Prior experience does not alter modulation of cutaneous reflexes during manual wheeling and symmetrical arm cycling

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MacGillivray MK, Klimstra M, Sawatzky B, Zehr EP, Lam T. Prior experience does not alter modulation of cutaneous reflexes during manual wheeling and symmetrical arm cycling. J Neurophysiol 109: 2345–2353, 2013. First published February 20, 2013; doi:10.1152/jn.00512.2012.—Previous research has reported that training and experience influence H-reflex amplitude during rhythmic activity; however, little research has yet examined the influence of training on cutaneous reflexes. Manual wheelchair users (MWUs) depend on their arms for locomotion. We postulated that the daily dependence and high amount of use of the arms for mobility in MWUs would show differences in cutaneous reflex modulation during upper limb cyclic movements compared with able-bodied control subjects. We hypothesized that MWUs would demonstrate increased reflex response amplitudes for both manual wheeling and symmetrical arm cycling tasks. The superficial radial nerve was stimulated randomly at different points of the movement cycle of manual wheeling and symmetrical arm cycling in MWUs and able-bodied subjects naïve to wheeling. Our results showed that there were no differences in amplitude modulation of early- or middle-latency cutaneous reflexes between the able-bodied group and the MWU group. However, there were several differences in amplitude modulation of cutaneous reflexes between tasks (manual wheeling and symmetrical arm cycling). Specifically, differences were observed in early-latency responses in the anterior and posterior deltoid muscles and biceps and triceps brachii as well as in middle-latency responses in the anterior and posterior deltoid. These data suggest that manual wheeling experience does not modify the pattern of cutaneous reflex amplitude modulation during manual wheeling. The differences in amplitude modulation of cutaneous reflexes between tasks may be a result of mechanical differences (i.e., hand contact) between tasks.

reflex; central pattern generator; manual wheeling; training; spinal cord injury

IT HAS BEEN POSTULATED that the basic features of human rhythmic movement (e.g., walking, running, cycling, swimming) are regulated by common oscillatory networks known as central pattern generators (CPGs) (McCrea and Rybak 2007; Zehr 2005; Zehr et al. 2007a). In humans, evidence supporting this concept comes from studies showing similarity in the patterns of reflex modulation in response to peripheral nerve stimulation during various rhythmic movements of the arms and legs including cycling, stepping, and walking (Zehr 2005; Zehr et al. 2007a, 2007b). However, despite similarities in patterns of reflex modulation across different tasks, there are notable task-dependent differences in responses that appear to be functionally related to the specific task demands.

It is well known that cutaneous input is used to functionally sculpt motor output during locomotion (Zehr and Stein 1999). For example, functionally tuned cutaneous reflexes are expressed during relevant phases of the gait cycle. Stimulation of the posterior tibialis nerve during the middle to late stance phase leads to excitation in the ipsilateral tibialis anterior and rectus femoris. This assists with knee joint stabilization and dorsiflexion of the ankle (Van Wezel et al. 1997). Cutaneous reflexes are also functionally modulated in a phase-dependent manner during upper limb cyclic tasks such as symmetrical arm cycling and rhythmic arm swing (Carroll et al. 2005; Zehr and Chua 2000; Zehr and Kido 2001). Interlimb coupling of the upper limbs does not appear to play a strong role in the modulation of cutaneous reflexes since the pattern of reflex responses during rhythmic arm cycling has been shown to be independent of contralateral limb movement (Carroll et al. 2005). Recently, Klimstra et al. (2011) described functionally relevant neuromechanical responses during arm cycling evoked by cutaneous stimulation at the hand. These responses are consistent with perturbation reactions that preserve the ongoing rhythmic action as previously described in the leg (Klimstra et al. 2011). Currently, the role of long-term taskspecific experience (training) in shaping these cutaneous reflex patterns is not fully understood.

Clearly, adaptive plasticity can be expressed in human reflex pathways (Haridas et al. 2006), and there are many examples of experience or training effects observed in muscle afferent pathways, such as the H-reflex. For example, after children with cerebral palsy underwent treadmill training for 10 min per day for 10 consecutive days, soleus H-reflexes were depressed during the swing phase of the gait cycle compared with pretraining values, while the H-reflex amplitude during standing did not change (Hodapp et al. 2009). Additionally, leg cycling training can also result in changes in soleus H-reflex amplitudes. H-reflex amplitudes were decreased during a skillful leg cycling task (maintaining a constant cycling speed during variable resistance changes) compared with cycling at a constant resistance or no cycling (Mazzocchio et al. 2006). Furthermore, improvements in performance during the skillful leg cycling task were correlated to the decrease in H-reflex amplitude (Mazzocchio et al. 2006). Together, these studies suggest that specific training of a rhythmic task can affect the gating of peripheral afferent feedback (as implied by the decrease in size of the H-reflex).
Animal studies have also demonstrated the plasticity of reflex transmission following locomotor training. It has been reported that spinalized cats that underwent daily locomotor training sessions showed modifications in 10 of 71 measured cutaneous afferent-motoneuronal pathways (Cote and Gossard 2004). The majority of the pathways that had decreased responses were involved in innervating the plantar surface of the foot (Cote and Gossard 2004). Another study found that after partial cutaneous denervation (cutting all except the tibial nerve) of the hind paw in the cat, there was a gradual and long-lasting increase in the cutaneous reflex response to stimulation of the tibial nerve during the swing phase of the gait cycle and a decrease in the threshold required to elicit a response (Bernard et al. 2007). These changes were significantly greater than the modifications in background EMG caused by the neurectomy (Bernard et al. 2007). These studies show that the locomotor system is able to reorganize in response to both active training (Cote and Gossard 2004) and chronic change in sensory feedback (Bernard et al. 2007). This may occur through changes in spared cutaneous pathways independent of an increase in motoneuron excitability. The efficacy of motor training on changes in locomotor circuits could be mediated via interactions with other reflex pathways (Cote and Gossard 2004).

Many people with physical disabilities rely on manual wheelchairs for their daily mobility. Manual wheeling involves repetitive use of the arms to provide locomotor propulsion, providing significant daily task-specific training of the arms. This provides a unique opportunity to study the effect of experience in a distinctive upper limb locomotor task on the modulation of cutaneous reflexes during rhythmic arm movements. Thus the purpose of this study was to examine the effect of chronic use of the arms for locomotion on cutaneous reflex amplitude modulation in experienced manual wheelchair users (MWUs) compared with able-bodied (AB) subjects (i.e., non-wheelchair users). To determine whether experience in manual wheeling can be generalized to other upper limb rhythmic movements, we also compared the amplitude modulation of cutaneous reflex modulation between manual wheeling and symmetrical arm cycling. We hypothesized that experienced MWUs would demonstrate larger reflexes across the movement cycle, for both manual wheeling and symmetrical arm cycling, compared with AB subjects. Since this work has never been conducted in manual wheeling, this study also provides reference data on the pattern of reflex modulation in this task. We further hypothesized that reflexes during manual wheeling would be modulated according to the phase of the wheeling cycle, similar to what has been observed during symmetrical arm cycling.

**METHODS**

**Subjects**

Thirteen (4 men, 9 women) AB control subjects who were inexperienced manual wheelchair users and nine (5 men, 4 women) experienced MWUs with 2–29 yr of experience were recruited to participate in this study. The mean age of the AB group was 26.1 (SD 1.5) yr, and their mean weight and height were 64.2 (SD 7.5) kg and 171.4 (SD 9.1) cm, respectively. The mean age of the MWU group was 44.7 (SD 11.9) yr, and their mean weight and height were 68 (SD 17) kg and 175.3 (SD 12.6) cm, respectively. All MWUs had a spinal cord injury at or below the T1 level and had used a manual wheelchair as their primary mode of mobility for an average of 15.8 yr. All subjects were capable of manual wheeling for 5- to 10-min spans. Subjects were excluded from the study if they had any injury to their arms or if they had upper limb or nerve pain that would prohibit them from wheeling a manual wheelchair, as assessed by the Wheelchair Users Shoulder Pain Index (WUSPI) (Curtis et al. 1999). This study was approved by the Behavioural Research Ethics Board of the University of British Columbia. All subjects provided written and informed consent prior to beginning the study.

**Protocol**

All subjects performed two rhythmic movement tasks (each at 60 Hz) for approximately 8 min each: 1) manual wheeling and 2) symmetrical arm cycling (Fig. 1). For manual wheeling, MWUs used their own manual wheelchair while AB subjects used a fitted Elevation wheelchair (Instinct Mobility, Vancouver, BC, Canada). Wheelchairs were secured to rollers, and subjects wheeled at their own comfortable self-selected manual wheeling speed. All subjects were given adequate time to familiarize themselves with the rollers and to find a comfortable manual wheeling cadence. To ensure that the cadence did not change throughout

![Fig. 1. Manual wheeling (A) and symmetrical arm cycling (B) rhythmic upper limb tasks. Both tasks involve upper limb movement in a clockwise direction.](http://jn.physiology.org/doi/10.1152/jn.00512.2012)
the course of the study, a metronome synchronized to the self-selected cadence was used to cue the subjects.

Symmetrical arm cycling was conducted with a commercially available arm crank ergometer with customized instrumentation (Monark 881). The ergometer was mounted on a table of adjustable height so that the table was level with the forearm when the elbow was flexed at 90° and the upper arm was perpendicular to the floor. The metronome was used to ensure the same cadence during symmetrical arm cycling and manual wheeling.

Nerve Stimulation

Flexible 1-cm disposable Ag-AgCl surface EMG electrodes were placed on the skin on the dorsal surface of the forearm just proximal to the radial head and the crease of the wrist joint to stimulate the superficial radial nerve (which innervates the skin of the dorsal-lateral aspect of the hand). Stimuli were delivered with trains of 5 × 1.0-ms pulses at 300 Hz (Grass S88 stimulator, Grass Instruments, West Warwick, RI). For each subject, the radiating threshold (RT) was identified. RT was defined as the minimum stimulus intensity required to elicit a nonpainful sensation spreading over the largest area of skin supplied by the nerve. To evoke reflexes, the target stimulus intensity was 2 × RT. However, the actual stimulus intensity used for the experiment was 1.84 (SD 0.26) × RT because some subjects found 2 × RT to be too uncomfortable. Stimuli were delivered randomly every 3–5 s throughout the symmetrical arm cycling and manual wheeling conditions. This ensured that each subject received between 96 and 160 stimulations per task.

Data Recording

Data from all subjects were recorded from the right side of the body. The skin above the muscles of interest was shaved, exfoliated, and wiped with an alcohol pad. EMG activity was recorded from the anterior deltoids (AD), posterior deltoids (PD), biceps brachii (BB), triceps brachii (TB) (long head), flexor carpi radialis (FCR), and extensor carpi radialis longus (ECR) (7HP511, Grass Technologies and Life Electronics, Edmonton, AB, Canada). EMG signals were collected at 1,000 Hz, preamplified (×2,000–5,000), and band-pass filtered between 100 and 300 Hz. Further off-line analysis was performed with a custom-made program using MATLAB (MathWorks, Natick, MA). Data were full-wave rectified and filtered with a fourth-order, 40-Hz low-pass Butterworth filter.

An active infrared-sensing motion capture system (Optotrak, NDI, Waterloo, ON, Canada) was used to record sagittal-plane upper limb kinematics on the right side of the body during manual wheeling. Two cameras, positioned at ~45° angles between the horizontal and sagittal planes creating a 90° angle between the two cameras, were used to collect the data. Active infrared markers were placed on the following landmarks: third metacarpophalangeal joint, radial styloid, lateral epicondyle, and acromion to represent the wrist, elbow, and shoulder joint centers, respectively. Kinematic data were collected at a sampling frequency of 200 Hz. All data were filtered with a fourth-order, 7-Hz low-pass Butterworth filter. All angles were calculated in the sagittal plane to approximate joint movement and show general differences between tasks. The wrist angle was calculated with the hand segment (3rd metacarpophalangeal joint and radial styloid) and lower arm segment (radial styloid and lateral epicondyle). The elbow angle was calculated with the lower arm and upper arm (lateral epicondyle and acromion) segments. The shoulder angle was defined as the angle between the longitudinal axis of the upper arm segment and a vertical plane through the acromion.

Data Analysis

Kinematic, EMG, and nerve stimulation data were synchronized by an external trigger pulse signal and divided into cycles based on maximum shoulder extension. For graphical purposes, data were normalized in time to 100% of the cycle. For each subject, the EMG data for each muscle were normalized to the peak rectified EMG value of that muscle during nonstimulated manual wheeling or symmetrical arm cycling for later descriptive group analyses. Shoulder, elbow, and wrist angles were also calculated from nonstimulated cycles and averaged for both groups for descriptive purposes.

Each movement cycle was divided into eight bins. For each subject, all cycles containing a single stimulation were categorized into one of the eight bins. Eight bins were selected to allow for several samples to be delivered per bin. Based on probability, each bin would contain 12–20 stimulations. Therefore the length of time for each task would not be excessive. All reflexes occurring in a given bin were averaged together to produce eight averaged reflexes for the eight bins of the movement cycle. From this, the early and middle latencies of the cutaneous reflexes were identified in each subject. The early-latency reflexes were those that occurred in the range of 50–75 ms after stimulation, and middle latency reflexes were those that occurred in the range of 75–120 ms after stimulation (Zehr and Chua 2000; Zehr and Kido 2001). Reflex amplitude was calculated by taking the average EMG amplitude over a 20-ms window around the peak response at each of the two latencies. EMG amplitudes were recorded for stimulated trials (EMGSTIM), and then the background EMG (EMGBG) was subtracted from the stimulated data to provide a subtracted value (EMGSUB representing the net reflex (EMGSUB = EMGSTIM − EMGBG). EMGSUB was defined as the EMG amplitude of the average nonstimulated cycles at the same time window (i.e., bin) of the cycle as when the stimulus occurred.

Statistical Analysis

The significance of all statistical tests was evaluated at P < 0.05, and analysis was conducted with SPSS 18.0 (SPSS, Chicago, IL).

To determine whether potential differences between tasks were directly related to differences in EMGSUB between tasks, a Pearson correlation was performed on the absolute difference between EMGBG and EMGSUB between the two tasks. The absolute difference would allow for any correlations with suppressive reflex values to be evaluated.

A three-way repeated-measures ANOVA was used to determine main and interaction effects on EMGSUB in each muscle with subject group (MWU, AB) as the between-groups factor and motor task (manual wheeling, symmetrical arm cycling) and bins (8) as the within-group factors. Post hoc paired-samples t-tests with a Bonferroni-corrected P value were used when indicated. An independent-samples t-test was used to determine differences in manual wheeling speed between groups (AB vs. MWU).

RESULTS

Figure 2 presents a general comparison of the muscle activation and joint kinematic patterns during manual wheeling and symmetrical arm cycling in the AB group. The beginning of each plot corresponds to maximum shoulder extension, which occurs around the onset of propulsion during manual wheeling or the 9 o’clock position during symmetrical arm cycling. Not surprisingly, there are visual differences in the phasing of muscle activity (EMG activity normalized to peak values) between manual wheeling and symmetrical arm cycling, particularly in the PD, TB, and FCR muscles. Although there were three pairs of antagonist muscles, PD/AD was the only pair that showed a clear reciprocal activation pattern during manual wheeling. Joint kinematic patterns, particularly at the shoulder and elbow, showed qualitatively similar temporal patterns, although differences in the range of motion are apparent.
Figure 3 displays the averaged reflexes normalized to EMG
of the AD during manual wheeling and symmetrical arm cycling in both AB and MWU groups for each bin of the cycle. Both AB and MWU subjects showed similar reflex patterns of modulation in each motor task. Reflexes during manual wheeling and symmetrical arm cycling consisted of an early-latency inhibitory response as well as a middle-latency excitatory response. The early-latency responses ranged from 64.4 to 83.2 ms (mean 75.5 ms, SD 3.9 ms) and the middle-latency responses ranged from 109.5 to 134.0 ms (mean 120.9 ms, SD 5.9 ms) for all muscles.

There were no significant main or interaction effects for group differences between manual wheeling and cycling in any reflexes (normalized to EMG<sub>BG</sub>) in the AD during manual wheeling and symmetrical arm cycling in able-bodied subjects (n = 13). Positive deflections denote flexion at the shoulder, extension at the elbow, extension at the wrist during manual wheeling, and symmetrical arm cycling. Thick black lines represent manual wheeling; thick gray lines represent symmetrical arm cycling. Thin lines represent SD.

**Early-Latency Responses**

All values for the early-latency responses are in units of normalized EMG (EMG<sub>SUB</sub>/peak EMG). For the early-latency responses, there were significant task × bin interaction effects in the AD [F(1,1,7) = 27.09, P < 0.001; Fig. 4A], PD [F(1,1,7) = 14.80, P < 0.001; Fig. 4B], BB [F(1,1,7) = 3.18, P = 0.036; Fig. 4C], and TB [F(1,1,7) = 11.23, P < 0.001; Fig. 4D]. There were no significant task × bin interaction effects in the ECR [F(1,1,7) = 1.46, P = 0.244; Fig. 4E] or FCR [F(1,1,7) = 2.34, P = 0.112; Fig. 4F].

**AD.** Post hoc tests showed that there were significant differences between manual wheeling and cycling in bins 1, 2, 5, 6, 7, and 8 (Fig. 4A, left and right). For bins 1 and 2, reflex amplitudes during manual wheeling were inhibitory, unlike those during cycling [bin 1: manual wheeling −0.20 (0.26) [mean (SD)], cycling 0.10 (0.09); bin 2: manual wheeling −0.19 (0.21), cycling 0.07 (0.13)]. For bins 5–8, reflex amplitudes during manual wheeling were facilitatory compared with those during cycling [bin 5: manual wheeling 0.10 (0.20), cycling −0.28 (0.19); bin 6: manual wheeling 0.11 (0.13), cycling −0.37 (0.22); bin 7: manual wheeling 0.14 (0.15), cycling −0.24 (0.17); bin 8: manual wheeling 0.03 (0.20), cycling −0.15 (0.09)].

**PD.** Post hoc tests showed that in bins 6–8 early-latency PD reflexes during manual wheeling were facilitatory compared with those during cycling [bin 6: manual wheeling 0.97 (0.87), cycling 0.35 (0.60); bin 7: manual wheeling 1.37 (1.06), cycling 0.40 (0.50); bin 8: manual wheeling 1.30 (1.13), cycling 0.46 (0.53)].

**BB.** Post hoc tests showed that in bins 5 and 6 early-latency BB reflexes during manual wheeling were facilitatory compared with those during cycling [bin 5: manual wheeling 0.20 (0.38), cycling −0.05 (0.23); bin 6: manual wheeling 0.24 (0.43), cycling 0.05 (0.31)].

**TB.** Post hoc testing showed that reflex amplitudes in bins 5–8 during manual wheeling were facilitatory compared with those during cycling [bin 5: manual wheeling 0.29 (0.32), cycling −0.02 (0.21); bin 6: manual wheeling 0.32 (0.36), cycling −0.16 (0.26); bin 7: manual wheeling 0.48 (0.55), cycling −0.24 (0.25); bin 8: manual wheeling 0.57 (0.66), cycling −0.23 (0.37)].

**Middle-Latency Responses**

All values for the middle-latency responses are in units of normalized EMG (EMG<sub>SUB</sub>/peak EMG). For the middle-latency responses, there were significant task × bin interaction effects in the AD [F(1,1,7) = 24.07, P < 0.001; Fig. 5A], PD

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There were no significant task × bin interaction effects in the ECR [F(1,1,7) = 2.16, P = 0.096; Fig. 5E] or FCR [F(1,1,7) = 0.797, P = 0.427; Fig. 5F].

AD. Post hoc testing showed that there were significant differences between manual wheeling and cycling in bins 1, 2, 5, 6, and 7 (Fig. 5A, left and right). For bins 1 and 2, reflex amplitudes during manual wheeling were facilitatory compared with those during symmetrical arm cycling [bin 1: manual wheeling 0.64 (0.47) [mean (SD)], cycling 0.09 (0.11); bin 2: manual wheeling 0.55 (0.46), cycling 0.02 (0.08)]. For bins 5–7, reflex amplitudes during manual wheeling were suppressed compared with those during symmetrical arm cycling [bin 5: manual wheeling −0.01, (0.07), cycling 0.45 (0.36); bin 6: manual wheeling 0.01 (0.10), cycling 0.50 (0.39); bin 7: manual wheeling 0.02 (0.09), cycling 0.33 (0.29)].

PD. Post hoc tests showed that reflex amplitudes in bins 6 and 7 during manual wheeling were inhibitory, unlike those during cycling [bin 6: manual wheeling −0.22 (0.39), cycling 0.21 (0.40); bin 7: manual wheeling −0.26 (0.40), cycling 0.19 (0.30)].

For BB and TB, we found no significant differences between manual wheeling and cycling in the post hoc analysis.

An analysis was conducted to determine whether potential differences between tasks were directly related to differences in EMG_{BG}. The difference in reflex amplitude between tasks did not correlate to the difference in EMG_{BG} between tasks (Table 1).

Finally, there were no differences in average manual wheeling speed between groups (AB vs. MWU). The AB group and the MWU group wheeled at 0.75 ± 0.10 m/s and 0.82 ± 0.32 m/s, respectively.

DISCUSSION
This study compared cutaneous reflexes evoked by stimulation of the superficial radial nerve during symmetrical arm cycling and manual wheeling in able-bodied individuals and spinal cord-injured MWUs. There was no effect of group for either manual wheeling or symmetrical arm cycling, suggesting that the years of manual wheeling experience and the reliance on manual wheeling for locomotion did not affect the pattern of cutaneous reflex modulation in the superficial radial nerve during rhythmic upper limb activities. However, we did show phase-dependent modulation of reflex amplitude that differed between manual wheeling and symmetrical arm cycling. The lack of correlation between EMG_{BG} and EMG_{SUB}...
suggests that the phase-dependent modulation of cutaneous reflexes observed here cannot be primarily ascribed to changes in motoneuronal excitability across the movement cycle.

**Experience and Reflex Modulation Patterns**

We hypothesized that the excitability of cutaneous afferent reflex pathways would change with manual wheeling experience (>1 yr of experience); however, we did not observe any differences between the two participant groups. This was surprising as previous work showed that with repeated practice of a functionally relevant motor task, adaptations in the nervous system could be discerned through changes in reflex pathways (Hodapp et al. 2009; Schneider and Capaday 2003; Trimble et al. 1998). Most of these studies were based on changes in H-reflex excitability after training. Reflex amplitude does not always necessarily decrease with training or experience. One study found that ballet dancers have significantly lower H-reflex amplitudes (normalized to maximal M response) compared with other moderately and well-trained athletes; however, their H-reflex amplitudes were not different compared with a group of nonathletes (Nielsen et al. 1993). The moderately and well-trained groups were aerobically trained, which has been shown to increase reflexes (Casabona et al. 1990). In our study the experienced MWUs were well trained in manual wheeling, but it is unknown whether they differed in terms of aerobic fitness compared with the AB group.

We stimulated the superficial radial nerve, which innervates the dorsal part of the hand. It is possible that we did not see differences between the AB and MWU groups here because there was not a large enough challenge to functional pathways mediated by the superficial radial nerve during either task. Stimulation of the median or ulnar nerves, which innervate the palm of the hand, could have yielded different results, as the...
palm has greater regular contact with the rim during manual wheeling. However, many MWUs (up to 73%) experience carpal tunnel syndrome and damage to the median and ulnar nerves (Boninger et al. 1999, 2004). Furthermore, there would have been interference in the reflex recordings from these nerves because of the mechanical perturbation of the palm hitting the pushrim of the wheelchair. Nevertheless, it is possible that experience-dependent differences in the modulation of reflexes from the superficial radial nerve may be observed only with more challenging manual wheeling tasks. Here, subjects performed manual wheeling on rollers, providing only continuous and consistent cyclic arm movements but no requirement to adapt to a challenging environment.

### Differences in Reflexes Between Manual Wheeling and Symmetrical Arm Cycling

We found several differences in the pattern of reflex modulation between manual wheeling and symmetrical arm cycling. This is consistent with previous research showing task-dependent differences in cutaneous reflex modulation between arm cycling and matched static positions (Zehr et al. 2001),

Table 1. Correlation values

<table>
<thead>
<tr>
<th>Muscle</th>
<th>AB (n = 13)</th>
<th>MWU (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Early</td>
<td>Middle</td>
</tr>
<tr>
<td>AD</td>
<td>0.300</td>
<td>0.040</td>
</tr>
<tr>
<td>PD</td>
<td>-0.109</td>
<td>0.025</td>
</tr>
<tr>
<td>BB</td>
<td>-0.111</td>
<td>0.242</td>
</tr>
<tr>
<td>TB</td>
<td>0.240</td>
<td>0.193</td>
</tr>
<tr>
<td>ECR</td>
<td>-0.152</td>
<td>-0.030</td>
</tr>
<tr>
<td>FCR</td>
<td>0.186</td>
<td>-0.015</td>
</tr>
</tbody>
</table>

AB, able-bodied subjects; MWU, manual wheelchair users; AD, anterior deltoid; PD, posterior deltoid; BB, biceps brachii; TB, triceps brachii; ECR, extensor carpi radialis longus; FCR, flexor carpi radialis.
running and standing (Duyssens et al. 1993), and walking and standing (Komiyama et al. 2000). Zehr et al. (2001) showed that cutaneous reflexes depend to a lesser extent on afferent feedback and are likely gated by central mechanisms.

Our findings of task-dependent cutaneous reflex responses across rhythmic arm tasks are similar to those in the lower limb comparing leg cycling and walking. For example, a study comparing superficial peroneal nerve stimulation during walking and leg cycling found that, although phase-dependent reflex modulation patterns were conserved across tasks, middle-latency reflex amplitudes in the tibialis anterior, vastus lateralis, and biceps femoris muscles were significantly different between the swing phase of the gait cycle and the corresponding phase of cycling (Zehr et al. 2007a). More specifically, the middle-latency reflex response during the swing phase of gait is significantly more facilitatory in the vastus lateralis and biceps femoris and more inhibitory in the tibialis anterior compared with leg cycling (Zehr et al. 2007a). The reflex pattern during walking has been described functionally as a stumble corrective response that enables knee flexion and reduced ankle dorsiflexion to overcome an imposed obstacle during swing (Zehr et al. 1997). This has also been observed during leg cycling (Mileva et al. 2004; Zehr et al. 2009).

The hand contact/noncontact phases during manual wheelchair could be comparable to the stance phase and swing phase in the lower limbs during walking, and it is tempting to speculate that some of the reflex response patterns we observed here could be analogous to well-described reflex responses during gait. In AD, PD, TB, and BB we see an overall trend of larger early-latency reflex response in manual wheelchair compared with symmetrical arm cycling during the recovery phase. The increased early-latency reflexes in BB and TB during the recovery phase could be analogous to the stumbling corrective response observed in the leg during the swing phase of gait. A functional interpretation of this response pattern could be that a cutaneous perturbation to the hand dorsum during the recovery phase of wheelchair (“swing phase”) will elicit reflexes to promote elbow flexion (BB) and shoulder extension (TB). At middle latency there were only significant differences between reflex responses observed in AD and PD. An interesting observation is that manual wheeling had excitatory responses in AD during power/propulsion with no response or small suppression during recovery while the reflex responses during symmetrical arm cycling were the opposite. This reversal in reflex response is similar to what is observed in the tibialis anterior when walking is compared to leg cycling and could be related to functional differences between the roles of the muscles during each task (Zehr et al. 2007b). In a study of the neuromechanical correlates of cutaneous reflexes during arm cycling, similar functions were suggested as for the legs during walking. That is, cutaneous inputs are useful for overall trajectory stabilization in response to perturbations (Klimstra et al. 2011). However, the responses in the arms are more complex to interpret than those in the legs because of the differences in fractionating portions of the step cycle.

Conclusions

In summary, we did not find evidence that experience in manual wheeling influences the amplitude of early- and middle-latency cutaneous reflexes from the superficial radial nerve during upper limb rhythmic tasks. However, we did find several differences in the pattern of phase-dependent modulation of these reflexes between symmetrical arm cycling and manual wheeling, which could be related to differences in the functional mechanics in these two tasks. While these observations are consistent with a common regulation of rhythmic neural control of the arms sculpted to the specific demands of each task, further mechanical investigation of these responses is necessary to properly evaluate their function. Results from this study could be used to further our understanding of the neural control and function of manual wheeling and potentially in upper limb mobility research related to injury prevention and the development of rehabilitative strategies and assistive devices.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS


REFERENCES


