Faster Speed Generates Larger Feedback Control for Gait Stability in the Anterior-Posterior Direction

Yang Geng[1], Jaap van Dieën[1], Sjoerd M. Bruijn[1]
[1]Department of Human Movement Sciences, Faculty of Behavioral and Movement Sciences, Amsterdam Movement Sciences, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands
Email: s.m.bruijn@vu.nl

Summary

This study examined the effect of gait speed on control of gait stability in the anterior-posterior direction. We found that as walking speed increased, estimated feedback delays decreased while position gains increased. The increased position gain indicates increased feedback involvement in fast walking, which presumably based on a dominant role of somatosensory feedback in high-speed locomotion.

Introduction

Gait stability requires control of the center of mass (COM) trajectory relative to the base of support. This is in part achieved by feedback based on sensory information [1]. However, it is unclear if, and how, this feedback control changes with walking speed, as the contributions from different sensory system showed opposite variations across speeds [2].

A recent tutorial provided a framework to assess feedback control in unperturbed walking by evaluating the relationship between preceding extrapolated center of mass and delayed ground reaction forces (GRFs) [3]. Using COM position and velocity, as independent predictors might be more accurate, and this has been shown effective to estimate feedback control in standing [4].

In this study, we applied the feedback model mentioned above [4] to walking, to investigate how walking speed changes feedback in gait stability control. In doing so, we focused on the anterior-posterior direction.

Methods

15 healthy young subjects (21 ± 4 yrs, 1.7 ± 0.1m, 63 ± 9kg; mean ± SD) participated in this study. Subjects walked on a treadmill at three different speeds: 2 km/h, 4.5 km/h, and 5.5 km/h, performed in a random order. Whole-body kinematics and ground reaction forces (GRFs) were recorded for 5 minutes after the participants had acclimated to the imposed walking speed.

Results and Discussion

The model fits ranged from $R^2 = 0.52$ to 0.81 across all speeds and all subjects, which indicates that the model can indeed be used to estimate feedback control of gait stability.

The estimated delays significantly decreased with increasing speed ($F_{2,28} = 11.7$, $p < 0.001$). During slow walking, the delay was 69% ± 7% of the gait cycle, which was significantly longer than in normal (64% ± 4%) and fast walking (61% ± 3%). Obviously, given shorter stride durations at higher speeds, also the absolute time lag decreased systematically as walking speed increased.

The estimated position gains significantly increased with increasing walking speed ($F_{2,28} = 9.4$, $p < 0.001$). The position gain in slow walking was the smallest, even smaller than the critical stiffness. The position gain during normal walking and fast walking, exceeded the critical stiffness by approximately 39% and 80%, respectively, while these differences were not statistically significant.

The estimated velocity gains remained consistent across walking speeds ($F_{2,28} = 0.03$, $p = 0.96$).

Our results show that the variations in GRFs during the stance phase can be predicted using information of the preceding COM position and velocity. The increased position gain suggests an increase in feedback control. Some studies reported decreased effects of vestibular and visual perturbations in the medio-lateral direction as gait speed increases [5, 6]. Therefore, the opposite results might be due to the control differences in anterior-posterior and medio-lateral directions. In addition, our results may reflect effects of somatosensory feedback, which appears to have larger contributions at higher speeds [2]. Also, passive contributions, related to collision forces at ground contact, to gait stability are likely speed dependent, but this cannot account for decreased relative delays.

Conclusions

Our results revealed a speed-dependent characteristic of gait stability control in the anterior-posterior direction. As walking speed increases, the estimated feedback delay decreased, while the position gain increased.

References

[1] Bauby, C.E. and A.D. Kuo. (2000) *J Biomech*, **33**: 1433-40.

[2] Akay, T. and A.J. Murray. (2021) *Int J Mol Sci*, **22** (3).

[3] van Dieen, J.H., S.M. Bruijn, and M. Afschrift. (2024) *J Electromyogr Kinesiol*, **78**:102915.

[4] Geng, Y., S.M. Bruijn, and J.H. van Dieen. (2024) *bioRxiv*.

[5] Jahn, K., et al.(2000) *Neuroreport,* **11**: 1745-8.

[6] Goodworth, A., et al. (2015) *Hum Mov Sci*, **42**: 15-26.