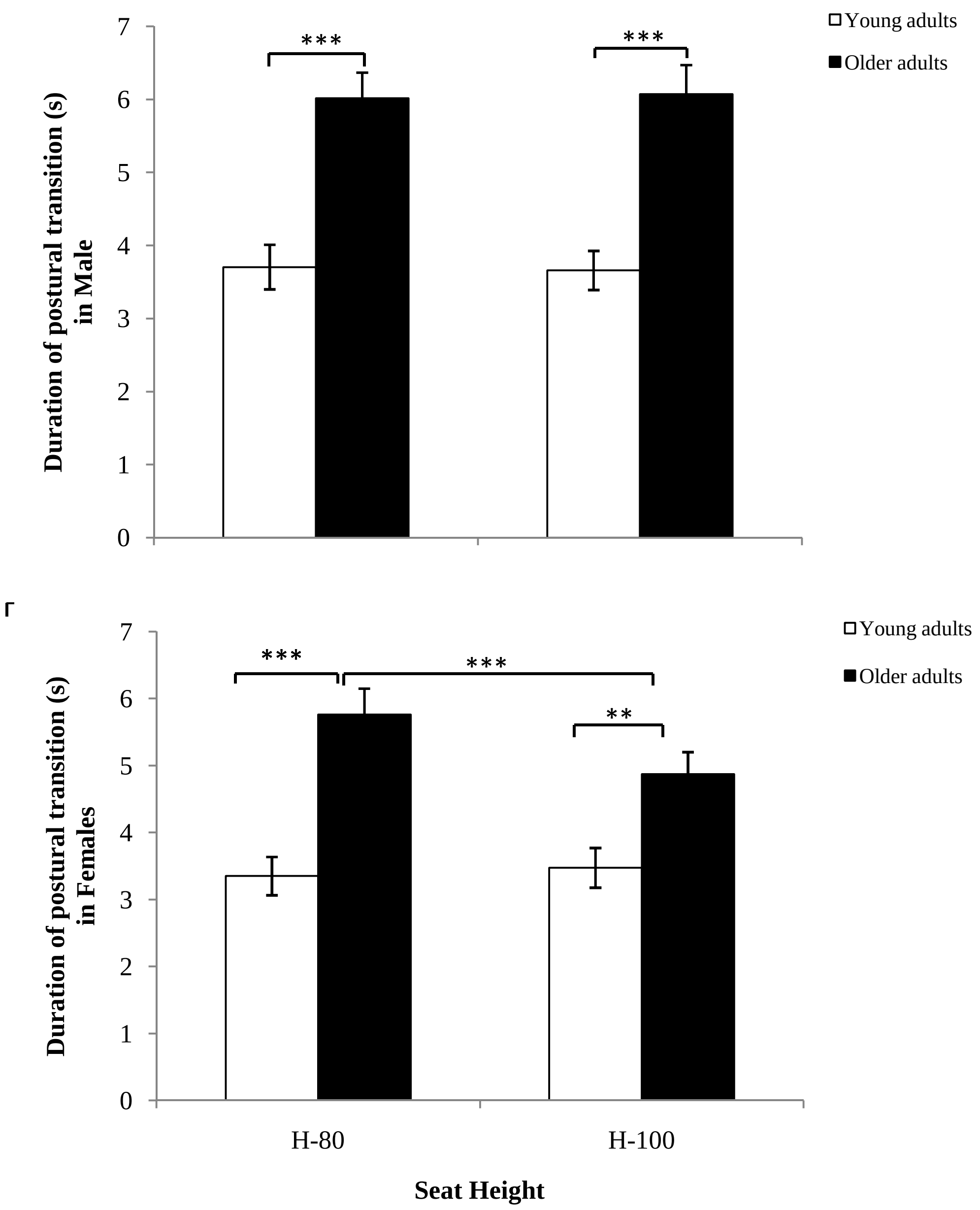


Figure 4-5: Effect of seat height and age on the duration of postural transition of male (top panel) and female (bottom panel) participants.

The main effect of age on the stability of postural transition was significant (*F* (1, 44) = 12.41, $p < .01$, $\eta_p^2 = .22$; young participants' CoP path length was shorter, meaning that their transition stability was greater; see Figure 4-6). Transitional stability was significantly greater when performing STS from the standard seat height (H100) (*F* (1, 44) = 4.31, $p < .05$, $\eta_p^2 = .09$), and the interaction between seat height and age was also significant (*F* (1, 44) = 11.03, $p < .01$, $\eta_p^2 = .20$). Older participants' CoP path length was longer (i.e., transition stability was less) with the low seat height condition (H80) than with the standard seat height condition (H100) ($p < .001$), whereas there was no significant difference in the stability of postural transition between seat height condition in young participants (Figure 4-7 and 4-8). The interaction between attentional focus and seat height was marginally significant (*F* (1, 44) = 3.34, $p = .07$, $\eta_p^2 = .07$); the stability of transition was greater in the muscular-internal focus with standard seat height than in the muscular-internal focus with low seat height ($p < .01$; see Figure 4-9). There were no other significant effects on the stability of postural transition.

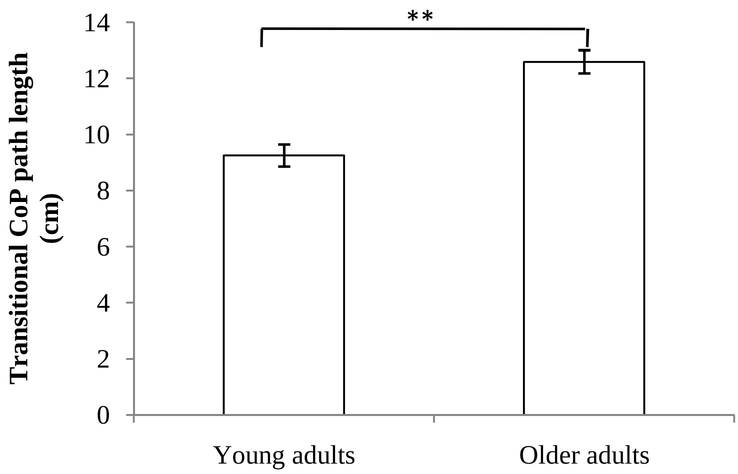


Figure 4-6: Effect of age on the stability of transition of young and older adults.

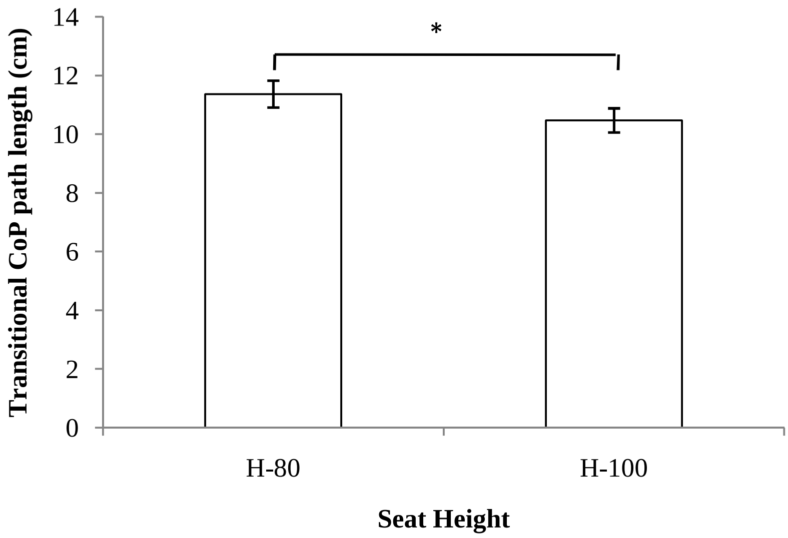


Figure 4-7: Effect of seat height on the stability of transition of young and older adults.

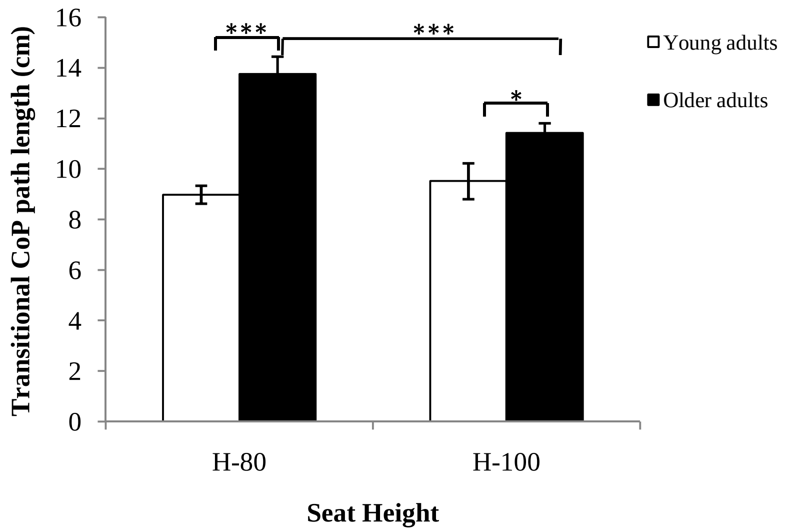


Figure 4-8: Effect of seat height and age on the stability of transition of young and older adults.

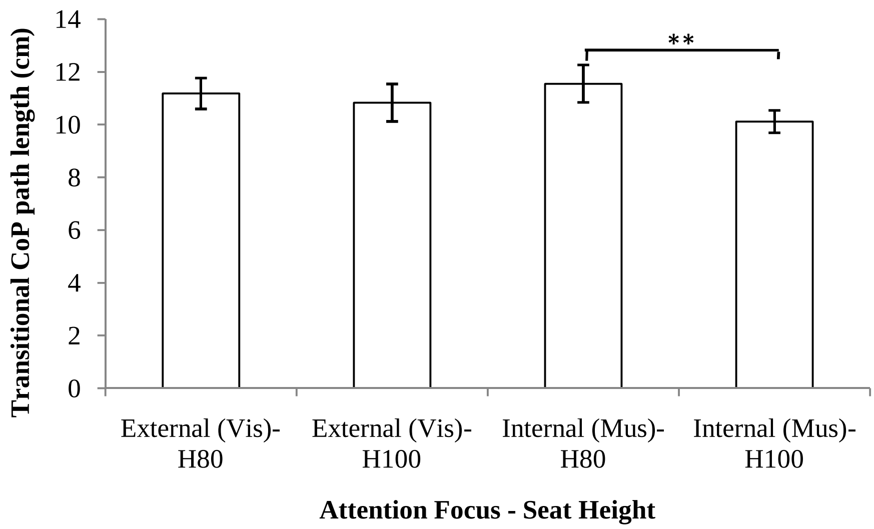


Figure 4-9: Effect of attentional focus and seat height on the stability of transition of young and older adults.

Unlike in Experiment 1, attentional focus did have an effect on older participants' duration of postural transition in this experiment. As shown in Figure 4-3, focusing on the load on thigh muscles enabled older participants to produce a more time-efficient STS movement when seat height was higher (and effort level was lower). We expected this effect based on the indication in Experiment 1 that older people accrue a performance advantage from muscular-internal attentional focus. Note that this modulation of movement speed was not found under external attentional focus in older adults, and under neither focus in young adults. However, the predicted benefit to the stability of postural transition under muscular focus (that was found in Experiment 1) did not occur here, even though lowering seat height did reduce stability, and did so to a greater extent in older adults, as we expected. One possibility is that the addition of the seat height manipulation, and the balance challenge that it introduced into the testing session, reduced the leeway for differences in transition stability that may have been available under less demanding conditions in Experiment 1. However, the effect of attentional focus on the duration of postural transition does reinforce (and complement) the novel finding from Experiment 1, that older adults' performance benefits from focusing attention on muscular activity.

4.3.2. Self-reported movement times

The main effect of age on the self-reported movement time was significantly different (F (1, 44) = 11.43, p < .01, η_p^2 = .21; the self-reported was longer in older participants). There were also significant main effects of seat height (F (1, 44) = 16.11, p < .001, η_p^2 = .27; self-reported movement time was longer in the low seat height condition (H80)), movement condition (F (1, 44) = 20.63, p < .001, η_p^2 = .32;

self-reported movement time was longer for imagined movements), and attentional focus (F (1, 44) = 13.85, $p < .001$, $\eta_p^2 = .24$; self-reported movement time was longer for muscular-internal focus; see Figure 4-10, 4-11, and 4-12). The interaction between seat height and age was significant (F (1, 44) = 4.12, $p < .05$, $\eta_p^2 = .09$); self-reported movement time was shorter during performing STS with standard seat height (H100) in both young and older participants ($p < .05$), but this difference was greater for older participants ($p < .001$) (Figure 4-10). The interaction between movement condition and age was also significant (F (1, 44) = 10.36, $p < .05$, η_p^2 = .19); self-reported movement time was longer during imagined movement in both age groups ($p < .05$), but this difference was greater for older participants ($p < .001$) (Figure 4-11). The interaction between attentional focus, age and gender was also significant (F (1, 44) = 9.62, $p < .01$, $\eta_p^2 = .18$). This interaction was further analysed as two 2(Age) x 2(Focus) ANOVAs, one each for male and female participants. There was a significant main effect of age for males (F (1, 94) = 37.19, $p < .001$, $\eta_p^2 = .28$), and for females (F (1, 94) = 4.06, $p < .05$, $\eta_p^2 = .04$); self-reported was longer in older participants. There were also significant main effects of attentional focus for males (F (1, 94) = 6.43, $p < .05$, $\eta_p^2 = .06$), and for females (F (1, 94) = 13.01, $p < .001$, $\eta_p^2 = .12$); self-reported movement time was longer for muscular-internal focus. The interaction between attentional focus and age was also significant for males (F (1, 94) = 5.20, $p < .05$, $\eta_p^2 = .05$), and for females (F (1, 94) = 7.94, $p < .01$, $\eta_p^2 = .08$); older males showed a greater increase in self-reported movement time for muscular-internal focus ($p < .01$), whereas young females' self-reported movement time was longer for muscular-internal focus ($p < .001$; see Figure 4-13).

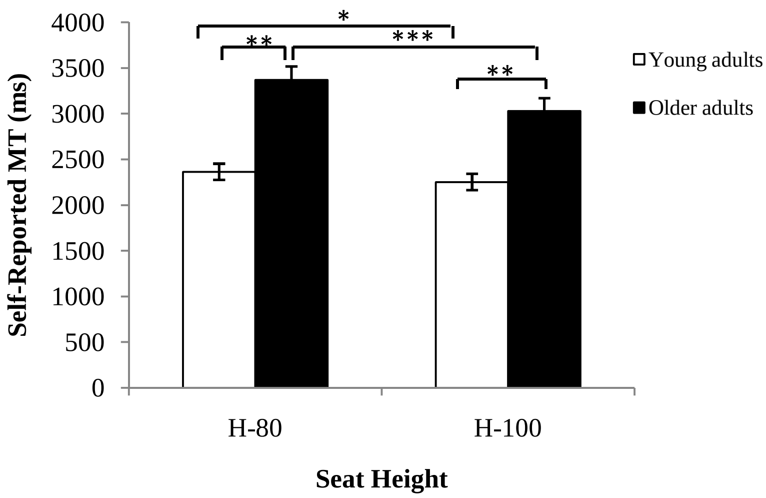


Figure 4-10: Effect of seat height on self-reported movement times of young and older adults.

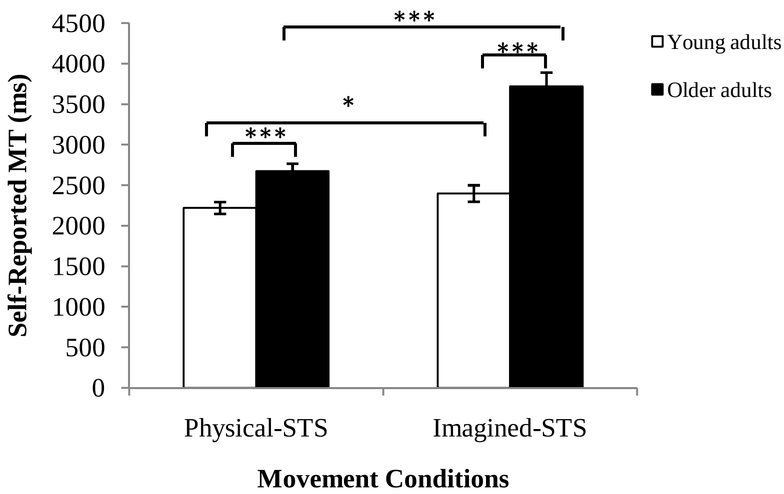


Figure 4-11: Effect of movement conditions on self-reported movement times of young and older adults. .

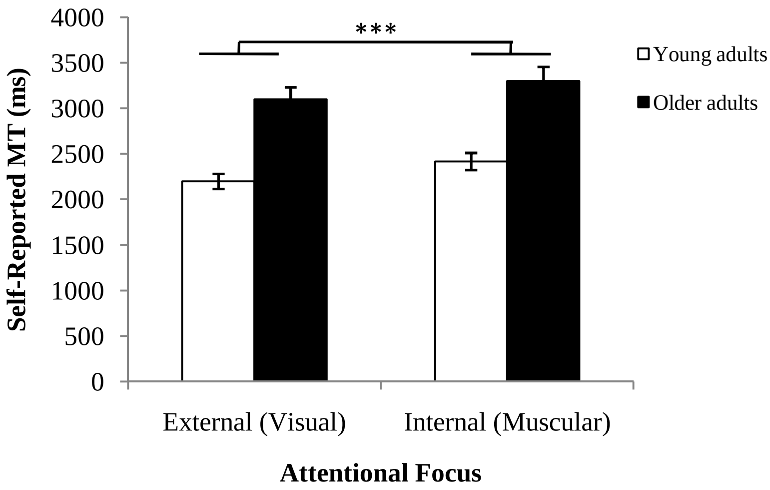


Figure 4-12: Effect of attentional focus on self-reported movement times of young and older adults.

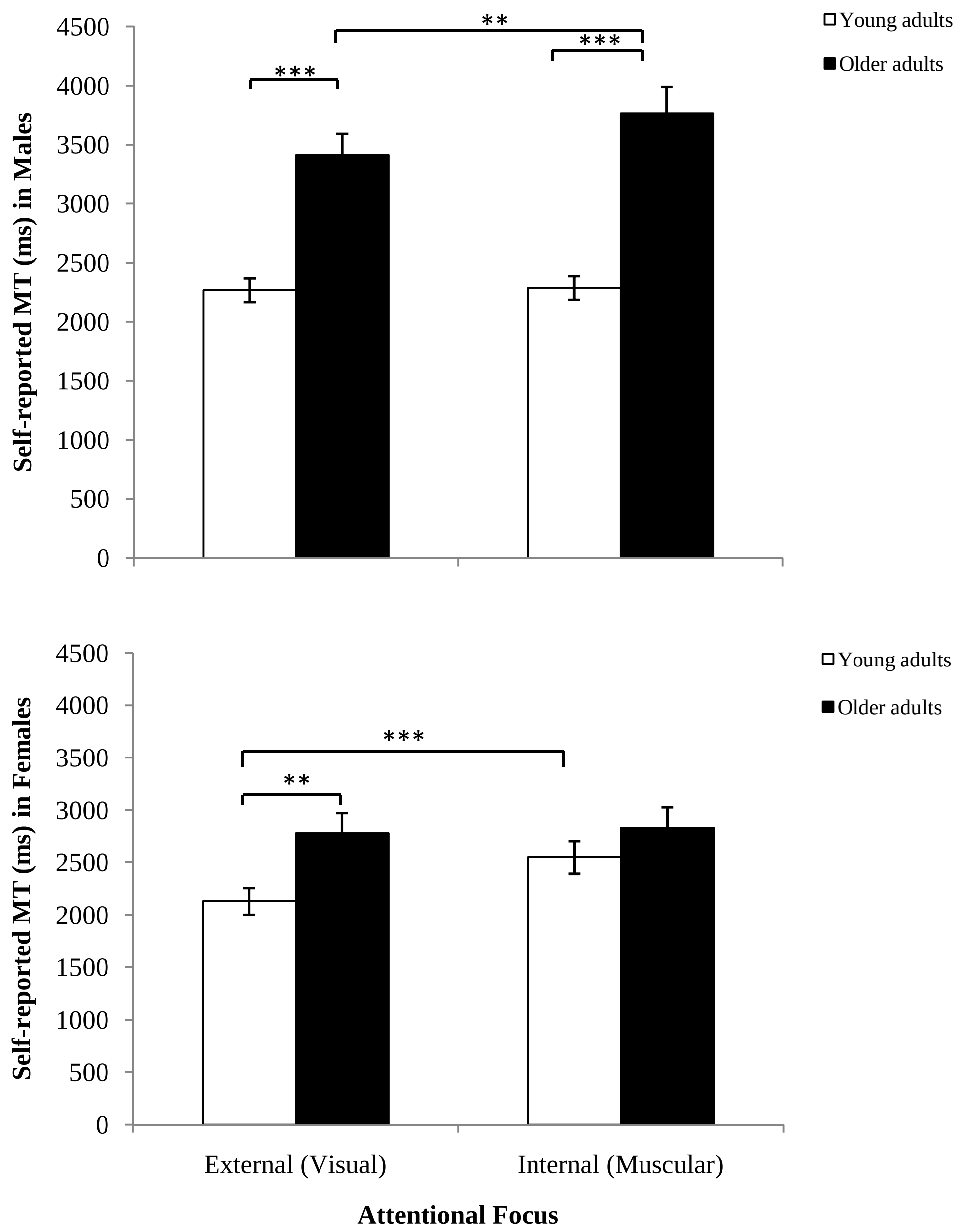


Figure 4-13: Effect of attentional focus and age on self-reported movement times of male (top panel) and female (bottom panel) participants.

As in Experiment 1, self-reported movement time was again longer, for both young and older participants, when they focused internally on muscular effort. As expected, reducing seat height (thereby increasing effort) resulted in longer self-reported movement time for both young and older participants, but the effect was numerically greater for the latter group. Interestingly, and unlike in Experiment 1, self-reported movement times were longer during imagery than execution, with the difference again being numerically larger for the older group. This difference between the experiments is likely to be the result of including a higher effort condition. Previous research on motor imagery has shown that, during motor execution, increased load may be met with increased effort so as to maintain movement speed, but during imagery, this increased effort is centrally coded along the temporal dimension, which results in reports of longer movement time instead (see, for example, Cerritelli et al., 2000; Decety, Jeannerod, & Prablanc, 1989). Longer self-reported movement time during imagery suggests that the seat height manipulation measurably affected the central motor planning process in all participants.

4.3.3. Muscular activation during imagined STS movements

The main effect of age on the range of ground reaction force was significant (F (1, 44) = 8.53, p < .01, η_p^2 = .16; force range was greater for older participants) (Figure 4-14). The main effect of seat height was also significant (F (1, 44) = 8.14, p < .01, η_p^2= .16); force range was greater when performing imagery STS with low seat height (H80) than with standard seat height (H100) (Figure 4-15). The interaction between attentional focus, seat height and age was significant (F (1, 44) = 5.31, p < .05, η_p^2 = .11). This interaction was further analysed as two 2(Age) x 2(Seat Height) ANOVAs, one each for external (visual) and internal (muscular) attentional focus conditions. There were significant main effects of age on the range of ground reaction force in external (visual) focus condition (F (1, 46) = 9.23, p < .01, η_p^2 = .17), and in internal (muscular) focus condition (F (1, 46) = 7.01, p < .05,

η_p^2 = .13); force range was greater for older participants. There were also significant main effects of seat height in external (visual) focus condition (F (1, 46) = 4.84, p < .05, η_p^2 = .10), and in internal (muscular) focus condition (F (1, 46) = 8.28, p < .05, η_p^2 = .15); force range was greater when performing imagery STS with low seat height (H80) than with standard seat height (H100). The interaction between seat height and age was also significant in internal (muscular) focus condition (F (1, 46) = 6.76, p < .05, η_p^2 = .13); older adults had a greater force range when performing imagery STS with low seat conditions (H80) than with standard seat height (H100) (p < .01; see Figure 4-16). Young participants' ground reaction force in external focus with low seat height was greater than with standard seat height (p < .01), although there was no significant interaction between seat height and age. There were no other significant effects on the range of ground reaction force.

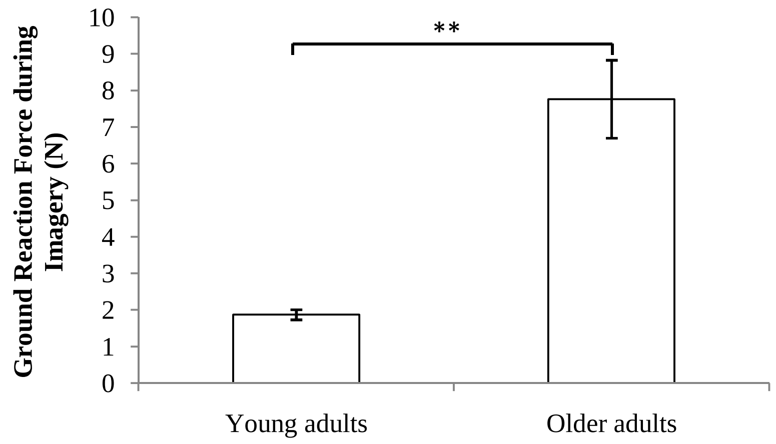


Figure 4-14: Effect of age on the ground reaction force of young and older adults.

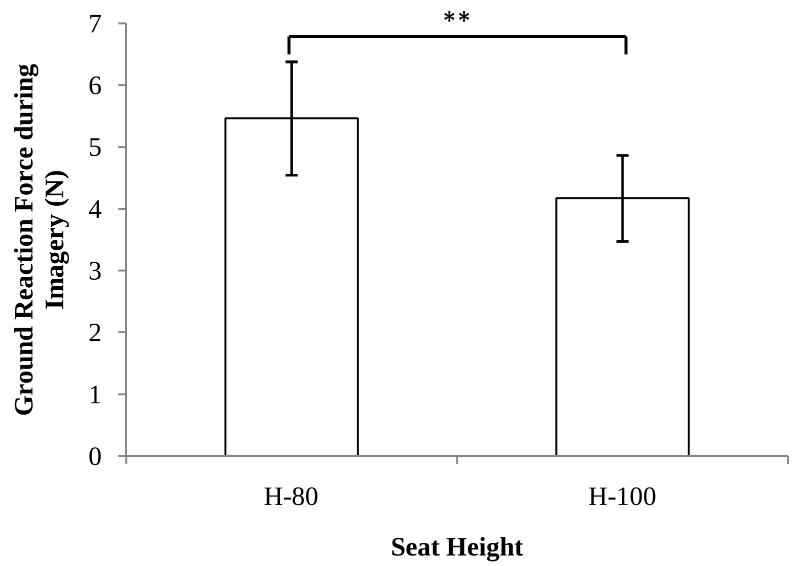


Figure 4-15: Effect of seat height on the ground reaction force of young and older adults.

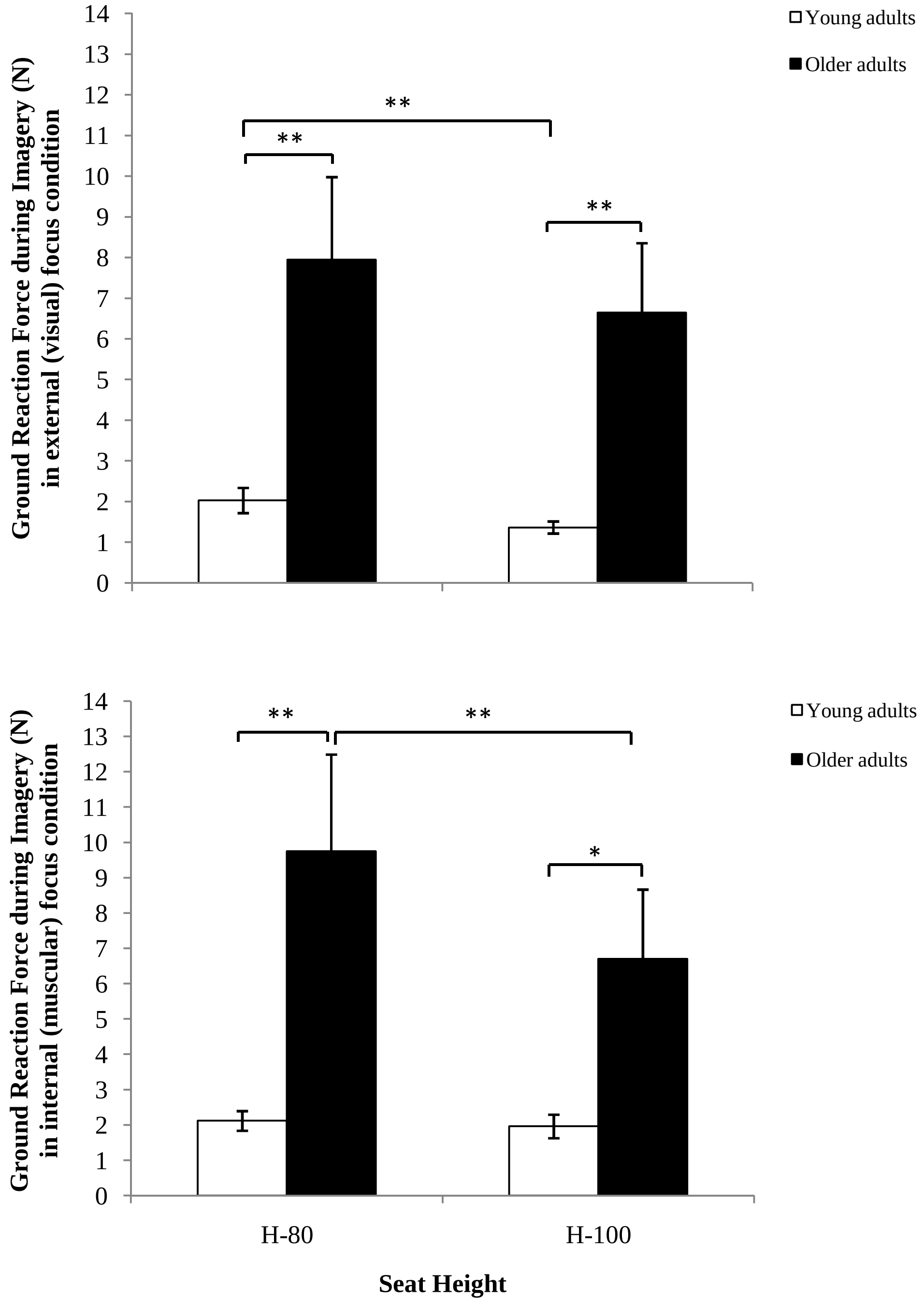


Figure 4-16: Effect of seat height and age on the ground reaction force in external (visual) focus condition (top panel) and internal (muscular) focus condition (bottom panel).

The amount of force transmitted to the ground was in the same 2 - 8 N range as observed Experiment 1, and older participants again exhibited greater muscular activity during imagery than young participants. Interestingly, increasing muscular effort by lowering seat height led to increased force generation during imagery (in both age groups), confirming that the observed force output was closely linked to task demands (e.g., Frank et al., 2001; Johnson, 2000), and therefore to the process of motor planning underlying imagery. Furthermore, this modulation of force production linked to seat height was found only for external attentional focus in the young participants and internal focus in the older group. This pattern reflects the age-related differences due to attentional focus that we previously observed in parameters of motor execution.

4.4. Conclusion

In the present study, duration of postural transition, stability of transition, self-reported movement time, and the ground reaction force produced during motor imagery were explored under different seat heights and attentional focus. The findings mainly showed three potential impacts of attentional focus on the planning and execution of STS movements. Firstly, when an effort manipulation was added by varying seat height, older participants' movement duration showed sensitivity to effort level, but only under muscular-internal attentional focus. However, the effect of attentional focus on older participants' stability no longer appeared. Secondly, older participants' self-reported movement time slowed for the lower seat height, and more so than for the young group, and self-reported movement times were now longer for imagined movements (for possible reasons discussed earlier). However, both age groups again self-reported quicker movement under external attentional focus. Finally, lowered seat height increased force production, but older participants showed a difference due to seat height (i.e., effort level) only under internal attentional focus, whereas young partipicants did so only under external focus.

In summary, young participants' movement execution and motor planning were convergent in their consistency with Wulf and colleagues' results (see a series of studies by Wulf et al.) in showing better performance under external attentional focus. Even their force transmission during imagery was modulated by effort requirements only under external focus condition. On the other hand, despite older adults' self-reported movement times for both physical and imagined trials indicated that they had the impression of more efficient coordination under external attentional focus, their physical STS performance benefitted from their attention being focused on muscular effort. Also, during imagined movements, older participants were able to modulate their leaked force output to the required effort level only under muscular-internal attentional focus. This could be an indication of reduced inhibition in older participants, or reflect older participants' felt need to generate greater force as a result of their higher weight (as was noted in Chapter 3). Here, it was observed that young adults modulated their force production (during imagery) under external focus, but older adults did so only in the internal focus condition. This suggests that differences between young and older adults' force production may not be simply a result of differences in body weight. However, the effect of attentional focus on the duration of postural transition during physical STS movements and force output during imagined STS movements do reinforce (and complement) the novel finding from Experiment 1, that older adults' performance benefits from focusing attention on muscular activity.

Chapter 5: Experiment 3

A secondary manual task differentially affects STS movements performed under different foci of attention

5.1. Introduction

In this experiment, we studied STS movements performed (or imagined) with different foci of attention under conditions of multi-tasking. Effective human function is characterised by the ability to perform more than one task at a time, such as carrying an object while walking, or holding an object while standing up. However, focusing on the performance of one task can affect performance of the other. Importantly, controlling body posture while performing a concurrent secondary task may be identified as a general problem for older adults, because they are more likely than young adults to exhibit dual-task interference in such situations (Fraizer & Mitra, 2008).

Experiment 1 showed that specific attentional focus can affect STS performance under single-task conditions. It is of interest to clarify the impact of engaging in another motor task during STS movements performed under different foci of attention. This experiment considered the ability to perform STS movements while holding (and balancing) an object in the hand. Sit-to-stand and stand-to-sit movements while carrying objects in the hands are common activity. Based on the literature, using the arms while performing STS movements appears to affect performance. Carr (1992) reported that arm position has an influence on the position of the body's CoM. The CoM moves forward at the end of STS movements with the arm pointed, whereas restricting the arm leads to a different pattern of angular displacement. Most previous research did not allow participants to use the arm during STS movements; participants were instructed to perform the movements with their hands by the side, on the lap, crossed on the chest, or placed on armrests (e.g., Alexander et al., 1991; Etnyre & Thomas, 2007; Gillette et al., 2012). This was despite the fact that some studies have reported that using the arm during STS movements is common among older adults and also among young people (Durward, 1994; Wheeler et al., 1985). We hypothesized that young and older participants may respond differently to changes in attentional focus from body-internal (proprioceptive) to body-external (visual) aspects of coordination while performing STS movement and simultaneously holding an object in the hand.

In the present experiment, we compared the effects of external versus internal focus on physical and imagined instances of STS movements while holding a juice bottle in the hand. As described below, the task involved not only holding the bottle in the hand, but also ensuring that it remained as vertical as possible (so as not to allow the juice to spill). We expected this emphasis on the orientation of the bottle in the environment to introduce an external attentional focus bias. In Experiments 1 and 2, older participants showed performance advantages when they focused attention on body-internal dynamics (such as the changing load on their thigh muscles), whereas young participants consistently performed better under external attentional focus. Thus, a key purpose of the present experiment was to study the effects across age groups of introducing a specific body-external goal during the postural transition. We expected young adults to continue to perform better under external attentional focus, but we wanted to investigate whether older people’s performance pattern would be altered under this novel task condition (i.e., whether they would continue to show performance advantages under internal-muscular focus when the task had a central body-external performance requirement).

We tested the effects on self-reported movement time of focusing on the change in viewpoint relative to the environment (external focus) or the change in muscular load on the thighs (internal focus) under three conditions - arms by the side, holding the juice bottle in the dominant hand, and holding the juice bottle in the non-dominant hand. We also measured the self-reported and actual movement times of physical STS movements, the smoothness or stability of the physical movements (which we measured as the path length of the centre of pressure during standing up), and the ground reaction force during imagined STS movement under these three arm tasks.

5.2. Method

The common method, described in Chapter 2, was used, but with the following differences.

5.2.1. Participants

Twenty four healthy young adults (18 - 30 yrs) and 24 older adults (60 - 80 yrs) took part in the study, receiving course credit and payment for their participation. Young adults (Male: N = 13, M_{age} 20.00 $\pm$ 0.57 yrs, M_{weight} 71.23 $\pm$ 2.72 kg, M_{height} 175.46 $\pm$ 1.64 cm; Female: N = 11, M_{age} 19.55 $\pm$ 0.58 yrs, M_{weight} 56.55 $\pm$ 2.99 kg, M_{height} 164.09 $\pm$ 1.76 cm) were recruited from the University of Warwick student population, and older adults (Male: N = 13, M_{age} 70.92 $\pm$ 1.05 yrs, M_{weight} 80.00 $\pm$ 3.50 kg, M_{height} 175.54 $\pm$ 1.48 cm; Female: N = 11, M_{age} 71.55 $\pm$ 1.06 yrs, M_{weight} 68.82 $\pm$ 2.73 kg, M_{height} 162.18 $\pm$ 2.20 cm) came from a community-based volunteer panel maintained by the research group. All participants were screened for unimpaired ability to stand up several times per session from a sitting position and had no significant medical history or current problem affecting balance or everyday motor function (Appendix 2). Two (1 male, 1 female) young adults reported having had a past medical condition affecting balance. Three young adults (male) and 2 older adults (1 male, 1 female) had past experience of loss of balance, falling or weakness in the legs, and 1 (female) older adult reported taking medication with possible effects on balance. In addition, all participants were asked about handedness using the Edinburgh Handedness Inventory Questionnaire. Twenty one young adults (11 male, 10 female) and 23 older adults (12 male, 11 female) were right handed. Only one (male) older adult was left handed, and 3 young adults (2 male, 1 female) were ambidextrous. Participant screening, consent procedures, and ethical approval were the same as in Experiment 1.

5.2.2. Experimental procedures

Participants performed physical and imagined STS movements while holding the juice bottle in the hand (there were three conditions - arms by the side, holding the juice bottle in the dominant hand, and holding the juice bottle in the non-dominant hand), and under two focus conditions– visual-external (focus on a fixation point on the wall) and muscular-internal (focus on the load on thigh muscles). Participants were randomly assigned to trial-order groups; 1) the visual-external and muscular-internal, and 2) the muscular-internal and visual-external. Participants were also counterbalanced into six different orders of each set; 1) arms resting–holding the juice bottle in the dominant hand–holding the juice bottle in the non-dominant hand, 2) arms resting–holding the juice bottle in the non-dominant hand–holding the juice bottle in the dominant hand, 3) holding the juice bottle in the dominant hand–arms resting-holding the juice bottle in the non-dominant hand, 4) holding the juice bottle in the dominant hand–holding the juice bottle in the non-dominant hand–arms resting, 5) holding the juice bottle in the non-dominant hand–arms resting–holding the juice bottle in the dominant hand, and 6) holding the juice bottle in the non-dominant hand–holding the juice bottle in the dominant hand–arms resting. The experimental session consisted of an hour's visit to the laboratory. The summary protocol is in figure 5-1.

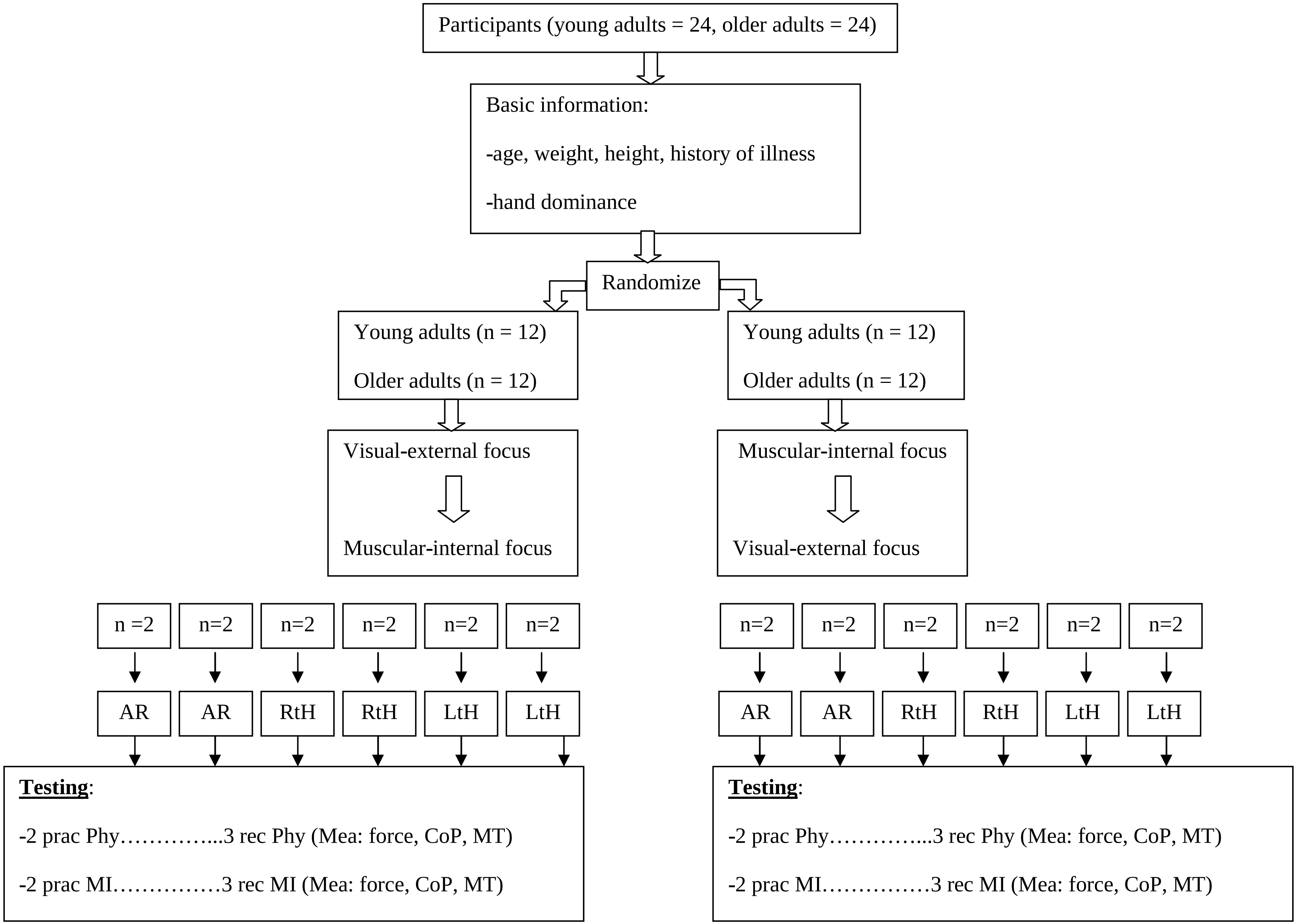
Participants performed STS movements while holding and balancing the juice bottle in the hand. The 500 ml bottle was cylindrical and did not have a separate handle (figure 5-2: A). It was filled with juice up to 400 ml (figure 5-2: B). Participants were asked to stand up as naturally as possible, while holding the bottle upright in the way they would do in everyday life (i.e., without tilting the bottle or spilling the juice). Above the level of the juice in the bottle, there was a tissue layer (figure 5-2: C) that would get wet if the bottle tilted and the juice contacted the tissue. Participants were asked not to tilt the bottle so much that this happened. They were informed, however, that the bottle was actually sealed, so the juice could not in fact spill out of the bottle.

5.2.3. Measures, Design and Data Analysis

Measures and data analysis procedures were identical to Experiment 1. The duration of postural transition and transitional CoP path length in physical movement trials were analyzed using a mixed ANOVA with age (young, old) and gender (male, female) as between subjects factors, and attentional focus (visual-external, muscular-internal), and manual task (arms by the side, holding the juice bottle in the dominant hand, holding the juice bottle in the non-dominant hand) as within subject factors.

Self-reported movement time in physical and imagined trials was analyzed using a mixed ANOVA with age (young, old) and gender (male, female) as between subjects, and movement condition (physical, imagined), attentional focus (visual-external, muscular-internal), and manual task (arms by the side, holding the juice bottle in the dominant hand and holding the juice bottle in the non-dominant hand) as within subject factors.

Ground reaction force data for the imagined movement trials were analyzed using a mixed ANOVA with age (young, old) and gender (male, female) as between subjects factors, and attentional focus (visual-external, muscular-internal), and manual task (arms by the side, holding the juice bottle in the dominant hand, holding the juice bottle in the non-dominant hand) as the within subject factor.


Participants (young adults = 24, older adults = 24)
Basic information:
-age, weight, height, history of illness
-hand dominance
Randomize
Young adults (n = 12)
Older adults (n = 12)
Young adults (n = 12)
Older adults (n = 12)
Visual-external focus
Muscular-internal focus
Muscular-internal focus
Visual-external focus
n =2
n=2
n=2
n=2
n=2
n=2
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AR
AR
RtH
RtH
LtH
LtH
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RtH
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LtH
Testing:
-2 prac Phy…………...3 rec Phy (Mea: force, CoP, MT)
-2 prac MI……………3 rec MI (Mea: force, CoP, MT)
Testing:
-2 prac Phy…………...3 rec Phy (Mea: force, CoP, MT)
-2 prac MI……………3 rec MI (Mea: force, CoP, MT)

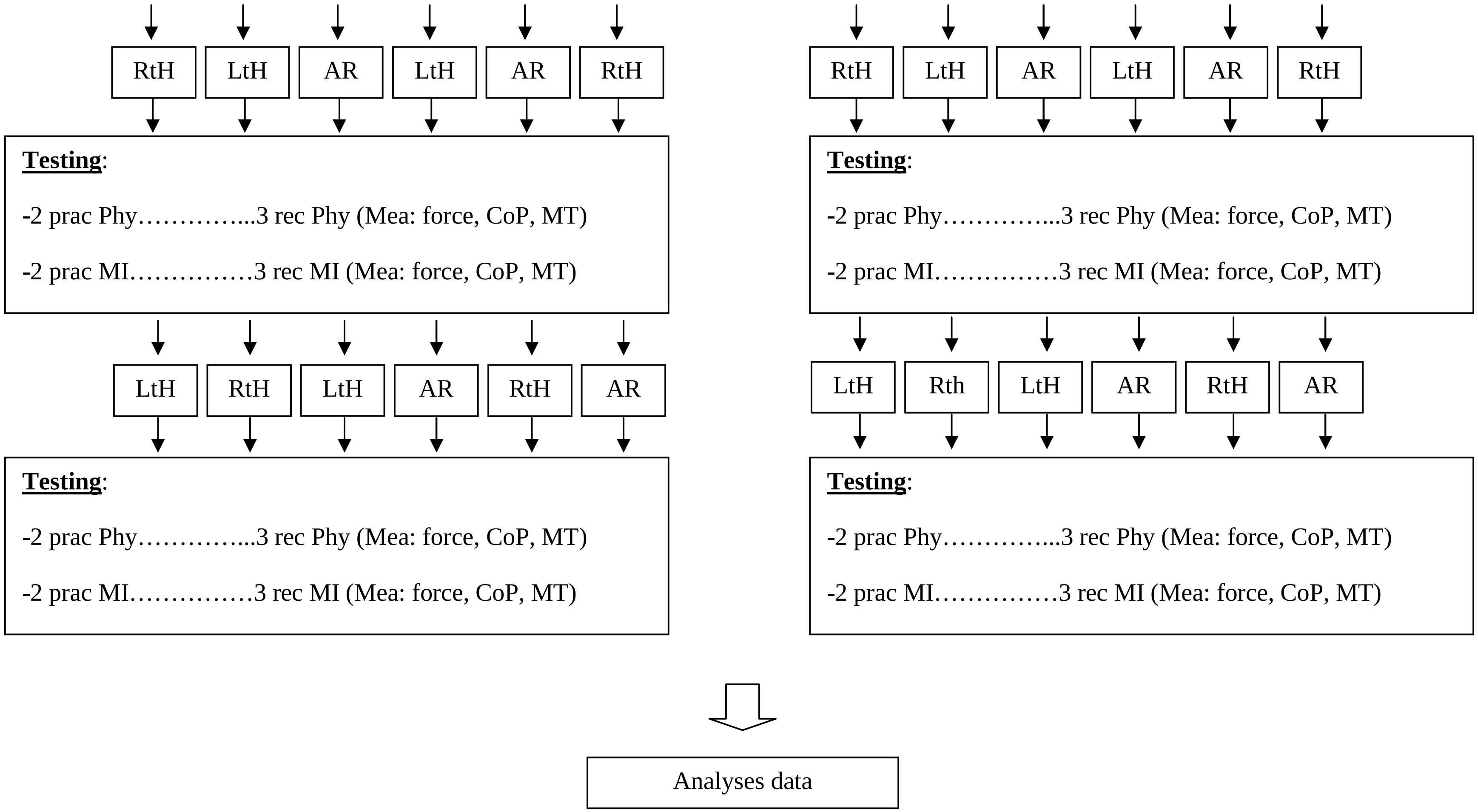


Figure 5-1: The summary protocol of Experiment 3

A B

C

Figure 5-2: The 500 ml juice bottle used in Experiment 3 (A). The bottle was filled to 400 ml (B), and a tissue was placed on the inside of the cap (C) so that contact between the juice and the cap would be detectable.

5.3. Results and Discussion

5.3.1. Duration of postural transition and stability of transition

The main effect of age on the duration of postural transition along the AP direction was significant (F (1, 44) = 10.54, p < .01, η_p^2 = .19; the transition was longer in older participants) (Figure 5-3). The main effect of attentional focus was significant (F (1, 44) = 6.40, p < .05, η_p^2 = .13; the duration of transition in the muscular-internal condition was longer than in the visual-external focus condition)

(Figure 5-4). Furthermore, the main effect of the manual task condition was significant (F (2, 88) = 3.97, p < .05, η_p^2 = .08; the duration of transition with arms at rest was longer than while holding the juice bottle in non-dominant hand) (Figure 5-5). The numerical trend was the same while holding the juice bottle in the dominant hand, but the difference from the rest condition was not significant. The interaction between manual task conditions and age was marginally significant (F (2, 88) = 2.45, p = .09, η_p^2 = .05); whereas older participants' transition duration with arms at rest was longer than while holding the juice bottle in the dominant hand (p < .05) (and, the mean for holding the bottle in the non-dominant hand was in the middle, but not significantly different from either), young participants' transitional duration did not change with manual task conditions (Figure 5-6). As before, the duration of postural transition extracted from CoP data tended to be longer than those self-reported by the participants.

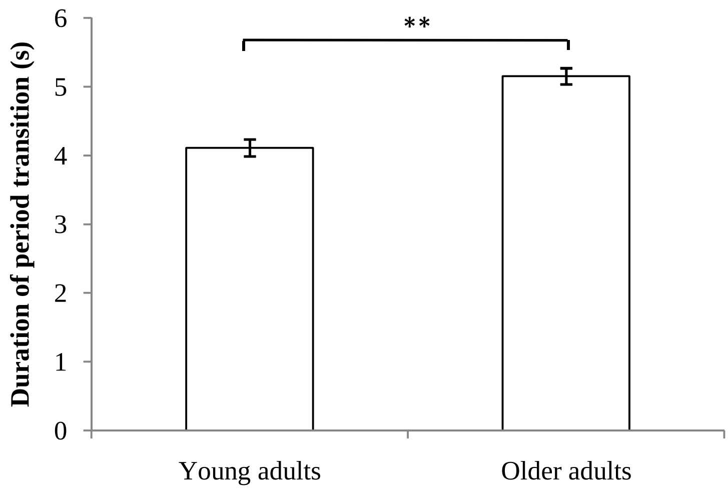


Figure 5-3: Effect of age on the duration of postural transition of young and older adults.

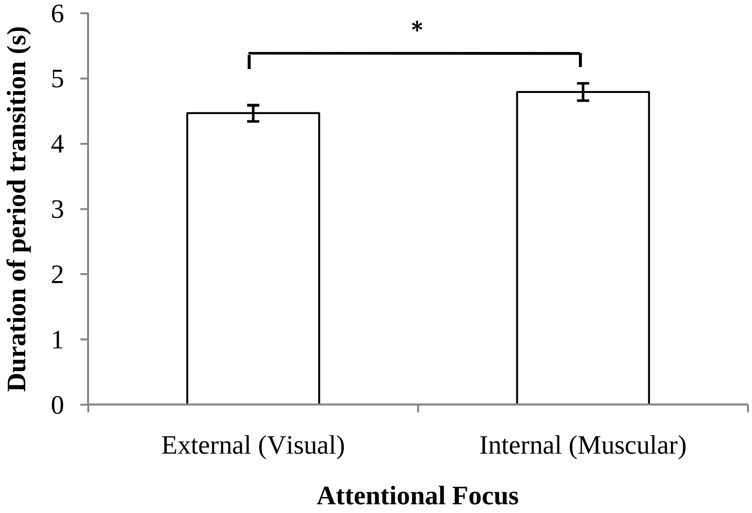


Figure 5-4: Effect of attentional focus on the duration of postural transition of young and older adults.

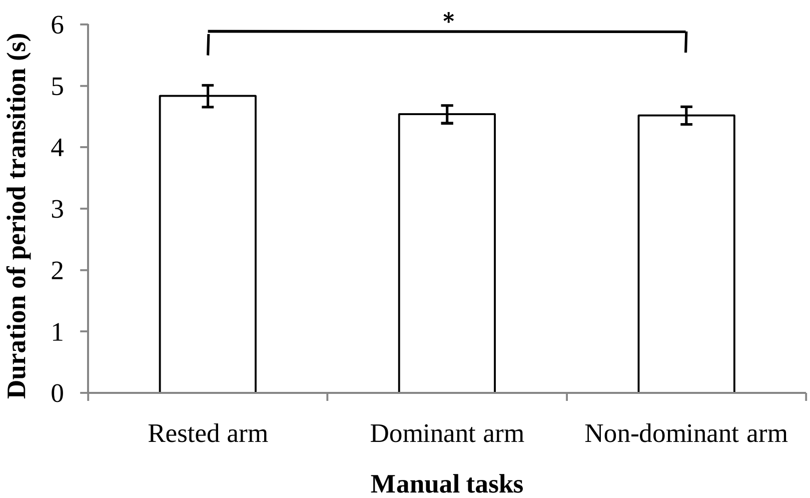


Figure 5-5: Effect of manual task on the duration of postural transition of young and older adults.

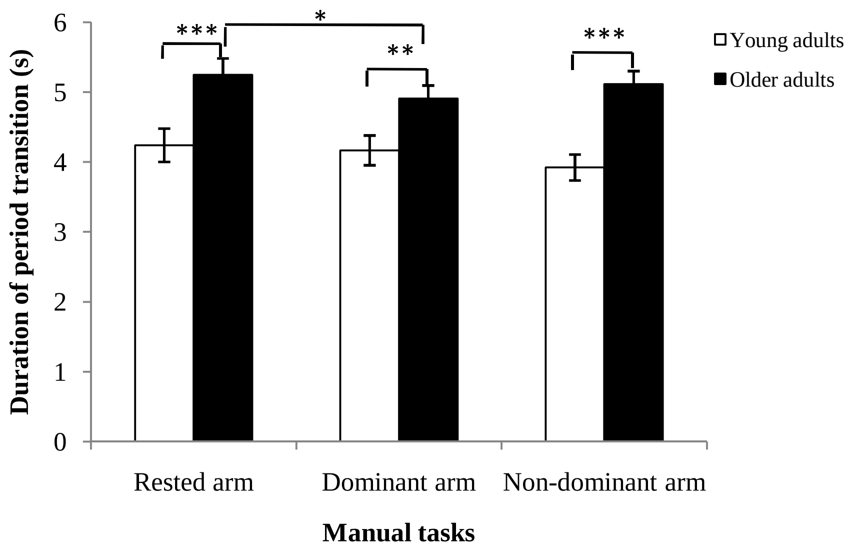


Figure 5-6: Effect of manual task and age on the duration of postural transition of young and older adults.

The stability of postural transition, as measured by the anteroposterior CoP path length during the transition interval, was greater in young participants (F (1, 44) = 15.98, p < .001, η_p^2 = .27; see Figure 5-7). There was no other significant effect on the stability of postural transition.

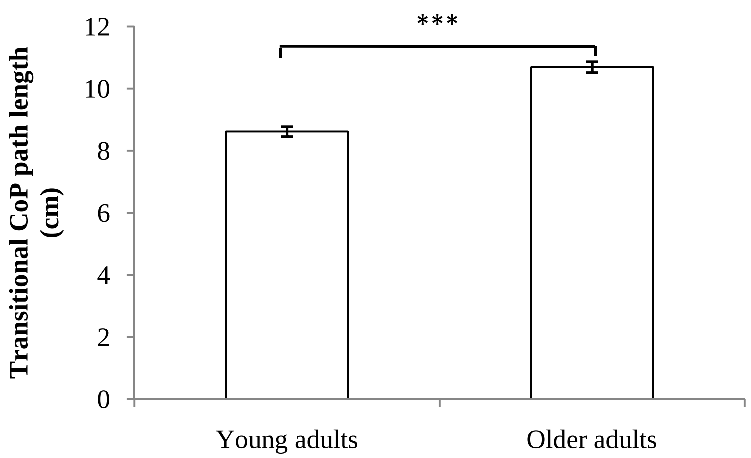


Figure 5-7: Effect of age on the stability of transition of young and older adults.

Unsurprisingly, older participants' postural transition was longer and less stable than young participants. The only effect of attentional focus was the main effect, showing a shorter postural duration in the external focus condition. As there was no interaction with age, this suggests that both age groups produced a more time-efficient STS movement when focusing externally. This was consistent with their shorter self-reported movement times in the external focus condition (for both physical and imagined movements, see below). This result agreed with the line of studies by Wulf and colleagues, and suggested that body-external attentional focus was beneficial in a task setting with explicit body-external goals. In older people, this amounted to a reversal in trend compared to Experiment 1.

The main effect of task condition showed a tendency to shorten the transition duration in the dual-task conditions. The marginally significant interaction with age suggests that this trend may have occurred more consistently in older participants. One possible interpretation is that this shortening of the STS transition was a strategic attempt to minimize the period of instability in the fluid level in the bottle.

5.3.2. Self-reported movement times

There was a significant main effect of movement condition (F (1, 44) = 9.02, p < .01, η_p^2 = .17); self-reported movement time was greater during imagined movement (Figure 5-8). The main effect of attentional focus was significant (F (1, 44) = 7.30, p < .01, η_p^2 = .14; self-reported movement time in the muscular-internal condition was longer than in the visual-external focus condition) (Figure 5-9). In addition, the main effect of manual task was significant (F (2, 88) = 6.35, p < .01, η_p^2 = .13); self-reported movement time with arms at rest was shorter than while holding the juice bottle in the dominant (p < .01) or non-dominant hand (p < .001; see Figure 5-10). There were no other significant effects on self-reported movement time.

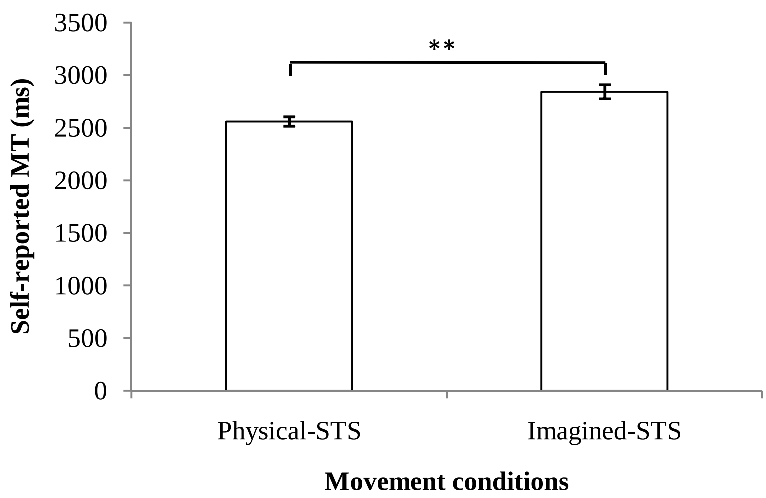


Figure 5-8: Effect of movement conditions on self-reported movement times of young and older adults.

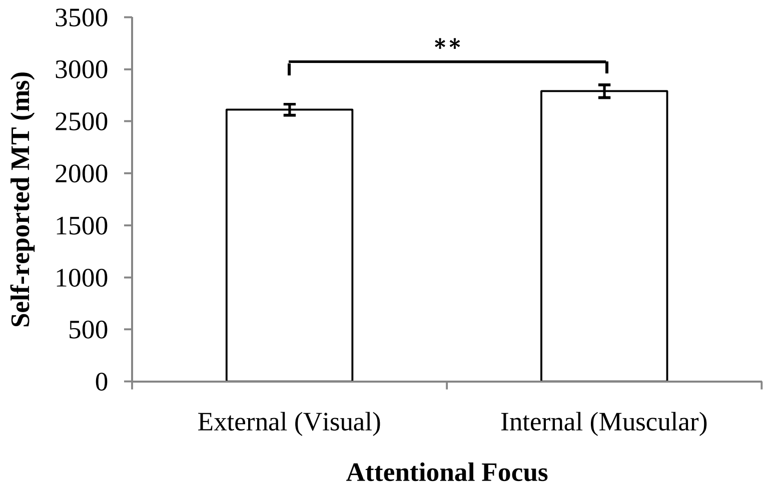


Figure 5-9: Effect of attentional focus on self-reported movement times of young and older adults.

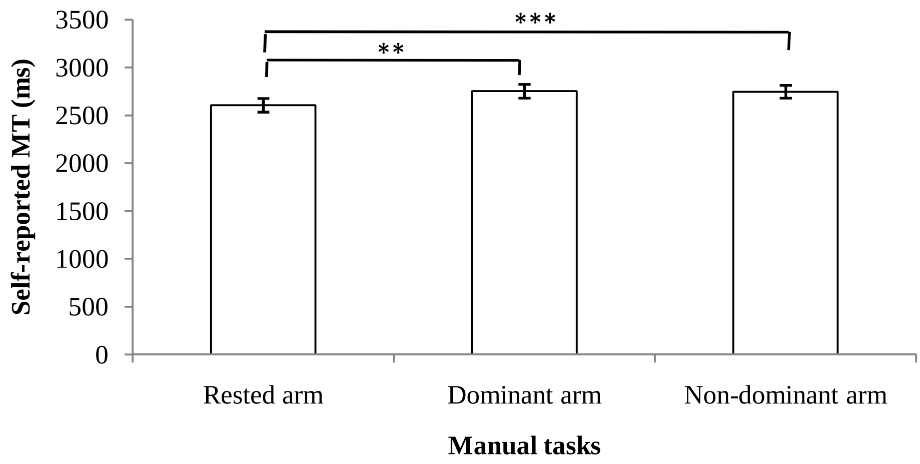


Figure 5-10: Effect of manual task on self-reported movement times of young and older adults.

As would be expected, participants reported longer MT when they had to hold the juice bottle while standing up, and ensure that the bottle remained vertical, than when they did not have this task to do. Participants also reported longer MT when they imagined, rather than performed the task. Carrying the juice bottle involved managing an added load, and it is likely that participants expressed this in the temporal dimension during imagery (see Section 4.3.2). Participants also reported longer MT when they focused attention internally rather than externally. This agrees with the notion that the manual task of holding (and not tilting) the juice bottle emphasized how the body (and the hand) was oriented relative to the environment, and therefore favoured an external attentional focus.

5.3.3. Muscular activation during imagined STS movements

The main effect of gender on the range of ground reaction force along the AP direction was significant (F (1, 44) = 5.23, p < .05, η_p^2 = .11; force range was greater for male participants) (Figure 5-11). The main effect of attentional focus was also significant (F (1, 44) = 5.64, p< .05, η_p^2 = .11; force range in the muscular-internal focus was greater than in the visual-external focus condition) (Figure 5-12).

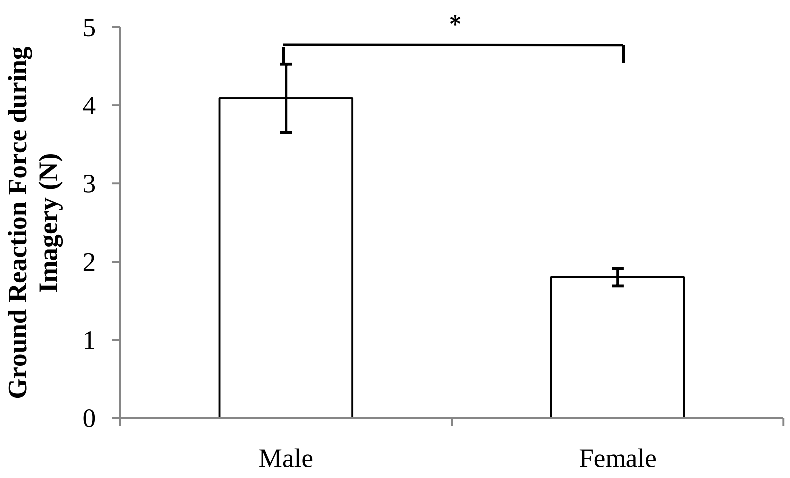


Figure 5-11: Effect of gender on the ground reaction force of young and older adults.

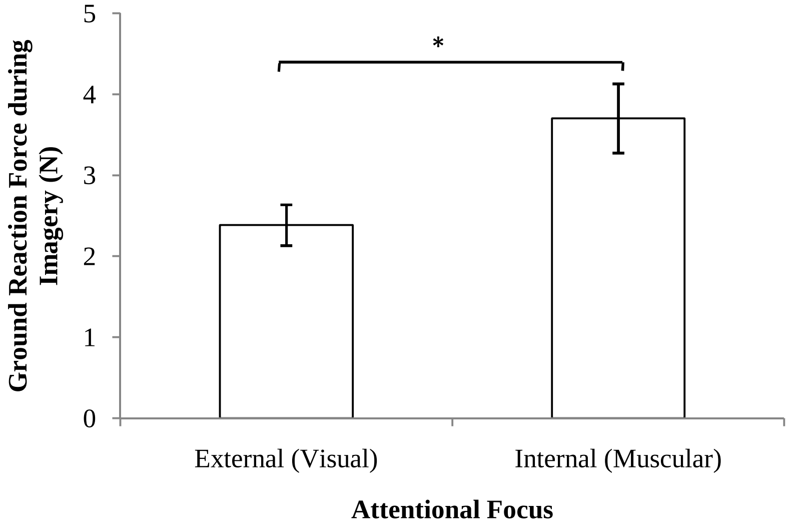


Figure 5-12: Effect of attentional focus on the ground reaction force of young and older adults.

As in Experiments 1 and 2, despite instructions to imagine, but not execute, the STS movements, both young and older participants transmitted a small amount of force to the ground (i.e., generated muscular activation) along the direction of imagined STS movements. The greater force production in male participants, and in the internal attentional focus condition, was consonant with previous results. The added manual task in the present experiment did not alter the pattern of force production during imagery.

5.4. Conclusion

This experiment studied self-reported movement times, duration of postural transition, stability of transition, and the ground reaction force produced during motor imagery under single (arms at rest) or dual task (holding a juice bottle upright) conditions. The manual task manipulation was an attempt to introduce a performance criterion relevant to the dynamic relationship between the body and the environment during the STS task. The objective was to observe whether this new task constraint would alter the effects of internal or external attentional focus in young and older participants. We expected young participants to show a performance advantage in the external focus condition, as they did in Experiment 1 (Chapter 3). The key question was how older participants' performance would be affected by the new task constraint. We found more time-efficient postural transitions in the external focus condition, and this was the case for both young and older participants. This result (a reversal of pattern in older participants when compared with Experiment 1) suggests that having a task constraint that emphasized the body's relationship with the environment (i.e., the direction of gravity) led to a performance benefit in the external attentional focus condition. It should be noted that the instructions for focusing attention were the same as in previous experiments (i.e., on how the viewpoint location changed relative to a fixation point on the wall), not on the container of fluid in the hand. Thus, it was the targeting of attention externally to the body, and not to the manual task itself, that led to more efficient postural transition. We return to the possible implications of this result for the use of motor imagery in rehabilitation in Chapter 7.

Chapter 6: Experiment 4

Effects of attentional focus on learning through motor imagery practice

6.1. Introduction

It is well known that engaging in motor imagery not only influences immediate performance, but also promotes motor learning and maintenance of performance level (e.g., Feltz & Landers, 1983; Hinshaw, 1991; Driskell et al., 1994; Boschker et al., 2000; Gould & Bamajian, 1997; Blair et al., 1993; Yue & Cole, 1992). In the preceding three studies, we investigated the impact of internal and external attentional focus on motor performance and imagery (Experiment 1), and also the effects of task features such as the level of effort required (Experiment 2), and the presence of a concurrent manual task (Experiment 3). Here, we turn to the effects of motor imagery practice under internal and external attentional focuses on motor learning of an aspect of STS performance.

The benefits of MI practice include the facts that it is easier to conduct, and lower in cost and time, than physical practice. As a result, it has been used as a new or additional technique combined with others to benefit performance, especially in older adults whose ability to perform functional movements has deteriorated. Only a few studies have investigated the effects of MI practice on the STS task (Malouin et al., 2004; Malouin et al., 2004; Malouin et al., 2009; Skoura et al., 2005; Oh et al., 2010). Moreover, how or whether attentional focus interacts with training characteristics has not been explored in this respect. Specifically, because of the well-known age-related differences in higher-level control, we hypothesized that young and older participants may respond differently to changes in attentional focus from body-internal to body-external aspects of coordination while performing STS movement after a training period.

In the present study, we directly compared the effects of multi-session motor imagery practice by young and older adults under external versus two internal focus conditions. The specific training goal concerned the lateral distribution of body weight during the STS postural transition–we asked participants to imagine (during imagery training) or try (during physical practice) to equalize the proportion of body weight they placed on the two legs. We expected progress with respect to this training goal to correspond with a decreasing range of lateral force (i.e., in a perfectly symmetrical postural transition, left and right ground reaction force components would cancel, and there would only be net force produced in the anteroposterior direction). We retained the three attentional focus conditions introduced in Experiment 1 as the imagery training conditions in the present experiment. We also included a condition in which participants physically performed the practice, and a final one in which there was no practice. It might be noted that the task of making the lateral load distribution more symmetrical potentially introduces an internal attentional bias (contrary to the external bias that may have been introduced by the manual balancing task in Experiment 3).

6.2. Method

The common method, described in Chapter 2, was used, but with the following differences.

6.2.1. Participants

Thirty healthy young adults (18 - 30 yrs) and 30 older adults (60 - 80 yrs) took part in the study, receiving payment for their participation. Young adults (Male:

N = 15, Female: N = 15, M_{age} 21.73 $\pm$ 2.03 yrs, M_{weight} 65.30 $\pm$ 10.86 kg, M_{height} 171.10 $\pm$ 8.30 cm) were recruited from the University of Warwick student population, and older adults (Male: N = 15, Female: N = 15, M_{age} 70.90 $\pm$ 4.57 yrs, M_{weight} 72.33 $\pm$ 12.06 kg, M_{height} 167.30 $\pm$ 10.72 cm) came from a community-based volunteer panel maintained by the research group. All participants were screened for unimpaired ability to stand up several times per session from a sitting position and had no significant medical history or current problem affecting balance or everyday motor function (see a questionnaire form in Appendix 2). One older adult reported having had a past medical condition affecting balance, and two older adults had past experience of loss of balance, falling or weakness in the legs. One young adult and 3 older adults reported taking medication with possible effects on balance.

All participants were evaluated for motor imagery ability. Motor imagery ability is important to one's capacity to engage in MI and therefore was measured with a motor imagery questionnaire, using the Movement Imagery Questionnaire-Revised (MIQ-R) (Hall & Martin, 1997; KI: $M_{young} > 20$ = high imagery ability, $M_{older} > 20$ = high imagery ability and VI: $M_{young} > 20$ = high imagery ability, $M_{older} > 20$ = high imagery ability). All participants also completed standardized tests of cognitive functioning (Wechsler, 1981): Forward Digit Span Task (M_{young} 7.8 $\pm$ 2.30, M_{older} 7.79 $\pm$ 2.39), Backward Digit Span Task (M_{young} 7.33 $\pm$ 1.83, M_{older} 6.71 $\pm$ 2.21), Total Digit Span Task (M_{young} 15.13 $\pm$ 3.51, M_{older} 14.50 $\pm$ 4.24) and history of fall or balance problem from the Activities-specific Balance Confidence (ABC) Scale (Powell & Myers, 1995; $M_{young} > 80\%$ = high level of physical functioning, $M_{older} > 80\%$ = high level of physical functioning). Participant screening, consent procedures, and ethical approval were the same as in Experiment 1.

6.2.2. Experimental Procedures

Participants were randomly assigned to one of five groups– no training, physical practice, and three imagined STS practice conditions: visual-external (focus on a fixation point on the wall), somatosensory-internal (focus on the pressure under feet), and muscular-internal (focus on the load on thigh muscles). The training was administrated three sessions per week, over a two-week period. Each session of training lasted for a 30-minute visit to the laboratory. The protocol summary is presented in figure 6-1.

6.2.2.1. Training protocol

No training:

Participants in the non-training group did not receive any training. They were tested before and after the training sessions received by participants in other groups.

The physical STS training:

Participants first practiced the physical STS movement three times. The participant was instructed hang the arms loosely by their sides while performing the physical STS movements. The training period consisted of a series of three blocks, each including five physical STS movement repetitions and rest intervals. Movement time, CoP position, and ground reaction force were recorded using the same procedures as in previous experiments. The instructions asked participants to stand up at their natural speed, and to keep the body in left-right balance as they did so. (see the detail of instructions in appendix 3.4).

The visual-external focus training:

In the visual-external focus condition, participants' instruction was to imagine standing up at their natural speed while focusing on the way their viewpoint's position changed relative to the fixation point. The fixation target was always positioned at the participants' standing eye-height. Participants practiced the movement three times. The training period consisted of a series of three blocks, each including five imagined STS movement repetitions and rest intervals. Movement time, CoP position, and ground reaction force were recorded using the same procedures as in previous experiments. During imagery, the participant was asked to feel their own self performing the STS movement rather than 'watch' themselves performing it. The instructions asked participants to imagine stand up at their natural speed, and try to keep the body in left-right balance as they stood up. (see the detail of instruction in appendix 3.4).

The somatosensory-internal focus training:

In the somatosensory-internal focus condition, participants were told to focus their attention on how "the pressure of your body weight feels under your feet." Participants practiced the movement three times. The training period consisted of a series of three blocks, each including five imagery STS movement repetitions and rest interval. Movement time, CoP position, and ground reaction force were recorded using the same procedures as in previous experiments. During imagery, each participant was asked to feel their own self performing the STS movement rather than 'watch' themselves performing it. The instructions asked participants to imagine standing up at their natural speed and feel the pressure under their feet as they went through the movement. They were asked to imagine equal levels of foot pressure as they straightened their legs to stand up. (see the detail of instruction in appendix 3.4).

The muscular-internal focus training:

In the muscular-internal focus condition, participants were asked to focus their attention on how the weight of the body felt in their thighs. Participant practiced the movement three times. The training period consisted of a series of three blocks, each including five imagined STS repetitions and rest interval. Movement time, CoP position, and ground reaction force were recorded using the same procedures as in previous experiments. During imagery, each participant was asked to feel their own self performing the STS movement rather than 'watch' themselves performing it. The instructions asked participants to imagine standing up at their natural speed and feel the weight of the body on the thighs as they went through the movement. They were asked to imagine equal levels of weight on both thighs as they straightened their legs to stand up. (see the detail of instruction in appendix 3.4).

6.2.2.2. Testing protocol

Each participant was tested by the same experimenter throughout the period of the experiment using the standardized instructions. Before testing, the participant was given instructions on how to perform the test and asked whether they had understood the directions. Each participant practiced standing up (at natural speed, without using hands) twice in order to familiarize themselves with the testing protocol. The test did not begin until the participant felt ready to perform the task. Three trials of physical STS movements were collected at the start and end of training. Each session of testing lasted for half an hour's visit to the laboratory.

6.2.3. Measures, Design and Data Analysis

The range of the lateral component of the ground reaction force in the pre-training and post-training sessions was analyzed using a mixed ANOVA with age (young, old) and type of training (no training, physical STS movement, visual-external, somatosensory-internal and muscular-internal) as between subjects, and time of test (pre-training and post-training) as within subject factors. We also analysed the anteroposterior duration and stability of postural transition as in previous experiments, and, in view of the learning task's emphasis on lateral balance, we also analysed the mediolateral components of these measures to note what changes, if any, to these aspects of performance accompanied participants' attempts to learn a more symmetrical postural transition.

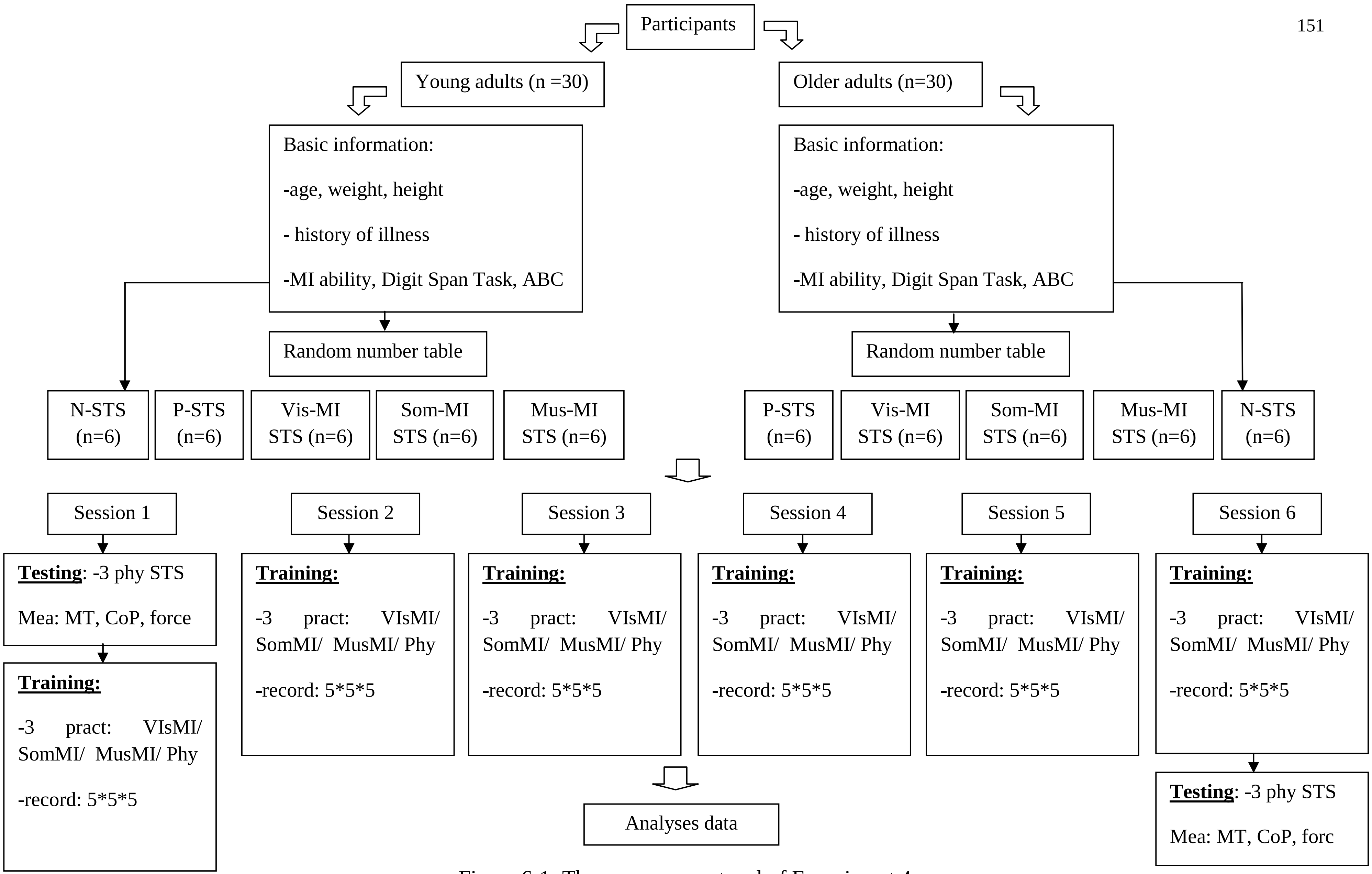


Figure 6-1: The summary protocol of Experiment 4

6.3. Results and Discussion

6.3.1. Duration of postural transition and stability of transition

The main effect of age on the duration of postural transition along the AP direction was significant (*F* (1, 48) = 12.73, $p < .001$, $\eta_p^2 = .21$; the transitional duration was longer in older participants) (Figure 6-2). The interaction between time of test and age was significant (*F* (1, 48) = 6.28, $p < .05$, $\eta_p^2 = .12$); whereas young participants' transition duration was longer at the end of training than at pre-training point ($p < .01$), older participants' transition duration did not change with the period of testing (Figure 6-4). The interaction between time of test and type of training was marginally significant (*F* (4, 48) = 2.39, $p = .064$, $\eta_p^2 = .17$); whereas somatosensory-internal focus groups' transition duration increased after training ($p < .05$), other groups' transition duration did not change with time of testing (Figure 6-5).

There were significant effects of time of test on the duration of postural transition along the ML direction (*F* (1, 48) = 4.74, $p < .05$, $\eta_p^2 = .09$; the transition was longer at the end of testing) (Figure 6-3). There were no other significant effects on the duration of postural transition.

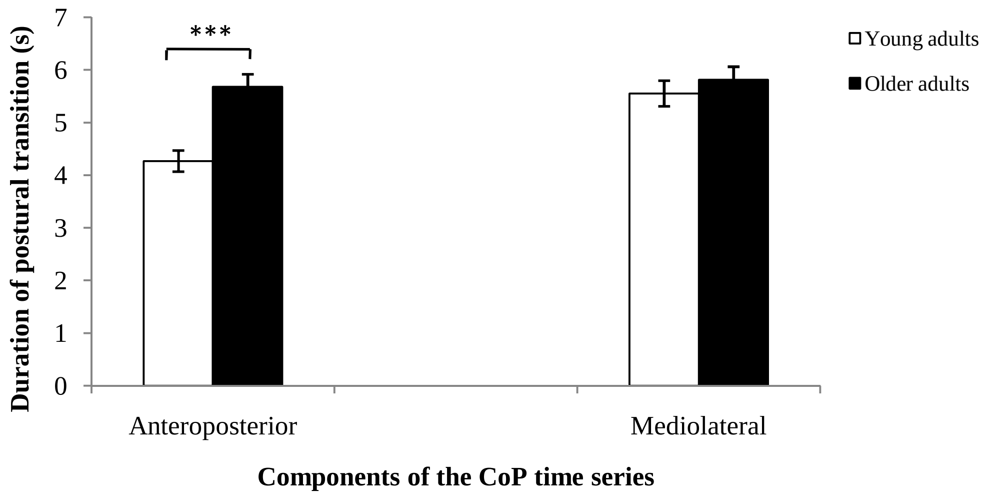


Figure 6-2: Effect of age on the duration of postural transition of young and older adults in anteroposterior and mediolateral components.

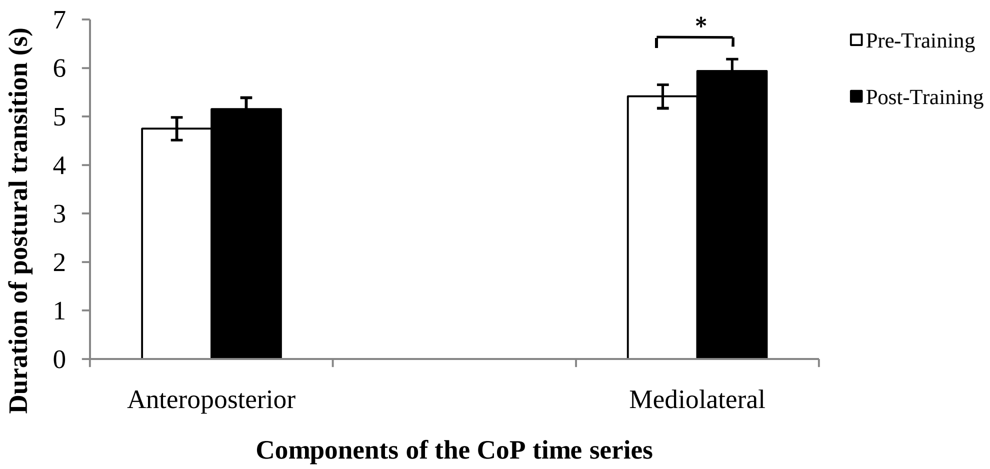


Figure 6-3: Effect of time of test on the duration of postural transition of young and older adults in anteroposterior and mediolateral components.

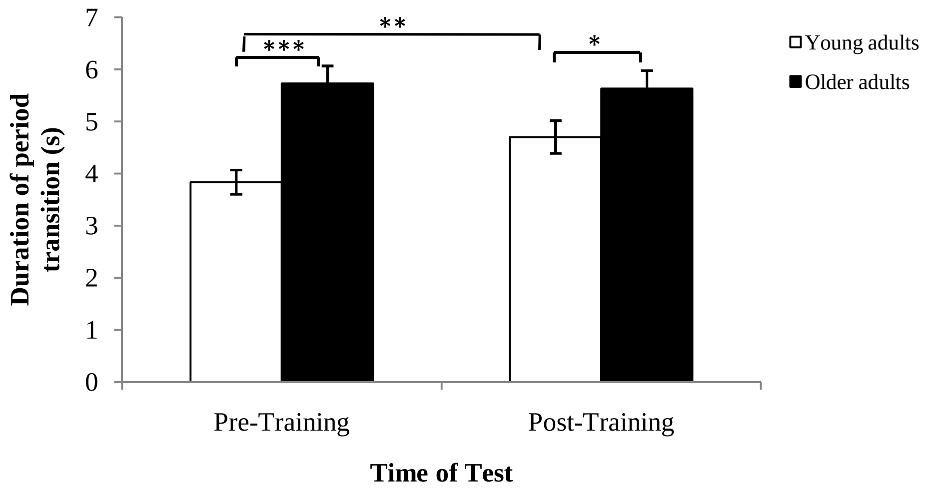


Figure 6-4: Effect of time of test and age on the duration of postural transition of young and older adults in anteroposterior component.

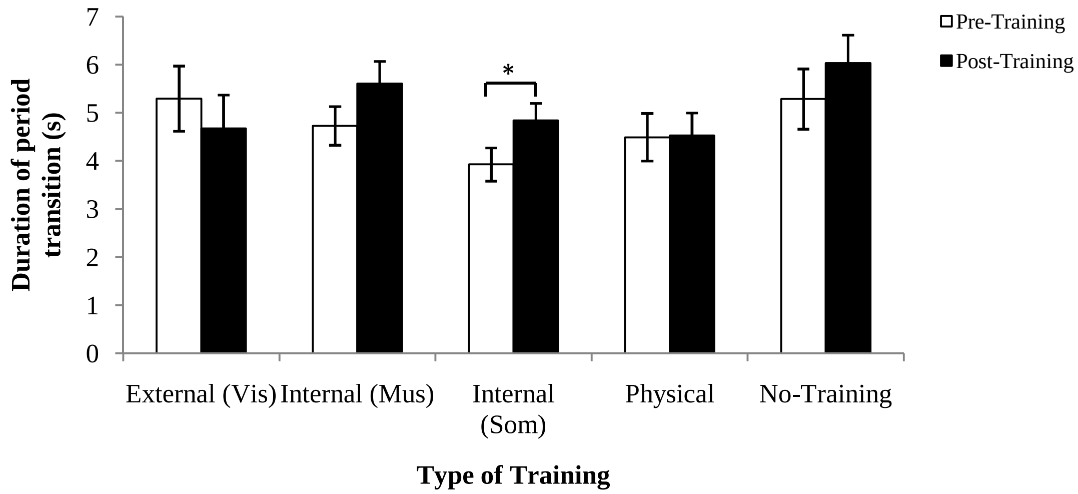


Figure 6-5: Effect of time of test and type of training on the duration of postural transition of young and older adults in anteroposterior component.

The stability of postural transition, as measured by the anteroposterior CoP path length during the transition interval, was greater in young participants (F (1, 48)

= 17.31, $p < .001$, $\eta_p^2 = .27$; see Figure 6-6). There were no other significant effects on the stability of postural transition along the AP direction.

The stability of postural transition, as measured by the mediolateral CoP path length during the transition interval, was greater in young participants (F (1, 48) = 7.53, $p < .01$, $\eta_p^2 = .14$; see Figure 6-6). There were no other significant effects on the stability of postural transition along the ML direction.

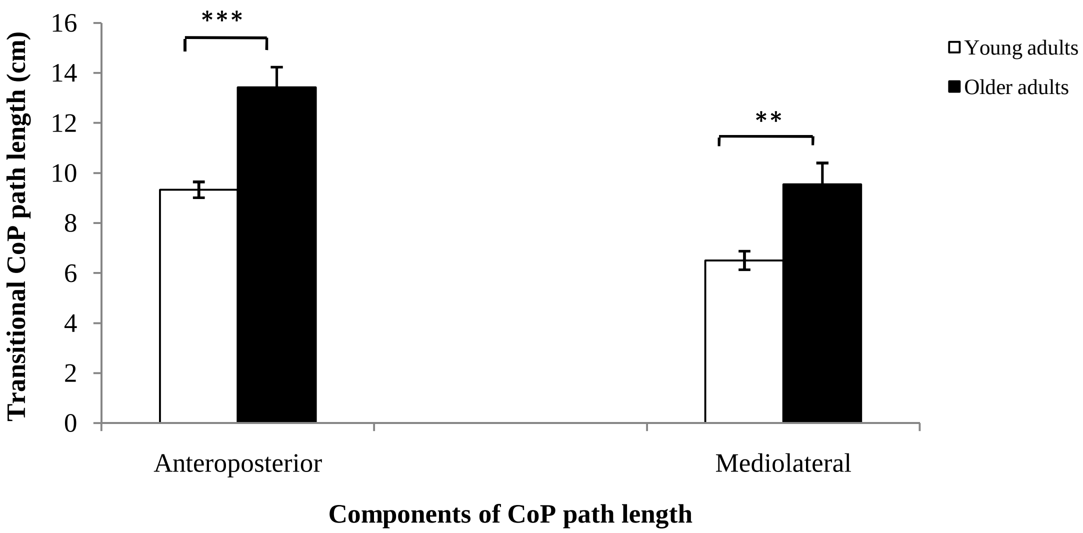


Figure 6-6: Effect of age on the stability of transition of young and older adults in anteroposterior and mediolateral components.

Unsurprisingly, older participants' postural transition was longer and less stable than young participants. Although the transitional duration was longer in older participants, older participants' transition duration did not change with the period of testing, whereas young participants' transition duration was longer at the end of training than at pre-training. These finding differed from a previous study (Guttman et al., 2012) that explored the effect of 4 weeks of motor imagery practice on STS performance in post-stroke hemiparesis. Their results showed that STS duration decreased after imagined the STS training for 4 weeks. The present study had a specific training goal that was different–participants were attempting to make their lateral weight distribution more symmetrical, a learning goal that may have required participants to significantly reorganize the movement. This may have resulted in a loss of automaticity, and this was expressed as increased movement time in some conditions. Further work is needed to understand this possible tradeoff in performance.

6.3.2. Lateral symmetry of ground reaction force

The main effect of age on the lateral range of ground reaction force (henceforth, force range) was significant (F (1, 48) = 14.11, p < .001, η_p^2 = .23; force range was greater for older participants (Figure 6-7). The main effect of time of test was significant (F (1, 48) = 6.17, p < .05, η_p^2 = .11; force range was greater at the end of testing) (Figure 6-8). The interaction between time of test and type of training was marginally significant (F (4, 48) = 2.51, p = .054, η_p^2 = .17); whereas ground reaction force at the baseline did not differ with type of training conditions, muscular-internal focus groups' force range was smaller than other conditions at the end of training period (p < .01; see Figure 6-9). The main effect of type of training (F (4, 48) = 3.09, p < .05, η_p^2 = .21, see Figure 6-10), the interaction between type of training and age (F (4, 48) = 3.45, p < .05, η_p^2 = .22; see Figure 6-11), and the interaction between type of training, time of test and age was also significant (F (4, 48) = 3.12, p < .05, η_p^2 = .21). This latter (3 way) interaction was further analysed using five 2(Age) x 2(Time of Test) ANOVAs, one for each type of attentional focus during training. There was a significant main effect of age on the lateral range of ground reaction force in the no-training condition (F (1, 10) = 18.67, p < .01, η_p^2 = .65; force range was greater for older participants; see figure 6-12: E). There was also a significant interaction between age and time of test in the muscular-internal focus condition (F (1, 10) = 5.23, p < .05, η_p^2 = .34); older participants' force range reduced marginally (p = .05) after training (see Figure 6-12: B).

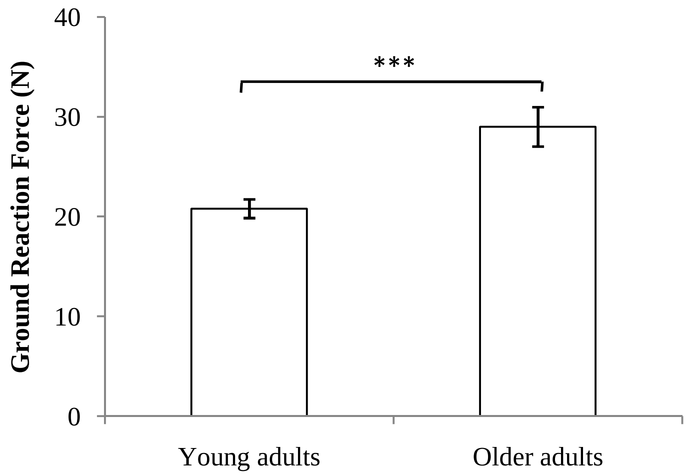


Figure 6-7: Effect of age on the ground reaction force of young and older adults.

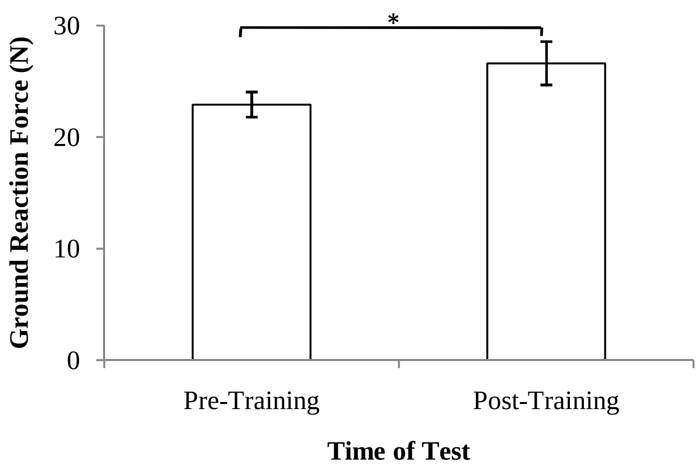


Figure 6-8: Effect of time of test on the ground reaction force of young and older adults.

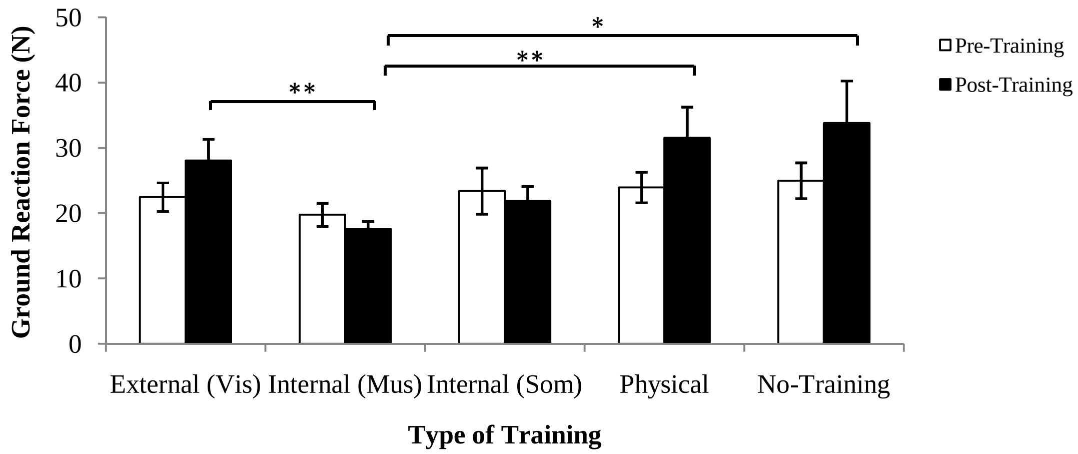


Figure 6-9: Effect of time of test and type of training on the ground reaction force of young and older adults.

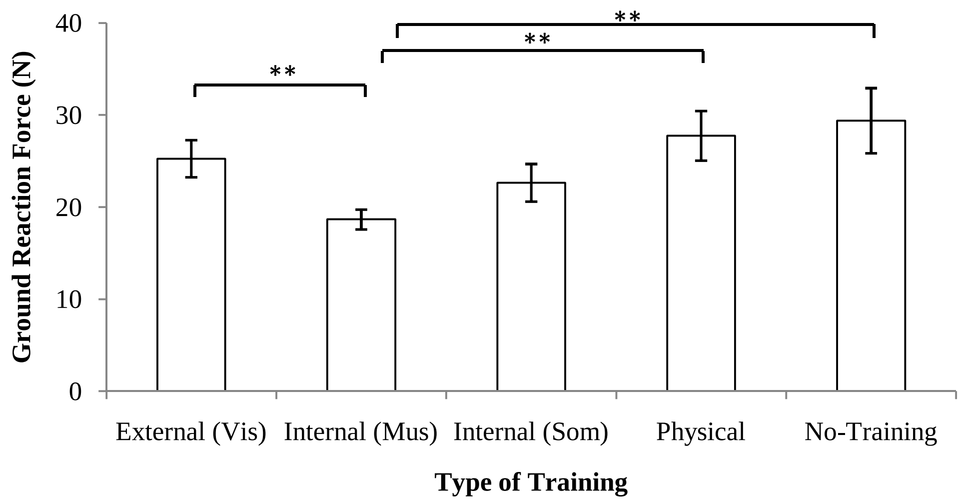


Figure 6-10: Effect of type of training on the ground reaction force of young and older adults.

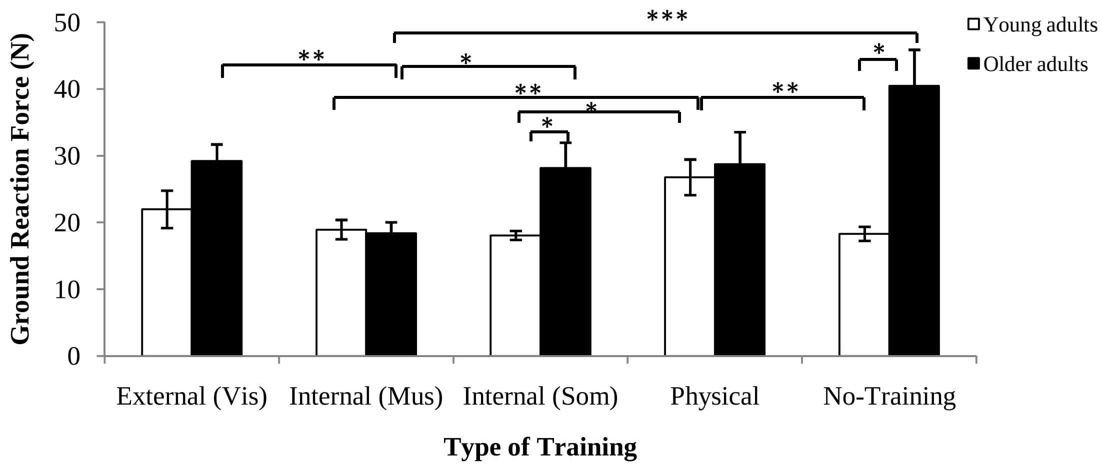
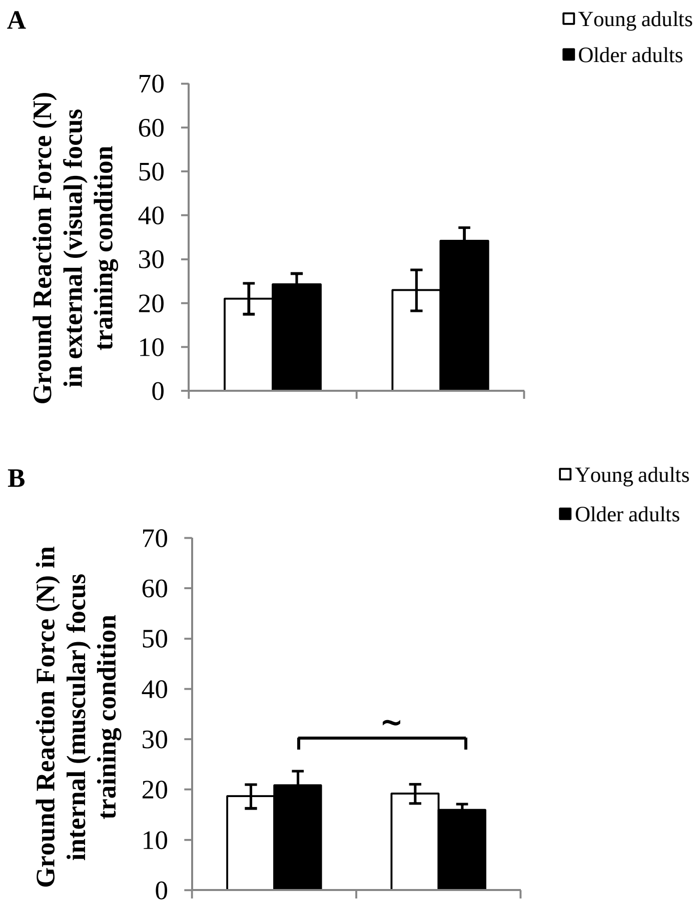


Figure 6-11: Effect of type of training and age on the ground reaction force of young and older adults.



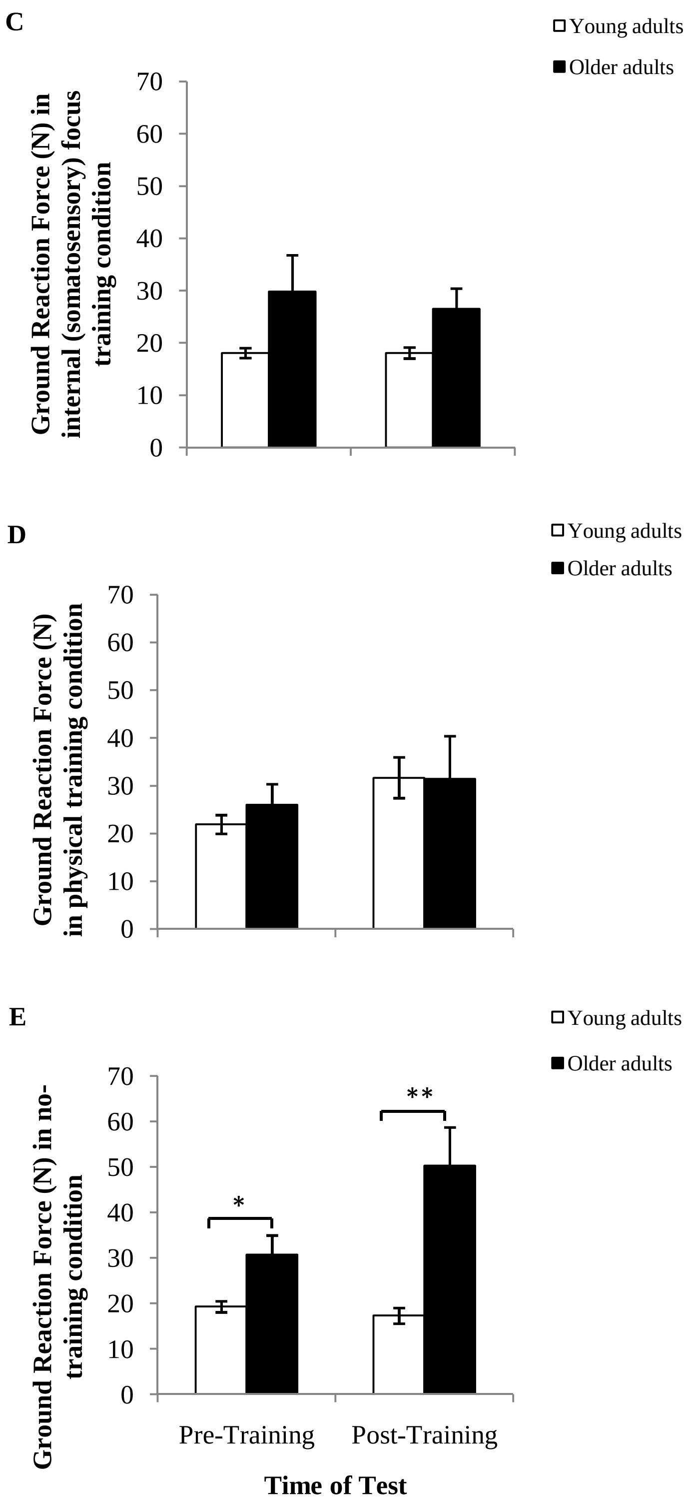


Figure 6-12: Effect of time of test and age on the ground reaction force in external (visual) focus training condition (A), internal (muscular) focus training condition (B), internal (somotosensory) focus training condition (C), physical training condition (D), and no-training condition (E). (~) indicates marginally significant at $p = .05$ level.

The effects related to training were small to marginal, as might be expected from the small numbers of participants and the relatively short duration of the training period. Overall, older participants' force range tended to be greater, suggesting less lateral symmetry of ground reaction force in that age group. However, older adults tended to have a smaller force range in the muscular-internal focus condition than in other conditions. Whereas the lateral range of ground reaction force before training did not differ between types of training conditions, the older, muscular-internal focus groups' force range was marginally smaller at the end of the training period. These findings far from solid, but they tentatively suggest that older adults may have had a tendency towards learning to perform STS movements more symmetrically in terms of lateral weight distribution when they adopted muscular-internal attentional focus during MI training. This numerical tendency differed from that of a previous study (Guttman et al., 2012) which explored the effect of motor imagery practice on the STS performance in post-stroke hemiparesis. They found that lateral weight distribution was not affected by MI training over a period of 4 weeks. In our results, healthy older adults' performance of STS movements showed a tendency toward became more symmetrical after imagery training using muscular-internal focus. Also, as pointed out earlier, participants in our study were explicitly asked to aim for a laterally symmetrical weight distribution. So, the combination of targeted instruction and muscular attentional focus may have aided older participants in making their STS movement somewhat more symmetrical. It is worth noting that this was the only trend in the direction of learning suggested by the instructions. No trend towards decreasing lateral force range was observed in young participants, or in older participants in any of the other training conditions.

6.4. Conclusion

It appears from the present results that a muscular attentional focus may have tended to benefitted older participants as learning goals in this study targeted changes to the way in which forces were applied during a task. The size of the present experiment, both in terms of participants as well as training during was too small to give sufficient power for clear conclusions. However, the trends in the data suggest that further exploration of learning protocols that combine specific learning goals and particular attentional focus instructions may be useful in developing our understanding of using motor imagery for training and rehabilitation. These data also tend to support our previous findings that specific instructions for focusing attention may affect young and older participants in different ways. The overall trend of greater benefit for older adults from muscular-internal attentional focus was again observed in a learning setting in this experiment.

Chapter 7: General Discussion

7.1. Goals of the project

The main interest in this project was to investigate the effects of focusing attention on body-external and body-internal aspects of STS movements. Firstly, we measured the duration and stability of postural transition from sitting to standing position. We were interested to see whether focusing on the change in the viewpoint's position (which addressed the relationship between the body and the environment), or focusing on the load felt on the thigh muscles, or pressure felt under the feet (both of which were aspects of the body's coordination of the movement), changed the time-efficiency or stability of the postural transition. We were particularly interested in possible age-related differences in the effects of attentional focus. Secondly, we measured self-reported movement times in the three different attentional focus conditions, and for both physical and imagined movements. Our goal in doing this was to compare the correspondence between actual timing and subjective impressions of timing as a function of attentional focus and age. This related to the level of correspondence between the planning of movements (as in imagery) and the execution of them (which also includes the absorption of feedback). We were particularly interested in how the level of this correspondence might be different between young and older participants. Thirdly, we measured the extent to which young and older participants produced muscular activity when they simply imagined STS movements, and how this differed as a function of attentional focus. We expected differences in this force production to indicate the extent of movement inhibition that accompanies imagery, and to what extent its level changes depending on attentional focus. The project included an experiment that manipulated muscular effort (by manipulating seat height) in an attempt to amplify timing differences between groups and conditions. It also included another experiment that investigated the impact of manually carrying and balancing an object with respect to the environment (a juice container that should not be tilted). Finally, there was an experiment on motor imagery-based training that was used to study what effects attentional focus could have on the effectiveness of imagery-based training.

7.2. Overview of experiment results

In Experiment 1, we compared the effects of external versus internal focus on physical and imagined instances of STS movements in young and older adults. We tested how focusing on the change in viewpoint relative to the environment (external focus) or the change in muscular load on the thighs, or cutaneous pressure under the feet (both internal focus), affected the self-reported movement times and the ground reaction force of imagined STS movements. We also measured the self-reported and actual movement times of physical STS movements, and the stability of the physical movements under these internal and external focus conditions. Our findings showed that young participants' self-reported (physical and imagined) movement time, postural transition duration and transition stability were convergent in showing better performance under body-external attentional focus. Older participants had the same self-reported movement time pattern, suggesting similar motor planning to young adults, but their movement benefited more from a body-internal focus on muscular load.The level of force transmitted to the ground during motor imagery was greater in older participants and greater in both age groups during kinesthetic imagery. An overview of the results of this experiment is in table 7-1. Judgments of vividness of imagery indicated an improvement in the self-reported clarity of imagery between the ends of the practice and data recording periods, but this difference was only significant in the external focus condition. However, the range of vividness judgments across conditions was very small, which supported reports in previous research of poor reliability of subjective impressions of motor image clarity.

In Experiment 2, we examined the effects of external versus internal focus on physical and imagined instances of STS movements under different seat heights in young and older adults. We tested the effects of focusing on the change in viewpoint relative to the environment (external focus) or the changes in muscular load on the thighs (internal focus) while standing up from seats with heights of 80% or 100% of lower leg length. The results of this experiment showed that older participants were able to adapt their movement times to the level of effort only when they focused on the load on their thighs. The difference in seat height did not change young participants' movement time. However, introducing the effort manipulation left no differences in the stability of postural transition in either age group. Young and older participants' self-reported movement times were again shorter in the external attentional focus condition. This highlighted the previously observed disconnection between the trends in self-reported and actual movement times in older participants in particular. The level of force transmitted to the ground showed effort-based modulation only in the external focus condition in young adults, and the internal focus condition in older adults. This suggested that the engagement of the motor system by imagery was better modulated when older participants focused on their muscular load. In the case of young participants, this occurred when they focused externally. An overview of the results of this experiment is in table 7-1.

In Experiment 3, we compared the effects of external versus internal attentional focus on physical and imagined instances of STS movements performed while holding and balancing an object in the dominant or non-dominant hand. The object in question was a fluid-filled container and the instruction was to stand up while holding it in the designated hand, and ensuring that the fluid did not spill. Unlike the manipulation in Experiment 2, which concerned the level of effort, a body-internal aspect of the coordination, the present manipulation emphasized the relationship of the body (or a part of the body, the hand) and the environment (in particular, the direction of gravity). The results showed that both age groups' postural transition was more time-efficient in the external focus condition, which was consistent with their shorter self-reported movement times in the external focus condition. This suggested that, in task conditions that specify constraints on the body-environment relationship, an external focus of attention is beneficial to performance. As noted in Chapter 5, participants' instructions were to focus attention on the way in which their viewpoint moved (with respect to the fixation point on the wall) during the STS movements, not on the fuild-filled container in their hand. Thus, if external attentional focus had a beneficial effect in terms of movement efficiency, it was likely because the target of attention and a key task requirement shared a spatial reference frame. This possibility raises interesting questions about the best way to design imagery-based protocols for enhancing or rehabilitating functional activities. Given that young and older adults tended to diverge in their performance as a function of internal or external focus, futher research should be done to systematically study how internal or external emphasis in task requirements interacts with the locus of attentional focus, and whether this interaction changes with age. The issue is further complicated by the fact that the level of force transmitted to the ground during motor imagery was greater under muscular-internal attentional focus in both age groups, suggesting that imagery continued to activate the motor system more when attention was internally focused. An overview of the results of this experiment is in table 7-1.

In Experiment 4, we gave motor imagery training to young and older participants with the goal to make their sit-to-stand movements more laterally symmetrical. Different groups of participants trained with imagery under body-external and body-internal focus, and there were also physical practice and no training conditions for comparison. The results were not conclusive, likely due to the lack of sufficient power, but the main numerical trend was that only older participants in the muscular-internal focus condition showed a tendency towards more symmetrical movement. Further work with larger numbers of participants and a greater range of training sessions (and training goals) would be required before the implications of attentional focus for motor imagery training in young and older people can be clarified. An overview of the results of this experiment is in table 7-1.

Across the experiments, a couple of patterns emerged in the data. First, young participants' self-reported and physical movement times corresponded to each other more closely than those of older participants. Young participants showed more time-efficient imagined and executed movements in the external-visual condition, suggesting similar motor planning processes in imagined and executed movements. In comparison, older adults' self-report showed the same pattern as young adults (e.g., in Experiments 1, 2 and 3), but their execution was divergent. In Experiment 1, the duration of their postural transitions did not differ as a function of attentional focus, and in Experiment 2, older participants tuned their transition duration to seat height (i.e., took significantly longer in the H80 condition) only in the internal focus condition (the latter result suggesting that their execution was more sensitive to task conditions when attention was internally focused). In Experiment 3, where the task included performance criteria addressing the relationship of the body and the environment (i.e., the direction of gravity), older adults' postural transition duration followed the same pattern as that of young adults, and showed a performance advantage under external focus. Thus, unlike young adults, older adults appeared to benefit from internal attentional focus in some task conditions in which specific body-external performance criteria were not specified. There was some indication of this in terms of the stability of postural transition as well - young participants showed a performance advantage under external focus, but older participants showed the opposite pattern (in Experiment 1).

Second, both young and older adults showed a tendency towards transmitting a small amount of force to the ground during imagined movements, and the level of force was greater for internal focus in both age groups. Additionally, older participants showed a tendency towards greater force transmission than young participants. This could be an indication of reduced inhibition in older participants, but as was noted in Chapter 3, it could also reflect older participants' felt need to generate greater force as a result of their higher weight. In Experiment 2, it was observed that young adults modulated their force production (during imagery) under external focus (i.e., produced more force in H80 than H100), but older adults did so only in the internal focus condition. This suggests that differences between young and older adults' force production may not be simply a result of differences in body weight. Clearly, further work, especially incorporating electromyographic measurement, is needed to better understand these differences between the age groups (We return to this point later in the chapter).

Table 7-1: Overview of experiment results to the thesis.

Study	Design	Self-reported movement times	Duration of postural transition and stability of transition	Muscular activation during imagined STS movements
Exp 1: the effects of external versus internal focus on physical and imagined instances of STS movements	Young adults (n=53)	More effectiveness under body-external attentional focus	More effectiveness under body-external attentional focus	More efficient during kinesthetic imagery under internal focus of attention
	Older adults (n=34)	More effectiveness under body-external attentional focus Similar between physical and imagined STS movements or between young and older adults	More effectiveness under muscular-internal attentional focus for stability	More efficient during kinesthetic imagery under internal focus of attention Greater in older than young adults
Exp 2: the effects of external versus internal focus on physical and imagined instances of STS movements **under different a seat heights**	Young adults (n=24)	More effectiveness under body-external attentional focus	Unchanged under different seat height and attentional focus	More efficient under external and internal focus of attention with low seat height
	Older adults (n=24)	More effectiveness under body-external attentional focus Differ between physical and imagined STS movements or between young and older adults	More effectiveness under body-internal attentional focus with standard seat height	More efficient under internal focus of attention with low seat height

Study	**Design**	**Self-reported movement times**	**Duration of postural transition and stability of transition**	**Muscular activation during imagined STS movements**
Exp 3: the effects of external versus internal focus on physical and imagined instances of STS movements **while holding an object in the hand**	Young adults (n=24)	More effectiveness under body-external attentional focus	More effectiveness under body-external attentional focus for transitional duration	More efficient under internal focus of attention
	Older adults (n=24)	More effectiveness under body-external attentional focus External attentional focus without holding was more effective Differ between physical and imagined STS movements or between young and older adults	More effectiveness under body-external attentional focus for transitional duration	More efficient under internal focus of attention
Exp 4: the effects of external versus internal focus on physical and imagined instances of STS movements **at the beginning and the end of training period**	Young adults (n=30)		Longer at the end of training	Small force range under muscular-internal focus of attention long ML direction in older adults during actual movement after training
	Older adults (n=30)		Unchanged with the period of testing Somatosensory-internal focus groups' transitional duration increased after training	

7.3. Analysis of the effects of attentional focus on physical performance

Our experimental results suggest that young participants' performance tended to benefit from external attentional focus. The results of Experiment 1 showed that young participants' duration of postural transition was shorter when they adopted external focus during physical STS movement, and this result was replicated later experiments (Experiment 3). This pattern is consistent with Wulf and colleagues' finding (e.g., Wulf, 2007) that body-external attentional focus results in better performance, because an external focus of attention promotes more automatic mode of motor control and allows the body to naturally self-organise (unconscious, fast and reflexive processes to control the movement). Automaticity refers to relatively effortless governance of coordination and fluent movements directed at environment goals. Among young adults, conscious control of body movement (as emphasized in the instructions for internal focus) may interrupt the motor control processes that automatically regulate movements (e.g., Shea & Wulf, 1999; Wulf et al., 1998).

Conversely, older participants' stability of postural transition was greater (in Experiment 1) when they adopted a muscular-internal focus. The trend was found again in Experiment 2, where older participants' duration of postural transition showed modulation as a function of seat height, which suggests that focusing on muscular effort enabled older participants to adjust their movement to task requirements. One explanation for the differences due to focus of attention between young and older adults may include changes in the coupling between task-level action planning and effector-level motor control (Wolpert & Kawato, 1998; Saltzman & Kelso, 1987) between the two age groups. Older adults are thought to make greater use of peripheral sensory feedback in controlling their movements and to prepare the same action in the future (Trewartha et al., 2009), and this process may benefit from attention being focused on proprioceptive feedback.

It is important to note that, when older adults were asked to stand up while holding a container in the hand (and not spilling the fluid in it), their duration of postural transition was shorter under external attentional focus. The pattern in this case was the same as for young participants. We have suggested that this reversal could be due to the nature of the task. The requirement to hold the container upright so that fluid did not spill from it introduced a task requirement that was tied to the direction of gravity. This placed greater importance on monitoring the position of the hand (and the rest of the body in relation to it) relative to the environment. Focusing attention externally may have benefitted this monitoring task by prioritizing the relationship between the body and the environment. However, it is worth noting that our findings differed from the study by Canning (2005). Canning reported that instruction to direct attention towards walking (internal focus of attention) was more effective for walking performance while carrying a tray and glasses, as opposed to attending to the concurrent task. In contrast, our findings showed better STS performance when participants adopted an external focus. The difference between our experiment and Canning’s might due to the difference in the type of population taking part. Participants in Canning’s study were Parkinson’s disease patients who suffered a loss of automaticity of well-learned movements due to defective functioning of the basal ganglia (Morris, Iansek, Matyas, & Summers, 1994), whereas participants in our study were healthy adults.

In addition, our results suggested that young participants’ duration of postural transition tended to become longer at the end of training (in Experiment 4), whereas older adults’ duration of transition remained unchanged after the immediate training period. Older adults showed a smaller lateral force range (and therefore more symmetry) after learning under the muscular-internal attentional focus condition. This trend was consistent with the suggestion that internal focus can assist STS performance in older adults, as mentioned earlier. However, to fully clarify the impact of training, a longer duration of training is required, because 2 weeks of training in our experiment might be too short to provide stable results. Also, resource limitations restricted the number of participants and therefore the power in our experiment.

7.4. Analysis of the effects of attentional focus on imagery performance

Self-reported movement time during imagined STS movement tended to be shorter with an external focus than an internal focus of attention. Experiment 1 showed a similar pattern between young and old adults, both with respect to internal or external attentional focus and whether the movements were physical or imagined. This pattern of results reappeared in our later experiments (Experiment 2 and 3), even though older participants' self-reported MT was slower than young adults when they performed STS movements from different seat heights or while holding a fluid container in the hand. These findings were consistent with previous studies on focus of attention (e.g. series of studies by Wulf). Body-external attentional focus is thought to result in better performance because it promotes more automatic modes of motor control, and allows the body to naturally self-organise (unconscious, fast and reflexive processes to control the movement). However, MI represents the result of conscious access to the contents of the intention of a movement, which is usually performed unconsciously during movement preparation. Conscious MI and unconscious motor preparation are able to share common mechanisms and are functionally equivalent (Jeannerod, 1994, 1995; Jackson et al., 2001; Annett, 1995). The evidence from the present study concurred that MI was able to share common mechanisms with an external focus of attention. That is, such a process may well be of value in motor performance and learning improvements.

In contrast, an internal focus of attention was more efficient for muscular activation during imagined STS movements in both young and older adults, although the level of force, hence muscular activity, was greater in older participants. These results were replicated in later our experiments (Experiment 2 and 3). A number of lines of evidence from behavioural, neurophysiological and neuroimaging studies supported the idea that MI using a first-perspective engages the motor system more than using a third-perspective (Jackson et al., 2006; Jackson et al., 2001; Bakker et al., 2008; Guillot et al., 2008; Fourkas et al., 2006; de Lange et al., 2006; Guillot et al., 2009; Stinear et al., 2006; Vargas et al., 2004). The present study enforced a strict first-person perspective in both the externally focused visual, and internally focused kinesthetic imagery conditions. Muscular activation observed during both the kinesthetic imagery conditions is consistent with previous work contrasting corticospinal excitation during visual and kinesthetic imagery (Harris & Robinson, 1986; Stinear et al., 2006; Bakker et al., 1996).

However, our findings disagree with the findings of previous attentional focus studies (Marchant et al., 2009; Wulf et al., 2007; Wulf, Chiviacosky, Schiller, & Avila, 2010; Wulf & Dufek, 2009; Wulf et al., 2010; Porter et al., 2010; Wu et al., 2012; Zarghami et al., 2012), suggesting that an external focus of attention was beneficial for enhancing maximum force production. Dissimilar results may originate from different organization in methodology. Previous literature determined the effect of attentional focus during actual movements. On the other hand, the present study clarified the impact of attentional focus on muscular activation during imagined actions, which is consistent with the findings of earlier imagery studies.

Muscular activity that occurred during MI might have originated from an incomplete motor command inhibition (Jeannerod, 1994), leading to tiny muscular contractions (Bonnet et al., 1997). Greater muscular activation during imagery in older people may be the result of deficits in motor inhibition. Alternatively, it may reflect attempts to amplify afferent signals from the motor periphery (which are known to contribute to the level of imagery-related brain activation (e.g., de Lange et al., 2006)) to mitigate against age-related decline in the ability to generate and control motor intentions (Skoura et al., 2005). Our data cannot distinguish between these possibilities, but neurophysiological measurements targeted at these age and attentional focus linked differences could clarify the nature of associated changes in the motor imagery process. Future studies are needed to clarify this.

Our results showed that the self-reported movement times during MI became slower than during physically performing STS movements when effort was manipulated through seat height (Experiment 2) or a secondary manual task was added (Experiment 3). Evidence from motor imagery research suggests that temporal equivalence between imagined and physical movements is not systematic and probably affected by several factors. Age was only one factor that influenced imagined movements. We interpreted our results on the basis of previous results from imagery experiments in which participants' encoded added effort as increased movement time during imagery, but simply increased effort to retain movement time during motor execution (Gentili et al., 2004; Papaxanthis et al., 2002).

Our results showed greater performance differences in older adults with respected to imagined or executed movements, or when imagining STS movements from different seat height levels or while holding an object in the hand. Duration of imagined movements was longer in older adults relative to young adults, probably because of declining cognitive mechanisms, loss of neural connectivity or decreased levels of neurotransmitters in the aging brain, as a consequence of proportional slowing of the basic neural processing steps (Dror & Kosslyn, 1994). Moreover, age-related effects on imagined movements may be dependent on the complexity of the motor task. Motor imagery is a cognitive process that retrieves information from long term memory, monitors intentions and action plans but consciously prevents them from execution. As a result, a high temporal organisation is necessary during performing imagined actions which requires attentional control and working memory (Briggs, Raz, & Marks, 1999; Logan, Sanders, Snyder, Morris, & Buckner, 2002; Reuter-Lorenz, 2002), resulting in difficulty in preserving the temporal aspects of movements. On the basic of evidence, this should be particularly true in older adults while performing complex attention-demanding actions. Furthermore, this divergence of older participants' performance also points to age-related changes in the coupling between task-level action planning and effector-level motor control (often considered modular elements of goal-directed action, for example, in Wolpert & Kawato (1998) or Saltzman & Kelso (1987)), whereby direct attentional focus on the latter may mitigate against reduced ability to translate behavioral goals into motor plans and effector control (Haaland et al., 1993; Skoura et al., 2005; Trewartha et al., 2009). However, the full potential of MI during complexities of motor tasks relative to age-related effects has not yet been sufficiently investigated, because there is a relatively small body of evidence concerning MI in these age groups. Further work is needed on the effects of ageing on various aspects of motor imagery.

7.5. Clinical implications

Because standing up is an important functional activity in daily life (Leo, 1985; Krebs et al., 1983; Lukert, 1982) and a good indicator of mobility and frailty of older people (Ragnarsson et al., 1981; Igaroski & Black, 1985; Paulus et al., 1984; Kerr et al., 1994; Lee et al., 1997; Shumway-Cook, Brauer, & Woollacott, 2000; Janssen et al., 2002; Studenski et al., 2003; Mathiyakom et al., 2005; Etnyre & Thomas 2007), it is often included in assessment and rehabilitation programs for people who present the inability to perform this basic skill due to impaired functioning and mobility in activities of daily living (ADL). It is important to understand how to help these populations change position from sitting to standing more easily and safely. Researchers and practioners have attempted to find the best techniques for improving STS performance and learning for over the past couple of decades. The possible role of motor imagery (e.g., Skoura et al., 2005; Malouin et al., 2004, 2009; Oh et al., 2010; Guttman et al., 2012) and attentional focus (e.g., a series of studies by Wulf; Canning, 2005; Landers et al., 2005; Laufer et al., 2007; Rotem-Lehrer & Laufer, 2007; Chiviacowsky et al., 2010; Porter & Anton, 2011; Chiviacowsky et al., 2012) are current interests that have been applied in clinical or rehabilitation activities directed at encouraging effectiveness and efficiency of motor performance and learning of motor tasks.

The present study showed age-related differences in the efficiency of STS outcomes during execution and imagery under different foci of attention. Our findings generally supported the effectiveness of kinesthetic imagery for older adults. This may have useful implications for rehabilitation. Firstly, imagining STS movements may be feasible as a means of assessing STS movement, and may be helpful when physical movement is not possible, especially among frail older adults and people who have difficulty moving. Secondly, although the literature on utilizing motor imagery records the benefits of first-person kinesthetic imagery, the age-linked difference in the impact of attentional focus observed here has not been previously appreciated, and should be systematically explored. In our experiments, young adults' movement efficiency and postural stability were greater under external attentional focus. In contrast, older adults' physical movement time and postural stability showed better performance under muscular-internal focus, even though they reported the same pattern of self-reported movement times as young participants. This suggests that older adults' movement benefited more from a body-internal focus on muscular load. Further studies are needed to test the generalizability of these results to a variety of populations and constraint conditions during STS movements.

Thirdly, an internal focus of attention was more efficient for muscular activation during imagined STS movements in both young and older adults, although the level of force, hence muscular activity, was greater in older participants. These findings mainly showed that older adults benefitted more when they focused on their own body movement. For young adults, performance may depend on movement goals and problems. For example, if a primary goal is to improve effectiveness of performance outcomes (e.g., movement time and postural stability), they should be instructed to focus on the effects of their movement rather than their movements themselves. If increasing muscular activation is the main objective, they would benefit from focusing attention on their body movement (particularly muscular-internal focus). From a rehabilitation viewpoint, a greater tendency to generate muscular activity during kinesthetic imagery may prove beneficial as a form of exercise, regardless of the precise mechanism involved. However, future studies are needed, because the present data cannot exactly indicate which muscles were involved in force production.

Finally, even though the training protocol of the learning experiment in this study was short, we could observe some trends in the training data. Older adults tended to have a smaller force range and more lateral symmetry when they adopted a muscular-internal focus during motor imagery training. This point to possible advantages of muscular-internal attentional focus conditionin training protocols designed for older adults.

The findings of this research should be useful to translate into practice in rehabilitation. Specifically, awareness of this evidence appears to be somewhat more advanced in physiotherapy and occupational therapy. Our protocols may be able to serve as a guideline for therapists in content and approach. In particular, precision and consideration in the wording of instructions is needed in designing STS practice. The present study recommended that instructions should direct attention differently for people from young and older age groups. It should also be responsive to individuals' specific goals and movement problems.

7.6. Looking forward

An accurate understanding of the benefits of targeting attentional focus during physical and imagined STS movement needs further studies. Firstly, when relating muscle actions to the goal of STS movements, the ground reaction force must be controlled so that balance is maintained (Toussaint, van Bar, van Langen, de Looze, & Dieen, 1992; Schultz et al., 1992). While the knee extensor appears to play a role during standing up, other leg muscles are also active through co-contraction mechanisms. Co-contraction was found in the muscles gluteus maximus, biceps femoris, rectus femoris, and vastus medialis, throughout STS movements (Kelley, Dainis, & Wood, 1976; Millington, Myklebust, & Shambes, 1992; Roebroeck et al., 1994). Moreover, the monoarticular muscles around the ankle are more or less active throughout the movement (Roebroeck et al., 1994). To identify the effects of changing attentional focus on motor imagery, some understanding of the involved muscular activity (EMG) is required. Recordings of the activation of such co-contraction muscles and the tibialis anterior muscle will be needed. Age-related effect on EMG during imagery would need to be determined as well. These data will provide crucial information about which muscles contribute to force production during imagery, and, accordingly, suggest what instructions should be given for particular task requirements.

Secondly, more experimental work is needed in relation to constraint conditions during physical STS movements. It would be interesting to relate the results to the case of imagined movements. In the present study, we explored the effect of different seat heights and secondary manual tasks. Other constraint conditions such as different foot positions and required speed of movement should be explored further. Thirdly, it is well known that MI requires a person who maintains and manipulates visual or kinesthetic information in their cognitive process (e.g., Malouin et al., 2004). Evidence from psychology and sport science studies also suggests that the modality of MI should depend on the type of task and the stage of learning. Visual imagery may bemore effective than kinesthetic imagery in improving stance stability, while kinesthetic imagery, may bemore effective for learning closed motor skills (Fery, 2003; Rodrigues et al., 2003; Hall et al., 1992). The STS movement is a closed motor skill and requires postural stability when standing. Further studies are needed to examine the effect of visual versus kinesthetic imagery on the STS performance. Comparison of the effects of first or third-person perspectives during imagery is also required. Future research should elucidate how STS performance and brain activity changes when imagined with different modality and perspective, and under different attentional focus conditions.

Next, despite the fact that motor imagery has been used for longer-term improvement of motor performance and learning (e.g,. series of study by Wulf; Feltz & Landers 1983; Hinshaw, 1991; Driskell et al., 1994; Boschker et al., 2000; Gould & Bamajian, 1997; Blair et al., 1993; Yue & Cole, 1992), our study presented data for only immediate performance after practice. A related question is how to extend our findings to the retention and transfer stages of motor learning. To answer this question, future research is needed. Moreover, to clarify the impact of training, longer duration of training is required, because the two-week training period in our Experiment 4 might be short for older adults. Future studies should also use a larger number of participants to have adequate power.

Finally, because of the wide use of motor imagery in rehabilitation, it would be interesting to examine whether the advantages of motor imagery under different foci of attention generalize to other populations with motor impairments, such as stroke, traumatic brain injury or Parkinson disease patients who are recovering function related to standing up. We hope that the present evidence will lead to important implications for practical settings. Changing the wording of instructions regarding the focus of attention during imagery and actual movement may have the potential to improve motor performance and learning. Consequently, procedures in practice or rehabilitation may become more effective and cost-efficient.

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Appendices

Appendix 1

Overview of studies using motor imagery and attentional focus

Table1-1: Overview of the example studies used the motor imagery training to improve performance in healthy people.

Study	Design	Outcome measures	Training methods	Results
Jarus & Ratzons (2000)	Healthy people Group1=children Group2=young adults Group3=older adults	Movement time of arm coordination task	Two-arm coordination task Sundivided into -PP -PP+MI	Older adults was slower than young adults at either acquisition or retention stage Older adults and children in PP+MI group made fewer errors than PP group Young adults and children did not differ at retention stage
Fansler et al (1985)	RCT Elderly healthy people N=37 (women) Group1= non-sense+ PP Group2= relaxation+ PP Group3= ideokinetic facilitation(MP) + PP	Single leg stance	Intervention consisted of MP by tape recorder	Improvement on balance

Study	Design	Outcome measures	Training methods	Results
Gentili et al (2006)	Healthy people Experimental group = MI and PP Control group = PC and AC	Movement time Speed	Experimental group: obtained MI or PP pointing task Control group: obtained passive or active eye movement training	Improvement in arm pointing capacity
Baston et al (2006)	RCT, before-after trail Elderly healthy people N=6 (women) Experimental group=3 Control group=3	BBS TUG ABC	Intervention lasted for 6 wk, 12 interval sessions with each session lasting for 1hr Experimental group received 20 min of MP of MI recorded on an audiotape, follow by 20 min PP with 10 min rest during transition time Subjects were asked to see yourself doing and feel yourself moving the task Control group obtained 20 min of health education, follow by 20 min PP with 10 min rest during transition time	Increase gait speed on TUG after a short period of physical training Not improvement on BBS and ABC Decreases balance confidence

Table 1-2: Overview of the example studies used the motor imagery for accessing the higher-level of control of complex body movements in healthy people.

Study	Design	Outcome measures	Training methods	Results
Courtine et al (2004)	Young healthy adults N= 20 In block group (N=10) In serial group (N=10)	Movement time (MT)	Perform imagery tasks (motor and internal imagery) and actual walking Along three paths; horizontal, uphill and downhill	High temporal similarities between overt and covert movements for both group and for all paths conditions
Skoura et al (2005)	RCT Healthy people N=24 (men and women) Young adults, older adult and elderly adults	-Temporal features of overt and covert movement (duration) -Temporal variability (movement speed)	Experiment 1: The walking, sit-stand-sit task and the pointing Experiment 2: A speed/accuracy trade off Before tested, all participants performed 3 time for STS and imagined 4-6 for STS by feel themselves executing the task During tested, Participants performed 10 overt and 10 covert trails for each task The whole program lasted for about 20 min, rest around 1 min after each cycle	Similar abilities of the walking and pointing tasks between overt and covert action in the 3 groups of age Dissimilarities for overt and covert action of sitting to standing and return task in the 3 groups of age Greater timing variability of covert movement compared to overt movement in the 3 groups of age Decreased movement speed with age both overt and covert execution

Study	Design	Outcome measures	Training methods	Results
Bakker et al (2007)	Young healthy adults N= 14	Movement time (MT)	Perform two imagery tasks (motor and visual) and actual walking MI = imagined walking along the walking trajectory VI = imagined seeing a disc moving along the walking trajectory	MT increased with increasing path length and decreasing path width in all three tasks The effect of path width on MT was closer between MI and actual walking
Beaudiet et al (2010)	Elderly and young healthy people N=162 (men and women)	TUG iTUG	TUG at self-selected speed and iTUG, tester gave standardized verbal instruction 'ready-set-go and then stop' For iTUG, test was stopped when the participant pronounce the word 'stop'	Slow TUG in older adults iTUG performance was faster than actual TUG performance

Table 1-3: Overview of the example studies used the motor imagery training to improve performance of upper extremities in people who have had disability.

Study	Design	Outcome measures	Training methods	Results
Page (2000)	RCT Patients with stroke N=16 (men) Experimental group N=8 Control group N=8	FMA	Audiotape record MP lasted for 20 min Experimental group received MP which administered1-2hr, 3 times a week for 4 wk combining with OT Control group received OT and education tape	The experimental group showed a significant improvement of UE function more than the control group
Page et al (2001 a)	RCT Patients with stroke N=13 (men and women) Experimental group N=8 Control group N=5	FMA ARAT	Participants receive OT/PT 3 time a week for 1 hr session, 6 wks Experimental group obtains 10 min audiotape recorded MP after therapy and at home 2 times a week Control group listened to stroke education tape for 10 min	The experimental group showed a significant improvement of UE function more than the control group

Study	Design	Outcome measures	Training methods	Results
Page et al (2001 b)	Case study Patients with stroke N=1 (man)	FMA STREAM (UE) ARAT	Audiotape record MP intervention lasted for about10 min The patient received MP which administered1hr a session, 3 times a week for 6 wks combining with PT	Improvement of UE on the affected side
Yoo et al (2001)	Single case, experimental, multiple-baseline design Patients with stroke N=3	Tracing	Auditory MP instruction 10 min for horizontal line-tracing training in 17 sessions After stop listening to the tape, participants were measured traced a horizontal and a curved line	Improvement of tracing accuracy and quality
Stevens & Phillips Stoykov (2003)	Case series Patients with stroke N=2 (1 man, 1 woman)	FMA Grip strength ROM Chedoke-McMaster Stroke Assessment Jebsen Test of Hand Function	Computer-facilitated imagery using movie focus on wrist and forearm movement was administered 1 hr, 3 times a week for 4 wk Mirror box-facilitated imagery administered 30 min, 3 times a week for 4 wk	Improved over all and stable over 3 months

Study	Design	Outcome measures	Training methods	Results
Crosbie et al (2004)	Case series Patients with stroke N=10 (1 man, 1 woman)	Motricity index (UE) Impairment	Intervention composed of videotape MP for a reach and grasp task combine with usual therapy for 2 wk	8 participant showed improvement (up till 3 days
Dijkerman et al (2004)	CCT Before-after trial Patients with stroke N=20 (1 man, 1 woman) Experimental group=10 Control group1=5 Control group2=5	Motor training task Modified motor training task Pegboard test Dynamometer Position sense 2 point discrimination Recovery Locus of Control Scale Test of everyday attention Barthel Index Modified Functional Limitation Profile	Intervention consisted of 4 wk home-base program. All participants practice physically moving task Experimental group practiced self-generate daily MP which contains 10 movement with their affected arm for 3 times a day Control group 1 received visually recalled a previously seen set of pictures Control group 2 was not involved in mental rehearsal	Improvement on Motor training task No effect of MI training on perceived or attentional control
Liu et al (2004)	RCT Patients with stroke N=46 Experimental group=26 Control group1=20	FMSA Attention control: CCT2 Task performance test	Intervention group: 60 min PT session with 60 min MI, 5 days a week for 3 wk Control group: 60 min PT session with 60 min instead of MI, 5 days a week for 3 wk	Significantly better results for MI group

Study	Design	Outcome measures	Training methods	Results
Page et al (2005)	RCT Patients with stroke N=11 (1 man, 1 woman) Experimental group=6 Control group=5	ARAT MAL (amount of use) MAL (quality of movement)	Intervention composed of 30 min therapy sessions, 2 times a week for 6 wk Experimental subjects obtained 30 min MP of the ADLs practice in therapy using audiotapes Control group got 30 min relaxation techniques	Greater improvement for the experimental group that control group
Butler and Page (2006)	Case Series Patients with stroke N=4 (1 man, 1 woman)	FMA Wolf Motor Function Test MAL	2 Participants got MP and CIMT, 1 obtains only MP, and 1 got only CIMT, 3 hr a day for 2 wk	Participants who obtained MP combined with CIMT showed a clinically improvement
Gaggioli et al (2006)	Case study Patients with stroke N=1 (man)	FMA ARAT	Intervention consisted of 30 min MP plus 30 min PT for 4 wk A virtual reality system was used to instruction MP at home, followed by 3 times a week for 1 month	Improvement on FMA and ARAT both during 4 wk of intervention and during the home-base training

Study	Design	Outcome measures	Training methods	Results
Hewett et al (2007)	Case series Patients with stroke N=5 (men and women)	Kinematic analysis of 2 functional reaching tasks with a plastic cylinder positioned at elbow height and shoulder height	Outpatient intervention Participants practiced imagined ADL the same set of physical practice After therapy lasted for 30 min, 2 times a week for 6 wk, participants practiced repeated MP	Improvement in reaching up ability and increased ROM of elbow and shoulder after training in both reaching up and reaching out
Mueller et al (2007)	CCT Patients with stroke N=17 (men and women) MP=6 PP group=6 Control group=5	Jebsen Hand Function Test Pinch strength	MP group obtained mental rehearsal a daily sequence of finger movement training of 30 min, 5 times a week for 4 wk via videotape PP group got physical practice a daily sequence of finger movement training Control group received standard OT/PT	Improvement on hand functional ability in MP and PP group

Study	Design	Outcome measures	Training methods	Results
Page et al (2007)	Case series Patients with stroke N=4 (men, women)	FMA ARAT Motor criteria to engage in mCIMT	Outpatient intervention Participants practiced imagined ADL the same set of physical practice After therapy lasted for 30 min, 2 times a week for 6 wk, participants practiced repeated MP	Improvement on FMA, ARAT, and mCIMT
Page et al (2007)	RCT Patients with stroke N=32 (men, women) Experimental group=16 Control group=16	FMA ARAT	Intervention composed of 30 min therapy sessions, 2 times a week for 6 wk Experimental subjects obtained 30 min MP after therapy session Control group got a shame intervention (relaxation technique)	Greater improvement for the experimental group that control group

Study	Design	Outcome measures	Training methods	Results
Simmons et al (2008)	Before-after trial single group Patients with stroke N=6 (men, women)	Motricity Index Nine-Hole Peg test Finger tapping ratio MAL ARAT	Intervention composed of 10 MP sessions combined with PP, 20 min period MP included imagined isolate movements, combined hand functional movement, combine the arm and hand functional movement Participants were given instruction, followed by 2 physically performing the tasks on the sound side, 2 imagined the sound side movements, then 9 imagined the affected side movements	Increased all outcome measures after training
Craje et al (2010)	Pilot study Before-after trial Patients with stroke N=4	Reaching Box and Blocks Test Perdue Pegboard Test	Intervention composed of 15 min MI training from first-perspective, 4 times a week for 3 wks at home, with an increasing complexity per week related to activities of daily living Week 1 perform reaching Week 2 perform grasping Week 3 perform fine dexterity	Improvement in hand function

Study	Design	Outcome measures	Training methods	Results
Guttman et al (2012)	Crossover intervention Patients with stroke N=13	STS duration STS speed Reaching velocity	Half of patients practice imagined the STS and the other half practice the reaching imagery, for 15 min 3 time a week for 4 wk	Improvement in the mean and maximum reaching velocity Decrease in STS duration

Table 1-4: Overview of the example studies used the motor imagery training to improve performance of lower extremities in people who have had disability.

Study	Design	Outcome measures	Training methods	Results
Dickstein et al (2004)	Case study Patients with stroke N=1	Tinetti ambulation scale Walking speed Temporal step parameters	Intervention focus on task-oriented gait and on impairment of the affected limbs for 15 min treatment session, 3 times a wk for 6 wks, using visual and kinesthetic imagery Each practice session included: -deep muscle relaxation for 1-2 min -the provision of information on task characteristics and environmental circumstance for 1-2 min -imaging of walking activity from an external perspective for 3-8 min -imaging of walking from an internal perspective for 3-8 in -refocusing of attention on the immediate surroundings and genuine body position for 1 min	Improvement on gait speed, reuction in double-support time and increase in ROM of knee

Study	Design	Outcome measures	Training methods	Results
Jackson et al (2004)	Case study Patients with stroke N=1	Response time of foot sequence task	Physically practiced a serial response time with lower limb during first two weeks, and then practiced MI combined with physical practice at the following week. After that practice only MI at home	Improvement in response time when combined MI with physical training improved rather than physical training alone. Retention of motor skill with MI training alone
Dunsky et al (2006)	Case Study Patients with stroke N=4	Kinematic gait parameters Clinical and functional gait measurement (Tinetti scale) FMA	Intervention focus on task-oriented gait and on impairment of the affected limbs for 15 min treatment session, 3 times a wk for 6 wks, using visual and kinesthetic imagery	Increase walking speed, step and stride length, single-support time of the affected limb and decrease double-support time
Cramer et al (2007)	Before-after trial Patients with SCI N=10 Control group (healthy people) N=10	Behavioral outcome (Tapping) Speed	Imagined movement of the tongue and foot for 7 days	Improvement in the behavioral outcome and speed of nonparalyzed muscles Activation of cortical networks in congruence with imagery of specific movements

Study	Design	Outcome measures	Training methods	Results
Tamir et al (2007)	RCT Patients with PD N=23 (men and women) Experimental group=12 Control group=11	Time required to complete sequences of movement Balance UPDRS Stroop and clock drawing test	Intervention lasted for 1 hr therapy sessions, 2 times a week for a total period of 12 wk The protocol of PP included: -callisthenic exercises in sitting position without support for 15-20 min, such as turn the shoulder, raising one buttock swinging arm up in opposite direction etc -practice of specific functional activities for 15-20 min, such as STS and walking -relaxation exercise Experimental subjects obtained PP combined with MP by external imagery and internal imagery which never lasted for more than 5 min -external imagery = viewed themselves performing the ADL task via video tape -internal imagery = recapitulation of the sensory experience of ADL task performance Control group received only PP	Improvement on ADL Greater improvement on movement sequence, mental and cognitive in combined treatment group

Study	Design	Outcome measures	Training methods	Results
Dunsky et al (2008)	Non RCT Patients with stroke N=17 (men and women)	Kinematic gait parameters Clinical and functional gait measurement (Tinetti, MFWCI, FMA)	MI trainings without physical intervention were provided in the patient's own home and administrated 15-20 min, 3 times a week for a total period of 6 wk, using visual and kinesthetic imagery Intervention protocol included: -familiarization with MI practice -focus of attention during training on the time application of propulsive force -training emphasis on loading of the affected limb during stand and walking -integrating prior practice into gait cycle -imagery practice of walking toward meaningful target	Increase walking speed, stride length, cadence, single-support time of the affected limb and decrease double-support time Improvement on clinical and functional gait scale

Table 1-5: Summary of the example studies used the motor imagery training to improve transitional performance in healthy and people who have had disability.

Study	Design	Outcome measures	Training methods	Results
Malouin et al (2004)	Before-after trail Patients with stroke N=4 Healthy people N=14	The percentage change in limb loading on the affected limb during standing up and sitting down STS = 5 trails	Single session mental practice of standing up and sitting down combine with physical practice 1 PP + 5 MP	Increased load on affected lower limb after MI training and at follow up
Malouin et al (2004)	Before-after trail Retention Patients with stroke N=12 Healthy people N=6	Vertical force Movement time STS = 5 trails	Familiarization procedure with visual feedback of motor performance Single session mental practice of standing up and sitting down combine with physical practice 7 Blocks, each including 1 PP + 5 MP	Increase in loading of the affect limb after a training session and remain 24 hr later The duration of the performance did not change with training
Malouin et al (2009)	Before-after trail Retention Patients with stroke N=12 MP+PP (N=5) Cog+PP (N=3) Not train (N=4)	Vertical force STS = 5 trails	Series of mental practice with internal perspective or cognitive practice of standing up and sitting down combine with physical practice, 3 times a week for 4 wk	Gain in loading of the affect limb after MP+PP training and retention

Study	Design	Outcome measures	Training methods	Results
Skoura et al (2005)	RCT Healthy people N=24 (men and women) Young (N=8) Elderly I (N=8) Elderly II (N=8)	-Temporal features of overt and covert movement (duration) -Temporal variability (movement speed)	No training The sit-stand-sit task; Before tested, all participants performed 3 time for STS and imagined 4-6 for STS by feel themselves executing the task During tested, Participants performed 10 overt and 10 covert trails for STS The whole program lasted for about 20 min, rest around 1 min interval	Dissimilarities in duration for overt and covert action of sitting to standing and return task
Oh et al (2010)	A single-subject multiple-baseline design across individuals Patients with stroke N=3	EMG in knee extensor on the affected side during performing the sit to stand and stand to it tasks	Auditory imagery instruction 10 min consists of the 5 stages -preparation -sit to stand task -weight shifting during stand -stand to sit task -complete MI training carry on once a day for 20 days, total of 20 sessions	Increased EMG activation ratio and decreased the onset time
Guttman et al (2012)	Crossover intervention Patients with stroke N=13	STS duration STS speed Reaching velocity	Half of patients practice imagined the STS and the other half practice the reaching imagery, for 15 min 3 time a week for 4 wk	Improvement in the mean and maximum reaching velocity Decrease in STS duration

Table 1-6: Overview of the example of attentional focus research.

Study	Design	Outcome measures	Method	Results
Baumeister, & Steinhilber (1984)	-Baseball players -Basketball players	Performance outcome	Conscious attention to the performer's body movement (internal focus)	Decrease in performance
Wulf & Weigelt (1997) (experiment 1)	Healthy people	Amplitude and frequency	Instructions to focus the timing of force directly on the body movement within the movement cycle (internal focus)	Decrease in performance
Wulf & Weigelt (1997) (experiment 2)	Healthy people	Amplitude and frequency	Instructions attention to body movement (internal focus)	Decrease in performance after extend practice
Wulf et al (1998) (experiment 1)	Healthy young people Group1= internal focus Group2 = external focus Group3 = control group	Slalom-type movement on a ski-simulator -Movement amplitude -Movement frequency	Participants learned slalom-type movements on a ski simulator for 2 consecutive days Instructions: -focus on the force exerted by the feet (internal focus) -focus on the force exerted on the wheel of the platform (external focus)	External focus was more effective performance than other conditions during practice and retention test Internal focus were not more effective than no instruction at all during practice and retention test

Study	Design	Outcome measures	Method	Results
Wulf et al (1998) (experiment 2)	Healthy young people Group1= internal focus Group2 = external focus	Balance on a moving platform (stabilometer)	Instruction directing attention to two makers attached to the balance platform directly in front of the feet horizontal (external focus) versus focus directing attention to the feet horizontal (internal focus)	External focus was more effective performance than other conditions in retention test
Shea & Wulf (1999)	Healthy people Group1,2= internal/external focus Group3,4= internal/ external feedback	Balance	Instruction directing attention to two makers attached to the platform (external focus/feedback) versus focus directing attention to the feet (internal focus/feedback)	External focus/feedback was more effective for learning than other conditions
Wulf et al (1999)	Participants without experience in golf practiced pitch shot Group1= internal focus Group2 = external focus	Golf pitch shot -Accuracy	Instruction to focus on the pendulum-like motion of the club (external focus) versus focus on the swing of the arms (internal focus)	External focus enhanced the accuracy of the shot both in practice and retention
Maddox et al (1999)	Healthy people Group1= internal focus Group2 = external focus	Tennis -Accuracy	Instruction to focus on the trajectory of the ball and it landing point (external focus) versus focus on the back swing and the racket-ball contact point (internal focus)	External focus enhanced the accuracy of the shot

Study	Design	Outcome measures	Method	Results
Wulf et al (2000) (experiment 1)	Healthy people Group1= external focus; antecedent Group2 = external focus; effect of movement	Forehand stroke and hitting tennis balls	Instruction focus on the ball approaching (antecedent) versus focus on the ball leaving the racket (effect of movement)	Focus on the effect of the movement showed better retention performance than other
Wulf et al (2000) (experiment 2)	Healthy people Group1= external focus Group2 = external focus; more distance	Accuracy	Instruction focus on the swing of the club (external focus) versus focus on trajectory of the ball and the target (external focus; more distance)	External focus with focusing on the club motion was more effective than another condition in practice and retention test
Wulf et al (2001)	Healthy people Group1= internal focus Group2 = external focus	Balance	Provided the option either an external (focus on makers attached to the board in front of the feet) or an internal focus (on the feet) of attention	External focus was chosen more than internal focus and showed superior balance performance than internal focus
Wulf et al (2001)	Healthy people Group1= internal focus Group2 = external focus	Probe RT	Instruction focus on the makers on the platform (external focus) versus focus on the feet (internal focus)	Shorter probe RT for the external focus group relative to the internal focus group

Study	Design	Outcome measures	Method	Results
McNevin & Wulf (2002)	Healthy people performed under three conditions (internal focus, external focus, and control)	Balance - Frequency of movement adjustment	Instruction to try to minimize movements of the curtain (external focus) versus to minimize curtain movements by focus on minimizing the finger movements (internal focus)	Higher -requency and lower-amplitude postural adjustments in the external focus as compared to other conditions
Al-Abood et al (2002)	Healthy people Group1= movement dynamics Group2 = movement effects	Throwing in basketball	Watched a video of an expert model perform a basketball free throw -In movement dynamics group: instructed to pay attention to the model of movement form -In movement effects group: instructed to focus on how the model scored a basket	Movement effects group was more effective for performance than movement dynamics group
Fasoli et al (2002)	Patients with stroke and control group performed under two conditions (internal focus, and external focus)	Reaching -MT -Velocity	Instruction focus on the objects they were to manipulate, e.g. pay attention to the can, (external focus) versus focus on their movement, e.g. pay attention to the arms (internal focus)	External focus was more effective for performance than internal focus
Wulf et al (2002)	Volleyball players or soccer players	Volleyball or soccer -Accuracy	Instruction referred either movement effects (external focus) versus body movements (internal focus)	External focus feedback resulted in greater accuracy than internal focus feedback

Study	Design	Outcome measures	Method	Results
Wulf et al (2003)	Healthy people Group1= internal focus Group2 = external focus Group3 = control group	Balance	Instruction focus on keeping the tube horizontal (external focus) versus focus on keeping the hands horizontal (internal focus)	External focus on the supra-postural task improved balance as compared to other conditions on transfer test
McNevin et al (2003)	Healthy people Group1= internal focus Group2 = far-outside Group3 = far-inside Group4 = near	-Balance -Frequency of movement adjustment	Instruction focus on the makers on the platform (external focus: far-outside, far-inside, near) versus focus on the feet (internal focus)	All external focus showed more effective balance learning than internal group Higher frequency values for external focus group relative to internal focus group Greater distance makers result in better performance
Perkins-Ceccato et al (2003)	High and low-skills golfers performed under two conditions (internal focus and external focus)	Shot variability	Instruction focus on hitting the ball as close to the target as possible (external focus) versus focus on the form of the golf swing and to adjust the force of the swing depend on distance of the shot (internal focus)	External focus was more effective for performance than other condition in high-skill golfers Internal focus was more effective for performance than other condition in low-skill golfers

Study	Design	Outcome measures	Method	Results
Wulf et al (2004)	Healthy people performed under two conditions (internal focus, and external focus)	Postural sway Stability of the pole	Instruction focus on the pole (external focus) versus focus on the hands (internal focus)	Less postural sway when with the external focus rather than the internal focus The pole was more stable when adopted the external focus as opposed to the internal focus
Vance et al (2004)	Healthy adults performed under two conditions (internal focus and external focus)	EMG	Instruction focus on the movement of the curl bar (external focus) versus focus on the arms (internal focus)	EMG was reduced with external focus rather than internal focus Movement efficiency was increased through a agonist and antagonist muscles
Canning (2005)	Patients with PD performed under two conditions (internal focus and external focus)	-Speed -Stride length	Instruction focus on a tray and glasses (external focus) versus focus on walking (internal focus)	Walked faster and longer strides when focusing on walking

Study	Design	Outcome measures	Method	Results
Zachry (2005)	Participants who no kicked a footall experience Group1= internal focus Group2 = external focus Group3 = control group	Kick a football	Instruction focus on the part of ball that contacting with the foot (external focus) versus focus on the part of the foot that contacting the ball (internal focus)	External focus was more effective for performance than other conditions
Zachry et al (2005)	Participants with some basketball experience performed under two conditions (internal focus and external focus)	Throwing in basketball -Accuracy -EMG	Instructions focus on the rim of the basket (external focus) versus focus directing on the wrist motion (internal focus)	External focus was more accuracy than internal focus EMG was reduced with external focus rather than internal focus
Landers et al (2005)	Patients with PD performed under three conditions (internal focus, external focus, and control)	Postural stability	Instructions focus on rectangles under the feet (external focus) versus focus directing on the feet (internal focus)	Improvement in postural stability when focusing on rectangles under the feet (external focus) The same results for internal and control condition

Study	Design	Outcome measures	Method	Results
Marchant et al (2006, 2008)	Healthy adults Group1= internal focus Group2 = external focus Group3 = control group	EMG	Instruction focus on the movement of the curl bar (external focus) versus focus on the arms (internal focus)	EMG was reduced with external focus rather than internal focus and control conditions
Jackson et al (2006)	Soccer players Group1= internal focus Group2 = external focus	Dribbling task -Speed	Instruction focus on related to the strategy, e.g. the position of ball (external focus) versus focus on related to technique (internal focus	Reduced the time with an external focus relative to internal
Wulf et al (2007)	Healthy people performed under three conditions (internal focus, external focus, and control)	Jump and reach height -Force -Displacement of the centre of mass	Instructions focus on the rungs to be touch (external focus) versus focus directing on the tipoff the fingers (internal focus)	External focus was more effective for performance than others
Wulf et al (2007) (experiment 1)	Healthy adults performed under three conditions (internal focus, external focus, and control)	Balance -Postural Sway	Instructions focus on rectangles and try to put an equal amount of pressure on each rectangle (external focus) versus focus on the feet and try to put an equal amount of pressure on each foot (internal focus)	External focus was more effective for performance than control group Internal focus did not differ from either external and control groups

Study	Design	Outcome measures	Method	Results
Wulf et al (2007) (experiment 2)	Healthy adults performed under three conditions (internal focus, external focus, and control)	Balance -Postural Sway	Instructions focus on moving the disk as little as possible (external focus) versus focus on moving the feet as little as possible (internal focus)	External focus was more effective for performance than internal and control groups in both standing on one leg and two legs
Wulf & Su (2007) (experiment 1)	Healthy adults Group1= internal focus Group2 = external focus Group3 = control group	Golf -Accuracy	Instructions focus on directed toward the pendulum-like motion of the club (external focus) versus focus on directed at the swinging motion of the arms (internal focus)	External focus was more effective for performance than internal and control groups in retention test
Laufer et al (2007)	Patients with ankle sprain Group1= internal focus Group2 = external focus	Balance -Stability	Instructions focus on keep balance by stabilizing the platform (external focus) versus focus on keep balance by stabilizing the body (internal focus)	External focus was more effective for learning of a postural control task than internal focus
Rotem-Lehrer & Laufer (2007)	Patients with ankle sprain Group1= internal focus Group2 = external focus	Postural control -Stability	Instructions to focus externally versus focus internally	External focus was more effective for transfer of learning of a postural control task than internal focus

Study	Design	Outcome measures	Method	Results
Marchant et al (2007)	Healthy people Group1= internal focus Group2 = external focus Group3 = control group	Dart throwing -Accuracy	Instruction focus on the centre of dart board; slowly begin to expand upon perspective on the dart board; refocus on the centre of dart board, expand the centre, make it as large as possible; and toss the dart when so focus (external focus) versus focus on feel the weight of the dart in the hand; think about drawing the dart back to the ear; feel the bend in the elbow; and feel the dart as it left the fingertips (internal focus)	External focus was more effective for performance than internal focus Control group was similar to that of the external focus group
Bell & Hardy (2009)	Golfers Group1= internal focus Group2 =external focus (proximal) Group3 = control group (distal)	Golf -Accuracy	Instructions focus on the flight of the ball (distal external focus) versus focus on the position of the clubface (distal external focus) and focus on the motion of the arms (internal focus)	Distal external focus was more effective for performance than other groups
Marchant et al (2009)	Healthy people performed under two conditions (internal focus and external focus)	Maximum force production EMG	Instructions focus on the crank bar while performing bicep curls(external focus) versus focus on the arm muscles (internal focus)	Increased peak joint torque and les EMG activity with external focus related to internal focus

Study	Design	Outcome measures	Method	Results
Wulf, & Dufek (2009)	Healthy people performed under two conditions (internal focus and external focus)	Jumping -Maximum force production -EMG	Instructions focus on the rugs of a Vertec (external focus) versus focus on the finger with which touched the rungs (internal focus)	Greater jump height and less EMG activity with external focus related to internal focus
Wulf et al (2009)	Patients with PD performed under three conditions (internal focus, external focus, and control)	Postural stability	Instructions focus on moving the disk as little as possible (external focus) versus focus on moving the feet little as possible (internal focus)	External focus improve postural stability more than other conditions
Wulf et al (2010)	Healthy people performed under two conditions (internal focus and external focus)	Vertical jump and reach task -EMG	Instructions focus on the rugs of the measurement device (external focus) versus focus on the finger with which touched the rungs (internal focus)	EMG activity was generally lower with an external focus
Chiviacowsky et al (2010)	Older adults Group1= internal focus Group2 = external focus	Balance task	Instructions focus on keeping makers on the platform horizontal (external focus) versus focus on keeping the feet horizontal (internal focus)	External focus group outperformed internal focus group in retention

Study	Design	Outcome measures	Method	Results
Lohse et al (2010)	Healthy people performed under two conditions (internal focus and external focus)	Dart throwing -Accuracy -EMG -Kinematics	Instructions focus flight of the dart (external focus) versus focus on movement of the arm (internal focus)	External focus led to better performance, reduced EMG activity
Porter et al (2010)	Healthy people performed under two conditions (internal focus and external focus)	Jumping distance	Instructions focus on jumping as far from the start line as possible (external focus) versus focus on extend the knees as rapidly as possible (internal focus)	Average jumping distance was greater with focus externally relative to internal focus
Porter et al (2010)	Healthy people performed under three conditions (internal focus, external focus, and control)	Agility task -MT	e.g. Instructions focus on running toward the cone as rapidly as possible (external focus) versus focus on moving the legs as rapidly as possible (internal focus)	Reduced the time taken to complete a whole-body agility task with an external focus relative to internal and control conditions
Freudenheim et al (2010)	Intermediate swimmers performed under three conditions (internal focus, external focus, and control)	Swim speed	Instructions focus on pushing the water back (external focus) versus focus on pulling the hands back (internal focus)	Reduced the time with an external focus relative to internal and control conditions

Study	Design	Outcome measures	Method	Results
Lowen (2010)	Healthy people performed under two conditions (internal focus and external focus)	Throwing -Accuracy on non-dominant hand	Instructions focus on directed toward the flight of the ball (external focus) versus focus on the movement of the arm (internal focus)	External focus was more effective for performance than internal focus
Jackson & Holmes (2011)	Healthy people Group1,2= internal focus (feet/board) Group3,4 = external focus (feet/board)	Balance	Instructions focus on keeping the board as level as possible (external focus) versus focus on keeping the feet as level as possible (internal focus); addition of two levels of task objective	External focus was more effective in acquisition when the task objective is external
Porter & Anton (2011)	Patients with chemo-brain performed under three conditions (internal focus, external focus, and control)	Movement time	Instructions focus on the handle of the stylus (external focus) versus focus on the hand (internal focus) while tracking the rotating light	External focus resulted in increased time on target relative to both internal and control conditions
Stoate & Wulf (2011)	Expert swimmers performed under three conditions (internal focus, external focus, and control)	Swim speed	Instructions focus on the overall outcome, e.g. speed, tempo, etc (external focus) versus focus on movement, e.g. spinning arm, high elbow etc (internal focus)	Reduced the time with an external focus relative to internal Similar results between external and control condition

Study	Design	Outcome measures	Method	Results
Mckay, & Wulf (2012)	Healthy people performed under two conditions (distal and proximal focus externally)	Dart throwing -Accuracy	Instructions focus on the target (distal external focus) versus focus on the flight of the dart hand (proximal external focus)	Distal focus enhanced accuracy more than other condition
Chiviacowsky et al (2012)	children with intellectual disabilities performed under two conditions (internal focus and external focus)	Accuracy	Instructions focus on the movement of the beanbag (external focus) versus focus on the movement of the hand (internal focus)	External focus enhanced accuracy more than other condition
Wu et al (2012)	Healthy people performed under three conditions (internal focus, external focus, and control)	Jumping distance	Instructions focus on jumping as close to the target as possible (external focus) versus internal focus	Average jumping distance was greater with focus externally relative to internal focus and control condition
Zarghami et al (2012)	Healthy people performed under two conditions (internal focus and external focus)	Throwing distance	Instructions focus on the discus (external focus) versus focus on the hand and wrist (internal focus)	Greater throwing distance with focus externally relative to internal focus

Study	Design	Outcome measures	Method	Results
Malek eta l (2012)	Badminton players (novice and expert) performed under four conditions (internal focus, external focus, and control)	Accuracy	Instructions far focus on the target zone (distal external focus) versus near focus on head of the racket (distal external focus) and focus on the hand movement (internal focus)	Distal external focus was more effective for performance than other condition No difference in expert group

Appendix 2

Questionnaires

THE UNIVERSITY OF WARWICK

PERSONAL DATA

Project Title: ……………………………………………………………………...

Participant number: ……………….

Gender: Male Female

Age: ....years

Body weight: ……………………………Kg.

Height: …………………………… cm.

Are you aware of having a medical condition that affects your movement or balance?

Yes No

(if yes, please explain ………………………………………………………..)

Are you currently taking any medication that can affect your movement or balance?:

Yes No

(if yes, pleaseexplain ………………………………………………………..)

Do you have anyhistory of losing your balance, falling, or weakness in your legs?:

Yes No

(if yes, please explain ………………………………………………………..)

Hand dominance

Please indicate your preferences in the use of hands in the following activities *by putting a check in the appropriate column*. Where the preference is so strong that you would never try to use the other hand, unless absolutely forced to, *put 2 checks*. If in any case you are really indifferent, *put a check in both columns*.

Some of the activities listed below require the use of both hands. In these cases, the part of the task, or object, for which hand preference is wanted is indicated in parentheses.

Please try and answer all of the questions, and only leave a blank if you have no experience at all with the object or task.

	Left	Right
1. Writing	☐ ☐	☐ ☐
2. Drawing	☐ ☐	☐ ☐
3. Throwing	☐ ☐	☐ ☐
4. Scissors	☐ ☐	☐ ☐
5. Toothbrush	☐ ☐	☐ ☐
6. Knife (without fork)	☐ ☐	☐ ☐
7. Spoon	☐ ☐	☐ ☐
8. Broom (upper hand)	☐ ☐	☐ ☐
9. Striking Match (match)	☐ ☐	☐ ☐
10. Opening box (lid)	☐ ☐	☐ ☐
TOTAL(count checks in both columns)		

Difference	Cumulative TOTAL	Result

Movement Imagery Questionnaire-Revised (MIO-R)

1. **STARTING POSITION:** Stand with your feet and legs together and your arms at your sides.

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

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

Rating

2. **STARTING POSITION:** Stand with your feet slightly apart and your hands at your sides.

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

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

Rating

3. **STARTING POSITION:** Extend the arm of your nondominant hand straight out to your side so that it is parallel to the ground, palm down.

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

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

Rating

4. **STARTING POSITION:** Stand with your feet slightly apart and your arms fully extended above your head.

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

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

Rating

5. **STARTING POSITION:** Stand with your feet slightly apart and your hands at your sides.

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

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

Rating

6. **STARTING POSITION:** Stand with your feet and legs together and your arms at your sides.

   ACTION: Raise your right knee as high as possible so that you are standing on two feet. Perform these actions slowly.

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

Rating

7. **STARTING POSITION:** Stand with your feet slightly apart and your arms fully extended above your head.

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

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

Rating

8. **STARTING POSITION:** Extend the arm of your non dominant hand straight out to your side so that it is parallel to the ground, palm down.

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

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

Rating

Movement Imagery Questionnaire-Revised (MIO-R)

RATING SCALES

Visual Imagery Scale

7	6	5	4	3	2	1
Very easy To see	Easy to see	Somewhat Easy to see	Neutral (Not easy not hard	Somewhat Hard to see	Hard to see	Very Hard to see

Kinesthetic Imagery Scale

7	6	5	4	3	2	1
Very easy To Feel	Easy to Feel	Somewhat Easy to Feel	Neutral (Not easy not hard	Somewhat Hard to Feel	Hard to Feel	Very Hard to Feel

The Activities-specific Balance Confidence (ABC) Scale

For each of the following activities, please indicate your level of self-confidence by choosing a corresponding number from the following rating scale:

0% 10 20 30 40 50 60 70 80 90 100%

no confidence **completely confident**

"How confident are you that you will not lose your balance or become unsteady when you…

No	Task	%
1	walk around the house	
2	walk up or down stairs	
3	bend over and pick up a slipper from the front of a closet floor	
4	reach for a small can off a shelf at eye level	
5	stand on your tiptoes and reach for something above your head	
6	stand on a chair and reach for something	
7	sweep the floor	
8	walk outside the house to a car parked in the driveway	
9	get into or out of a car	
10	walk across a parking lot to the mall	
11	walk up or down a ramp	
12	walk in a crowded mall where people rapidly walk past you	
13	are bumped into by people as you walk through the mall	
14	step onto or off an escalator while you are holding onto a railing	
15	step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing	
16	walk outside on icy sidewalks	

Digit Span Task

Participant number: ……………….

3 DIGIT SPAN	**Discontinue after failure on BOTH TRIALS of any item. Administer BOTH TRIALS of each item, even if subject passes first trial.**							
Digits Forward		Pass-Fall	Score 2,1,0	Digits Backward*		Pass-Fall	Score 2,1,0
1	5-8-2			1	2-4		
	6-9-4				5-8		
2	6-4-3-9			2	6-2-9		
	7-2-8-6				4-1-5		
3	4-2-7-3-1			3	3-2-7-9		
	7-5-8-3-6				4-9-6-8		
4	6-1-9-4-7-3			4	1-5-2-8-6		
	3-9-2-4-8-7				6-1-8-4-3		
5	5-9-1-7-4-2-8			5	5-3-9-4-1-8		
	4-1-7-9-3-8-6				7-2-4-8-5-6		
6	5-8-1-9-2-6-4-7			6	8-1-2-9-3-6-5		
	3-8-2-9-5-1-7-4				4-7-3-9-1-2-8		
7	2-7-5-8-6-2-5-8-4			7	9-4-3-7-6-2-5-8		
	7-1-3-9-4-2-5-6-8				7-2-8-1-9-6-5-3		
	Total Forward				Total Backward		

Forward	+	Backward	=	Total

*Administer DIGITS BACKWARD even if subject scores 0 on DIGITS FORWARD.

Vividness of Imagery

RATING SCALE

1 2 3 4 5

<u>RATING SCALE</u>**:**

1 = Perfectly clear and as vivid as the **Feel of Actual Movement**

2 = Clear and reasonably vivid

3 = Somewhat clear and vivid

4 = Vague and dim

5 = No image at all, you only “know” that you are thinking of the movement

Appendix 3

Instructions

Appendix 3.1

Instruction of Experiment I

Sit-to-Stand (STS) movement instruction

Welcome to the Sit-To-Stand (STS) laboratory. As healthy active individuals, sit-to-stand is an activity we do many times a day without problems. However, the task requires sophisticated coordination between visual, vestibular and proprioceptive systems and muscular control networks as your body weight shifts, your centre of gravity rises and your base of support shrinks as you balance on your feet. In rehabilitation settings, for example, after stroke or other brain trauma, sit-to-stand is a very important stage in physiotherapy. Problems with STS are also important factors in old age mobility and independent living. This experiment starts a series of studies on STS we are conducting with healthy young adults from the university population and healthy older adult volunteers from the local community. Our goal is to contribute to the development of a particular type of rehabilitation approach about which we will tell you a little bit at the end of the experiment.

PARTS OF THIS SESSION:

1. We will record your age, weight, height, any medical condition that may affect your STS performance.

2. We will then move to the experimental section of the session.

EXPERIMENTAL SECTION

In this section, you will be asked to sit comfortably on a height-adjustable chair set to the height of the lower leg length. Then, you will be asked to keep the arms by the side of the body and look forward.

Your feet will rest on the marker on force platform with heels about 10 cm apart without shoes. Your ankles will be positioned with specific joint angles measured using a handheld goniometer. Before each trial, the position of the trunk, the legs, and the feet and the placement of the feet will be checked and corrected if necessary.

Once your position is sorted, you will be asked to MAKE a set of STS movements, or IMAGINE making the movements, in the manner given in the instructions. Each trial will begin with the experimenter giving a Ready … Go signal. Following this you will stand up (or imagine standing up in the manner instructed).

In the trials where you are asked to physically stand up, there will be a fixation point on the wall. You will be asked to fix your gaze on it from the start of the trial and maintain your fixation on it through the STS movement. Once you are in standing position, please stay steady with your eyes on the fixation point until the experimenter indicates the end of the trial (by saying DONE). You can then sit down.

In the trials where you are asked to imagine the STS movement, the experimenter will give you the imagination instruction. You will then take the starting seated position and wear a blindfold with eye closed. You will be handed a computer mouse and asked to keep the index finger of your right hand on the left button of the mouse. In each trial, you will hear the Ready … Go signal. Immediately following this, you will imagine making the STS movement. As soon as you feel that you've completed the imagined movement and are 'standing' comfortably and steadily, you will press the mouse button to indicate the end of the imagined movement.

In different sections, the experimenter will give you instructions to direct your imagination of the STS movement in particular ways. It is very important that you follow these directions to the best of your ability. Also, at the end of each trial, you will be asked for a vividness-of-imagination judgement.

CONDITION A:

PHYSICAL STS:

In this section of the experiment, you will first practice standing up at natural speed, with your eyes open, without using your arms, which should hang loosely on either side of the body.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then **stand up at your natural speed, with your eyes on the fixation target**. **Remember this feeling.** As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION A:

IMAGINARY STS:

In this section of the experiment, you will first practice imagining the STS movements you made in the previous section. You will take up seated position just like before. You will then put on a blindfold with eye closed and hold your head in straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. The arm should hang loose by the side of the body as before. You should imagine yourself as you are sitting, looking at the fixation target. Once you hear the READY … GO, **imagine standing up at your natural speed while keeping your eyes on the fixation target**. As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be THREE imaginary practice trials and then TWO physical practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B:

PHYSICAL STS:

In this section of the experiment, you will first practice standing up at natural speed, with your eyes open, without using your arms, which should hang loosely on either side of the body.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then stand up at your natural speed, with your eyes on the fixation target. **As you stand up, focus your attention to how the weight of your body *feels* in your thighs as you perform this movement. Remember this feeling.** As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B:

IMAGINARY STS:

In this section of the experiment, you will first practice imagining the STS movements you made in the previous section. You will take up seated position just like before. You will then put on a blindfold with eye closed and hold your head in straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. The arm should hang loose by the side of the body as before. You should imagine yourself as you are sitting. Once you hear the READY … GO, **imagine yourself standing up, and focus on how the weight of your body *feels* in your thighs as you 'stand up' at your natural speed**. As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be THREE imaginary practice trials and then TWO physical practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION C:

PHYSICAL STS:

In this section of the experiment, you will first practice standing up at natural speed, with your eyes open, without using your arms, which should hang loosely on either side of the body.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then stand up at your natural speed, with your eyes on the fixation target. **As you stand up, focus your attention to how the pressure of your body weight *feels* under your feetas you perform this movement. Remember this feeling.** As soon as you feel you have completed the movement and are now ‘standing’ comfortably and steadily, press the mouse button to indicate that you’ve completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION C:

IMAGINARY STS:

In this section of the experiment, you will first practice imagining the STS movements you made in the previous section. You will take up seated position just like before. You will then put on a blindfold with eye closed and hold your head in straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. The arm should hang loose by the side of the body as before. You should imagine yourself as you are sitting. Once you hear the READY … GO, **imagine yourself standing up, and focus on how the pressure of your body weight *feels* under your feet as you 'stand up' at your natural speed**. As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be THREE imaginary practice trials and then TWO physical practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

Appendix 3.2

Instruction of Experiment II

Sit-to-Stand (STS) movement instruction

Welcome to the Sit-To-Stand (STS) laboratory. As healthy active individuals, sit-to-stand is an activity we do many times a day without problems. However, the task requires sophisticated coordination between visual, vestibular and proprioceptive systems and muscular control networks as your body weight shifts, your centre of gravity rises and your base of support shrinks as you balance on your feet. In rehabilitation settings, for example, after stroke or other brain trauma, sit-to-stand is a very important stage in physiotherapy. Problems with STS are also important factors in old age mobility and independent living. This experiment starts a series of studies on STS we are conducting with healthy young adults from the university population and healthy older adult volunteers from the local community. Our goal is to contribute to the development of a particular type of rehabilitation approach about which we will tell you a little bit at the end of the experiment.

PARTS OF THIS SESSION:

1. We will record your age, weight, height, any medical condition that may affect your STS performance.

2. We will then move to the experimental section of the session.

The experimenter will give you instructions. It is very important that you follow these directions to the best of your ability.

EXPERIMENTAL SECTION

In this section, you will be asked to sit comfortably on a height-adjustable chair. Then, you will be asked to keep your arms by the side of your body and look forward. Your feet will rest on the marker on the force platform with heels about 10 cm apart without shoes. Your ankles will be positioned with specific joint angles measured using a handheld goniometer. Before each trial, the position of the trunk, the legs, and the feet and the placement of the feet will be checked and corrected if necessary.

The seat will be set to two different heights. One will be the height of your lower leg. The other will be set to the 80% of your lower leg's length. Once your position is sorted, you will be asked to MAKEa set of STS movements, or IMAGINE making the movements, in the manner given in the instructions. Each trial will begin with the experimenter giving a Ready … Go signal. Following this you will stand up (or imagine standing up in the manner instructed).

In different sections, the experimenter will give you instructions to direct your imagination of the STS movement in particular ways. It is very important that you follow these directions to the best of your ability. Also, at the end of each trial, you will be asked for a vividness-of-imagination judgement.

CONDITION A: Standard seat height

PHYSICAL STS:

In this section of the experiment, your seat will be set to the height of your lower leg. You will first practice standing up at natural speed, with your eyes open, without using your arms, which should hang loosely on either side of the body.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then **stand up at your natural speed, with your eyes on the fixation target**. **Remember this feeling.**As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION A: Standard seat height

IMAGINARY STS:

In this section of the experiment, your seat will be set to the height of your lower leg. You will first practice imagining the STS movements you made in the previous section. You will take up seated position just like before. You will then put on a blindfold with eyes closed and hold your head in a straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. The arm should hang loose by the side of the body as before. You should imagine yourself as you are sitting, looking at the fixation target. Once you hear the READY … GO, **imagine standing up at your natural speed while keeping your eyes on the fixation target**. As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then carry on imagining standing steadily until you hear the experimenter say DONE. You can then imagine sitting back down. Take a rest and prepare for the next trial.

There will be TWO imaginary practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B: Standard seat height

PHYSICAL STS:

In this section of the experiment, your seat will be set to the height of your lower leg. You will first practice standing up at natural speed, with your eyes open, without using your arms, which should hang loosely on either side of the body.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then stand up at your natural speed, with your eyes on the fixation target. **As you stand up, focus your attention to how the weight of your body *feels* in your thighs as you perform this movement. Remember this feeling.** As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B: Standard seat height

IMAGINARY STS:

In this section of the experiment, your seat will be set to the height of your lower leg. You will first practice imagining the STS movements you made in the previous section. You will take up seated position just like before. You will then put on a blindfold with eyes closed and hold your head in a straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. The arm should hang loose by the side of the body as before. You should imagine yourself as you are sitting. Once you hear the READY … GO, **imagine yourself standing up, and focus on how the weight of your body *feels* in your thighs as you ‘stand up’ at your natural speed**. As soon as you feel you have completed the movement and are now ‘standing’ comfortably and steadily, press the mouse button to indicate that you’ve completed the imaginary movement and then carry on imagining standing steadily until you hear the experimenter say DONE. You can then imagine sitting back down. Take a rest and prepare for the next trial.

There will be TWO imaginary practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION A: Low seat height

PHYSICAL STS:

In this section of the experiment, your seat's height will be set to 80% of your lower leg's length. You will first practice standing up at natural speed, with your eyes open, without using your arms, which should hang loosely on either side of the body.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then **stand up at your natural speed, with your eyes on the fixation target**. **Remember this feeling.** As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION A: Low seat height

IMAGINARY STS:

In this section of the experiment, your seat's height will be set to 80% of your lower leg's length. You will first practice imagining the STS movements you made in the previous section. You will take up seated position just like before. You will then put on a blindfold with eye closed and hold your head in a straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. The arms should hang loose by the side of the body as before. You should imagine yourself as you are sitting, looking at the fixation target. Once you hear the READY … GO, **imagine standing up at your natural speed while keeping your eyes on the fixation target**. As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then carry on imagining standing steadily until you hear the experimenter say DONE. You can then imagine sitting back down. Take a rest and prepare for the next trial.

There will be TWO imaginary practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B: Low seat height

PHYSICAL STS:

In this section of the experiment, your seat's height will be set to 80% of your lower leg's length. You will first practice standing up at natural speed, with your eyes open, without using your arms, which should hang loosely on either side of the body.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then stand up at your natural speed, with your eyes on the fixation target. **As you stand up, focus your attention to how the weight of your body *feels* in your thighs as you perform this movement. Remember this feeling.** As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B: Low seat height

IMAGINARY STS:

In this section of the experiment, your seat's height will be set to 80% of your lower leg's length. You will first practice imagining the STS movements you made in the previous section. You will take up seated position just like before. You will then put on a blindfold with eyes closed and hold your head in a straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. The arm should hang loose by the side of the body as before. You should imagine yourself as you are sitting. Once you hear the READY … GO, **imagine yourself standing up, and focus on how the weight of your body *feels* in your thighs as you 'stand up' at your natural speed**. As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then carry on imagining standing steadily until you hear the experimenter say DONE. You can then imagine sitting back down. Take a rest and prepare for the next trial.

There will be TWO imaginary practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

Appendix 3.3

Instruction of Experiment III

Sit-to-Stand (STS) movement instruction

Welcome to the Sit-To-Stand (STS) laboratory. As healthy active individuals, sit-to-stand is an activity we do many times a day without problems. However, the task requires sophisticated coordination between visual, vestibular and proprioceptive systems and muscular control networks as your body weight shifts, your centre of gravity rises and your base of support shrinks as you balance on your feet. In rehabilitation settings, for example, after stroke or other brain trauma, sit-to-stand is a very important stage in physiotherapy. Problems with STS are also important factors in old age mobility and independent living. This experiment starts a series of studies on STS we are conducting with healthy young adults from the university population and healthy older adult volunteers from the local community. Our goal is to contribute to the development of a particular type of rehabilitation approach about which we will tell you a little bit at the end of the experiment.

PARTS OF THIS SESSION:

1. We will record your age, weight, height, any medical condition that may affect your STS performance, and whether you are right- or left-hand dominant.

2. We will then move to the experimental section of the session.

The experimenter will give you instructions. It is very important that you follow these directions to the best of your ability.

EXPERIMENTAL SECTION

In this section, you will be asked to sit comfortably on a height-adjustable chair set to the height of the lower leg length. Your feet will rest on the marker on the force platform with heels about 10 cm apart without shoes. Your ankles will be positioned with specific joint angles measured using a handheld goniometer. Before each trial, the position of the trunk, the legs, and the feet and the placement of the feet will be checked and corrected if necessary.

In this experiment, you will perform standing up movements while you hold and balance a juice bottle in your hand. In one condition, there will be nothing to hold, and you will be asked to keep the arms by the side of the body. In another condition, you will be asked to hold the juice bottle in your right hand. In yet another condition, you will be asked to hold the juice bottle in your left hand. Once your position is sorted, you will be asked to MAKE a set of STS movements, or IMAGINE making the movements, in the manner given in the instructions. Each trial will begin with the experimenter giving a Ready … Go signal. Following this you will stand up (or imagine standing up) in the manner instructed.

In different sections, the experimenter will give you instructions to direct your imagination of the STS movement in particular ways. It is very important that you follow these directions to the best of your ability. Also, at the end of each trial, you will be asked for a vividness-of-imagination judgement.

CONDITION A: Arms at rest

PHYSICAL STS:

In this section of the experiment, you will first practice standing up at natural speed, with your eyes open, without using your arms, which should hang loosely on either side of the body.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then **stand up at your natural speed, with your eyes on the fixation target**. **Remember this feeling.** As soon as you feel you have completed the movement and are now standing comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION A: Arms at rest

IMAGINARY STS:

In this section of the experiment, you will first practice imagining the STS movements you made in the previous section. You will take up seated position just like before. You will then put on a blindfold with eyes closed and hold your head in straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. The arm should hang loose by the side of the body as before. You should imagine yourself as you are sitting, looking at the fixation target. Once you hear the READY … GO, **imagine standing up at your natural speed while keeping your eyes on the fixation target**. As soon as you feel you have completed the imaginary movement and are now imagining standing comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then carry on imagining standing steadily until you hear the experimenter say DONE. You can then imagine sitting back down. Take a rest and prepare for the next trial.

There will be TWO imaginary practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B: Arms at rest

PHYSICAL STS:

In this section of the experiment, you will first practice standing up at natural speed, with your eyes open, without using your arms, which should hang loosely on either side of the body.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then stand up at your natural speed, with your eyes on the fixation target. **As you stand up, focus your attention to how the weight of your body *feels* in your thighs as you perform this movement. Remember this feeling.** As soon as you feel you have completed the movement and are now standing comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B: Arms at rest

IMAGINARY STS:

In this section of the experiment, you will first practice imagining the STS movements you made in the previous section. You will take up seated position just like before. You will then put on a blindfold with eye closed and hold your head in straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. The arms should hang loose by the side of the body as before. You should imagine yourself as you are sitting. Once you hear the READY … GO, **imagine yourself standing up, and focus on how the weight of your body *feels* in your thighs as you 'stand up' at your natural speed**. As soon as you feel you have completed the imaginary movement and are now imagining standing comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then carry on imagining standing steadily until you hear the experimenter say DONE. You can then imagine sitting back down. Take a rest and prepare for the next trial.

There will be TWO imaginary practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION A: Holding a bottle with your right hand

PHYSICAL STS:

In this section of the experiment, you will first practice standing up at natural speed, with your eyes open, while holding the given bottle in your right hand. The bottle will be full of juice up to a level as shown by the experimenter. She will also show you the position in which you should hold the bottle at the start of each trial. Your objective is to stand up as naturally as possible, while holding the bottle upright in the way you would do in everyday life (i.e., without tilting the bottle or spilling the juice). Above the level of the juice in the bottle, the experimenter will show you a tissue layer that will get wet if the bottle tilts and the juice contacts the tissue. Please try not to tilt the bottle so much that this happens. Note, however, that the bottle is actually sealed, so the juice cannot in fact spill out of the bottle.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your left hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then **stand up at your natural speed, with your eyes on the fixation target**. **Remember this feeling.** As soon as you feel you have completed the movement and are now standing comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION A: Holding a bottle with your right hand

IMAGINARY STS:

In this section of the experiment, you will first practice imagining the STS movements you made in the previous section, while holding the given bottle in your right hand. You will take up seated position just like before. You will then put on a blindfold with eyes closed and hold your head in straight position.

As before, the bottle will be full of juice up to a level as shown by the experimenter. You should hold the bottle at the start of each trial in the manner shown previously. Your objective in this section is to **imagine standing up** as naturally as possible, while holding the bottle upright in the way you would do in everyday life (i.e., without tilting the bottle or spilling the juice).

The experimenter will give you the bottle of juice to hold in the same way as you have previously. She will then ask you to imagine making STS movements (without 'spilling' the juice, as before). She will give you a computer mouse to hold in your left hand, and place your index finger on the left button. The left arm should hang loose by the side of the body as before. You should imagine yourself as you are sitting and holding the bottle. Once you hear the READY … GO, **imagine standing up at your natural speed while keeping your eyes on the fixation target (while holding the bottle upright, as before, so as not to 'spill' the juice)**. As soon as you feel you have completed the imaginary movement and are now imagining standing comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then carry on imagining standing steadily until you hear the experimenter say DONE. You can then imagine sitting back down. Take a rest and prepare for the next trial.

There will be TWO imaginary practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B: Holding a bottle with your right hand

PHYSICAL STS:

In this section of the experiment, you will first practice standing up at natural speed, with your eyes open, while holding the given bottle in your right hand. The bottle will be full of juice up to a level as shown by the experimenter. She will also show you the position in which you should hold the bottle at the start of each trial. Your objective is to stand up as naturally as possible, while holding the bottle upright in the way you would do in everyday life (i.e., without tilting the bottle or spilling the juice). Above the level of the juice in the bottle, the experimenter will show you a tissue layer that will get wet if the bottle tilts and the juice contacts the tissue. Please try not to tilt the bottle so much that this happens. Note, however, that the bottle is actually sealed, so the juice cannot in fact spill out of the bottle.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your left hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then stand up at your natural speed, with your eyes on the fixation target. **As you stand up, focus your attention to how the weight of your body *feels* in your thighs as you perform this movement. Remember this feeling.** As soon as you feel you have completed the movement and are now ‘standing’ comfortably and steadily, press the mouse button to indicate that you’ve completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B: Holding a bottle with your right hand

IMAGINARY STS:

In this section of the experiment, you will first practice imagining the STS movements you made in the previous section, while holding the given bottle in your right hand. You will take up seated position just like before. You will then put on a blindfold with eyes closed and hold your head in straight position.

As before, the bottle will be full of juice up to a level as shown by the experimenter. You should hold the bottle at the start of each trial in the manner shown previously. Your objective in this section is to **imagine standing up** as naturally as possible, while holding the bottle upright in the way you would do in everyday life (i.e., without tilting the bottle or spilling the juice).

The experimenter will give you the bottle of juice to hold in the same way as you have previously. She will then ask you to imagine making STS movements (without 'spilling' the juice, as before). She will give you a computer mouse to hold in your left hand, and place your index finger on the left button. The left arm should hang loose by the side of the body as before. You should imagine yourself as you are sitting and holding the bottle. Once you hear the READY … GO, **imagine yourself standing up, and focus on how the weight of your body *feels* in your thighs as you 'stand up' at your natural speed (while holding the bottle upright, as before, so as not to 'spill' the juice)**. As soon as you feel you have completed the imaginary movement and are now imagining standing comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then carry on imagining standing steadily until you hear the experimenter say DONE. You can then imagine sitting back down. Take a rest and prepare for the next trial.

There will be TWO imaginary practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION A: Holding an object on the left hand side

PHYSICAL STS:

In this section of the experiment, you will first practice standing up at natural speed, with your eyes open, while holding the given bottle in your left hand. The bottle will be full of juice up to a level as shown by the experimenter. She will also show you the position in which you should hold the bottle at the start of each trial. Your objective is to stand up as naturally as possible, while holding the bottle upright in the way you would do in everyday life (i.e., without tilting the bottle or spilling the juice). Above the level of the juice in the bottle, the experimenter will show you a tissue layer that will get wet if the bottle tilts and the juice contacts the tissue. Please try not to tilt the bottle so much that this happens. Note, however, that the bottle is actually sealed, so the juice cannot in fact spill out of the bottle.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then **stand up at your natural speed, with your eyes on the fixation target**. **Remember this feeling.** As soon as you feel you have completed the movement and are now standing comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION A: Holding a bottle with your left hand

IMAGINARY STS:

In this section of the experiment, you will first practice imagining the STS movements you made in the previous section, while holding the given bottle in your left hand. You will take up seated position just like before. You will then put on a blindfold with eyes closed and hold your head in straight position.

As before, the bottle will be full of juice up to a level as shown by the experimenter. You should hold the bottle at the start of each trial in the manner shown previously. Your objective in this section is to **imagine standing up** as naturally as possible, while holding the bottle upright in the way you would do in everyday life (i.e., without tilting the bottle or spilling the juice).

The experimenter will give you the bottle of juice to hold in the same way as you have previously. She will then ask you to imagine making STS movements (without 'spilling' the juice, as before). She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. The right arm should hang loose by the side of the body as before. You should imagine yourself as you are sitting and holding the bottle. Once you hear the READY … GO, **imagine standing up at your natural speed while keeping your eyes on the fixation target (while holding the bottle upright, as before, so as not to 'spill' the juice)**. As soon as you feel you have completed the imaginary movement and are now imagining standing comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then carry on imagining standing steadily until you hear the experimenter say DONE. You can then imagine sitting back down. Take a rest and prepare for the next trial.

There will be TWO imaginary practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B: Holding a bottle with your left hand

PHYSICAL STS:

In this section of the experiment, you will first practice standing up at natural speed, with your eyes open, while holding the given bottle in your left hand. The bottle will be full of juice up to a level as shown by the experimenter. She will also show you the position in which you should hold the bottle at the start of each trial. Your objective is to stand up as naturally as possible, while holding the bottle upright in the way you would do in everyday life (i.e., without tilting the bottle or spilling the juice). Above the level of the juice in the bottle, the experimenter will show you a tissue layer that will get wet if the bottle tilts and the juice contacts the tissue. Please try not to tilt the bottle so much that this happens. Note, however, that the bottle is actually sealed, so the juice cannot in fact spill out of the bottle.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then stand up at your natural speed, with your eyes on the fixation target. **As you stand up, focus your attention to how the weight of your body *feels* in your thighs as you perform this movement. Remember this feeling.** As soon as you feel you have completed the movement and are now standing comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

CONDITION B: Holding a bottle with your left hand

IMAGINARY STS:

In this section of the experiment, you will first practice imagining the STS movements you made in the previous section, while holding the given bottle in your left hand. You will take up seated position just like before. You will then put on a blindfold with eyes closed and hold your head in straight position.

As before, the bottle will be full of juice up to a level as shown by the experimenter. You should hold the bottle at the start of each trial in the manner shown previously. Your objective in this section is to **imagine standing up** as naturally as possible, while holding the bottle upright in the way you would do in everyday life (i.e., without tilting the bottle or spilling the juice).

The experimenter will give you the bottle of juice to hold in the same way as you have previously. She will then ask you to imagine making STS movements (without 'spilling' the juice, as before). She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. The right arm should hang loose by the side of the body as before. You should imagine yourself as you are sitting and holding the bottle. Once you hear the READY … GO, **imagine yourself standing up, and focus on how the weight of your body *feels* in your thighs as you 'stand up' at your natural speed (while holding the bottle upright, as before, so as not to 'spill' the juice)**. As soon as you feel you have completed the imaginary movement and are now imagining standing comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then carry on imagining standing steadily until you hear the experimenter say DONE. You can then imagine sitting back down. Take a rest and prepare for the next trial.

There will be TWO imaginary practice trials, followed by THREE imaginary recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

Appendix 3.4

Instruction of Experiment IV

Sit-to-Stand (STS) movement instruction

Welcome to the Sit-To-Stand (STS) laboratory. As healthy active individuals, sit-to-stand is an activity we do many times a day without problems. However, the task requires sophisticated coordination between visual, vestibular and proprioceptive systems and muscular control networks as your body weight shifts, your centre of gravity rises and your base of support shrinks as you balance on your feet. In rehabilitation settings, for example, after stroke or other brain trauma, sit-to-stand is a very important stage in physiotherapy. Problems with STS are also important factors in old age mobility and independent living. This experiment starts a series of studies on STS we are conducting with healthy young adults from the university population and healthy older adult volunteers from the local community. Our goal is to contribute to the development of a particular type of rehabilitation approach about which we will tell you a little bit at the end of the experiment.

PARTS OF THIS SESSION:

1. We will record your age, weight, height, any medical condition that may affect your STS performance.

2. We will carry out a structured evaluation of your ability to imagine body movements.

3. We will then move to the experimental section of the session.

The experimenter will give you instructions. It is very important that you follow these directions to the best of your ability.

TESTING SECTION

In this section, you will be asked to sit comfortably on a height-adjustable chair set to the height of the lower leg length. Then, you will be asked to keep the arms by the side of the body and look forward. Your feet will rest on the marker on force platform with heels about 10 cm apart without shoes. Your ankles will be positioned with specific joint angles measured using a handheld goniometer. Before each trial, the position of the trunk, the legs, and the feet and the placement of the feet will be checked and corrected if necessary.

You will first practice standing up at natural speed, with your eyes open, without using your arms, which should hang loosely on either side of the body.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then **stand up at your natural speed, with your eyes on the fixation target**. As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be TWO of these practice trials, followed by THREE recorded trials.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

GENERAL IMAGERY STS TRAINING

In this section of the experiment, you will first practice imagining the STS movements. You will take up seated position just like before and hang your arm by the body sides. You will then put on a blindfold with eye closed and hold your head in straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. You should imagine yourself as you are sitting. Once you hear the READY … GO, **imagine standing up at your natural speed while your eye closed. Feel your body move forward and stand up. Try to keep your body in left-right balance as you stand up.** As soon as you feel you have completed the movement and are now ‘standing’ comfortably and steadily, press the mouse button to indicate that you’ve completed the imaginary movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial. At the end of each session, you will be asked for a vividness-of-imagination judgment.

There will be THREE imaginary practice trials and followed by a series of THREE blocks exercise, each including FIVE imagery STS movement repetitions and rest interval.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

SPECIFIC MUSCULAR IMAGERY STS TRAINING

In this section of the experiment, you will first practice imagining the STS movements. You will take up seated position just like before and hang your arm by the body sides. You will then put on a blindfold with eye closed and hold your head in straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. You should imagine yourself as you are sitting. Once you hear the READY … GO, **imagine standing up at your natural speed while your eye closed. Feel the weight of your body on your thighs as you go through the movement. Imagine equal level of weight on both thighs as you straighten your legs and then move forward and up.** As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial. At the end of each session, you will be asked for a vividness-of-imagination judgment.

There will be THREE imaginary practice trials and followed by a series of THREE blocks exercise, each including FIVE imagery STS movement repetitions and rest interval.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

SOMATOSENSORY IMAGERY STS TRAINING

In this section of the experiment, you will first practice imagining the STS movements. You will take up seated position just like before and hang your arm by the body sides. You will then put on a blindfold with eye closed and hold your head in straight position.

The experimenter will then ask you to imagine making STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. You should imagine yourself as you are sitting. Once you hear the READY … GO, **imagine standing up at your natural speed while your eye closed. Feel the pressure under your feet as you go through the movement. Imagine equal level of foot pressure as you straighten your legs and then move forward and up. Imagine equal pressure under both feet as you stand up.** As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the imaginary movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial. At the end of each session, you will be asked for a vividness-of-imagination judgment.

There will be THREE imaginary practice trials and followed by a series of THREE blocks exercise, each including FIVE imagery STS movement repetitions and rest interval.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

PHYSICAL STS TRAINING

In this section of the experiment, you will take up seated position just like before and first practices standing up at natural speed, with your eyes open, without using your arms, which should hang loosely on either side of the body.

The experimenter will then ask you to perform STS movements. She will give you a computer mouse to hold in your right hand, and place your index finger on the left button. At the start of every trial, after you are in position, you will hear READY … GO. You should then **stand up at your natural speed, with your eyes on the fixation target**. **Move your body forward and stand up**. **Try to keep your body in left-right balance as you stand up..** As soon as you feel you have completed the movement and are now 'standing' comfortably and steadily, press the mouse button to indicate that you've completed the movement and then stay standing steadily until you hear the experimenter say DONE. You can then sit back down, rest and prepare for the next trial.

There will be THREE of these practice trials, followed by a series of THREE blocks exercise, each including FIVE physical STS movement repetitions and rest interval.

PRACTICE TRIALS:

ACTUAL DATA COLLECTION:

Appendix 4

Example:

Consent form and Information sheet

THE UNIVERSITY OF WARWICK

CONSENT FORM

Project Title: ……………………………………………………………………...

Name of Researcher: Kanokwan Srisupornkornkool

Name of Supervisor: Dr Joy Mitra

Participant number: ……………….

I confirm that I have read and understood the information sheet dated................. for the above study and have had the opportunity to ask questions I may have.

I agree to take part in the above study and am willing to:

…………………………………………………………………………………………………....

…………………………………………………………………………………………………....

…………………………………………………………………………………………………....

I understand that my performance data will be held and analysed for dissemination through PhD thesis, conference presentations and scientific journal publications. Information about my identity will be purely for internal administrative purposes. Performance data will remain anonymous in all forms of dissemination.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without any of my rights being affected.

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Name of Participant Date Signature

-------------------------------------- ---------------- ---------------------------------

Name of Researcher Date Signature

When completed, you will be given a copy of this from to keep for your record.

THE UNIVERSITY OF WARWICK

INFORMATION SHEET

Project Title: ……………………………………………………………………..

Name of Researcher: Kanokwan Srisupornkornkool

Name of Supervisor: Dr Joy Mitra

Dear Participant

My name is Kanokwan Srisupornkornkool and I am a PhD research student working at the Psychology Department at the University of Warwick. I am interested in investigating the effect of movement imagery on standing up performance. In gathering this data, we aim to measure and compare the time needed to complete the activities, force output and the centre of pressure under the feet during actual and imagined sit-to-stand movements. The research has ethical approval from the University of Warwick's HSSREC.

I would really appreciate it if you would consider volunteering for my research project. In terms of informed consent, before you decide, it is important for you to understand why the research is being done and what it would involve. Please read the following information carefully and discuss it with others as appropriate.

This information sheet hopefully provides a clear explanation of the study including the research's aims, benefits and risks and also what participation would mean for you and any implications concerning your involvement. If there is any aspect of the study that is unclear, please contact me or my supervisor who will be happy to answer your questions. Our contact details can be found at the end of this information sheet.

Thank you for your time.

What is the purpose of this investigation?

…………………………………………………………………………………………………....
…………………………………………………………………………………………………....
…………………………………………………………………………………………………....

Why I have been invited to take part?

You have been invited to take part in this project because you meet the inclusion criteria for this project. You are being invited to participate in this research as one of …….. participants.

Do I have to take part?

Participation in this study is entirely voluntary. You are free to consider whether or not to take part. If you decide to participate, you will be asked to sign a form to confirm that the study was clearly explained to you, and that you agreed to take part. Youwill be free to withdraw at any time, without giving a reasonand any or your rights being affected.

What does taking part involve?

If you contact us, I will arrange to discuss the project in more detail, to complete the forms if you wish to continue, and to agree a time and date for your participation.

…………………………………………………………………………………………………....
…………………………………………………………………………………………………....
…………………………………………………………………………………………………....

What are the possible benefits of taking part?

…………………………………………………………………………………………………....
…………………………………………………………………………………………………....
…………………………………………………………………………………………………....

Will my taking part in the study be kept confidential?

Each participant will be registered with a unique reference number without any allusion to personal details. Data collected will be named with the reference number and stored in a password protected computer in University of Warwick. Access to the data will only be provided to the Chief Investigator and other research staffs. Personal details (name, address, telephone number only) will be kept in paper format along with the relevant trial reference number in a locked filling cabinet in the psychological department, University of Warwick.

What will happen to the results of the research study?

The results will be published through peer reviewed scientific journals and conference presentations. If you wish, at the end of the study, we will be very happy to explain the outcome of the research to you.

What happens next?

If youare happy to be involved in the please contact us, using the details in the next section, and I will arrange a time to discuss the project further. I will also send you the consent forms so that you can see them in advance of our meeting.

If you do not wish to participate, we thank you for your time and attention. You do not have to do anything else.

Miss Kanokwan Srisupornkornkool
Psycholoy Department
University of Warwick
Coventry, CV4 7AL
0777 2528 170
K.Srisupornkornkool@warwick.ac.uk

Dr Joy Mitra (supervisor)
Psycholoy Department
University of Warwick
Coventry, CV4 7AL
0247 652 2484
Subhobrata.Mitra@warwick.ac.uk

Thank you for your time and co-operation.