2014 CMBEC37 Conference
Vancouver, BC
May 21 – 23, 2014

CO-ACTIVATION OF LEG MUSCLES DIFFERS WHILE ASCENDING AND DESCENDING STAIRS

Kazushige Kimura, and Zahra Moussavi
Biomedical Engineering Department, University of Manitoba, Winnipeg, MB

ABSTRACT

Co-activation of the agonist-antagonist leg muscles has been studied during walking on flat, uphill, and downhill surfaces. This study aimed to examine any plausible difference between the amount of co-activation of the leg muscles while ascending and descending stairs. Twelve healthy individuals (20-32y, 9 males) went up 12 stairs one at a time, and then down one at a time. Surface electrodes were placed on tibialis anterior and gastrocnemius muscles of the subjects' left leg, and electromyography (EMG) signals were amplified within 15-250 Hz, and recorded at 1 kHz sampling rate. The signals were segmented to each step's data; the root-mean-square (RMS) values of each segment were calculated over 100 ms windows with 50% overlap between successive windows. The baseline activity, defined as the averaged RMS value over 500 ms before stepping forward, was subtracted from the recorded data. Then, the signal of each segment was normalized by the maximum value during the cycle. Co-activation, defined as the overlapped area between RMS value of the EMG signals of the agonist and antagonist muscles, was calculated for every ascending and descending step and averaged for all ascending (and descending) steps for each subject. Results showed co-activation during ascending stairs was significantly ($p<0.01$) larger than that of during descending.

INTRODUCTION

Co-activation of the leg's agonist and antagonist muscles has been studied by electromyography (EMG) signal analysis during walking on flat or slope surface [1, 2], and during stair stepping [3, 4]. The increase of co-activation has been observed to increase joints stiffness and enhance stability stepping down stairs [4] and also during arm movement [5].

It was found that timing of leg's muscles activities in a gait cycle during uphill walking was different from that of during flat or downhill walking. Thus, co-activation of gastrocnemius and tibialis anterior muscles during downhill walking was found significantly different from that of during level walking [1].

Based on these findings, we hypothesize the co-activation of the agonist-antagonist leg muscles during ascending stairs would be different from that of during descending stairs. We investigated this hypothesis by EMG analysis of 12 individuals' leg agonist-antagonist muscles while walking up and down stairs. We also investigated the plausible differences during stance and swing phases.

METHOD

<u>Experimental design</u>

Study subjects included 12 healthy (20 - 32 y, 9 males); they went up 12 stair at a time, then went down at a time; the subjects stepped forward with their left leg for both upstairs and downstairs. Surface electrodes were placed on the left tibialis anterior and gastrocnemius muscles and recorded in bipolar configuration. EMG signals from the two muscles were amplified within 15 – 250 Hz and recorded at a sampling rate of 1 kHz. Figure 1 shows the recording procedure.

The subjects were instructed to step forward with the left leg, pause for a couple of seconds, step forward with the right leg, and pause a couple of seconds again before taking the next step; this procedure was repeated until they completed ascending or descending the stairs.

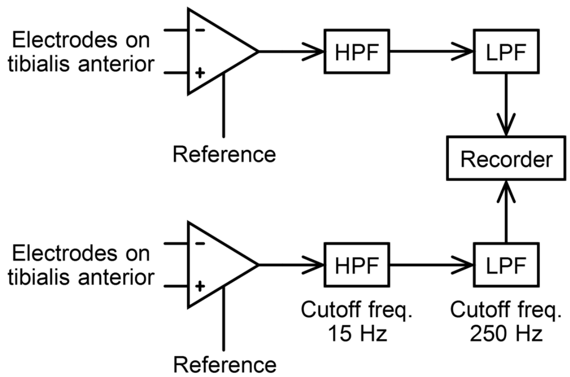

Figure 1: Recording system for EMG signals from tibialis anterior and gastrocnemius. The signals were amplified within 15-250 Hz then recorded at sampling rate of 1 kHz.

<u>Signal processing</u>

The recorded signals were sequestered into every step's data; note that each step could be either swing or stance phase. Then, root-mean-square (RMS) values for each step's data were calculated over 100 ms windows with 50% overlap between successive windows (Fig. 2). The average baseline activity, defined as the averaged RMS value over 500 ms before each stepping forward, were subtracted from each step's EMG data, and then the signal was normalized by its maximum value during that step. Co-activation, defined as the overlapped area between the agonist-antagonist muscles above the average baseline activity [6], was calculated for every step's data. Figure 3 shows typical RMS signals of leg's agonist-antagonist muscles and their co-activation during a step during ascending the stairs.

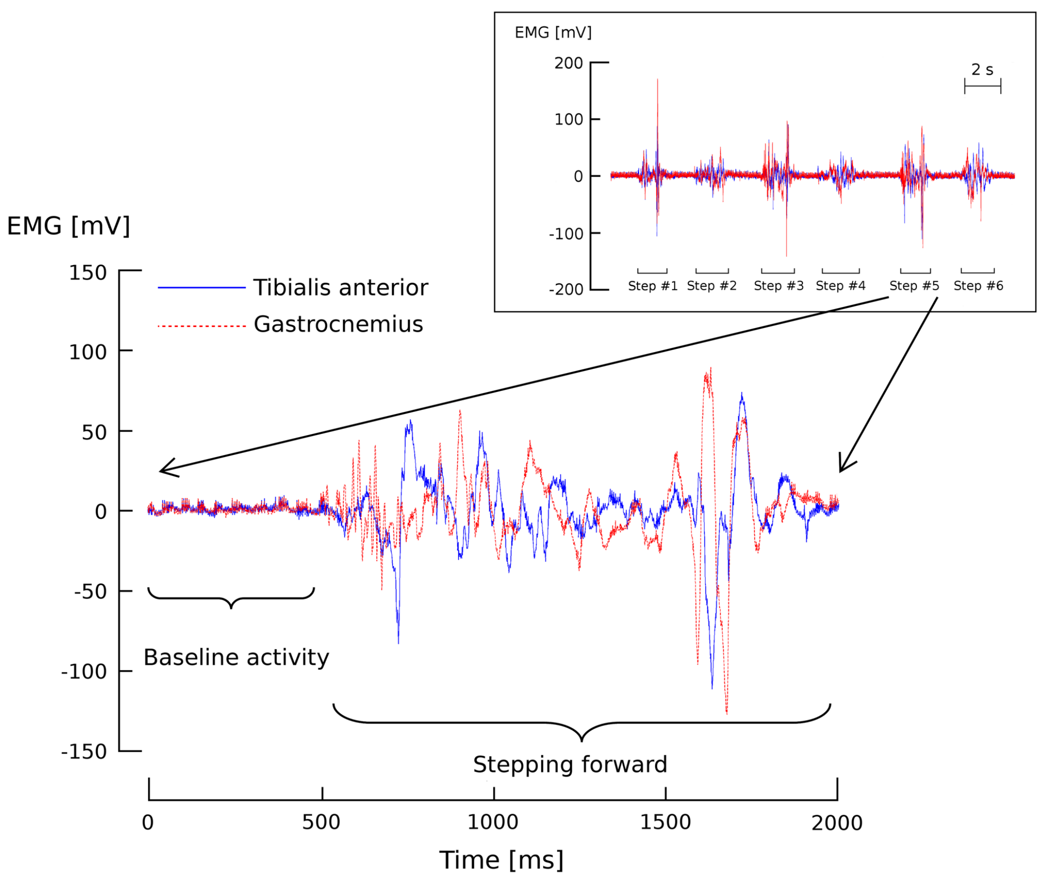

Figure 2: Typical EMG signals during a step of tibialis anterior (blue, solid line), and gastrocnemius (red, dashed line). The signals correspond to the step #5 shown in the inlet. The step #1, #3, and #5 correspond to the swing phase, while the step #2, 4, 6 correspond to the stance phase. The subject was instructed to stop from 0 to 500 ms, and instructed to step forward at 500 ms.

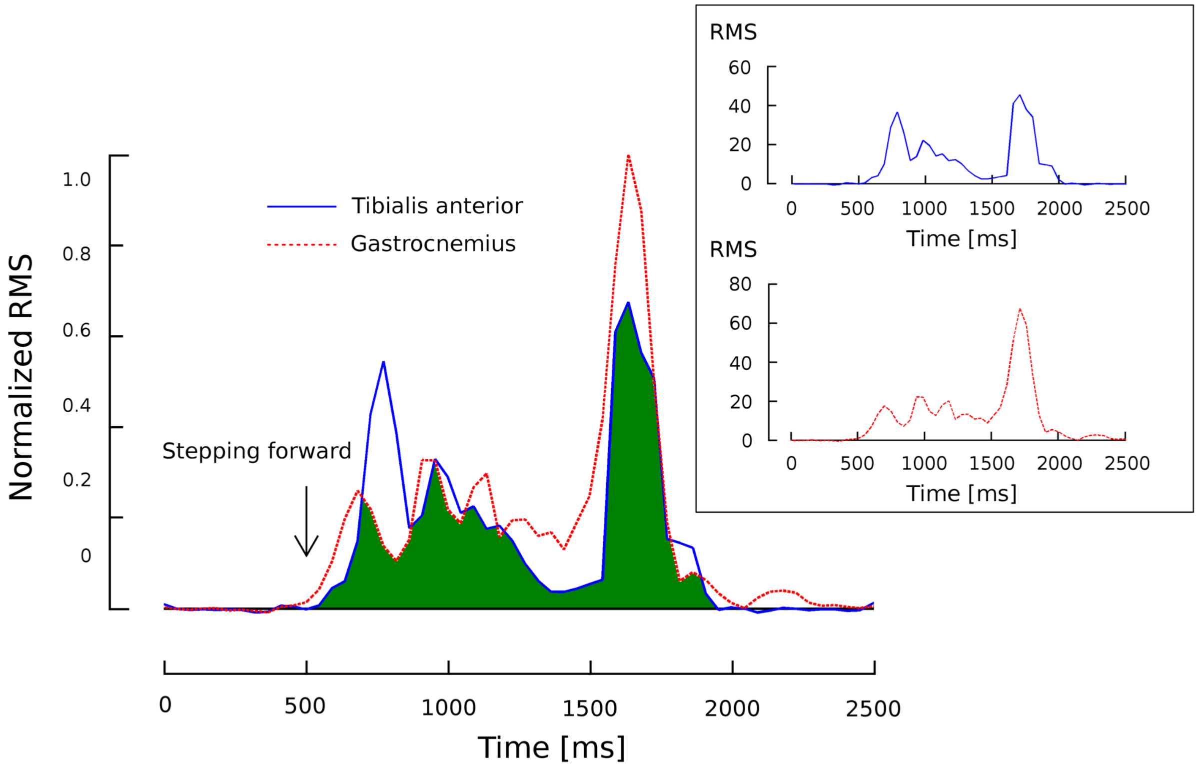

Figure 3: Typical RMS signals of agonist-antagonist muscles; the green marked area shows the co-activation between the two muscles. The average baseline activity, defined as the averaged RMS value within 500 ms prior to taking a step, was subtracted from the RMS signals followed by normalizing the signal by its maximum value during the step. The inlet shows RMS values before subtracting the baseline activities and normalization.

The calculated co-activation values were then grouped based on the direction and phases: (a) descending-stance phase, (b) descending-swing phase, (c) ascending-stance phase, and (d) ascending-swing phase. Finally, Analysis of Variance (ANOVA) statistical test was used to examine any significant differences between the above four conditions.

RESULTS

Table 1 shows the *p*-values of the statistical tests between the four conditions mentioned above. No significant difference was found between stance and swing phases but the co-activation during ascending was significantly larger ($p<0.01$) than that of during descending.

Table 1: The results of statistical test on the co-activation values of the four conditions (n = 72)

Direction	Co-activation ($\mu \pm \sigma$)		p-value
	Stance phase	***Swing phase***	
Ascending	209 ± 105	236 ± 107	0.001
Descending	193 ± 106	160 ± 81	
p-value	0.446		0.051

These results clearly show the co-activation of the leg muscle during ascending is different from that of during descending. Furthermore, the results also support idea that functional role and/or timing of muscle activities vary between going up or down stairs.

DISCUSSION

Generally, agonist-antagonist muscles co-activation increases when there is a need for more stability. Thus, higher co-activation can be expected when walking downhill; this has been shown in [1], where the lower leg's agonist and antagonist muscles showed an increased co-activation compared to that of walking uphill. However, our results show the opposite: the co-activation increased during ascending compared to that of descending stairs. This could be due to the way we instructed our subjects to walk the stairs. We instructed them to pause a couple of seconds before taking the next step. With that instruction, to step forward, when one lifts the foot to the level of the next stair tread, s/he must have slight trunk flexion to move the body's center of mass to the base of support; thus, have the hip and knee flexed, and foot held in neutral or slight dorsiflexion to keep the toes from catching. With this scenario, the activity of gastrocnemius is likely related to knee flexion and will be concentric; the activity of tibialis anterior is likely related to keeping the foot in neutral (isometric) or slight dorsiflexion (concentric) as gravity will try to pull the foot into plantarflexion.

During the heel strike (Fig. 3, ~1500 ms timeline), as the foot contacts the tread of the stair, the momentum of the trunk (as it moves over the fixed foot) has to be braked to prevent further plantarflexion; that accounts for the high level of gastrocnemius activity (eccentric) (Fig. 3, ~1500-1800 ms). However, because the timeline of this event is very short, there is likely high acceleration, and therefore a high impact force, which may require co-activation to provide stability; hence, the increased co-activation with tibialis anterior.

The above speculation of what has occurred in our experiments, is indirectly in line with the finding [7], in which they showed walking stairs has lower risk of fall compared to that of downhill walk; this implies the increased level of co-activation that was shown to occur during downhill walk, may not happen during stepping down, and that is what our study shows indirectly.

ACKNOWLEDGMENT

The authors are grateful for Professor Julliete Cooper's (University of Manitoba) help in interpretation of the results.

REFERENCES

[1] Jason R. Franz and Rodger Kram, "How does age affect leg muscle activity/coactivity during uphill and downhill walking?," Gait & Posture vol. 37, pp. 378-384, 2013.

[2] Tibor Hortobágyi, Adria Finch, Stanislaw Solnik, Patrick Rider, and Paul DeVita, "Association Between Muscle Activation and Metabolic Cost of Walking in Young and Old Adults," J Gerontol A Biol Sci Med Sci. 2011 May;66A(5):541–547

[3] Anders Holsgaard Larsen, Lis Puggaard, Ulpu Hamalainen, and Per Aagaard, "Comparison of ground reaction forces and antagonist muscle coactivation during stair walking with ageing," Journal of Electromyography and Kinesiology vol. 18, pp. 568-580, 2008.

[4] Tibor Hortobágyi, Paul DeVita, "Muscle pre- and coactivity during downward stepping areassociated with leg stiffness in aging," Journal of Electromyography and Kinesiology, Vol.10, pp.117–126, 2000

[5] YUNJU LEE and JAMES A. ASHTON-MILLER, The Effects of Gender, "Level of Co-Contraction, and Initial Angle on Elbow Extensor Muscle Stiffness and Damping Under a Step Increase in Elbow Flexion Moment," Annals of Biomedical Engineering, Vol. 39, No. 10, October 2011 pp. 2542–2549

[6] Moussavi Z., "Coactivation Pattern of Arm Muscles in Reaching Movements," Proc. CMBEC, pp. 14-15, Oct. 2000.

[7] Riley C. Sheehan, Jinger S. Gottschall, "At similar angles, slope walking has a greater fall risk than stair walking," Applied Ergonomics 43 (2012) 473-478.