RECOVERY FROM POSTURAL PERTURBATIONS WITHOUT STEPPING FOLLOWING LOCALIZED MUSCLE FATIGUE

[1] Bradley Davidson, [2]Michael Madigan, [2]Maury Nussbaum, and [3]Laura Wojcik
[1]University of Colorado Denver, [2]Virginia Tech, [3]Packer Engineering
email: bradley.davidson@ucdenver.edu

INTRODUCTION

Falls from heights continue to be problematic, recently accounting for 14.2% of reported occupational fatalities in the US [1]. Several investigations have demonstrated changes in postural sway following localized muscle fatigue (LMF) [2,3]. Since a link between increased postural sway and falling has been established (albeit among older adults) [4], these findings may indicate that LMF contributes to the risk of falling. Quiet standing is a relatively easy task for most individuals, and workplace related falls may be precipitated by postural perturbations. Wilson et al. [5] reported a LMF-induced shift in strategy during a perturbation; however, this is not indicative of changes in ability to recover with LMF. Therefore, the goal of this investigation was to assess the effects of LMF on measures of balance recovery (BR) following a postural perturbation. Both young and older adults were included, and two different muscle groups were fatigued. We hypothesized that LMF would increase center of mass (COM)-based variables and would decrease the maximum perturbation that could be withstood without stepping.

METHODS

Thirty-two participants were recruited including 16 young (19.4±1.4 years) and 16 older adults (62.2±5.1 years). Participants performed two sessions, separated by one week, during which they underwent a series of postural perturbations before and after LMF. In one session the ankle plantar flexors were fatigued; in the other session the lumbar extensors were fatigued [6]. Perturbations were administered with 13 kg padded pendulums (Figure 1) and perturbation magnitude was defined as the linear momentum just before impact. Each series of perturbations consisted of equal numbers of randomly-ordered anterior directed (AD) and posterior directed (PD) perturbations. Only results for AD perturbations are reported here.

Figure 1: Pendulums positioned in the front and back of the participant.

The experiment began with an initial series of 20 perturbations (10 N·s AD, 7 N·s PD) to allow any adaptation in BR to occur prior to investigating the effects of LMF. Next, a series of increasing magnitude AD and PD perturbations beginning at 6 N·s and 5 N·s, respectively, were applied. Following a successful recovery without stepping, the magnitude was increased by 2 N·s for AD and 1 N·s for PD perturbations. If a step occurred, the same magnitude was repeated. If two stepping responses occurred for a given magnitude, the previous magnitude was recorded as the maximum perturbation withstood without stepping. Sixteen constant-magnitude perturbations were then administered at 4 N·s and 2 N·s below the maximum AD and PD perturbations, respectively, and used to investigate the effects of fatigue and age on COM kinematics.

Positions of 16 anatomical markers were sampled at 100 Hz and low-pass filtered at 5 Hz. An anthropometrically correct six-segment kinematic model (feet, shanks, thighs, pelvis, torso/arms, and head) was used to approximate the COM trajectory. Measures of BR included the maximum perturbation that could be withstood without stepping, and descriptors of the COM trajectory including peak displacement relative to initial position, time-to-peak displacement, peak AD velocity, time-to-peak velocity, minimum time-to-boundary, and time-to-return to within 20% of peak displacement. COM-based displacement measures were normalized by ankle-to-toe length and velocity measures were normalized by multiplying by participant mass to account for inertial effects.

A repeated measures analysis of variance was used to examine the effects of fatigue (unfatigued, fatigued), muscle (ankle plantar flexor, lumbar extensor), and age (young, older) on BR measures. Covariates included perturbation magnitude and COM kinematics at the instant of pendulum contact. Effect size was quantified using Hedge's *g*.

RESULTS AND DISCUSSION

Statistical tests revealed no interactive effects, and no effects of muscle group for any of the dependent variables. Four of the six COM-based measures were affected by LMF including a 2.7% increase in peak COM displacement (*p*<0.001, Hedge's *g*=0.32), a 4.1% increase in time-to-peak COM peak displacement (*p*<0.001, *g*=0.47), a 0.6% increase in peak COM velocity (*p*=0.011, *g*=0.22), and a 3.5% increase in time-to-return within 20% of peak COM displacement (*p*=0.002, *g*=0.28). The maximum perturbation that could be withstood without stepping decreased 3.6% and exhibited a moderate effect size (*g*=0.43), but did not reach statistical significance (*p*=0.086).

The maximum perturbation that could be withstood without stepping was 17.8% lower among the older adults (*p*=0.029, *g*=0.57). Older adults exhibited an 8.6% higher peak COM velocity (*p*=0.006, *g*=0.31) and a 4.6% lower time-to-peak COM velocity (*p*=0.042, *g*=0.23).

Overall, our results showed that COM excursion during BR increased after LMF. COM-based measures exhibited greater excursions with LMF. Both peak COM displacement and time-to-return within 20% of the peak displacement indicated that the perturbed COM not only moved closer to the base-of-support boundary, but was displaced for a longer period of time following LMF. Increases in the peak COM velocity and time-to-peak COM displacement corresponded with an increase in peak angular momentum and a delay in reversing the direction of momentum, respectively. When considered together, these changes imply a greater likelihood of stepping and possibly a decrease in the ability to recover without stepping. Consistent with this interpretation, the maximum perturbation that could be withstood without stepping tended to decrease with LMF (effect size *g*=0.47). However, the increment in perturbation magnitude used to identify this maximum perturbation may have, in retrospect, been too large to detect small effects of LMF.

In summary, the results indicate that LMF impaired BR in both age groups in a similar manner. These changes occurred during submaximal perturbations, and may imply a higher likelihood of requiring an alternate strategy (such as stepping) with slightly larger perturbations.

REFERENCES

1. BLS. Report from US Dept of Labor , 2005
2. Corbeil P, et al. *Gait Posture* **18**, 92-100, 2003.
3. Lundin T, et al. *J Appl Biomech* **9**, 191-201, 1993.
4. Maki B, et al. *J Gerontol* **49,** M72-84, 1994.
5. Wilson E, et al. *Gait Posture* **23**:348-354, 2006.
6. Davidson B, et al. *Gait Posture* **29**, 552-557, 2009.

ACKNOWLEDGEMENT

This research was supported by R01 OH07882-02.

Table 1: Least squares mean ± SE for each measure categorized by fatigue level and age group.

Balance Recovery Measure	Young		Older	
	unfatigued	fatigued	unfatigued	fatigued
max. perturbation magnitude (N·s) †	7.41±0.14	7.38±0.14	6.31±0.14	5.88±0.14
peak displacement (%) *	26.1±0.3	26.6±0.3	25.2±0.3	25.9±0.3
time-to peak displacement (msec) *	591.0±7.9	608.4±8.4	538.1±8.5	567.2±8.1
peak velocity (N·s) ***,†**	16.57±0.08	16.65±0.08	17.96±0.08	18.09±0.08
time-to peak velocity (msec) †	145.8±0.8	146.7±0.9	139.5±0.9	139.5±0.8
min. time-to-boundary (msec)	572.3±10.2	57.09±10.7	587.9±10.5	585.6±9.9
return to 20% (msec) *	1336±27	1334±28	1295±29	1369±28

* significant effect of fatigue, † significant effect of age