Soleus H-Reflex Modulation During Stance Phase of Walking With Altered Arm Swing Patterns

Chetan P. Phadke, Marc Klimstra, E Paul. Zehr, Floyd J. Thompson, and Andrea L. Behrman

The purpose of this study was to test the effect of arm swing on modulation of soleus H-reflexes amplitudes during walking. Fifteen subjects walked (1.07 m/s) on a treadmill in 4 arm swing conditions: 1-natural arm swing (control), 2-active restraint, 3-passive restraint, and 4-passive-assisted. Tibial nerve was electrically stimulated and soleus EMG was recorded. H-reflex amplitude was significantly greater during active than during passive restraint (p = .013). Remaining arm swing conditions were not significantly different. We detected a subtle effect of arm swing on soleus H-reflex amplitude. Descending regulation may serve as a gating mechanism to control the effect of arm movements on reflex pathways for leg muscles. This gating mechanism may be impaired postneural injury, potentially enhancing the modulation of peripheral sensory inputs on reflexes in leg muscles during walking. Future experiments to test additional conditions and evoking reflexes in more phases of walking are recommended.

Rhythmic arm and leg coordination is seen in all human locomotor activities such as walking, running, swimming, and these general coordination patterns are similar to those observed in habitual quadrupeds (Juvin, Simmers, & Morin, 2005; Wannier, Bastiaan, Colombo, & Dietz, 2001). In agreement with this general trend, arm and leg swing during walking occur in synchrony. However, walking can be achieved without arm swing and consequently the role of arm swing during walking has been little addressed. Rhythmic arm swing during normal walking is considered to functionally assist walking with respect to propulsion, balance, and posture (Eke-Okoro, Gregoric, & Larsson, 1997). Furthermore, inhibiting the arm swing results in quantifiable mechanical changes in gait, such as abnormal leg movements, decreased forward propulsion, and decrease in walking speed (Eke-Okoro et al., 1997; Ford, Wagenaar, & Newell, 2007).

Alongside mechanical changes in gait due to alterations in arm swing parameters, there is justifiable evidence that neural coupling exists between the cervical...
and lumbar locomotor pattern generators that underlie coordinated movement of the arms and the legs (Haridas & Zehr, 2003). The potential neural connections responsible for interlimb coordination (via propriospinal tracts) between all four limbs have been identified and described in quadrupedal locomotion (Juvin et al., 2005). Consequently, rhythmic swinging of arms during walking may be attributed to persistence of these neural connections (Pierrot-Deseilligny, 2002) during evolution from quadrupedal to bipedal gait (Dietz, 2002; Zehr, Hundza, & Vasudevan, 2009). Arm movements during standing (Kawanishi, Yahagi, & Kasai, 1999) induce significant depression of soleus H-reflex. In addition, during passive locomotor-like leg movements in patients with cervical spinal cord injury, inducing upper limb movements results in increased soleus EMG activity (Kawashima, Nozaki, Abe, & Nakazawa, 2008). Thus, rhythmic arm swing may contribute to task-related adjustments in soleus H-reflex and the generation of coordinated walking.

Our earlier paper using an arm and leg cycling model showed that the effect of arm movement on reflex modulation in leg muscles was subtle but significant (Zehr, Balter et al., 2007). However, since the arm and leg cycling paradigm represents a reduced portion of the neural activity related to walking (Zehr, Balter et al., 2007), we wanted to determine if the interactions between arm and leg movement could be detected during walking using the simplest approach possible. In the current study, we examined the effect of altering arm swing patterns on soleus H-reflex excitability during the stance phase of walking.

**Methods**

Fifteen subjects (Mean age 37.5 years; 3 Females, 12 Males) with no history of neural or orthopedic impairment of arms, legs, or trunk and no walking disability were recruited. In accordance with the ethical standards laid down in the 1964 Declaration of Helsinki, all persons gave their informed consent approved by University of Florida Institutional Review Board before their inclusion in the study.

Subjects walked over the treadmill at 1.07 m/s speed over four different pseudo-randomly ordered arm swing conditions: 1) Natural reciprocal arm swing. No specific instructions were given and subjects walked with natural reciprocal arm swing at this speed (1.07 m/s); Altered arm swing conditions: 2) Active restraint of arm swing. Subjects walked holding arms by the side of the trunk, thus actively inhibiting natural arm swing; 3) Passive restraint of arm swing. Subject’s arms were lightly strapped to the torso using elastic bandages such that arms were passively held by side of the trunk in neutral position throughout the walking condition; 4) Passive assisted arm swing. Subjects were asked to relax their arms while walking as a trainer provided rhythmic reciprocal arm swing to match their natural arm swing pattern. In the passive assisted condition, the arm swing assistance was provided using two ski poles (subject’s hands were secured over the ski pole handle using elastic bandages). A trainer held the other end of the ski pole to provide rhythmic arm swing (Behrman & Harkema, 2000).

Since the use of arm activity has been advocated for gait retraining (Behrman & Harkema, 2000; Ferris, Huang, & Kao, 2006; Zehr et al., 2009), the conditions in this study were aimed at replicating some of the conditions during pathological gait. In those cases it is conceivable that weakness of the arms or use of hand-held walking aids can interfere with the production of normal reciprocal arm swing.
during the task of walking. The arm swing conditions in this study were specifically chosen to examine the neural effect of inability to swing the arms and the neural changes caused by external facilitation of the arm swing. All subjects wore a harness connected overhead to provide support in an event of a trip or fall. This harness, however, did not support the person’s body weight while walking. All subjects were then familiarized with the walking conditions for one minute each before stimulation procedures were implemented.

**Electromyography (EMG):** The skin was shaved and cleaned for application of surface electrodes (Ag/AgCl—Therapeutics Unlimited, Iowa City, Iowa). These electrodes have a built in preamplifier circuitry and a second stage amplifier provides a total gain of 1000× with a 20-Hz high-pass filter. The tibial nerve was stimulated at the popliteal fossa using a button shaped silver electrode strapped around the knee. A ground electrode was placed medial to the shin, between the surface EMG electrodes on soleus and tibialis anterior. EMG recordings were also taken from the tibialis anterior muscle. Stimulus was delivered using a Grass stimulator (Grass Instruments, model S88 with a modified CCU1. Astro-Med Industrial Park, 600 East Greenwich Avenue, West Warwick, RI-02893). Data were acquired at a sample rate of 10 KHz per channel and stored digitally using Data-Pac III software (Run Technologies, 22702 Via Santa Maria, Mission Viejo, CA 92691) on a personal computer.

**Evoking Soleus H-Reflexes**

Ten soleus H-reflexes were evoked in the midstance phase of walking in all four arm swing conditions. For the purpose of consistency, the soleus H-reflexes were examined on the dominant leg (determined by the preferred kicking leg). We chose the midstance phase of walking to evoke H-reflexes because the soleus muscle is typically active and reflexes are greater compared with the swing phase. The point of stimulation was visually determined and verified using the foot switch data. To minimize movement, the stimulating electrode was firmly wrapped around the leg using an elastic strap to minimize electrode movement. To account for potential electrode movement due to continuous movement of the knee during walking, Mmax (maximum amplitude M wave) was recorded in all subjects in the midstance phase of walking and in all the arm swing conditions. The M wave was continuously monitored and stimulation intensity was adjusted to maintain M wave values between 4–6% Mmax; H-reflexes outside the 4–6% Mmax range were discarded from the analysis. To minimize the effect of postactivation depression, the intervals between two consecutive stimulations were set at 3–5 s across all walking conditions. All subjects were given a 2 min break between the testing conditions.

We further explored the effect of arm swing on H-reflexes of different sizes in 4 subjects. Complete H-reflex recruitment curves were recorded in all four walking conditions by steadily increasing the stimulation intensity until the H-reflex was completely depressed and Mmax was obtained.

**Data Acquisition and Analysis**

EMG activity 100ms before electrical stimulation was recorded to examine if the H-reflex systematically changed with EMG activity. Three Mmax responses were evoked in the midstance phase of walking in all the arm swing conditions.
The H-reflexes were normalized to the mean Mmax in each testing condition for subsequent analysis. The mean of 10 H-reflexes was compared between the two conditions. As recently applied (Klimstra & Zehr, 2008), we used the sigmoid function to characterize the ascending limb of the H-reflex recruitment curve.

**Statistics**

Mean H-reflex amplitudes in the altered arm swing conditions were normalized to the control natural reciprocal arm swing condition. Using the software program SPSS, a one factor repeated-measures ANOVA (within-subject model) was used to compare mean H-reflexes between the altered arm swing conditions ($p \leq .05$) followed by pairwise comparisons using the Bonferroni adjustment method.

**Results**

Within subjects, main effects between the three arm swing conditions were not significantly different ($p = .12$). Pairwise comparisons using Bonferroni adjustment (for multiple comparisons) revealed that mean H-reflex amplitude in active restraint condition was significantly greater than the passive restraint condition ($p = .013$; see Figure 1; Westfall, Johnson, & Utts, 1997). None of the other pairwise comparisons were significant (Observed power: 0.903; partial eta squared: 0.556). All the measures related to full excitability of the M-H recruitment curves obtained for four subjects were similar across all walking conditions (not shown).

EMG activity in tibialis anterior and soleus muscles did not differ systematically between different arm swing conditions (Table 1).

![Figure 1](image-url)

*statistically significant difference ($p<0.05$)

**Figure 1** — Soleus H-reflex amplitude in the altered arm swing conditions expressed as the percentage of the control (natural reciprocal arm swing) condition.
Table 1  EMG Activity in Ankle Muscles Collected 100 ms Before H-reflexes in the Midstance Phase of Walking

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Discussion

We previously reported a subtle interaction between arms and legs using an arm, and leg cycling model (Zehr, Klimstra et al., 2007). The arm and leg cycling paradigm showed strong correlation with walking and supports common neural patterning as the regulator of many forms of rhythmic arm and leg movement (Zehr, Balter et al., 2007). However, arm and leg cycling does not capture all of the neural drive of walking. Hence in the current study we tested the arm-leg reflex interaction in the task of walking. We were interested in testing if the arm-leg interaction could be more readily tested in the walking condition. Although we did not use any reflex facilitation techniques, we found a significant difference in the soleus H-reflex amplitude between the active restraint and passive restraint conditions.

No significant differences were observed between passive restraint and passive assisted conditions and between active restraint and passive assisted arm swing conditions. Our results are in contrast with previous reports of a robust change in H-reflex amplitude as a result of manipulation of sensory inputs of upper limb origin in static nonlocomotor tasks (Baldissera, Cavallari, & Leocani, 1998; Kawanishi et al., 1999). The contrasting results are most likely because we performed this study during the task of walking. Sensory inputs such as perturbation to the torso during the task of walking have been reported to have no effect on the ipsilateral cutaneous reflexes (Haridas, Zehr, & Misiaszek, 2005). Haridas et al. (2008) recently reported that inhibiting arm swing by crossing the arms during walking did not change the cutaneous reflexes (Haridas, Zehr, & Misiaszek, 2008). In addition, any effect of manipulation of arm movement conditions is likely swamped by the dominant effect of leg activity (Balter & Zehr, 2007). The strength of this study’s finding relies on the fact that any true determination of the effect of arm movement on reflex modulation as it refers to locomotion should be viewed within the context of walking, while other studies have used reduced preparations (Baldissera et al., 1998; Kawanishi et al., 1999). However, as walking is under dynamic neural regulation other factors may blunt the ability to quantify the effect of arm movement on the reflex modulation and make it difficult to separate central from peripheral influence.

Previous studies have manipulated diverse sensory inputs during walking including knee range of motion (Garrett, Kerr, & Caulfield, 1999), percentage of leg loading (Ferris, Aagaard, Simonsen, Farley, & Dyhre-Poulsen, 2001), and walking environment (Phadke, Wu, Thompson, & Behrman, 2007). Generally, it has been reported that H-reflex amplitude was relatively resistant to modulation when conditioning sources are peripheral, thus suggesting a central control of locomotor reflex modulation. Peripheral afferent inputs modulate soleus H-reflex amplitude in static tasks like standing and sitting (Capaday, Lavoie, & Comeau, 1995; Shoji, Kobayashi, Ushiba, Kagamihara, & Masakado, 2005), but during walking these same peripheral afferent inputs are most likely gated such that H-reflexes elicited during walking are not altered. Thus, the H-reflex amplitude during the stance phase of walking is unaffected by a conditioning stimulus that normally depresses the H-reflex in standing (Capaday et al., 1995) or sitting (Shoji et al., 2005). Altered arm swing conditions are known to produce kinematic and kinetic changes in gait patterns; however it is unlikely that the change in gait parameters can alter H-reflex amplitude. EMG activity recorded in soleus and tibialis anterior muscles did not change during walking in different arm swing conditions (Table 1).
Restraining the natural arm swing may also induce a sensation of postural threat during the task of walking (Krauss & Misiaszek, 2007). In a recent study Krauss and Misiaszek (2007) reported that crossing the arms across the chest induced an increase in the soleus H-reflex amplitude similar to other postural perturbations during walking. However, these changes were predominantly seen at heel strike, but the soleus H-reflexes in the midstance phase did not increase (Krauss & Misiaszek, 2007). The arms crossed condition (a form of postural perturbation) used by Krauss and Misiaszek (2007) was similar to our active restraint condition and thus it is conceivable that variations of arm swing restraint may induce postural perturbation.

Krauss and Misiaszek (2007) report in their study that the H-reflexes evoked at heel strike are most susceptible to postural threats. In contrast, we only tested in midstance phase which is less likely to be affected by the changes in postural threat. In their study, Krauss and Misiaszek (2007) found that in “holding the handle” walking condition, H-reflex in the midstance phase was depressed. This can be explained by the decrease in postural threat by using a handle to hold on to during walking. If the arms folded condition induced a postural threat in midstance phase of walking, then the H-reflexes should have been facilitated in this walking condition. On the contrary, the arms folded across the chest walking condition induced a decrease in H-reflex amplitude in the midstance phase. If the arms folded condition increased postural threat, then the H-reflex amplitude should have increased and not decreased. Again, if the postural threat is expected to increase H-reflex amplitude, then in the postural threat conditions such as anterior-posterior (AP) perturbation, the H-reflex amplitude should increase, but there was no such change in H-reflex amplitude in the midstance phase. The above findings suggest that postural threat had no effect on H-reflex amplitude in midstance phase, but is more likely to be a factor in the heel-strike phase of walking.

Since we tested H-reflexes in the midstance phase only, our arm swing conditions were probably not affected as much by the postural threat induced by arm restraint. Thus it is likely that the neurophysiologic changes seen in our experiment were as a result of arm swing restraint independent of the postural threat. Krauss and Misiaszek (2007) found that the reflexes tested in midstance phase actually depressed significantly in the arms folded condition but did not change in the anterior-posterior perturbation condition. Their result suggests that “restraint” of arm swing (by folding arms across the chest) and the associated change in sensory input, and not postural perturbation, may have likely been responsible for the change in H-reflex amplitude.

Typically, rhythmic arm swing actively offsets the significant whole body angular momentum induced by the leg movements about the vertical (“twist”) axis during walking and subsequently reduces free vertical moments at the foot and therefore is important in balance regulation during walking (Li, Wang, Crompton, & Gunther, 2001; Misiaszek & Krauss, 2005; Zehr et al., 2009). However our focus was not on the specific effect of postural perturbation but rather the crossed effects of altering activity state and movement state of the arms during locomotion. In this study we report significant differences in soleus H-reflex amplitude between active and passive restraint of arm swing. Thus, although our arm swing restraint condition may have induced postural perturbation, our current results support the previous finding by Krauss and Misiaszek (2007) that the activity state of the arms is one of the factors affecting modulation of the H-reflexes during walking.
We found that H-reflex was significantly greater in the active restraint condition compared with passive restraint condition. A possible mechanism responsible for the difference in H-reflex amplitude could be increased activation of the corticomo-toneuronal connections. Jendrassik maneuver, which involves a significant amount of corticomotoneuronal activation, is known to facilitate H-reflexes by altering presynaptic inhibition. Given the nature of difference between active and passive restraint, it is possible that there was higher activation of corticomotorneuronal pathways to the arm muscles during the active restraint task. Dietz (2002) proposed that greater corticomotorneuronal excitation in skilled hand movement inhibits activity in the cervical propriospinal system (Dietz, 2002). Although, active restraint task in our experiment was not a skilled movement, it is possible that increased level of cortical excitation may have inhibited the cervical propriospinal pathways purportedly involved in interlimb coordination (Pierrot-Deseilligny, 2002) resulting in greater H-reflex amplitude compared with the passive restraint condition. Our results suggest that descending regulation may serve as a gating mechanism to control the effect of arm movements on lower limb reflex modulation.

Interestingly, the recent study in arm and leg cycling showed a significant influence on soleus H-reflex amplitude from cutaneous input evoked at the wrist (Zehr, Klimstra et al., 2007). A portion of this effect was speculated to have a proprioceptive contribution. This is of translational interest since numerous groups suggest incorporating arm swing into walking retraining after neurotrauma to promote the recovery of a normal pattern of walking (Behrman & Harkema, 2000; Ferris et al., 2006). However, the actual neural effect of arm swing patterns on reflex excitability in leg muscles needs to be systematically examined during walking after neurotrauma.

We anticipated modulation of soleus H-reflex amplitudes in response to altering arm swing patterns. However, our earlier finding of the subtle nature of the arm-leg interaction observed during arm and leg cycling (Zehr, Klimstra et al., 2007) was confirmed in the current study. Further experiments need more comprehensive methodology such as including additional exploration of active and passive conditions, eliciting reflexes in more phases, and making use of conditioned reflex amplitudes are suggested.

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