ISB 2013 BRAZIL
24th CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS

EFFECTS OF UNILATERAL LEG MUSCLE FATIGUE ON GAIT STABILITY IN ELDERLY

[1]Jaap van Dieën, [1]Marcel Toebes, [2]Joost Dekker and [1]Marco Hoozemans
[1]MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, the Netherlands
[2] EMGO+, Department of Rehabilitation Medicine, VU University Medical Center, the Netherlands;
email: j.van.dieen@vu.nl, web: www.move.vu.nl

SUMMARY

Balance corrections made by the stance leg may be important for gait stability and may be limited by muscle strength. To test this assumption, we studied effects of unilateral leg muscle fatigue on variability and local dynamic stability of unperturbed gait and on responses to small perturbations during stance and swing phases of the fatigued leg in ten healthy elderly.

No effects on unperturbed gait were found, while fatigue reduced initial resistance to perturbations in the stance phase only. Subsequent responses to perturbations were more effective in the fatigued condition, in particular for perturbations applied during the swing phase. Although muscle fatigue reduces the initial resistance against perturbations, slow gait in healthy elderly is quite robust against effects of muscle fatigue.

INTRODUCTION

Balance control in gait can be conceptualized as control of the center of pressure of the ground reaction force (CoP) relative to the extrapolated center of mass of the body (XCoM, a function of center of mass position and velocity) [1]. Foot placement is the main determinant of the relative CoP, and it is mainly controlled by modifying swing leg dynamics [2], which requires only low actuation torques. However, joint torques in the stance leg can, within the limitations determined by foot placement, modify the relative CoP. After major perturbations of gait, such as trips, stance leg responses involving fast development of high joint torques are crucial [3,4] and consequently muscle strength is a limiting factor in balance recovery [5]. Surprisingly, local dynamic stability of unperturbed gait is also associated with muscle strength [6,7]. This may suggest that balance corrections made by the stance leg, as reflected in CoP movements that correct for ‘errors’ in foot placement [8], are important for gait stability and are limited by muscle strength. To test this assumption, we studied the effects of unilateral leg muscle fatigue on the variability and local dynamic stability of unperturbed gait, as well as on the responses to small perturbations during the stance and swing phases of the fatigued leg.

METHODS

10 healthy elderly subjects (N_{male}=4, age 63.4 (SD 5.5) years) participated. Trunk and feet kinematics of 300 s of unperturbed and 900 s of perturbed treadmill walking at 3.0 km/h were collected as reference data. Perturbations were applied to the trunk, by pneumatic actuators which pulled the subject over a distance of ~8 cm laterally at the moment of contralateral heel contact (Figure 1). The fatiguing protocol consisted of 12 blocks of repetitive unilateral knee bending (0.25 Hz) until task failure, which were alternated by 100 seconds of treadmill walking (3 unperturbed and 9 perturbed trials).

The difference in voluntary maximal knee extensor torque at the beginning and end of the protocol was used to verify that muscle fatigue was present.

For unperturbed gait, the stride-to-stride variability of the medio-lateral velocity of the trunk center of mass was calculated at each instant of the stride cycle and averaged over the stance and swing phases of the fatigued leg (11-50 and 61-100% of the stride cycle). In addition, the Lyapunov exponent of the linear and angular trunk kinematics combined was estimated, to assess local dynamic stability [6,7,9,10].

For perturbed gait trials, the peak perturbation force was determined, as a measure of perturbation resistance. In addition, the deviation (of the kinematic state of the trunk) from normal walking at the first heel contact after the perturbation, expressed in standard deviations of the normal walking pattern, was calculated, as a measure of balance recovery [10].

Repeated measures ANOVA was used to test for differences between fatigued and unfatigued conditions and where applicable for differences between the stance and swing phases of the fatigued leg. Note that swing phase perturbations were in fact initiated during double support, but for clarity we will use the term swing phase throughout. In case of interactions, fatigue effects were compared between gait phases using paired t-tests.

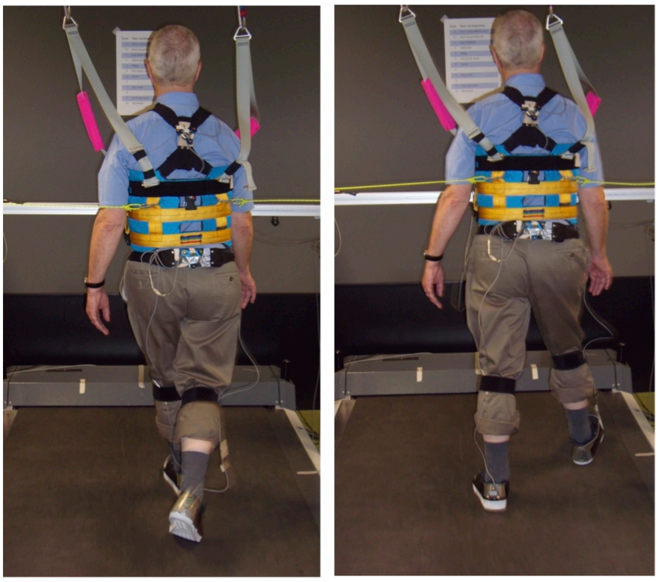

Figure 1: Photographs of a subject on the treadmill at onset of a perturbation and at the first heel contact after a perturbation to the right.

RESULTS AND DISCUSSION

The protocol caused substantial leg muscle fatigue, as evidenced by an average decrease in knee extensor torque of 17% ($p<0.001$).

In unperturbed gait, no effects of fatigue on the variability of medio-lateral trunk velocity were detected, not during the stance phase, nor during the swing phase of the fatigued leg ($p=0.35$). Similarly, local dynamic stability of trunk movement was not affected ($p=0.41$).

The results of this study thus indicate that measures of gait quality of unperturbed gait are not strongly affected by fatigue. This is possibly related to the substantial within-subject variance in measures of gait quality for unperturbed gait [11], indicating that relatively fit subjects can tolerate substantial variations in gait quality.

For gait perturbations, as expected in view of the position controlled perturbation device, the maximal deviation from normal walking was not different between the fatigued and unfatigued conditions. However, an interaction effect of fatigue and phase was found for the maximum perturbation force ($p = 0.020$). Compared to unfatigued walking, subjects were more easily perturbed in the stance phase of the fatigued leg, as evidenced by a 4% lower peak perturbation force ($p=0.005$), while fatigue had no effect on the initial resistance to the perturbation in the swing phase of the fatigued leg ($p=0.850$). These data thus indicate that fatigue reduces the initial resistance against perturbations occurring in the stance phase of the fatigued leg, while such an effect was not found for perturbations in the swing phase of the fatigued leg.

The deviation in kinematic state at the first heel contact after the perturbation was smaller in the fatigued than in the unfatigued conditions ($p=0.030$). The timing of first heel contact after the initiation of the perturbation was not affected by fatigue. These results thus indicate that fatigue enhanced the rate of recovery after perturbations. This effect is not likely due to learning, as the subjects had experienced many perturbations already prior to the unfatigued trials used here. Possibly, subjects were more alert and could hence respond more quickly to the perturbation effect in the fatigued condition [12]. The timing of heel contact did tend to be delayed after the perturbations in the stance phase of the fatigued leg ($p=0.087$, with $p=0.128$ for the interaction of fatigue and phase). The latter suggests that subjects benefited more from an enhanced recovery response with fatigue when they were standing on the unfatigued leg.

It should be noted that effects reported here may not solely be attributable to a decrease of force producing capacity of the leg musculature with fatigue. It is known that fatigue also impairs proprioception [13], which may negatively affect balance responses.

CONCLUSIONS

Overall, gait at low speed, in healthy older adults, was quite robust against unilateral leg muscle fatigue. Small perturbations during the stance phase of the fatigued leg were less effectively counteracted than perturbations applied in the unfatigued condition, or when applied during the swing phase of the fatigued leg. This finding supports the idea that initial responses in the stance leg to relatively mild perturbations of balance in gait may be limited by muscle strength. On the other hand muscle fatigue did not affect unperturbed gait and did not limit, but rather enhanced, subsequent corrective responses to these relatively mild balance perturbations, which suggests that muscle strength is not a limiting factor in balance maintenance during gait, when no major perturbations occur.

REFERENCES

1. Hof A. *Hum Mov Sci.* **27**:757-759, 2013.
2. van Dieën JH, et al., *J Biomech.* **40**:3641-3649, 2007.
3. Pijnappels M, et al., *J Biomech.* **37**:1811-1818, 2004.
4. Pijnappels M, et al., *J Biomech.* **38**:627-634, 2005.
5. Pijnappels M, et al., *Eur J Appl Physiol.* **102**:585-592, 2008.
6. Kang HG, Dingwell JB, *J Biomech*. **41**:2899-2905, 2008.
7. Toebes MJP, et al., submitted
8. Hof A. et al., *Gait Posture.* **25**:250-258, 2007.
9. Toebes MJP, et al., *Gait Posture.* **36**:527-531, 2012.
10. Bruijn SM. et al., *Exp Biol*. **213**:3945-3952, 2010.
11. Toebes MJP, et al., submitted
12. Lambourne K, Tomporowski P, *Brain Res.* **1341**:12-24, 2010.
13. Corbeil P, et al., *Gait Posture.* **18**:92-100, 2003.