WALKING MUSCLE SYNERGIES INFLUENCE PROPENSITY OF SEVERE SLIPIPNG

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INTRODUCTION

Annually, injuries caused by slips, trips, and falls contribute to the loss of over $16 billion [1]. Slips and resulting falls contribute to a significant share of these injuries [2]. Understanding how gait patterns influence the risk of a severe slip may lead to new methods of targeting and developing slip prevention strategies.

Previous research suggests that the control of gait may influence an individual's risk of experiencing a slip. For example, kinematic gait metrics like shoe-floor angle, step length and cadence are known to be associated with slip severity [3]. The kinematics of gait are effected predominantly by muscle activation patterns in the lower extremities. It has been suggested that the central nervous system may control the gait and slipping using a lower dimensional organization of muscle synergies [5]. Therefore, a logical next step in understanding how gait patterns influence slipping risk is to quantify differences in gait synergies between individuals whose gait leads to high severity slips versus those who did not.

The objective of this study is to compare the walking muscle synergies of the mild and severe slippers to find the possible inter-group discrepancies.

METHODS

A total number of twenty healthy subjects (11 male/9 female, age (mean ± SD): 23.6 ± 2.52), free of walking disorders, were asked to walk at their self-selected speed in a pathway with an embedded force plate. The starting location of each subject was altered in a way to secure a foot strike on the force plate. Subjects were fitted with appropriate size PVC-soled shoes and donned an over-head safety harness and gave written consent prior to participation in this IRB-approved study at University of Pittsburgh. The data analysis was done at Texas A&M University upon approval of the IRB of both institutions.

Throughout the experiment, EMG signals were recorded at 1080 Hz from medial hamstring (*MH*), tibialis anterior (*TA*), vastus lateralis (*VL*), and medial gastrocnemius (*MG*) on both limbs (right/trailing/non-slipping leg (*NS*) and left/leading/slipping leg (*S*)). The slipping leg refers to the leg that experienced a slip in the following trial since EMG data was only collected from baseline walking conditions. A motion capture system (Vicon 612, Oxford, UK) was utilized to capture heel kinematics at 120 Hz.

Subjects first performed a normal walking trial in which the data was recorded for synergy extraction. After the normal walking trials, without informing the subjects of a change in walkway condition, a slippery solution (75% glycerol, 25% water) was applied to the surface and a "slip trial" was recorded. The peak heel velocity (PHV) of each subject was used as representative of slip severity: Persons with a PHV higher than 1.44 m/s were considered severe slippers [4].

EMG signals were processed (demeaned, rectified, filtered) for the walking trial according to the procedures in [5]. The gait duration was then normalized to 100 points (0 being right heel strike) and a matrix factorization technique was used to extract four walking synergies and their coefficients from the normalized gate cycle for each subject [5]. Muscle synergies of each severity group were then sorted and ordered according to their similarity using correlation coefficients (*r*) [5]. An independent *t*-test (α=0.05) was used (SPSS v21, IBM, Chicago, IL) to detect the significant differences in gain coefficient and muscle activation levels between mild and severe slippers' synergies.

RESULTS AND DISCUSSION

PHV measurement classified twelve subjects as mild slippers. No significant differences were found in sex, height, mass, and age across severity levels. Statistical analysis revealed significant differences in both walking synergies and their activation coefficients (Fig.1). Significant differences in gains of three muscles were found. *MH_S* and *VL_NS* activation were significantly higher for mild slippers while *TA_S* activation was significantly higher in severe slippers (Fig. 1, W1 and W3). The inter-group comparison also found differences in activation of the first and the third walking synergies (Fig. 1, C1 and C3). The first synergy coefficient 'C1', was statistically different between mild and severe slippers from 10^{th} until 18^{th} percent (Fig.1) of the gait cycle (Table 1). Also, the activation coefficient of the third muscle synergy, 'C3', was found to be different for the two groups from 37^{th} percent to 46^{th} percent (Fig. 1) of the gait cycle (Table 1).

Table 1 Significant differences according to the *t*-test

Variable		p-value	Variable		p-value
W1	VL_NS	0.003	C1	18th	0.043
W3	MH_S	0.010	C3	37th	0.019
	TA_S	0.009		38th	0.008
C1	10th	0.037		39th	0.007
	11th	0.015		40th	0.029
	12th	0.011		41st	0.023
	13th	0.008		42nd	0.019
	14th	0.008		43rd	0.012
	15th	0.012		44th	0.010
	16th	0.025		45th	0.023
	17th	0.026		46th	0.033

According to the results, it can be argued that a higher activation of the *MH* muscle right before the heel strike is associated with less severe slips. This point can be seen in both higher contribution of *MH_S* in the third synergy (W3), and in its higher activation coefficient (C3), right before the *S* limb's heel strike (which happens at 50%). Hamstring muscle is known to be involved in deceleration of the swing leg in terminal swing phase [6], hence, contributing to less slip severity.

Moreover, the results suggest that a higher activation of the *VL* muscle right after the heel strike is associated with less severity in slips. This conclusion was made upon observation of a higher contribution of *VL_NS* in W1 along with a higher activation in C1, right after the *NS* limb's heel strike (which happens at 0%, Fig. 1). Considering the role of *VL* in load acceptance, this conclusion stays consistent with existing studies claiming that a late activation of the *VL* may reduce the forward velocity of the center of mass relative to the base of support, resulting in less stability [7].

The results also revealed an association between higher activation of the *TA* muscle before the heel strike and high slip severity. *TA_S* muscle has both a higher contribution in the third muscle synergy (W3) and a higher activation coefficient (C3) before the *S* limb's heel strike (at 50%). High activation of TA may increase the foot-floor-angle (FFA) which is known to be associated with severe slips [3]. To verify that, using our markers data we calculate the FFA for both mild and severe slippers and found that FFA at heel strike was significantly lower for mild slippers from 25th to 49th percent of the gait ($p<0.05$). It is also known that a zero FFA (i.e. flat-foot walking) is a strategy used by individuals to increase dynamic stability of the gait [8] that substantiates our findings.

CONCLUSION

Our study investigated the walking differences between mild and severe slippers using a muscle synergy approach. We found that mild slippers and severe slippers have different muscle contributions and activation pattern in their normal walking muscle synergies. The findings of this study may have identified underlying gait control patterns that influence slip risk. Future studies would assess the efficacy of these methods in identification severe slippers and developing strategies that modify their gait control.

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Figure 1 Walking muscle synergies and their coefficients (averaged) for each severity group. Error bars indicate Standard Error. Asterisks indicate significant differences. (Right/NS heel strike at 0%, Left/S heel strike at 50% (dashed line))