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CORRELATION BETWEEN SLIP SEVERITY AND MUSCLE SYNERGIES OF SLIPPING

[1] Mohammad Moein Nazifi, [2] Kurt Beschorner, PhD and [1] Pilwon Hur, PhD

[1] Department of Mechanical Engineering, Texas A&M University, College Station, TX, USA
[2] Department of Bioengineering, University of Pittsburgh, Pittsburgh, PA, USA
email: {moeinnazifi,pilwonhur}@tamu.edu, beschorn@pitt.edu, web: http://hurgroup.net

INTRODUCTION

Slips, trips and falls caused 27 percent of the total days-away-from-work cases in 2014 and fall injuries have been growing [1]. Slipping is the main trigger to falls in working adults [2]. Understanding the contributing factors to slips and falls is an important step toward fall prevention. Specifically, motor patterns associated with “hazardous slips”, which are more likely to result in falls, are of important concern.

It has been reported that human central nervous system controls motor tasks using a lower dimensional set of muscle modules, called muscle synergies [3]. Previously, muscle synergies of healthy young adults during slipping were found to be shared with normal walking [4]. However, previous research has not examined muscle synergies in the context of slip severity. This gap is important since this research may either reveal the cause of severe slips or the typical response to severe slips.

The objective of this study is to look into the muscle synergies and activation coefficients of “severe slippers” and “mild slippers” to determine if there is a significant difference between the two groups.

METHODS

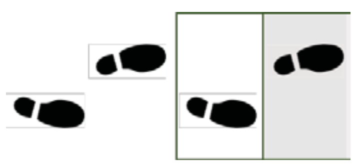

Figure 1: Top view of the pathway, right, and left foot strikes. Gray color indicates slippery surface.

Twenty healthy young adults (11 male and 9 female, age 23.6 ± 2.52) participated in an IRB approved study at University of Pittsburgh. All subjects gave informed consent prior to participation. Subjects, free of walking disorders, were asked to walk on a pathway with two force plates embedded. While practicing, their starting location was adjusted to have each force plate receive exactly one step (Fig. 1). Subjects were provided PVC-soled shoes and a safety harness to catch subjects in case of total loss of balance. Subjects were informed that the surface would not be slippery for the first few trials. However, after two or three “dry walk” trials in dimmed light, a slippery contaminant (75% glycerol, 25% water) was applied to the surface without notification to the subjects.

Subjects were fitted with surface EMG electrodes on medial hamstring (*MH*), tibialis anterior (*TA*), vastus lateralis (*VL*), and medial gastrocnemius (*MG*) on both right/trailing/non-slipping leg (*NS*) and left/leading/slipping leg (*S*). The EMG was collected at 1080 Hz. A motion capture system (Vicon 612, Oxford, UK) was used to collect joint kinematics data at 120 Hz. The data was then transferred to Texas A&M University for further analysis on approval from the IRB of both institutions.

The EMG data were processed using MATLAB (v2014a, Mathworks, Natick, MA). Data was resampled to 1000 Hz, mean bias corrected, low-pass filtered (4th order Butterworth, cut-off frequency of 15 Hz), normalized to subject’s maximum muscle activity for each muscle in all trials, and then averaged over each 10 ms. A nonnegative matrix factorization technique was used to extract four slipping synergies and their coefficients from the first 300 ms after heel strike on the second force plate [4].

Using the marker data, peak heel velocity (PHV) was measured for each subject. Subjects with a PHV of greater than 1.44 m/s were considered “severe” and rest were counted as “mild” slippers [5]. Following the same procedure in [4], i.e., using correlation coefficients (r) as similarity criterion, muscle synergies and activation coefficients were ordered and grouped in descending order of similarity (Figure 2). Independent t-tests were ran (significance level of 0.05) between synergies of two groups and every time point of activation coefficients of two groups (SPSS v21, IBM, Chicago, IL).

RESULTS AND DISCUSSION

Eight subjects were classified as severe slippers and the rest were mild slippers (Table 1). Synergies and their coefficients were extracted and averaged for each group (Fig. 2). Independent t-test showed a significant difference in contribution of *MH_S* in the first synergy between mild and severe slippers (Table 2, W1). Contribution of *TA_S* in the third synergy and *VL_S* in the fourth synergy were different between groups (Table 2, W3 and W4). A significant difference was found in activation pattern of the second synergy (14th and 15th time step) and in activation of the fourth synergy (during 11th to 14th time step), (Table 2, C2 and C4).

Table 1 Group information (Mean (SD), M/F)

	PHV	Age	Mass	Height	Sex
Mild	0.63	24.17	68.41	171.75	5/7

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	(0.25)	(2.79)	(11.89)	(8.59)	
Severe	1.87 (0.27)	22.75 (1.48)	70.00 (11.37)	175.19 (7.57)	6/2

Table 2 Significant differences according to *t*-tests. Mean (SD)

Variable		Mild	Severe	p-value
W1	MH_S	0.45 (0.29)	0.19 (0.19)	0.040
W3	TA_S	0.35 (0.31)	0.67 (0.28)	0.032
W4	VL_S	0.50 (0.29)	0.19 (0.20)	0.017
C2	14th	0.22 (0.24)	0.06 (0.07)	0.045
	15th	0.12 (0.12)	0.01 (0.02)	0.010
C4	11th	0.14 (0.16)	0.02 (0.03)	0.026
	12th	0.12 (0.12)	0.01 (0.02)	0.010
	13th	0.09 (0.09)	0.01 (0.02)	0.012
	14th	0.09 (0.09)	0.02 (0.04)	0.043

The results show that a more powerful *MH* and *VL* is associated with a more successful recovery. Increased hamstring gain in the primary synergy may have been beneficial in preventing severe slips since the hamstring has been associated with slowing the slipping foot and decelerating base of support (BOS) [7]. Conversely, higher activation of *TA_S* was associated with higher severity as it prevents achieving flat-foot and disrupts recovery [6]. Since all of the discrepancies in muscle contributions occurred on the slipping limb, it could be argued that the severity is mainly affected by the perturbed limbs' muscles responses and *NS* limb is less involved in recovery process.

Higher activation peaks show that the mild group has a faster reaction to slip (Fig. 2). Since the second synergy is mainly responsible for activation of *VL_S* (Fig. 2), it could be concluded that faster activation of *VL* is associated with less severity [6]. Late activation of VL in hazardous slips may indicate a delay in progressing the center of mass over the base of support and reduced load bearing that is associated with loss of balance [6]. The fourth synergy is likely to be responsible for stabilizing the non-slipping leg, as it mainly activates *NS* muscles. Hence, a faster activation of the fourth synergy shows that mild slippers are able to stabilize their *NS* limb faster. It also stays consistent with previous studies suggesting high association of the latency in activation of knee extensors with severe slips [6].

The effects in this study are conceptually consistent with the concept that the motor response influences the severity of the slip as opposed to vice versa. However, additional research utilizing computationally modeling or control over the muscle responses would be needed to better establish causality.

CONCLUSION

This study examined discrepancies in muscle synergies of individuals with different slip severities and found a significant difference in activation of synergies and contributions of some muscles. This study identified the factors responsible for severe slips, which may contribute to more effective targeted rehabilitation programs. Future studies will focus on how the synergies can change after training or rehabilitation.

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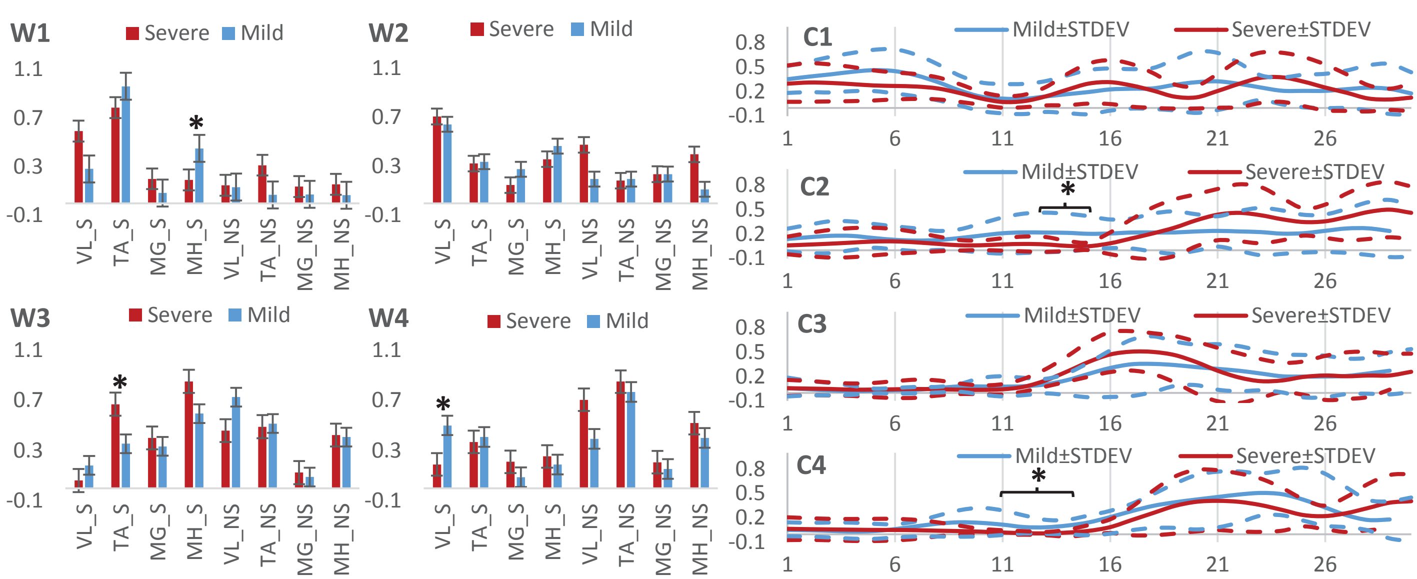

Figure 2: Averaged synergies and their coefficients for each severity group. Error bars indicate SE. Asterisks indicate significant differences.