The effect of motor imagery on quality of movement when performing reaching tasks in healthy subjects: a proof of concept

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ABSTRACT

Introduction: The use of motor imagery (MI) has been shown to offer significant improvements in movement performance in sports, and is now receiving a lot of attention as a relatively new therapeutic approach which can be applied in rehabilitation. However, the effects of MI on the quality of movement is still unclear. This study explored the immediate effect of MI on reaching tasks in healthy subjects.

Methods: 17 healthy individuals (33 ± 8.2 years) participated in the study. Surface electromyography (sEMG) and inertial measurement units (IMU) were used to identify muscle activity and angular velocity in both upper limbs. Participants performed a reach task using their dominant and non-dominant arms at their most comfortable speed, they were then asked to imagine themselves performing the same reaching task, and finally they were asked to repeat the reaching task.

Results: Significant decreases were seen in the muscle activity between pre and post MI for Biceps Brachii, Anterior Deltoid and Triceps Brachii. In addition, a significant increase was seen in extension angular velocity post MI.

Discussion: The results indicate that the use of MI just after physical practice appears to have an immediate effect on the muscle activity and kinematics during a reaching task, which may suggest an improved quality of movement.

Conclusion: This proof of concept study shows the potential for MI to improve the quality of performing reaching task and offers a possible therapeutic option for Stroke survivors and other neuromuscular disorders.

Keywords: motor imagery; reaching task; surface electromyography; angular velocity

INTRODUCTION

The use of motor imagery (MI), the imagining of an action without its physical execution, represents a motor learning technique which has been shown to offer significant improvements in movement performance in sports (Suinn 2006). MI is commonly used by sportsman and musicians as a motor learning technique as part of their training (Mulder 2007). MI is now receiving a lot of attention as a relatively new therapeutic approach which can be applied in rehabilitation and has been shown to enhance mobility and supports motor recovery in orthopaedic and neurological patients (Harris & Herbert 2015; Ietswaart et al 2011). Especially the combination of MI and physical practice which has been shown to be more efficient than just physical practice alone (Lebon et al 2010). The most recent work by Zapparoli et al (2020) showed that MI training in combination with physiotherapy can speed up motor recovery and decreases the risk of falls in patients after total knee arthroplasty.

MI as a pure cognitive process elicits activity in neural structures that are normally activated during actual task performance while the real motion is inhibited (Hardwick et al 2018; Hétu et al 2013; Ruffino et al 2017) and produces cortical reorganizations comparable to those elicited through physical practice (Ruffino et al 2017). Thus, training using MI, and not just motion execution itself, can promote neuroplastic adaptations behind the motor learning processes (Gentili & Papaxanthis 2015; Di Rienzo et al 2016, Ruffino et al 2017). The neuroplastic mechanisms as a consequence of MI were presented by Ruffino et al (2017) who suggested that MI facilitates corticospinal excitability which induces synaptic adaptations in the motor cortex leading to shifts in cortical representation patterns. MI has been reported to rely on the efferent copy and on the working memory without actual sensory feedback (Nicholson et al 2018), and the positive effects of MI on motor performance may be due to estimations based on internal forward model predictions (Gentili et al 2010; Gentili et al 2015).

The efficiency of motor learning processes is apparent at a behavioural level through improved movement execution, determined through changes in accuracy, efficiency or speed (Di Rienzo et al. 2016; Gentili et al 2006) or by increased muscle strength (Lebon et al 2010). Behavioural changes, which are fundamental for improvement in motion performance and for the acquisition of new motor skills can occur within even a single training session (Doyon & Benali 2006; Fukumoto et al 2016; Gentili et al 2010; Nicholson et al 2018).

The behavioural changes resulting from motor learning, including MI techniques, on motor performance can be estimated by the assessment of the quality of the movement performed. Standard clinical measures may not adequately capture movement quality and may be insensitive to detecting motor pattern changes in the execution of movements (Kwakkel et al 2019). To evaluate effects of rehabilitation in stroke patients there is a need to distinguish between behavioural restitution or compensatory mechanisms, and technologies allowing objective measurement of movement kinematics and kinetics have been suggested as the best way to tackle this problem (Kwakkel et al 2019). Improvement in motion coordination and movement speed, as a consequence of motor learning, has been previously described by measuring muscle activity and kinematic variables in stroke patients (Caimmi et al 2008; Richards et al 2003). Measures such as angular velocity (Richards et al 2003) and surface electromyography (Thoroughman & Shadme 1999) have been shown to represent sensitive measurements which are able to assess quality of movement and motor control. As the use of measurement instrumentation to quantify the assessment of movements can be time consuming, expensive, and require access to a specialized laboratory, alternative techniques are needed for motion assessment (Sgrò et al 2016). Previously, lower cost options have been explored, and good agreement between electrogoniometers and motion analysis systems have been shown when measuring angular velocity (Pomeroy et al 2006). More recently, the use of wearable inertial measurement units (IMUs), has become more widely used for human movement analysis (Masci et al 2012), and these have recently been shown to measure clinically important changes in motor control or balance abilities using segment angular velocity data (Brabants et al 2018; Budini et al 2018).

The effect of MI on improvements in physical performance and motor learning processes is more likely to be achieved in subjects with good imagery abilities (Ruffino et al 2017). Subjective measures of MI ability exist including motor imagery questionnaires or mental chronometry which are easy to use in a rehabilitation context (Rulleau et al 2015; 2018). The most recent version of the Movement Imagery Questionnaire (MIQ) is the 3rd revised version (MIQ-3), which is intended for implementation in healthy adult subjects and has been shown to have good internal reliability and predictive validity (Williams et al 2012).

As a consequence of MI increased neural activity has been reported (Ruffino et al 2017; Hétu et al 2013, Mulder, 2007), and shown to have long-term improvements in motor performance (Lee and Hwang, 2019), as well as an immediate learning effect on motor performance (Gentili et al., 2010; Nicholson et al., 2018). However, the potential of MI to improve motor control and quality of movement during activities of daily living has yet to be explored. Therefore, the aim of this study was to determine the immediate effect of motor imagery during a reaching task on muscle activity and angular velocity in healthy subjects. The hypothesis was that MI can offer immediate improvements to the physical performance and execution of a reaching task.

METHODS

Participants

Seventeen healthy subjects (10 females, 7 males) with a mean (±SD), age of 33 ± 8.2 years, height 175.9 ± 8.8 cm and weight 74.3 ± 11.9 kg were recruited. All participants tested had a right dominant upper limb. All participants had at least good kinaesthetic and visual (internal and external) MI ability according to the Movement Imagery Questionnaire-3 (MIQ-3), with a mean (±SD) of (6±0.6) for internal visual imagery, (6±0.6) for external visual imagery and (6±0.9) for kinaesthetic imagery.

To be included, participants needed to be healthy and have a good level of cognitive and communicative functions. Exclusion criteria were any motion disability, history of surgical procedures and musculoskeletal or neurological impairment affecting the upper limbs. All participants were recruited from a university student and staff population, and details of age, weight and height were recorded.

Materials

All participants completed questionnaires relating to their imagery ability using the MIQ-3 (Williams et al 2012). The MIQ-3 consists of 12 items including the imagination of four movements; leg raise, jump, arm abduction and adduction, standing hip flexion, and uses internal and external visual imagery, and kinesthetic imagery. The MIQ-3 uses a seven-point scale ranging from 1 (very hard to see/feel) to 7 (very easy to see/feel) (Williams et al 2012), with a score of at least 4 in each type of imagery indicating a good imagery ability (Williams et al 2012). Upper limb dominance was assessed by the test of the preferred arm perform well-learned skills such as writing and throwing a ball which has been reported to be a good single indicator of handedness (Oldfield 1971; Abe & Loenneke, 2015). All participants underwent an experimental protocol which consisted of performing a reaching task before and after a period of MI. Experimental protocol and procedures were approved by the STEMH Ethics Committee of the University of Central Lancashire (STEMH 970).

Experimental protocol

The participants were positioned at a table whilst sitting comfortably on a chair without a back support; the distance between the participants' chest and the table was set to 20 cm. The tested upper arm was positioned with the ulnar surface of the hand on the table with the shoulder slightly abducted, the elbow was positioned in line with the table edge, the forearm in semi-pronation, and all fingers including the thumb were extended and adducted. A cup was placed 30 cm from the hand. The untested upper arm was placed with the palmar surface of the hand on the table with the forearm in pronation and shoulder slightly abducted. Participants performed 10 repetitions with the following instructions; reach forward to a cup of water placed on the table, pick it up and move it 30 cm towards them at their most comfortable speed without dropping the cup, pre-imagination reaching task (PRE condition), see Figure 1. They were then asked to imagine themselves performing the same reaching task from the first person (internal) perspective (as if they were actually inside themselves performing and seeing the motion through their own eyes) ten times with their eyes closed, with the instruction to do this as closely as possible to their real motion performance. During MI they were seated in the start position for the reach task. Finally, they were asked to repeat the reaching task ten times again in the same manner as before MI, post-imagination reaching task (POST condition). Ten repetition of the imagined and real task were performed to keep conditions consistent and to avoid mental fatigue (Rozand et al 2015).

Experimental measurements

During the ten repetitions of reaching task for both PRE and POST surface electromyography (sEMG) and segment kinematic data were collected using Trigno EMG/IMU wireless sensors (Delsys®, Boston, USA). Each sensor comprises of sEMG and inertial measurement units, with built-in tri-axial gyroscopes and accelerometers. sEMG signals were collected from the Biceps Brachii, Triceps Brachii, Anterior Deltoid and Upper Trapezius muscles. For the placement of the electrodes each muscle belly was palpated during a submaximal isometric contraction, and the skin surface directly overlying the centre of the muscle belly was cleaned using alcohol wipes in accordance with the SENIAM guidelines (Stegeman & Hermens 1998). During the task kinematic data were collected from the IMU sensors placed on the skin directly overlying the upper arm above the lateral epicondyle in parallel with the humerus, see Figure 2.

Data processing and analysis

EMG data and angular velocity data were exported from EMGworks (Delsys Inc.) for further data processing and analysis in Visual 3D (C-motion Inc, USA). EMG data was processed by removing the mean and was high pass filtered at 20Hz to remove movement artefacts. The data were then full wave rectified, from which the integrated EMG (iEMG) for each repetition for each muscle was found. In addition, the rectified data were then low pass filtered using a 15Hz Butterworth filter from which the peak EMG was found. The peak and average EMG signals over the reaching task were then normalised to the maximum observed signal within all trials. From the kinematic data the angular velocity of the upper arm reflecting the acceleration and deceleration phase during extension through to the end position of the reaching task were recorded from the gyroscopes from the Trigno EMG/IMU sensors, Figure 1. For the angular velocity data, the peak flexion, extension and range of segment velocities were found for the upper arm, Table 1 and 2. This method is supported by Brabants et al (2018) and Budini et al (2018) who were able to determine clinically important changes in motor control from segment angular velocity data, and by Richards et al (2003) who determined that lower limb angular velocities appeared more sensitive than angle and timing measures alone when considering clinically important differences between paretic and non-paretic sides in stroke survivors.

Statistical analysis

Shapiro–Wilk tests were performed on the kinematic and EMG measures, and all data were found suitable for parametric analysis. A 2x2 Repeated Measure ANOVA was then used to explore the muscle activity and the angular velocity between pre and post MI and between the dominant and non-dominant limbs, and p-values and effects sizes were reported using partial eta squared (np^2). Where significant main effects were seen, post hoc pairwise comparisons using Least Significant Difference tests were performed and the mean difference, standard error, p-values and confidence intervals of the differences were reported. All statistical analysis were carried out in SPSS version 27 (IBM Corp, USA).

RESULTS

The repeated measures ANOVA showed no interaction effects between pre and post MI and limb side. No significant main effects were seen between the dominant and non-dominant sides ($p=0.090$ to $p=0.746$). Significant main effects were seen between pre and post MI for the peak normalized muscle activity for Biceps Brachii ($F(1,16)= 32.3$, $p<0.001$, $np^2=0.68$), Anterior Deltoid ($F(1,16)=11.8$, $p=0.004$, $np^2=0.44$), Trapezius ($F(1,16)=10.3$, $p=0.005$, $np^2=0.39$), and Triceps Brachii ($F(1,16)= 21.9$, $p<0.001$, $np^2=0.58$), and for the average normalized muscle activity for Biceps Brachii ($F(1,16)=41.6$, $p<0.001$, $np^2=0.73$), Anterior Deltoid ($F(1,16)=14.3$, $p=0.002$, $np^2=0.49$), and Triceps Brachii ($F(1,16)=20.6$, $p<0.001$, $np^2=0.56$), and extension angular velocity ($F(1,16)=5.2$, $p=0.036$, $np^2=0.25$). However no significant differences were seen for average normalized muscle activity for Trapezius ($F(1,16)=1.6$, $p=0.222$, $np^2=0.09$), upper arm flexion angular velocity ($F(1,16)=1.00$, $p=0.330$, $np^2=0.06$), or for upper arm range of angular velocity ($F(1,16)=4.4$, $p=0.053$, $np^2=0.21$), although the latter showed a trend towards a significant difference, Table 1. Further post hoc pairwise comparisons using Least Significant Difference showed significant decreases between pre and post MI for peak normalized muscle activity for Biceps Brachii (mean difference=0.066, $p<0.001$), Anterior Deltoid (mean difference=0.051, $p=0.004$), Trapezius (mean difference=0.06, $p=0.005$), and Triceps Brachii (mean difference=0.109; $p<0.001$) and for the average normalized muscle activity for Biceps Brachii (mean difference=0.061, $p<0.001$), Anterior Deltoid (mean difference=0.051, p=0.002), and Triceps Brachii (mean difference=0.085, p<0.001), and an increase in extension angular velocity (mean difference=3.25, p=0.036), Table 2.

DISCUSSION

The aim of this study was to determine the immediate effect of MI during a reaching task on motion quality reflected by changes in muscle activity and angular velocity in healthy subjects. Optimizing motor function to increase independence in activities of daily living is one of the key goals of rehabilitation. Current evidence supports intensive task specific training as one of the most effective rehabilitation strategies especially in patients after stroke (French et al 2016; Harris & Herbert 2015; Pollock et al 2014). As the options of intensive task specific training might be limited in some circumstances due to weakness; low resistance against fatigue, limb immobilization, or limited dose of activity-related training (Hayward & Brauer 2015), alternative modalities of functional training are required. One such technique is MI, which might be used as an adjunct to standard physiotherapy. Lee and Hwang (2019) showed in their meta-analysis that therapy including MI can have a positive effect on improving upper extremity function in people with a hemiparetic stroke. However, a greater understanding of the mechanisms behind motor performance improvement after MI training is needed. To date the evidence supports the effect of MI on neural structures (Hardwick et al 2018; Hétu et al 2013; Ruffino et al 2017) or on improved motion execution determined through changes in accuracy or speed of motion (Gentili et al 2006; Gentili et al 2015; Sobierajewicz et al 2016; Relleau et al 2018). But still little is known about the effects of MI on the quality of movement measured determined through changes in of angular velocity or muscle activity during activities of daily living. Reaching and grasping, evaluated in this study, represent an essential part of independent living (Coats & Wann 2012), and MI has previously been reported to be effective in the rehabilitation of these tasks in stroke survivors (Crajé et al 2010). In addition, the Stroke

Recovery and Rehabilitation Roundtable have recommended a focus on the evaluation of reaching and grasping with the emphasis on the assessment of the quality of movement using objective kinetic or kinematic measurements to better understand the neural processes and details on motion execution (Kwakkel et al 2019; Zeiler & Krakauer 2013). In our study we showed an immediate effect of MI training on a reaching task in healthy subjects. This showed that after MI the average and peak EMG activity was lower in Biceps Brachii (8% and 11%), Anterior Deltoid (6% and 8%) and Triceps Brachii (13% and 11%), as was the average EMG for Trapezius (10%). The changes in muscle activity as a consequence of motor imagery have been previously described (Guillot et al 2012, Kolářová et al 2016), and includes a reported decrease in muscle activity (Aoyama & Kohno 2020, Lay et al 2002). Aoyama & Kohno (2020) further highlighted that "*EMG activity decreases with the progress of motor learning and that the extent of decrease is positively correlated with the improvement in motor skills*".

This would suggest that a lower peak muscle force was required during the motion after MI in our study, indicating a change in movement control. In addition, a significant increase in extension angular velocity after MI was seen, which has been previously suggested to be a measure of improved quality of movement (Richards et al 2003), although it should be noted the percentage increase was only 4%. However, this supports the concept of changes in motor performance as a consequence of mental training in healthy subjects (Gentili et al 2010; Gentili & Papaxanthis 2015; Luger et al 2019), and in individuals with chronic hemiparetic stroke for both simple reaching tasks without grasping and sit to stand tasks (Guttman et al 2012; Lee et al 2016).

Our data supports the previously suggested hypothesis that MI immediately following performance allows learning of motor skills and results in motion improvements when subsequently performing the skill (Fukumoto et al 2016; Gentili et al 2010; Nicholson et al 2018). Gentili et al 2010 showed that both MI and physical training led to immediate motion performance improvements by means of faster and straighter arm movements. The results of this current study suggest that MI had an immediate effect on the reaching task on upper limb muscle activity and extension movements. The significant decrease in muscle activity might reflect to some extent a motor learning effect during the execution of the movement (Ruffino et a 2017), which is further supported by the findings of Luger et al (2019) who reported an increased angular velocity and decreased muscle activity after physical motor training. These findings need further consideration with the addition of a control group to confirm that the effects seen were not obtained just as a result of physical practice only.

MI is believed to rely on the efferent copy of a motor command and working memory, which utilizes the forward internal model by predicting the future sensory motor state of the body motion (Gentili et al 2015; Nicholson et al 2018), indicating that sensory motor predictions are required for motor commands, that are enhanced by previous real sensory feedback (Rulleau et al 2018). This current study may be considered as a proof of concept for the immediate effect of MI as we had a relatively low number of healthy participants. When considering the number of repetitions, healthy participants would have been able to easily perform more physical and MI repetitions without mental fatigue (Feltz & Landers 1983; Driskel et al., 1994; Guillot et Collet, 2008). However, this study aimed to explore a number of repetitions which would be manageable for stroke survivors, which is supported by Rozand et al (2015), who suggested that the performance of 10 repetitions of imagined movement and accompanied by actual movement execution are necessary to achieve sensory feedback whilst avoiding mental fatigue.

There are some limitations to this study which include a small sample size, and the potential for a training effect by performing the repetitions of the movements before and after MI. For further studies, the inclusion of a control group with no MI condition should be considered to see to what extent the effect of motor performance improvement may be considered as a result of the MI training. The next steps are to explore the effect of MI training using this protocol with stroke survivors, as reaching tasks have been suggested as suitable functional movements to explore quality of movement in more detail, which may help our understanding of the mechanisms of quality of movement and performance recovery in stroke survivors. In future studies even the circadian rhythms of participants should be considered as the MI ability may vary with time of day (Rulleau et al 2015). Furthermore, within rehabilitation settings, the use usage of a more appropriate version of MIQ, such as the MIQ-RS for stroke survivors (Gregg et al., 2010), is recommended.

CLINICAL RELEVANCE

- MI following the physical practice has potential as motor learning technique
- MI following the physical practice improves quality of upper limb motion in healthy subjects
- Just after MI muscle activity decreased and angular velocity increased

CONCLUSION

This study demonstrated an immediate decrease in upper limb muscle activity with an increase in extension angular velocity during the performance of reaching task after MI training following the physical practice. These results suggest a learning effect during the execution of the movement and improved quality of movement as an effect of motor learning, however further work is required to determine if this effect can be reproduced in different patient groups.

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TABLES

Table 1. Descriptive Statistics, Main Effects and Partial Eta-Square (np^2) for Reach Task over the whole reaching task

	Pre MI REACH		Post MI REACH			
	Dominant	**Non-dominant**	**Dominant**	**Non-dominant**	**Pre versus Post**	**Dominant versus Non-dominant**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**p-value (np^2)**	**p-value (np^2)**
Upper Arm Flexion angular velocity	58.94 (14.82)	54.31 (15.13)	61.66 (17.47)	54.37 (11.93)	0.330 (0.06)	0.090 (0.17)
Upper Arm Extension angular velocity	-66.05 (17.46)	-63.41 (15.44)	-70.95 (18.88)	-65.01 (14.83)	0.036 (0.25)*	0.233 (0.09)
Upper Arm Range of angular velocity	124.98 (31.73)	117.72 (27.84)	132.62 (35.18)	119.38 (25.86)	0.053 (0.21)	0.14 (0.13)
Peak Biceps EMG	0.85 (0.04)	0.88 (0.06)	0.78 (0.06)	0.82 (0.08)	<0.001 (0.68)*	0.061 (0.21)
Average Biceps EMG	0.53 (0.08)	0.55 (0.13)	0.46 (0.09)	0.50 (0.14)	<0.001 (0.73)*	0.458 (0.04)
Peak Anterior Deltoid EMG	0.87 (0.05)	0.86 (0.06)	0.82 (0.09)	0.80 (0.06)	0.004 (0.44)*	0.389 (0.05)
Average Anterior Deltoid EMG	0.59 (0.08)	0.56 (0.14)	0.52 (0.06)	0.53 (0.12)	0.002 (0.49)*	0.702 (0.01)
Peak Trapezius EMG	0.84 (0.06)	0.88 (0.05)	0.80 (0.09)	0.80 (0.05)	0.005 (0.39)*	0.131 (0.14)
Average Trapezius EMG	0.53 (0.07)	0.55 (0.11)	0.52 (0.09)	0.52 (0.13)	0.222 (0.09)	0.721 (0.01)
Peak Triceps EMG	0.82 (0.10)	0.82 (0.19)	0.70 (0.20)	0.72 (0.18)	<0.001 (0.58)*	0.746 (0.01)
Average Triceps EMG	0.58 (0.13)	0.59 (0.16)	0.49 (0.18)	0.51 (0.13)	<0.001 (0.56)*	0.713 (0.01)

***** Significant difference

Table 2. Mean differences, Pairwise Comparisons and Confidence Intervals for the Differences between Pre vs Post MI

	Mean difference	**p-value**	**CIs of the differences**
Right Upper Arm Extension angular velocity Pre vs Post MI	3.25	0.036	0.24-6.27
Peak Biceps Pre vs Post MI	0.07	<0.001	0.04-0.09
Average Biceps EMG Pre vs Post MI	0.06	<0.001	0.04-0.08
Peak Deltoid Pre vs Post MI	0.05	0.004	0.02-0.08
Average Deltoid EMG Pre vs Post MI	0.05	0.002	0.02-0.08
Peak Triceps Pre vs Post MI	0.11	0.005	0.06-0.16
Average Triceps EMG Pre vs Post MI	0.09	<0.001	0.05-0.12
Peak Trapezius Pre vs Post MI	0.06	<0.001	0.02-0.1

FIGURES

Figure 1. Reaching task; a) Starting position, b) Extension phase, c) lifting the cup, d) end position

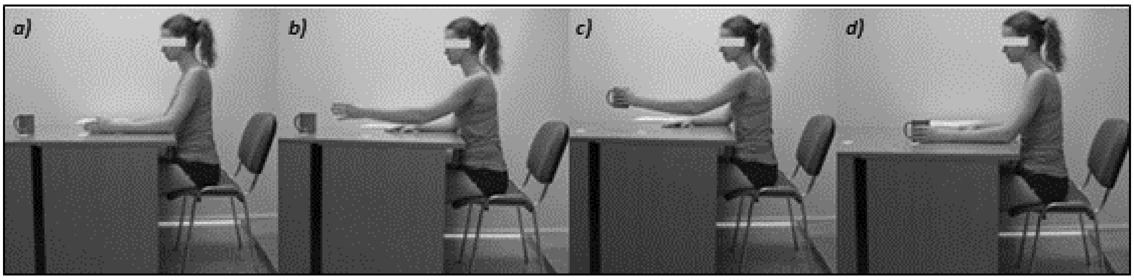

Figure 2. Illustrative sensors placement. In white-coloured is arm IMU sensor for spatiotemporal data. Sensors (1-4) are for electromyographic data, where 1 is Upper Trapezius, 2 Anterior Deltoid, 3 Biceps Brachii, 4 Tricpes Brachii