

Alissa D. Fourkas · Alessio Avenanti · Cosimo Urgesi
Salvatore M. Aglioti

Corticospinal facilitation during first and third person imagery

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Abstract Motor imagery can be defined as the covert rehearsal of movement. Previous research with transcranial magnetic stimulation (TMS) has demonstrated that motor imagery increases the corticospinal excitability of the primary motor cortex in the area corresponding to the representation of the muscle involved in the imagined movement. This research, however, has been limited to imagery of oneself in motion. We extend the TMS research by contrasting first person imagery and third person imagery of index finger abduction-adduction movements. Motor evoked potentials were recorded from first dorsal interosseous (FDI) and abductor digiti minimi (ADM) during single pulse TMS. Participants performed first and third person motor imagery, visual imagery, and static imagery. Visual imagery involved non biological motion while static imagery involved a first person perspective of the unmoving hand. Relative to static imagery, excitability during imagined movement increased in FDI but not ADM. The facilitation in first person imagery adds to previous findings. A greater facilitation of MEPs recorded from FDI was found in third person imagery where the action was clearly attributable to another person. We interpret this novel result in the context of observed action and imagined observation of self action, and attribute the result to activation of mirror systems for matching the imagined action with an inner visuo-motor template.

Keywords Motor imagery · TMS · Perspective taking · Motor evoked potentials

Introduction

Motor imagery can be defined as the covert rehearsal of moving the body. Yet as a purely covert activity, it is difficult to know what exactly is meant by motor imagery. To consider a motor image as merely an internal representation of muscle forces and proprioception seems strikingly simplistic when the motor system itself relies heavily on sensory input from several modalities, particularly vision. People can perform imagery of motor tasks using an internal visual perspective of themselves, an external visual perspective of themselves or someone else, and sometimes switch back and forth (Harris and Robinson 1986). Both perspectives incorporate information relevant to the motor task including, possibly, visuospatial characteristics of the environment and actor, and task motivation and goals. Moreover, behavioral studies indicate that kinesthetic (tension, stretch, proprioception) imagery can accompany both internal and external perspectives (White and Hardy 1995; Hardy and Callow 1999), although it appears that one must be the agent of the action in order to experience kinesthetic imagery during an external perspective (Callow and Hardy 2004). Thus, unless one distinguishes motor imagery from the imagery of action or movement, it is clear that a motor image is frequently multimodal and may involve a variety of spatial codes (c.f. Annett 1995; Vogt 1996; Smyth and Waller 1998; Féry 2003).

The fact that people switch between external of self and internal perspectives during imagery suggests that the definition of first person perspective as ‘imagery of oneself performing’ is ambiguous. In this study we have explicitly defined first person imagery as that which uses an internal or egocentric perspective. Moreover, as external (non egocentric) imagery can involve either a sense of agency or be attributable to another person, we

A. D. Fourkas (✉) · A. Avenanti · C. Urgesi · S. M. Aglioti
Department of Psychology, University of Rome “La Sapienza”,
via dei Marsi 78, Rome, 00185, Italy
E-mail: alissa.fourkas@uniroma1.it
Tel.: +39-06-49917635
Fax: +39-06-49917635

A. Avenanti · S. M. Aglioti
IRCCS, Foundation Santa Lucia, Rome, Italy

C. Urgesi
Department of Neurological and Vision science,
University of Verona, Italy

have explicitly defined a third person image or perspective as external imagery of someone else performing.

Some neurophysiological studies of motor imagery report specific perspectives and modalities through instructions or via movement imagery questionnaires, while also obtaining introspective reports of the imagery experienced (Lafleur et al. 2002; Luft et al. 1998; Ogiso et al. 2000). The majority provide relatively imprecise (e.g. 'imagine yourself performing the movement') instructions (Stephan et al. 1995; Naito et al. 2002; Roth et al. 1996) or fail to provide details of the imagery experience (Lotze et al. 1999; Porro et al. 1996; Schnitzler et al. 1997), leaving some doubt as to what exactly was measured. Altogether, however, there is strong evidence that the neural structures activated by motor imagery largely overlap those activated by the actual execution of movement (Decety 1996; Grèzes and Decety 2001).

Via single pulse transcranial magnetic stimulation (TMS), it has been demonstrated that motor imagery increases corticospinal excitability in the primary motor cortex (M1) and that the increase is specific to the representation of the body part whose movement is imagined (Facchini et al. 2002; Fadiga et al. 1999; Yahagi and Kasai 1999). This effect appears to occur primarily on the cortical level as no modulation has been detected at the spinal level with the H reflex (Hashimoto and Rothwell 1999; Kasai et al. 1997), although the F wave is less conclusive (Rossini et al. 1999; Stinear and Byblow 2003). Furthermore, single and paired pulse TMS have been used to illustrate that kinesthetic imagery and the observation of movements (self and non-self) lead to comparable levels of excitability with no modulation of the H reflex or F wave (Patuzzo et al. 2003). No TMS studies have, however, compared the corticospinal excitability during first person imagery to that which occurs during third person imagery.

First person and third person imagery have some cortical areas in common. With both first and third person motor imagery, significant levels of activation in the precentral gyrus (M1), supplementary motor area, precuneus and MT/V5 were detected with positron emission tomography (Ruby and Decety 2001); additional activation was found during third person imagery in the right inferior parietal cortex and precuneus, and during first person imagery in the left inferior parietal cortex and somatosensory areas, suggesting a role for these areas in distinguishing the agent of the action. Moreover, performance was impaired in brain damaged patients (motor cortex or putamen) when they used either perspective to learn movement sequences involving multiple body parts (head, torso, right arm and left arm) and then had to decide which photo in a series contained a 'correct' final posture (Li 2000). This effect was not found in control subjects. Of particular relevance to our research is the fact that these studies suggest a role for the motor cortex in imagery regardless of perspective. We extend the understanding of the involvement of M1 by measuring changes in corticospinal excitability with

single pulse TMS during first and third person imagery of index finger abduction and adduction.

Visual imagery is related, but not identical, to motor imagery that happens to be visual in nature. We included an imagery task requiring the conscious manipulation of visual information in order to assess whether increased corticospinal excitability can be induced by the abstract visual components of movement or by motor imagery only. The task involves non biological motion but, like our first and third person movement imagery conditions, requires the manipulation of direction and velocity information.

Rest normally serves as a baseline value to which neural activity during cognitive tasks is compared. Neural activity, however, is nevertheless present during rest (Stark and Squire 2001). Of particular concern to our research is the occurrence of 'task unrelated thoughts', including imagery (Binder et al. 1999) which even explicit instructions to avoid does not prevent (Mazoyer et al. 2001) during rest. Thus we placed restrictions on the imagery by defining our baseline as static (no movement) imagery of the hand. As such, our investigation specifically addresses the corticospinal excitability of the motor system during imagined movement. Should the involvement of the motor system during imagery be largely due to egocentricity or the representation of body parts, we likely will find little corticospinal modulation. However, we suspect that the involvement of the motor system results from the imagination of movement itself, particularly when conscious monitoring is required.

Method and Materials

Participants

Thirty subjects (age 20–44; 18 female) were recruited from and tested at the Faculty of Psychology 1, University of Rome "La Sapienza". Twenty eight were right handed (two left handed) according to a modified version of Briggs and Nebes (1975) handedness inventory, and were neurologically healthy, without psychiatric or other medical disorders, and without any contraindications to TMS (cf., Wassermann 1998). The study was approved by the local ethical committee and carried out in accordance with the ethical standards of the 1964 Declaration of Helsinki. Subjects gave written informed consent prior to participating.

Electromyography (EMG)

Surface Ag-AgCl cup electrodes (1-cm-diameter) were placed over the first dorsal interosseous (FDI) and abductor digiti minimi (ADM) in belly-tendon montage of the dominant hand. Recordings were made using a CED Power 1401 (Cambridge Electronic Design Ltd,

Cambridge, UK) connected to an Isolated Patient Amplifier System Model D360 (Digitimer Limited, Hertfordshire, UK), and interfaced with CED Spike 2 software. The second order Butterworth filter was set between 20 and 2,500 Hz (sampling rate 10 kHz). Signals were amplified at a gain of 1000. Auditory feedback of the EMG signals was used to help subjects maintain voluntary muscle relaxation during electrophysiological preparation.

Transcranial Magnetic stimulation

Focal TMS was performed with a figure eight shaped stimulation coil (outer diameter of each wing 70 mm), connected to a Magstim 200 Mono Pulse (Magstim Whitland, Dyfed, UK), over the contralateral primary motor cortex. The optimal scalp position (OSP) for eliciting motor evoked potentials (MEPs) was found by moving the coil in steps of 1 cm until the largest MEP was found and then marked with a pen. To control whether the modulation of MEP amplitudes in either muscle reflected the location of the OSP, FDI was used in 15 subjects and ADM in 15 subjects. The coil was held tangential to the scalp with the handle pointing backward and laterally at approximately 45° from the midline. Resting motor threshold (rMT) was defined as the lowest stimulus intensity to evoke at least five out of ten (MEPs) with an amplitude of at least 50 μ V (Pascual-Leone et al. 1994) in both muscles. Stimulus intensity was kept at 20% above rMT during data collection.

Procedures

Participants were seated comfortably in a chair with their dominant arm and hand resting, pronated, on a pillow placed on their lap. Written imagery instructions were supplied at the start of each condition in order to standardize instructions across participants. Participant's eyes were closed during imagery. During static imagery, participants were instructed to imagine their hand lying on the pillow and that their imagined hand should be completely stationary. This control condition was performed as the first for half of the participants and last for the other half. The other three conditions were performed in separate blocks, with the presentation order counterbalanced across subjects. Prior to beginning the visual imagery condition, participants viewed the movement to be imagined for 10 s (a ball moving up-down on a monitor), and were instructed to focus on both the vertical motion and constant pace of the object. The object was a two dimensional ball with a 5 cm diameter that was viewed from a distance of 30 cm. In first person imagery, participants were instructed to imagine abduction-adduction movements of the index finger of their dominant hand. In third person imagery, participants were instructed to imagine abduction-adduction of the experimenter's index finger (on the

hand corresponding to the participant's dominant hand). Prior to imaging, they watched themselves (or the experimenter, seated immediately in front of and facing the participant with his hand resting on his leg) physically perform the movement for 10 s and were instructed to notice the horizontal motion and constant pace of the movement.

On each trial, a computer beep indicated that the participant should begin performing imagery, and initiated EMG recording. In order to avoid priming effects, a variable interval of 3–3.5 s elapsed between the beep signal and the TMS pulse. In the movement conditions, task compliance was externally monitored by having participants report the direction of movement (up/down for the moving ball, left/right for the moving finger) when the pulse was delivered. EMG data were recorded for another 0.5 s after the TMS pulse was delivered. A rest period of 7 s elapsed before the next trial (time between pulses, 10.5–11 s). The choice of interstimulus interval was based on research by Chen et al. (1997) which demonstrated no change in corticospinal excitability with repetitive TMS at 0.1 Hz for 1 h using intervals of 10 s. Fifteen trials were performed in each condition, with approximately 3 min between conditions.

We concluded the experiment by obtaining introspective reports in order to assess the imagery experienced *in each condition* (Murphy 1994; Jack and Roepstorff 2002). The introspective report asked for a written description of the imagery experienced. This was followed by a specific query regarding the use of kinesthetic imagery (defined as a 'feeling or physical sensation'), which required participants to describe any feeling or physical sensation imagined. Perspective switching was controlled for by asking participants about the visual perspective used. Behavioural research has indicated that the ability to control the action occurring in an image, as well as the clarity and vividness of the image, can be important to the ability to use imagery to affect the motor system (cf. Start and Richardson 1964; Housner and Hoffman 1981; Goss et al. 1986; Isaac and Marks 1995). In view of this, we asked two questions regarding the quality of the imagery experienced. For each question, subjects marked one answer (strongly disagree, disagree, not sure, agree, strongly agree) along a Likert five-point scale.

Data Handling

Task compliance was high, as assessed via immediate verbal responses of imagined movement direction after the TMS pulse. MEPs were analysed off-line. The absence of background EMG activity was confirmed through visual inspection of the data. Trials with background activity within 100 ms of the TMS pulse, or on which movement was observed, were discarded (total = 31), as were trials with an MEP amplitude that was difficult to clearly distinguished from background EMG

activity ($< 90 \mu\text{V}$) (total=42). Two participants were replaced in the data set: one due to a problem with the MEP recording, the other due to her first person imagery involving an external image of herself rather than an egocentric perspective. Peak to peak amplitude (in mV) was calculated using CED Spike 2 software. Outliers (± 2 Sd of the mean) were identified for each muscle in each condition and the data removed for both muscles, (1–7 trials per subject, $M=3.5$). Across all data cleaning procedures, subjects lost a total of 2–13 trials, $M=6$. Data were normalized using natural log transformations to address non normality resulting from positive skew. In accordance with recommendations by Osborne (2002), a natural log and constant value of 1 were selected to resolve the issue while maintaining as closely as possible the order and spacing of the original distribution.

The manipulation checks revealed different strategies used in the movement imagery conditions. In first person imagery, some participants described purely visual imagery while others reported a combination of visual and kinesthetic components. In third person imagery of finger movement and visual imagery of a moving ball, all participants reported imagery that was purely visual in nature, with one exception; one subject experienced kinesthetic imagery of his own finger moving while ‘seeing’ a third person image of the experimenter performing the action. Participants generally (strongly) agreed that their imagery was controllable and clear/vivid (see Table 1).

Table 1 Summary of self-assessed imagery quality

	Third person	First person	Visual	Static
Easy to Control				
(Completely) Agree	$n=17$	21	25	25
(Completely) Disagree	3	3	1	3
Not Sure	10	6	4	2
Clear and Vivid				
(Completely) Agree	21	19	26	22
(Completely) Disagree	3	4	1	2
Not Sure	6	7	3	6

Participants marked one response in each condition, rating how easy it was to control the image and the clarity/vividness of the image. The small number of “(completely) disagree” responses suggests that the imagery experienced was relatively controllable, clear, and vivid

Results

The principle analysis involved separate mixed model ANOVA (2 OSPs \times 4 Conditions) for each muscle (means and standard deviations reported in Table 2), a preliminary analysis having confirmed no difference in resting motor threshold for the two optimal scalp positions, $t(28)=0.10$, $p=0.92$. Individual raw MEPs from one representative subject are shown in Fig. 1.

In the ADM muscle, the main effect for Condition, $F(3,84)=1.7496$, $p=0.16$, and OSP, $F(1,28)=0.000$, $p=0.997$, as well as the interaction, $F(3,84)=0.2571$, $p=0.86$, were all nonsignificant. The interaction failed to reach significance in the FDI muscle, $F(3,84)=0.7795$, $p=0.51$, indicating that the pattern of modulation was consistent regardless of which OSP was used. The main effect of OSP location, $F(1,28)=3.2032$, $p=0.084$, indicated a trend for the optimal scalp position of FDI to result in larger MEPs ($M=1.07$) than the position of ADM ($M=0.81$). Crucially, the factor Condition was significant, $F(3,84)=6.4469$, $p=0.0006$.

Post-hoc comparisons for the factor Condition were carried out using the Newman-Keuls procedure. Amplitudes recorded in FDI during third person imagery were increased compared to static hand imagery ($p=0.0004$), visual imagery ($p=0.024$), and first person imagery ($p=0.044$). A trend for first person imagery to lead to larger amplitudes than static hand imagery was present ($p=0.061$). Visual imagery did not differ from first person or static hand imagery. Mean MEP amplitude in the different imagery conditions for muscle FDI are shown in Fig. 2.

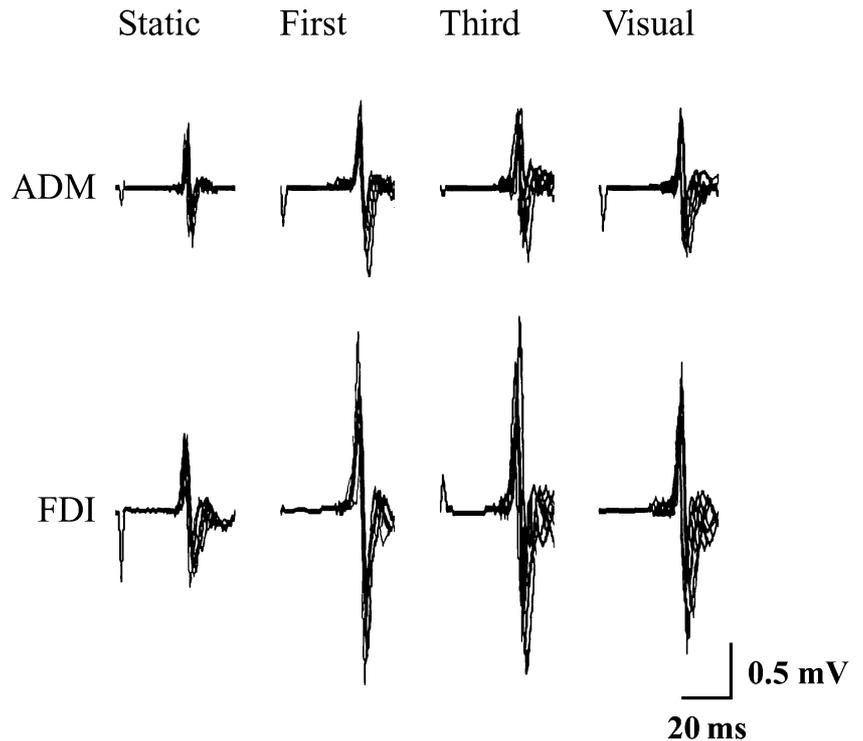
Based on information obtained from the introspective reports, we controlled whether imagery modality influenced corticospinal excitability in first person imagery. A two-sample t-test compared the MEP amplitudes obtained in the FDI muscle for those participants reporting visual images only ($n=21$; 10 with OSP FDI) and those combining visual and kinesthetic images ($n=9$; 5 with OSP FDI). We found no difference in MEP amplitude associated with the strategies used to imagine the action [$t(28)=0.13$, $p=0.90$] (Fig. 3).

Supplementary analyses explored the technical question of whether the two optimal scalp positions were similarly sensitive in terms of detecting differences in MEP amplitude across conditions (Fig. 4). As the effect of OSP was highly non significant in the mixed model analysis of

Table 2 Mean peak to peak MEP amplitude (and standard deviations) calculated from transformed (mV) data

	Third person	First person	Visual	Static
FDI Muscle ($N=30$)	1.03 (0.40)	0.95 (0.44)	0.92 (0.44)	0.85 (0.43)
OSP FDI ($n=15$)	1.18 (0.42)	1.10 (0.43)	1.04 (0.51)	0.95 (0.45)
OSP ADM ($n=15$)	0.88 (0.33)	0.80 (0.41)	0.81 (0.35)	0.76 (0.40)
ADM Muscle ($N=30$)	0.51 (0.22)	0.50 (0.24)	0.49 (0.26)	0.45 (0.28)
OSP FDI ($n=15$)	0.51 (0.21)	0.50 (0.23)	0.50 (0.29)	0.44 (0.27)
OSP ADM ($n=15$)	0.50 (0.24)	0.49 (0.26)	0.49 (0.23)	0.46 (0.30)

Fig. 1 Raw MEPs recorded in ADM and FDI for one representative subject. Data from the 15 trials in each condition are superimposed to illustrate the size and shape of the recorded motor evoked potentials. Data for the muscle ADM are shown in the upper panel and FDI in the lower panel



ADM muscle data, only FDI was subsequently analyzed. A one-way repeated measures ANOVA of data recorded in the FDI muscle when FDI was used as the OSP ($n = 15$) was significant, $F(3,42) = 5.145$, $p = 0.004$. The Newman-Keuls post-hoc indicated that third person imagery was different from static imagery ($p = 0.003$) and visual imagery ($p = 0.058$); first person imagery also differed from static imagery ($p = 0.049$). First person and third person imagery were not different ($p = 0.18$).

In contrast, when the ADM OSP was used ($n = 15$) the ANOVA failed to reach significance, $F(3,42) = 1.82$, $p = 0.157$. Thus, even though the mixed model ANOVA indicated that both OSPs detected the same pattern of activation across conditions, we conclude that the ADM OSP was less sensitive.

Discussion

The results indicate that increased excitability in the motor system was related to the imagination of a body part moving. This increased excitability was found only in the muscle that would be involved in performing the imagined movement, and was detected most strongly during third person imagery. The effect of first person imagery of movement above the motor activation generated by static hand imagery was clearly detectable only when the optimal scalp position was located directly above the muscle whose movement was imagined. In first person imagery, the strategy used (visual only, or combined visual and kinesthetic) did not affect the level of excitability that was detected.

Previous studies have found that the application of single pulse TMS over a specific muscle representation in M1 during first person imagery results in an increase in MEP amplitude compared to rest (Kasai et al. 1997; Facchini et al. 2002; Stinear and Byblow 2003), listening to auditory signals (Hashimoto and Rothwell 1999), or imagining a bar of light shrinking-expanding (Fadiga et al. 1999). In the present study, image perspective was controlled for by first asking participants to physically perform and observe the task they would subsequently

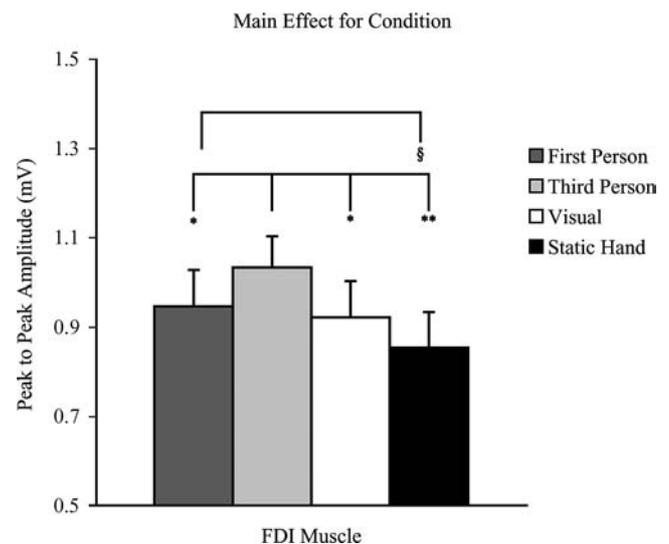


Fig. 2 Mean peak to peak MEP amplitudes and standard errors per condition ($N = 30$) in FDI (first dorsal interosseous); significant difference detected with Newman-Keuls post hoc, § $p = 0.06$, * $p < .05$, ** $p < .001$

Effect of Strategy in First Person Imagery

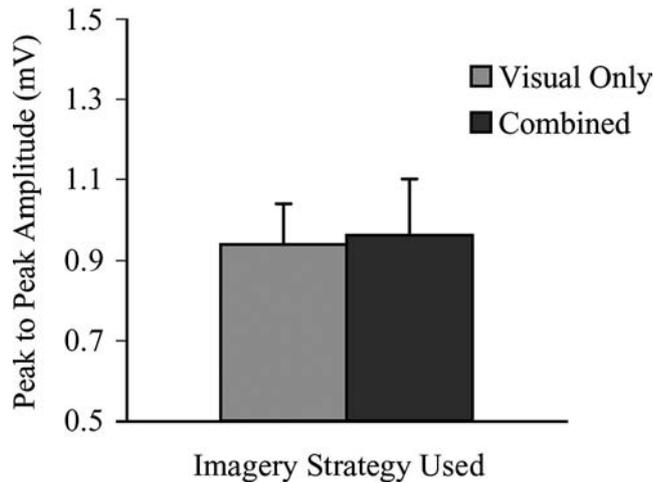


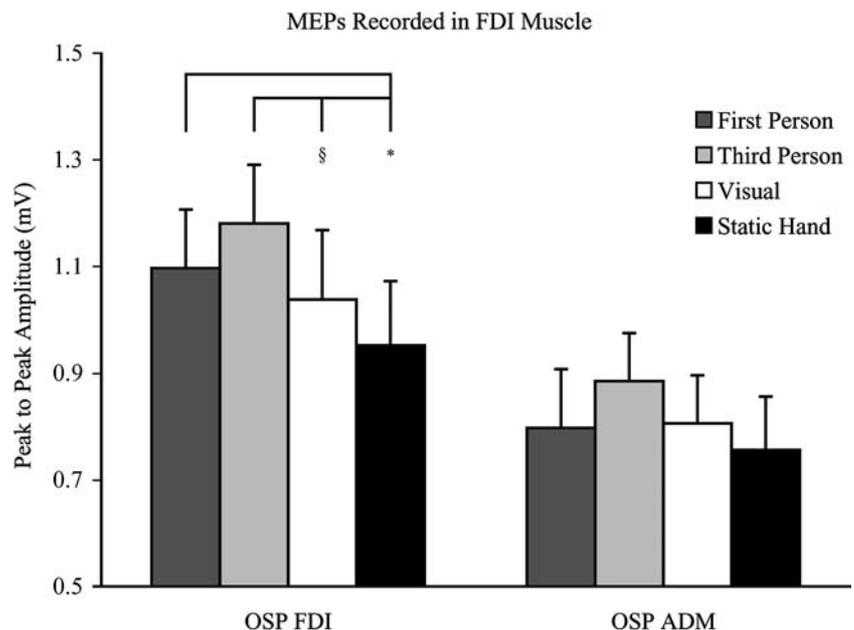
Fig. 3 Illustrates no difference in excitability in the FDI (first dorsal interosseous) muscle during first person imagery for participants using visual imagery alone ($n=21$) and those combining visual and kinesthetic imagery ($n=9$). Values depicted are mean peak to peak MEP amplitude and standard errors

imagine, and then obtaining introspective reports to confirm that a first person perspective was maintained. We provide evidence that the MEPs recorded during first person imagery are higher than those during static imagery when the optimal scalp position is located over the FDI muscle. We suspect the failure to obtain the same result using the ADM OSP reflects two factors. First, we had intentionally selected a static image of a hand as a baseline condition in order to assess whether corticospinal facilitation is largely due to the motor representation of a body part or from the imagination of

the movement itself; that is, static imagery was a motor image. Moreover, it appears that the additional facilitation which is specific to imagined movement is relatively small and can be detected only if the TMS pulse is directed specifically at the M1 site of the muscle involved in the imagined movement.

The excitability obtained for the two imagery strategies spontaneously adopted by participants (combined imagery, or visual imagery alone) did not differ, a result that seems counterintuitive. One might expect that first person imagery which incorporates kinesthetic components in addition to visual components to be more closely associated with motor control as it creates a more 'real' representation. That is, kinesthetic imagery involves the imagination of sensorimotor information (e.g. muscle tension, proprioception) and therefore kinesthetic imagery should be a critical aspect of motor imagery (cf. Jeannerod 1994). Alternately, we might presume that the 'completeness' of the internal representation is important, and therefore a combination of modalities will produce a more 'real' representation. Hence the emphasis by sport psychologists: "imagery can and should involve all the senses ... using all appropriate senses may help the athlete create more vivid images. The more vivid the image, the more effective it is (Vealey 1986, p 210)". It has been argued elsewhere, however, that imagined information (e.g. tension, finger placement, spatial relations, timing) benefits motor performance only when it provides information that would otherwise be unavailable (Hardy 1997). As our participants described their imagery as clear/ vivid and controllable, the lack of significant difference in MEP amplitude may be due to the inability of participants to gain useful information about the simple finger movements from kinesthetic imagery, which was not already provided by visual imagery. Other motor imagery tasks

Fig. 4 MEPs recorded in the FDI muscle, with data obtained from participants with OSP FDI ($n=15$) separated from participants with OSP ADM ($n=15$). Significant differences within the analysis of OSP FDI were detected with the Newman-Keuls post hoc, § $p=0.06$, * $p < .05$



where kinesthetic information is critical (e.g. muscle tension in tying sutures) may then lead to different levels of facilitation depending on imagery strategy.

We not only detected increased excitability when participants imagined themselves performing, but also when they imagined someone else performing. This indicates that an influence of third person imagery can be detected in the motor system even though it involves a purely visual external image, contrary to arguments advanced by Jeannerod (1994). An effect in the motor system, however, is logical; imagery of another person performing, particularly a model, is frequently used in mental rehearsal by novice athletes in order to alter their own motor system. Via third person imagery an athlete can make approximations of the desired movement when the model is no longer present, and continue with the process until an accurate first person image can be formed. In such circumstances, third person imagery is clearly related to observational learning (White and Hardy 1995).

Corticospinal excitability increases when people observe someone performing, and the activation is similar to that which occurs during execution of the same movement (Fadiga et al. 1995). The effect is highly tuned, as evidenced by the presence of temporal modulation of facilitation during different phases of the observed action (Gangitano et al. 2001). This facilitation is thought to result from the activation of cortico-cortical connections between premotor mirror neurons (primate F5; human area 44 [Broca]) and M1, subthreshold activation of M1 itself, or both (Gallese et al. 1996). The imagined observation of self movement (external imagery of oneself) also activates premotor areas (Binkofski et al. 2000; Seitz et al. 2000), providing a plausible explanation for the comparable levels of MEP facilitation that occur during imagery of previously observed action and the observation (passive or with the intention to imitate) of action (Clark et al. 2004). Although Clark et al asked participants to imagine the hand action they had previously observed, there is no indication what perspective participants actually used. The increase in corticospinal excitability we detected following the observation of movement occurred during external imagery of someone else. While we note that when real or imagined observation is of oneself, rather than of somebody else, the person remains the agent of the action (cf. Bandura 1989), this distinction appears to have no bearing on increases in excitability as both agent-as-self and agent-as-other attributions of action causation involve the primary motor cortex (Farrer and Frith 2002).

We used a visual imagery task as a contrast to motor imagery based on the assumption that the imagined action reflects a visual behavior which may also involve motor areas. For instance, previous research has indicated that while corticospinal excitability is not modulated by passively viewing a moving dot (Patuzzo et al. 2003), the motor cortex is active when the observation of motion is accompanied by a search for pattern features (Hari et al. 1998). The generalizability of these results to

the imagination of a dot moving is unclear as both studies involved the perception of movement. Of the two, our instructions were more similar to those of Hari et al. (1998); presuming we are justified in describing static imagery as a motor image, the similarity in excitability during visual and static imagery may be related to the fact that participants were instructed to actively attend to the imagined stimulus and report the direction of the imagined movement when the TMS pulse was delivered. We intentionally used vertical motion in the visual imagery condition to try and minimize or even avoid an unconscious mental transformation into horizontal finger movement. Although a clear understanding would require further investigation, we note that single cell recording studies demonstrate that neurons in the monkey primary motor cortex respond to real and apparent motion (Merchant et al. 2004; Merchant et al. 2004) as well as the optic flow of visual stimuli (Merchant et al. 2001) in the absence of a motor response.

In summary, we attempted to discriminate what aspects of motor imagery we were measuring by providing written instructions and obtaining introspective reports. Based on this information, we have determined that our results reflect neural activity of visuomotor imagery. The imagination of movement increased corticospinal excitability above that which occurred during static imagery of a body part; this effect was highly evident during third person imagery, while the detection during first person imagery depended on which optimal scalp position was used. No difference between visual and combined imagery was apparent in first person imagery. We conclude that motor imagery is a dynamic process which is multimodal and may involve a variety of spatial codes.

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