

EFFECTS OF PLANTARFLEXOR MUSCLE FATIGUE ON GAIT CHARACTERISTICS

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INTRODUCTION

Injuries and fatalities related to slips, trips, and falls continue to be prevalent in several occupational environments. A number of previous studies have found that localized muscle fatigue (LMF) can lead to gait changes that can increase the risk of slips and falls. For example, knee extensor fatigue increased the required coefficient of friction (RCOF) and heel contact velocity (HCV), both indicators of higher slip risk [1].

Among the lower extremity muscles, the ankle musculature plays an important role in human locomotion and maintaining standing balance [2]. Yet, changes in biomechanical gait parameters associated with ankle muscle fatigue, and its relationship to slip- and trip-induced fall accidents, have not been reported previously to our knowledge. Therefore, the primary objective of the current study was to investigate the effects of ankle fatigue on gait characteristics. It was hypothesized that LMF of the ankle would affect both kinematic and kinetic variables in a way that potentially leads to higher risks of slip- and trip-induced falls.

METHODS

Fifteen healthy young adults (9 males and 6 females), with no self-reported musculoskeletal disorders, completed the experiment after giving informed consent (procedures were approved by the Virginia Tech IRB). Participant mean (SD) age, stature, and body mass were 36.9 (11.6) yr, 176.9 (7.4) cm, and 73.7 (14.3) kg, respectively. Each participant performed walking trials, both prior to and after inducement of fatigue, on a linear walkway (15.5×1.5m) embedded with two force platforms. A 6-camera system (ProReflex, Qualysis) was used to monitor segmental kinematics, using passive markers placed on bony landmarks.

Prior to the walking trials, maximum voluntary isokinetic exertions (MVE) were obtained during bilateral ankle plantarflexion, using a commercial dynamometer (Biodex System 3 Pro). Isokinetic MVE was defined as the maximum concentric, plantarflexion torque produced during 3 trials performed at 60°/sec. Participants were seated on the Biodex chair in a recumbent position with the knee in 90° of flexion and the feet secured to a plate attached to the dynamometer. Participants' thigh and pelvis were immobilized using Velcro straps. After MVE testing, participants were instructed to walk at their self-preferred pace on the walking track, and gait characteristics were assessed in the middle portion (5 m) of this walkway. Trials were repeated until three "good" trials were obtained (i.e., each foot contacted one force platform sequentially)

Ankle fatigue exercises were performed using the same attachment and with the dynamometer in isotonic mode and set to 70% of initial plantar flexion MVE. Participants repeatedly performed isotonic contractions at 22 rep/min. They were considered fatigued when their isokinetic MVE after exercise (measured each 5 min) fell below 70% of initial isokinetic MVE. Similar to the pre-fatigue walking trials, three good walking trials were collected after the fatiguing exercise.

Diverse measures were used to characterize gait and slip and trip risk, specifically: step length (SL), walking velocity (WV), RCOF, HCV, and minimum toe clearance (MTC). All parameters were calculated using methods from former studies [3,4].

Separate analyses of covariance (ANCOVAs) were performed to assess the effects of ankle fatigue status (FS: pre- and post-fatigue) on each gait parameter. Gender was included as a blocking effect, and WV was included as a continuous covariate. All statistical analyses were conducted using JMP Pro 11 (SAS Institute Inc., Cary, NC), and statistical significance was determined when $p < 0.05$.

RESULTS AND DISCUSSION

A summary of ANCOVA results is given in Table 1. FS significantly increased both SL and HCV, by ~2.1% and 24.2%, respectively, while MTC decreased (~17.1%). Although RCOF increased by ~1.7% post-fatigue, this difference was not significant. However, RCOF showed significantly more dependence on WV pre- vs. post-fatigue (Figure 1).

Table 1: Summary of ANCOVA results for the main and interaction effects of Gender (G), Fatigue Status (FS), and Walking Velocity (WV) on several gait parameters. F (p) values are presented, with significant effects highlighted in bold font.

DV	G	FS	WV	G×FS	G×WV	FS×WV
SL	5.88 (0.032)	4.57 (0.035)	4.17 (0.044)	0.20 (0.67)	0.02 (0.88)	3.18 (0.079)
RCOF	1.15 (0.30)	1.43 (0.24)	0.49 (0.49)	0.09 (0.77)	0.00 (0.95)	4.68 (0.034)
HCV	3.87 (0.081)	5.35 (0.023)	0.39 (0.54)	2.60 (0.11)	0.40 (0.53)	0.46 (0.50)
MTC	1.23 (0.29)	15.51 (0.000)	0.29 (0.59)	0.18 (0.67)	2.47 (0.12)	0.73 (0.40)

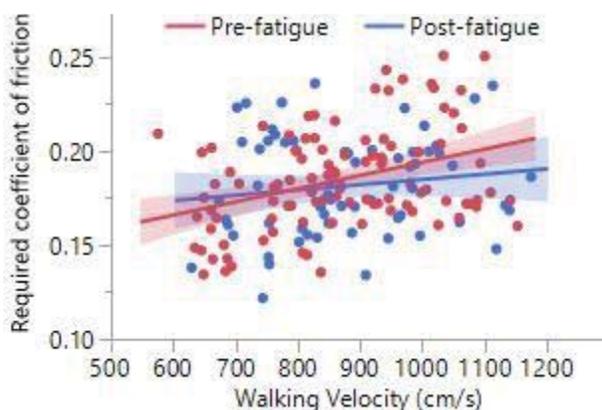


Figure 1: Interaction effect of FS×WV on RCOF.

Previous studies have shown mixed outcomes regarding the effects of LMF on HCV and RCOF, likely due to differences in the fatigue protocols used. For example, Lew and Qu [5] did not find a significant difference in RCOF, though did observe lower HCV after fatiguing a combination of lower extremity joints. However, Parijat and Lockhart [1] reported higher RCOF and HCV due to LMF of the knee extensors. Similarly, we found higher RCOF (~1.7%) and HCV (~24.2%) after LMF of the ankle plantarflexors, potentially indicating a higher risk of slip initiation after fatigue. Differences in earlier

work may also be related to the incorporation of different postural control strategies with different fatigue protocols, specifically in response to single-joint versus multi-joint fatigue. In multi-joint fatigue, participants may perceive the fatigue more substantially, and subsequently adopt a “cautious” postural control strategy to control HCV and reduce the likelihood of slip initiation. Such a strategy was not apparent after single-joint muscle fatigue here.

SL also has an important effect on slip potential; with a larger SL, the ratio of shear to normal forces at heel contact increases, which may increase the risk of a slip and fall [6]. Here, SL significantly increased (~2.1%), indicating the potential for some increased risk of slip after ankle plantarflexor fatigue.

MTC is an important parameter related to the risk of trips. The time at MTC is considered hazardous, since most of the trips occurs at this point [7]. Similar to the earlier study by Parijat and Lockhart [1], we observed substantially lower MTC (~17.1%) after ankle fatigue, suggesting a higher risk of tripping due to the LMF of ankle muscles.

Overall, LMF of the ankle plantarflexor muscles appears to increase the risk of slips and trips, as reflected by adverse impacts on important gait parameters (RCOF, HCV, SL, and MTC). These results extend existing knowledge about the effects of LMF in different body regions on gait and the risk of slips/trips, and suggest that the mechanisms and magnitude of LMF effects may be specific to the area(s) fatigued. Future research is still needed to develop specific guidelines to help control slip/trip/fall risks related to LMF.

ACKNOWLEDGEMENT

This research was supported by the CDC/NIOSH (R01 OH009222).

REFERENCES

- Parijat, P. and T.E. Lockhart, *Gait & Posture*, 2008. **28**(4): p. 568-73.
- Laughton, C.A., et al., *Gait & Posture*, 2003. **18**(2): p. 101-108.
- Perkins, P., American Society of Testing and Materials: Special Technical Publication, 1978. **649**: p. 71-87.
- Lockhart, T.E., J.C. Woldstad, and J.L. Smith, *Ergonomics*, 2003. **46**(12): p. 1136-1160.
- Lew, F.L. and X. Qu, *Journal of Biomechanics*, 2014. **47**(1): p. 59-64.
- Redfern, M., et al., *Ergonomics*, 2001. **44**(13): p. 1138-1166.
- Winter, D.A., *Physical Therapy*, 1992. **72**(1): p. 45-53.