Title	Effect of Gait Imagery Tasks on Lower Limb Muscle Activity With Respect to Body Posture
Type	Article
URL	https://clok.uclan.ac.uk/14576/
DOI	https://doi.org/10.1177/0031512516640377
Date	2016
Citation	Kolarova, B., Krobot, A., Polehlova, K., Hlustik, P. and Richards, Jim (2016) Effect of Gait Imagery Tasks on Lower Limb Muscle Activity With Respect to Body Posture. Perceptual and Motor Skills, 122 (2). pp. 411-431. ISSN 0031-5125
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EFFECT OF GAIT IMAGERY TASKS ON LOWER LIMB MUSCLE ACTIVITY WITH RESPECT TO BODY POSTURE

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Summary. ~~***(max 180 words)***~~

The objective of this study was to evaluate the effect of gait imagery tasks on lower limb muscle activity with respect to body posture. The sitting and standing position and lower limb muscle activity was evaluated in 27 healthy female students (24.4 ± 1.3 yrs, 167.2 ± 5.2 cm, 60.10 ± 6.4 kg). Surface electromyography was assessed during rest and in three different experimental conditions using mental imagery. These included; a rhythmic gait, rhythmic gait simultaneously with observation of a model and rhythmic gait after performing rhythmic gait. The normalized rmsEMG values with respect to corresponding rest position were compared using non-parametric statistics. Standing gait imagery tasks had facilitatory effect on proximal lower limb muscle activity. However, EMG activity of distal leg muscles decreased for all gait imagery tasks in the sitting position, when the proprioceptive feedback was less appropriate. For subsequent gait motor imagery tasks the muscle activity decreased, probably as result of habituation. In conclusion the effect of motor imagery on muscle activity appears to depend on relative strength of facilitatory and inhibitory inputs.

Keywords: gait, motor imagery, surface electromyography

Motor imagery (MI) represents a pure cognitive process, which positively influences motor performance in healthy subjects which has been shown for sport performance, e.g. gymnastics, ballet and tennis (Guillot, Di Rienzo, Macintyre, Moran, & Collet, 2012). In addtition this has been shown in patients following motor impairment and has been used in physical therapy during recovery of function (Lotze & Halsband, 2006; Mizuguchi et al., 2012). Specifically walking skills in neurological patients improved after motor imagery exercise (Dunsky, Dickstein, Marcovitz, Levy, & Deutsch, 2008; Oostra, Oomen, Vanderstraeten, & Vingerhoets, 2015). Home-based motor imagery gait training programs have been shown to improve gait parameters including; walking speed, stride length, cadence, single and double support time in chronic post-stroke subjects (Dunsky, Dickstein, Marcovitz, Levy, & Deutsch, 2008). Motor imagery training includes imagery of walking tasks in combination with physical therapy has been suggested to be more effective for improving gait velocity in sub-acute stroke patients then physical therapy alone (Oostra, Oomen, Vanderstraeten, & Vingerhoets, 2015). In addition videotape-based locomotor imagery training together with regular physical therapy has been shown to improve walking ability in post-stroke and people with Parkinson’s disease more than gait training alone (El-Wishy & Fayez, 2013; Hwang et al., 2010).

Motor imagery can be described as a conscious mental simulation of an action without actual execution, is accompanied by activity in specific neural substrates (both supraspinal and spinal) similar to those involved in the actual executed movement. Meta-analysis on effect of motor imagery on brain structures conducted by Hetu, *et al.* (2013) provided evidence that motor imagery activates motor related brain networks including large fronto-parietal and subcortical regions involved in motor execution. Several studies provided evidence that motor imagery increases excitability in corticospinal tracts which projects directly to motoneurons and their interneurons controlling the muscles (Clark, Mahato, Nakazawa, Law, & Thomas, 2014; Cowley, Clark, & Ploutz-Snyder, 2008; Oku, Ishida, Okada, & Hiraoka, 2011; Roosink & Zijdewind, 2010). This has been shown to increase the excitability of spinal reflexes (Li, Kamper, Stevens, & Rymer, 2004) and also in muscle proprioceptive structures (muscle spindle Ia afferent fibers) (Bonnet, Decety, Jeannerod, & Requin, 1997). So it seems that the motoneuron pool of muscle involved in imaginary movement receives summation of neural inputs via descending and ascending neural pathways in similar way as during real movement. The possibility that mental imagery can have an effect on the muscles that create the movement is supported by the positive influence of motor imagery training on muscle strength (Clark et al., 2014; Yue & Cole, 1992). However the influence of motor imagery on electromyography (EMG) measures is not clear yet. To date several studies have found no significant effect of motor imagery on electromyographic activity during imaginary pointing arm movement for upper limb muscles (Demougeot & Papaxanthis, 2011; Gentili, Papaxanthis, & Pozzo, 2006) during imaginary pointing arm movement for upper limb muscles including anterior deltoid, tricpes and biceps brachii, pectoralis major. In addition, Ranganathan, Siemionow, Liu, Sahgal, & Yue (2004) found no increase in activity of biceps brachii and finger abductor during imaginary isometric little finger abduction and elbow flexion, and Lemos, Rodrigues, & Vargas (2014) who found no increase in activity of the gastrocnemius lateralis during imaginary rising on tiptoes. However, Oku, Ishida, Okada, & Hiraoka (2011) found increased EMG in extensor carpi radialis activity during imaginary wrist extension and Guillot et al. (2007) and Dickstein, Gazit-Grunwald, Plax, Dunsky, & Marcovitz (2005) showed increased EMG activity of nine upper limb muscles in agonists, synergists, fixators and antagonists during imaginary lifting a weighted dumbbell and increased EMG activity of gastrocnemius medialis and rectus femoris when performing imaginary rising on tiptoes respectively.

Surface electromyographic measurements reflect, to some extent, the effort of neural system for movement execution as EMG signal is usually proportional to the level of motor unit activity (Richards, 2008). The muscle activity is altered by variations in the balance between inhibitory and facilitatory input which go in parallel to the motoneuron pool, the terminal part of spinal afferent or efferent sensory/motor pathways (Daroff et al., 2012). So it might accepted that even during MI the magnitude of EMG activity reflects the summation of facilitory and inhibitory inputs. This assumption is supported by recent findings, which had shown that the increase of EMG activity during MI mirrors a number of facilitatory inputs including mental effort related to e.g. characteristics of imagined object, the heavier was the object lifted in imagination the showed a greater EMG signal during MI (Bakker, Boschker, & Chung, 1996) and tends to be more pronounced in complex functional movements (Bakker et al., 1996; Guillot et al., 2012; Guillot et al., 2007). The EMG signal during motor imagery is classified mostly as subliminal (Guillot et al., 2012; Guillot et al., 2007) or background muscle activity (Oku, Ishida, Okada, & Hiraoka, 2011) which indicates that detectable muscle activity during MI does not have comparable magnitude and phasic pattern to real movement execution. As the amount of increase in EMG amplitude during motor imagery is positively correlated with the amount of corticospinal excitability (Oku, Ishida, Okada, & Hiraoka, 2011) and with respect to previous findings that corticospinal excitability and brain activity during motor imagery is enhanced with the real sensory feedback generated by holding an object which is imaginary manipulated (Mizuguchi et al., 2012) we speculate that EMG activity during gait imagery may be influenced by character of sensory feedback with respect to sitting (non-default position for walking) or standing (default position for walking) body position during imagination.

With respect to imaginary training protocols in sport or in rehabilitation it has been suggested that simultaneously observing somebody doing the task during motor imagery further positively influences neural activity and enhances motor learning processes (Nedelko, Hassa, Hamzei, Schoenfeld, & Dettmers, 2012; Roosink & Zijdewind, 2010; Wright, Williams, & Holmes, 2014). In similar way with respect to motor learning even previous practice of imaginary movement facilitates neural activity more than imagery before practice, improves imagination ability of this movement (Wriessnegger, Steyrl, Koschutnig, & Muller-Putz, 2014) and combination of imagination with real practice is more effective for motor recovery then movement imagination or execution alone. Therefore the simultaneous observing of imaginary movement will have facilitatory effect on muscle activity.

It has also been previously suggested that the effectivity of the motor imagery training depends on individual's imaging ability (Gregg, Hall, & Butler, 2010). Subjects with a good motor imagery ability show a greater performance improvement following motor imagery training than do subjects with a poor imagery ability (Mizuguchi, Yamagishi, Nakata, & Kanosue, 2015).

The aim of the present study was to analyze the effect of gait imagery tasks from the first person perspective on both proximal and distal lower limb muscle activity. Based on the prior finding that motor imagery activates neural structures in similar way as movement execution and that muscle activity reflects the summation of neural inputs coming to motoneuron pool via afferent and efferent pathways we hypothesized that: (1) imagination of gait (which is considered as complex functional task) modulates lower limb muscle activity, (2) the magnitude of muscle activity reflects character of peripheral sensory inflow during imagination with respect to body posture and (3) the magnitude of muscle activity is further influenced with respect to additional cognitive and motor task.

Therefore this study aimed to evaluate the electromyographic activity of proximal and distal lower limb muscles, which participate synergically on gait execution, during gait imagery tasks compare to rest conditions. This would potentially further our understanding of influence of gait imagery task on motor system and the effect of imagining or observing gait activity of lower limb muscles. This in turn provides important information for gait imagery rehabilitation protocols and could increase our understanding of gait control mechanisms.

Method

Participants

Twenty seven healthy females participated in this study. Their mean (± SD) age, height and weight were 24.4 ± 1.3 yrs, 167.2 ± 5.2 cm and 60.10 ± 6.4 kg. All participants were recruited from students from a Physiotherapy department of Palacky University. All participants had good cognitive function and communicative skills necessary for motor imagery and were able to generate gait motor imagery. Only participants with at least moderate visual and kinesthetic imagery ability, evaluated by Revised Movement Imagery Questionnaire (MIQ-R), were included in the study (Smith & Collins, 2004). MIQ-R represents a reliable tool to assess motor imagery ability in healthy persons. MIQ-R consists of an eight-item self-report questionnaire using two 7-point scales to evaluate ability to form visual and kinaesthetic mental images (Hall & Martin, 1997). The exclusion criteria included psychiatric, neurological or musculoskeletal disorders, balance or walking problems, the use of a walking aid, chronic pain, pregnancy, the use of medication affecting the level of vigilance and uncorrected visual impairments. The dominant lower limb was the right side in all participants, determined as preference for kicking a ball (Seeley, Umberger, & Shapiro, 2008). Testing occurred in a quiet room in one day. All participants signed an informed consent prior to participating in this study. The procedures, which were approved by the local ethics committee, were performed according to the ethical standards of the Declaration of Helsinki.

Motor imagery ability measures

When completing the MIQ-R, participants are asked to perform one of four movement tasks and then rate the ease with which they form visual and kinaesthetic images of this movement (from 1 = "*very hard to see/feel*" to 7 = "*very easy to see/feel*"). In the study mean MIQ-R scores (SD) were 47.7 (5.9) for both subscales, 24.15 (2.94) for the visual subscale, and 23.15 (3.15) for the kinaesthetic subscale. The MIQ-R has demonstrated adequate internal consistency with Cronbach α coefficients 0.78 and 0.76 for visual and kinaesthetic subscales respectively. MIQ-R mean scores and consistency were comparable to those observed in previous MI studies (Hall & Martin, 1997; Guillot, et al., 2012).

Electromyography measures

Muscle activity was measured using surface EMG using two self-adhesive electrodes (Ag-AgCl). The electrodes were placed in parallel to the muscle fibers in the midline over the muscle belly with an inter electrode distance of 2 cm. Prior to placing the EMG surface electrodes, the skin was abraded and cleaned. EMG activity was recorded from biarticular lower limb muscles involved with gait execution by synergistic action (Chvatal & Ting, 2012). Three distal muscles of the dominant lower limb: tibialis anterior (TA), gastrocnemius lateralis (GL), gastrocnemius medialis (GM), and three proximal muscles of the dominant lower limb: biceps femoris (BF), semitendinosus (ST) and rectus femoris (RF) were measured. The reference electrode was placed over the fibula head. EMG data were recorded at 1000 Hz using the wireless system TeleMyo 2400T G2 (Noraxon Co., USA) with a system bandwidth was 20-1000 Hz. Real-time EMG signals were sent via telemetry at 1,000 Hz to an A-D converter (Noraxon Co., USA). The raw EMG signals were full wave rectified and the root mean squared value of EMG (rmsEMG) signals was calculated using a time averaging period of 25 ms (Guillot, *et al.*, 2007). The processing of the signal was performed by using the software MyoResearch XP Master Edition 1.08.17 (Noraxon Co., USA). Raw EMG signal was visually checked prior to processing and analysis to verify the absence of any artifacts.

Procedure

The test protocol was conducted with respect to previous findings such that the imagination ability was enhanced when imagination was done from first person perspective, and is performed with externally given auditive feedback (Guillot, *et al.*, 2007; Heremans, *et al.*, 2012; Koehler, *et al.*, 2012; Mizuguchi, *et al.*, 2012; Roosink & Zijdewind, 2010).

EMG data were initially collected in two default rest positions, sitting (non-default position for walking) and standing (default position for walking) without performing any voluntary activity or motor imagery, and then within six motor imagery experimental conditions in the following order:

1. gait imagery in the sitting position, gait imagery in the standing position,
2. gait imagery and simultaneous gait observation in the sitting position, gait imagery and simultaneous gait observation in the standing position,
3. gait imagery in the sitting position after gait execution, gait imagery in the standing position after gait execution.

Experimental conditions are illustratively demonstrated in Figure 1.

FIGURE 1

Figure 1 insert here

Default sitting or standing positions were standardized for all experimental conditions. In the sitting position, the participants were seated upright in a chair that leaned against the back and arm rest. In the standing position, the participants were standing upright with hands along their body. In both default positions, the feet were placed a pelvic width apart. In all experimental situations, the position of the feet was unchanged.

For every participant and for all tested conditions, the rhythm of gait was given to the participants using a metronome set at 110 beats per minute, to replicate a normal gait cadence All tested participants reported that they were able to imagine gait well at this step frequency. In the first experimental imaginary gait conditions for sitting and standing, the participants were instructed to imagine a rhythmic gait as vividly as possible, in the first person perspective, the instruction was "*Imagine yourself walking on the pace of the metronome*" without making any actual movements. In second tested conditions, the participants observed the rhythmic gait of a second person in frontal plane from posterior side on the projection screen (200 x 200 cm) placed 2 meters in front of them. The participants were instructed to watch the gait and to simultaneously imagine a rhythmic gait as if they were walking (the instruction was "*Observe the woman on the screen walking at the pace of the* metronome *and simultaneously imagine yourself walking* at the same pace"). Next, real rhythmic walking at the pace of the metronome in hospital corridor was performed by the participants for a few minutes to enhance further rhythmic gait imagination ability (Wriessnegger, Steyrl, Koschutnig, & Muller-Putz, 2014). Just after real rhythmic walking, third experimental conditions were performed, the instruction within the gait imagery task after gait execution was the same task as in the first experimental conditions "*Imagine yourself walking on the pace of the metronome*". Each gait imagery task lasted for approximately 60 seconds. None of participants mentioned feelings of fatigue during the experimental session.

Data processing

The rmsEMG [%] was calculated for every experimental condition in sitting or standing position and then normalized to the rmsEMG of default sitting or standing rest positions. For the rest sitting and standing positions the average rmsEMG values of all tested the muscles were calculated over a 20 seconds interval. These values calculated during the rest condition without any motor imaginary were considered as reference values. For all rhythmic gait imagery tasks the mean rmsEMG values were calculated over six gait cycles for the dominant lower limb. The duration of evaluated EMG period was 6.6 seconds which was calculated from the metronome frequency where one gait cycle was 1.1 seconds. This period was selected from the middle part of the measured data for every experimental condition with respect to adaptation on the imagery task. The mean rmsEMG values during experimental gait imagery tasks were expressed as a percentage of reference value. Gait imaginary experimental tasks conducted in sitting position were normalized to the respective reference value obtained in rest sitting position and gait imaginary tasks conducted in standing position were normalized to the respective reference value obtained in rest standing position for every participant and tested muscle.

Statistical analysis

Data were tested to determine if they were normally distributed using Kolmogorov-Smirnov test. All data were found not to be normally distributed, ($p< 0.05$), therefore non-parametric tests were used throughout the analysis. For the statistical analysis the non-parametric Wilcoxon signed-rank test was performed with the alpha value was set at $p<0.05$. This allowed the comparison of the reference values for sitting and standing positions and normalized EMG data for experimental conditions in sitting and standing positions respectively (hypothesis 1). And the comparison of normalized EMG data with respect to the default sitting and standing positions (hypothesis 2) alpha value was set at $p<0.05$. The differences between each of the gait imagery conditions in the sitting or standing position (hypothesis 3) were explored with Friedman tests with post-hoc Wilcoxon tests. As normalizaed data for three experimental imagery conditions were compared and the alpha value was calculated using Bonferroni's adjustment as 0.05/3 and set at $p<0.017$). In addition the effect size for non-parametric data (Fritz, Morris, & Richler, 2012) Z values were computed. All statistical analysis were performed using Statistica 9.0.

Results

For all tested muscles in rest default sitting and standing position the EMG activity was almost silent, the mean and standard deviation reference rest electromyography data [µV] are presented in **Table 1**. All experimental gait imagery conditions were normalized as a percentage of the rest values separately for each posture, muscle and participant, descriptive statistics of these data are presented in **Table 2**. First gait imagery task in standing position had facilitatory effect on proximal lower limb muscle activity (Table 2, Table 3). However, EMG activity of distal leg muscles decreased for all gait imagery tasks in the sitting position, when the proprioceptive feedback was less appropriate.

TABLE 1

Table 1 insert here

TABLE 2

Table 2 insert here

Gait imagery tasks vs. rest (Hypothesis 1)

Conditions using rhythmic gait imagery mostly indicated an inhibitory effect on lower limb muscle activity compared to the rest default positions (**Table 3**). In the sitting position this was apparent for GM and GL and for TA in all experimental conditions, for BF and ST during gait imagery and simultaneous gait observation and gait imagery after gait execution.

In the standing position significant inhibition was only present in GL for second gait imagery condition and in TA for second and third gait imagery condition. In the standing position, the first gait imagery task in the proximal tested muscles (BF, RF) resulted in an increased EMG activity.

TABLE 3

Table 3 insert here

Standing vs. sitting position (Hypothesis 2)

When comparing of the normalized EMG data between experimental conditions and between the sitting and standing positions, muscle activity was mostly higher in the standing position (**Table 3**). This support the hypothesis that standing facilitates muscle activity in comparison to sitting. The difference were significant for GL ($p<0.01$, $ES>0.3$) and BF ($p<0.05$, $ES>0.3$) in every experimental condition, for GM and TA ($p<0.05$, $ES>0.3$) in the first (SI1 × TI1) and third gait imagery condition (SI3 × TI3), for ST and RF ($p<0.05$, $ES>0.3$) in first gait imagery (SI1 × TI1) and imagery during gait observation (SI2 × TI2) conditions.

Subsequent gait imagery tasks (Hypothesis 3)

When comparing experimental conditions, in sitting position the EMG activity was lower during the rhythmic gait imagery after rhythmic gait execution in comparison to the second gait imagery condition for GM (Z=2.83, p=0.005, ES=0.36), GL (Z=3.24, p=0.001, ES=0.038), and TA (Z=3.73, p<0.001, r=0.49) and in comparison to the first gait imagery condition (SI1 × SI3) for GM (Z=2.64, p=0.01, ES=0.39), GL (Z=2.79, p<0.001, ES=0.44), and TA (Z=3.63, p<0.001, ES=0.51). In the standing position, the muscle activity was lower in the third tested condition compared to the first tested condition for RF (Z=3.05, p<0.001, ES=0.42). For other comparisons the values did not differ significantly.

Discussion

Guillot (2007) showed that MI was accompanied by subliminal EMG activity of muscles participating on imagined movement execution. However the increase of lower limb muscle activity during rhythmic gait imagery was not major finding in our study. Lower limb muscles mostly decreased EMG activity during the experimental tasks using gait imagery compared to the rest conditions, where EMG activity of all muscles was almost silent (Table 1). This was significant especially for distal leg muscles in the sitting position (Table 2 and Table 3). The muscle activity increase during MI compared to rest conditions was previously demonstrated mostly for upper limb tasks (Bakker, *et al.*, 1996; Guillot, Di Rienzo, *et al.*, 2012; Guillot, *et al.*, 2007; Solodkin, *et al.*, 2004) or for non-gait foot tasks (Bakker, *et al.*, 2007; Bonnet, *et al.*, 1997). To follow on from the results of Bakker et al. (2008) it could be suggested that during gait imagery compared to imagery of non-gait or postural foot task supraspinal control is suppressed to some extent. Bakker et al. (2008) compared corticospinal excitability within motor imagery of simple foot task (dorsiflexion) and MI of gait measured by motor evoked potentials from task-related muscle m. tibialis anterior in sitting position. They found that motor evoked potentials areas increased during motor imagery of simple foot task, however corticospinal excitability within gait imagery increased just in selected group of subjects (5 from 16) who had larger increased during imagined foot dorsiflexion, so compared to the majority of participants this simple task did not show and increase in muscle activity during gait imagery.

As supraspinal control might be suppressed during imagery of postural task we speculate that the less expressed effect of gait imagery on muscle activity could be influenced by neural gait control mechanisms. Rhythmic complex patterns of synergistic muscle activity required for locomotion are to great extent under control of neural autonomy of CPG, neural networks located in lumbosacral spine connected with supraspinal motor regions and with lower limb afferent peripheral sensors (Solopova et al, 2015, Dietz, 2003, 2010; Chvatal & Ting, 2012; Dietz, 2003; MacKay-Lyons, 2002).

Motor imagery of lower-limb movements including gait relies mainly on the supplementary motor area, cerebellum, putamen, and parietal regions (Hetu et al., 2013). Activity of these areas is required more for gait planning with respect to changes of external environment rather than for stereotype locomotion which has been shown to be more automatic (Hetu, *et al.*, 2013; la Fougere, *et al.*, 2010). Activity of CPG might be modulated to a great extent by afferent sensory feedback from lower limb receptors even with suppressed supraspinal control than has been previously demonstrated on spinal-cord-injured humans (Bussel et al, 1996, Dietz, 2003, 2010; Harkema, *et al.*, 1997;) or in situations without any extra demands on gait with respect to e.g. additional task or changes in the external environment (Bussel, *et al.*, 1996; Calancie, *et al.*, 1994). Particularly phasic peripheral sensory information associated with lower limb loading during walking evokes lower limb muscle activity (Harkema et al., 1997). Harkema et al. (1997) found that by 70% unloaded body weight stepping (but not 100% unloaded body weight stepping) movements induced by a driven gait orthosis on a treadmill in healthy subjects elicited muscle activity of distal extensor lower limb muscles, namely gastrocnemius medialis and soleus. So the EMG activity of distal lower limb muscles during the gait is to a great extent dependent on phasic peripheral sensory information especially in situations when no extra attention or demands on posture control are needed. The importance of proprioceptive feedback for muscle activity during walking was suggested further McCrea (2001), who found that feedback from extensor proprioceptors induces locomotor dependent reflexes that contribute considerably to extensor muscle activity during real walking. So it is probable that especially distal lower limb motor neurons don’t receive enough facilitatory inputs to evoke muscle activity during stereotype rhythmic gait imagery tasks in sitting position. Furthermore it seems that during ~~the~~ imagining of gait in a position in which walking is impossible dominate inhibitory effect over possible facilitatory on the muscle activity.

The emerging question from these current findings is not only why tested gait imagery conditions do not have facilitatory effect on muscle activity, which was the major focus in previous studies, but why gait imagery tasks resulted in decreased muscle activity compared to the rest condition in our experiment.

To date a decrease of EMG activity during imagination of movement execution task has not been described. Decreased excitability of motor neural system during movement imagery compared to rest condition, specifically decreased activity of corticospinal tract, has been previously reported for imagination of muscle relaxation (Kato, Watanabe, Muraoka, & Kanosue, 2015) or during imagination of suppressing movements (Sohn, Dang, & Hallett, 2003) for upper limb tasks. Few studies found decreased corticospinal excitability during imagination of postural tasks in comparison to rest conditions (Hiraoka, 2002; Oishi et al., 1994). Hiraoka (2002) suggested that imagination of stumbling in standing posture lead to decrease excitability of soleus H-reflex and Oishi (1994) found that imaginary of skating motion in elite skate sprinters led to suppression of soleus H-reflex during whole period of imaginary movement. All these finding are support the previous suggestion that motor commands during motor imagery must be inhibited throughout the neural system to some extent to prevent overt movement execution (Guillot, 2007; Jeanarod, 2001) as EMG activity (if present) is just at subliminal intensity without tonic specific activity as during real movement (Guillot, 2007; Guillot, 2012; Jeanarod, 2001).

Inhibitory processes, which presumably propagate to the spinal motoneurons in parallel with the excitatory inputs might have origin on the cortical, brainstem or either on spinal level (Jeannerod, 2006; Prut & Fetz, 1999). We speculate that the cause of EMG decrease, which occurred mostly in sitting position during gait imagery tasks, presumably mostly took place on spinal level as sitting and standing differs mostly by means of different proprioceptive input. It is probable that muscle spindle afferents is gating the strength of Ia afferent synaptic input onto target motor neurons during gait imagery in the same way as during gait execution (MacKay-Lyons, 2002). One of proposed mechanisms of muscle activity inhibition is presynaptic inhibition according to a previous finding that soleus H-reflex excitability as function of EMG level is decreased during gait (Stein & Capaday, 1998). Presynaptic inhibition reduces the amount of neurotransmitter released at the presynaptic terminal of the Ia axon which lead to decrease in EMG activity (Brooke et al., 1997; Bonnet et al. 1997). Furthermore we speculate that muscle activity decrease during gait imagery task might be influenced by depression of afferent neuronal discharge as has been demonstrated during fictive locomotion in the cat induced by mesencephalic locomotor region stimulation (Perreault et al., 1999). Decrease of muscle and cutaneous afferent-evoked monosynaptic field potentials reflected a reduction of depolarizing synaptic current into spinal neurons during fictive locomotion (Perreault et al., 1999).

The influence of posture

For all tested muscles in most of experimental conditions was muscle activity during gait imaginary tasks significantly lower in sitting position compared to muscle activity during gait imaginary tasks in standing position (see Table 2, 3). Thus, the standing position compared to sitting position had an excitatory effect on muscle activity during rhythmic gait imagery tasks. Standing posture is congruent with walking and thus offer more appropriate somatosensory (tactile, proprioceptive and visual) feedback compared to incongruent positions with walking such as sitting or lying. Presence of real somatosensory feedback facilitates activity of neural structures within motor imagery and motor observation (Mizuguchi et al., 2012; Vargas et al., 2004). Mizuguchi et al. (2012) found that imagination of squeezing the ball and holding the real ball at the same time enhanced the MEPs in comparison to the same situation just without the ball. Vargas et al. (2004) observed that corticospinal excitability increased in situation when hand posture was compatible with the imagined task compared to incompatible hand posture with the imagined task. Saimpont et al., 2012) proved that posture might influence even accuracy of imagined movement, in their experiment the time duration of gait motor imagery in standing posture (body posture congruent with walking) was more comparable with real gait than gait motor imagery in sitting posture. It has been also previously shown, that standing posture compared to supine posture (the one most used throughout the studies concerning effect of gait observation or gait imagery) has excitatory effect on neural structures (Nakazawa et al., 2003; Shimba et al., 2010). Nakazawa et al. (2003) demonstrated that both stretch reflex and MEP elicited in tibialis anterior were significantly greater in standing compare to supine posture (background EMG was silent in both conditions). Shimba et al. (2010) found that even passive standing posture (accomplished by using gait orthosis) had higher impact on increased stretch reflex of m. soleus compared to supine position. This might reflect facilitatory effect of standing position on muscle spindle Ia afferent fibers. Facilitation of muscle spindle activity with respect to position congruent with imaginary movement found also Bonnet et al. (1997). In their study they showed that mental simulation of pressure on a pedal with the foot in reclined sitting position with their feet on two pedals led to larger changes in T-reflex amplitude compared to H-reflex amplitude (activity of muscle spindle Ia afferent fibres is elicited within the T-reflex, but not by H-reflex) in the leg involved in the simulation. Even the extension of the hip in the standing position might have facilitatory effect on muscle activity compared to sitting position, because also afferent input from hip joints is important for the leg muscle activation during locomotion in dependence on hip position (Dietz and Duysens, 2000; Dietz et al., 2002; Grillner & Rossignol, 1978). Grillner & Rossignol (1978) previously proved that preventing the hip from extension in chronic spinal cats inhibits the flexors muscle activity. As EMG activity depends on level of motoneuron pool excitation it is probable that muscle proprioceptive (muscle spindle) afferents is gating the strength of Ia afferent synaptic insput onto target motoneurons during gait imagery, same as during gait execution (MacKay-Lyons, 2002). Then the level of proprioreceptors activation might be crucial for the the subtreshold activation of target muscles during gait imagery tasks. This assumption is in accordance with previous studies the appropriate propriceptive feedback (concretly posture congruent with imaginary task) provided excitatory input to the motor system and facilitates muscle activity.

For the proximal tested muscles (BF and RF) the gait imagery task in the standing position was the only experimental condition when the muscle activity increased compared to the rest position. It has been previously suggested that the proximal leg muscles (e.g., BF) are mostly controlled by the monosynaptic corticospinal pathways compared to mostly polysynaptic corticospinal innervations of the distal leg muscles (e.g., GM) (Brouwer & Ashby, 1991; Cowan, Day, Marsden, & Rothwell, 1986). So presumably during the gait imagery task, the direct neural input from the cortex to the motoneuron may enhance the ability of the cortex to control the proximal leg muscles (Brouwer & Ashby, 1991). This assumption is in accordance with previous findings that during hand movements dominates monosynaptic cortical-motoneuronal input (Nicolas et al., 2001) and mostly for upper limb movements the presence of EMG activity during imagery tasks has been already demonstrated. It is possible that motor imagery does not provide equivalent neural input to proximal and distal leg muscles, but this has to be further explored. And still just biarticular lower limb muscles were measured. To follow our results it is likely that the imagining of rhythmic gait provides inhibitory input mostly to the distal leg muscles in the default sitting position. In accordance to previously mentioned studies inhibition might reflect the summation of several factors including: decreased supraspinal effort for stereotype gait imagery tasks, spinal inhibitory mechanisms (presynaptic inhibition), different neural drive to the motoneurons of distal and proximal leg muscles, and default sitting posture which does not provide appropriate feedback for real walking. However the results of this study are limited to young woman population with good imagery ability, and to stereotype rhythmic gait imagery task. Therefore, further research is required with respect to different genders and populations.

Comparison of EMG activity during experimental conditions

Combination of motor imagery and observation (Wright, Williams, & Holmes, 2014) or previous imagined movement execution (Wriessnegger, Steyrl, Koschutnig, & Muller-Putz, 2014) enhances activity of neural structures and motor learning processes (Gomes, *et al*., 2014; Nedelko, Hassa, Hamzei, Schoenfeld, & Dettmers, 2012) compared to motor imagery itself. Based on this assumption we hypothesized, that both simultaneous motor imagery with motor observation and previous execution of imagined movement would have further facilitatory effect on muscle activity compared to gait imagery alone. So we added these “augmented” imagery conditions in given order to the experimental protocol. However in our experiment the second and the third experimental condition mostly led to muscle activity decrease compared to the first tested situation. As the order of first, second and third experimental conditions were not randomized we suggest that the decrease in muscle activity within repeated tested motor imagery tasks in our experiment might reflect to some extent the gradual habituation effect. It has been previously described, that cortical activity is mostly pronounced during initial trials of complex motor imagery tasks (imagery of volleyball spike attack) compared to second and third motor imagery where the short-term habituation effect might be present (Stecklow et al., 2010). None of tested participants reported feelings of tiredness during the experiment the mental fatigue, which has been previously reported for prolonged imagery tasks (Rozand et al., 2016), was not the reason of decreased muscle activity for subsequent imagery tasks.

We suggest here that more challenging imagery tasks as part of gait rehabilitation are required, then habituation effect might be avoided (Marchal-Crespo et al., 2014).

The results of this study potentially further our understanding of influence of rhythmic gait imagination on lower limb muscles with respect to the body posture. This in turn provides important information for gait imagery rehabilitation protocols and could increase our understanding of gait control mechanisms.

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Abeer A. El-Wishy, Eman S. Fayez Effect of Locomotor Imagery Training Added to Physical Therapy Program on Gait Performance in Parkinson Patients: A Randomized Controlled Study

(Chvatal & Ting, 2012 - Voluntary and Reactive Recruitment of Locomotor Muscle Synergies during Perturbed Walking)

Spinal circuitry of sensorimotor control of locomotion

David A McCrea Depression of muscle and cutaneous afferent-evoked monosynaptic field potentials during fictive locomotion in the cat
M-C Perreault, S J Shefchyk, I Jimenez, D A McCrea
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From mental power to muscle power--gaining strength by using the mind.

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FIGURE 1

Illustration of tested experimental conditions

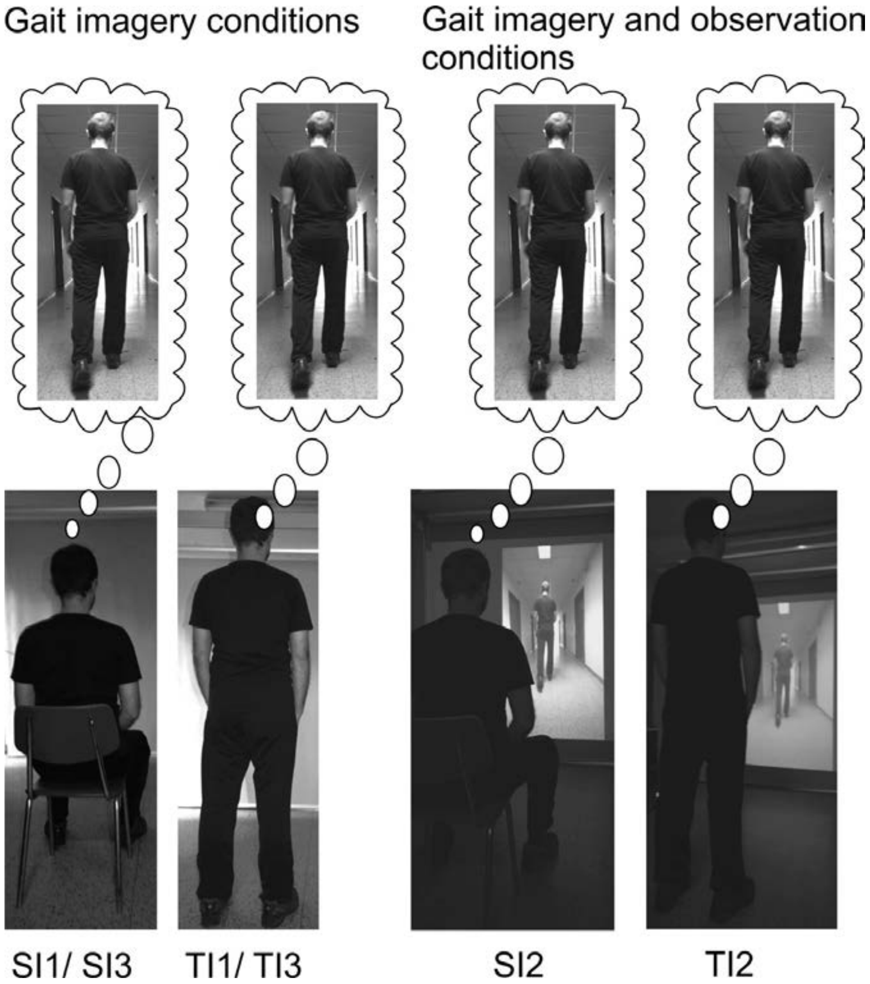

TABLE 1

Mean EMG [µV] reference values (±SD) for all tested muscles in default sitting and standing positions

	Gastrocnemius medialis		Gastrocnemius lateralis		Tibialis anterior		Biceps femoris		Semitendinosus		Rectus femoris	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Sitting position	1.35	0.53	1.48	0.52	1.59	0.53	1.3	0.39	1.2	0.4	1.21	0.48
Standing position	6.17	3.72	3.65	1.79	2.45	0.96	2.6	2.57	2.82	3.6	1.72	1.4

TABLE 2

Normalized elekctromyographic activity with respect to reference value for every muscle [%] during gait imagery tasks in sitting and standing position

		Gait imagery		Gait imagery and observation		Gait imagery after gait execution	
		Med	*IQR(Q1 – Q3)*	*Med*	*IQR (Q1 – Q3)*	*Med*	*IQR (Q1 – Q3)*
Gastrocnemius lateralis	S	73.15	(58.31–97.48)	69.07	(54.05–92.82)	61.62	(45.73–84.55)
	T	95.33	(85.23–127.63)	87.31	(70.27–95.68)	89.85	(81.15–106.95)
Gastrocnemius medialis	S	80.64	(54.15–97.92)	79.13	(51.56–98.24)	60.22	(45.91–91.24)
	T	97.19	(78.13–129.47)	84.53	(70.58–109.11)	91.09	(75.83–122.77)
Tibialis anterior	S	75.24	(64.25–112.14)	77.7	(62.84–95)	59.53	(50.49–86.9)
	T	96.58	(75.73–119.36)	88.13	(82.11–99.03)	85.34	(70.78–103.78)
Biceps femoris	S	117.9	(91.09–221.63)	101.49	(86.37–151.14)	104.77	(82.31–129.04)
	T	93.5	(88.57–103.43)	91.48	(82.49–102.03)	85.86	(78.97–98.64)
Semitendinosus	S	92.26	(78.35–108.78)	88.40	(76.73–102.7)	87.33	(76.62–107.02)
	T	111.28	(89.03–158.43)	99.1	(87.29–129.14)	98.15	(71.07–148.37)
Rectus femoris	S	91.32	(86.17–106.95)	90.33	(82.06–100.34)	90.83	(75.08–104.5)
	T	111.11	(93.8–270.79)	98.3	(84.09–156.77)	97.24	(78.19–154.44)

S – sitting position, T – standing position, Med – median, (*Q1 – Q3)* – (25th – 75th percentile of data)

TABLE 3

Results of statistical analysis (Wilcoxon signed rank test and Effect Size) of changes in the muscle activity during gait imagery tasks

		gait imagery tasks in the sitting position compare to default sitting rest position			gait imagery tasks in the standing position compare to default standing rest position			gait imagery tasks in the sitting position compare to gait imagery tasks in the standing position		
		Wilcoxon´s Z	*p*	*Effect Size*	*Wilcoxon´s Z*	*p*	*Effect Size*	*Wilcoxon´s Z*	*p*	*Effect Size*
Gastrocnemius medialis	I1	3.00	**<.001**	**0.41**	0.29	0.77	0.04	2.21	**0.03**	**0.3**
	I2	3.15	**<.001**	**0.43**	1.78	0.08	0.24	1.42	0.16	0.19
	I3	4.08	**<.001**	**0.56**	0.29	0.77	0.04	3.99	**<.001**	**0.54**
Gastrocnemeius lateralis	I1	3.29	**<.001**	**0.45**	0.65	0.52	-0.08	4.30	**<.001**	**0.58**
	I2	4.04	**<.001**	**0.55**	2.71	**0.01**	**0.34**	2.79	**0.01**	**0.38**
	I3	4.42	**<.001**	**0.6**	1.15	0.25	0.16	4.18	**<.001**	**0.59**
Tibialis anterior	I1	2.16	**0.03**	**0.29**	0.36	0.72	0.05	2.38	**0.02**	**0.32**
	I2	2.26	**0.02**	**0.31**	2.07	**0.04**	**0.28**	1.39	0.16	0.19
	I3	3.89	**<.001**	**0.53**	2.81	**<.001**	**0.38**	3.08	**<.001**	**0.42**
Biceps Femoris	I1	1.71	0.09	0.23	2.16	**0.03**	-0.29	2.59	**0.01**	**0.35**
	I2	3.05	**<.001**	0.42	1.13	0.26	-0.15	2.64	**0.01**	**0.36**
	I3	3.10	**<.001**	0.42	0.77	0.44	-0.11	1.99	**0.05**	**0.271**
Semitendinosus	I1	1.42	0.16	0.19	1.75	0.08	0.24	2.50	**0.01**	**0.34**
	I2	3.17	**<.001**	0.43	0.53	0.60	-0.07	1.80	0.07	0.26
	I3	2.09	**0.04**	0.28	0,22	0,83	-0.03	1,13	0.26	0.15
Rectus femoris	I1	1.18	0.24	0.16	2.45	**0.01**	-0.33	3.39	**<.001**	**0.46**
	I2	1.95	0.05	0.27	0.86	0.39	-0.12	2.35	**0.02**	**0.32**
	I3	1.49	0.14	0.2	0.26	0.79	-0.04	0.96	0.34	0.13

I1 - gait imagery, I2 - gait imagrey and observation, I3 - gait imagery after gait execution

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