Sensorimotor transformations in perturbed walking

Maarten Afschrift
Department Mechanical Engineering
KU Leuven, Belgium
maarten.afschrift@kuleuven.be

Ilse Jonkers
Department of Movement Sciences
KU Leuven, Belgium
ilse.jonkers@kuleuven.be

Friedl De Groote
Department of Movement Sciences
KU Leuven, Belgium
friedl.degroote@kuleuven.be

I. Introduction

In response to perturbations during human movement, the nervous system processes sensory information to generate descending motor commands to activate muscle to control balance. In standing balance, this sensorimotor transformation can be described by delayed feedback of center of mass (COM) kinematics. Changes in muscle activity in response to a perturbation can be reconstructed with delayed feedback of COM kinematics [1]. This indicates that the nervous system integrates sensory information from multiple systems to derive relevant feedback information about the motor task.

In walking, it is unclear if task-level feedback of COM kinematics can also explain this sensorimotor transformation. In response to sagittal plane perturbations, humans mainly control balance by adjusting center of pressure location with the ankle moment [2]. This ankle strategy is however not included in current neuromechanical models of walking, that control balance using stepping strategies [3]. First, we showed that delayed feedback from COM kinematics can explain reactive muscle activity in publicly available datasets of perturbed walking. We used different perturbation modalities, support surface translations [4,5] and pelvis pushes [2], that excited the neuromechanical system in multiple ways. We then used the same datasets to identify the parameters of an additional supra-spinal feedback pathway in a neuromechanical model of walking [3].

II. Methods

COM position and velocity feedback gains (K_p, K_v) were estimated from the measured deviation in COM kinematics $(\Delta\, COM)$, joint moments (ΔT) and muscle activity (ΔEMG) by solving a least-squared regression. A neural delay of 100 ms was used for the joint moment (τ_T) and 70 ms for reactive muscle activity (τ_m).

$$\Delta T(t) = K_p \Delta COM(t-\tau_T) + K_v \Delta C\dot{O}M(t-\tau_T)$$
$$\Delta EMG(t) = K_p \Delta COM(t-\tau_m) + K_v \Delta C\dot{O}M(t-\tau_m)$$

The phase-dependent modulation of the feedback gains in the gait cycle was estimated from a dataset with discrete changes in belt speed at different instances in the gait cycle and from a dataset with continuous changes in belt speed [5].

III. Resuls and Discussion

We found a strong correlation between delayed COM kinematics and the change in ankle joint moment in response to surface and pelvis push perturbations (R^2 = 0.81, Fig. A). A similar correlation was found for reactive activity of the muscles around the ankle joint (soleus: R^2 = 0.39 and tibialis anterior: R^2 = 0.50), which shows that this is at least a partially active control mechanism. In addition, we found that the COM based feedback gains are modulated during the gait cycle (Fig. B) and with gait speed.

Incorporating COM feedback as an additional feedback loop in a model of walking [3] improved the simulation of the ankle moment in response to a support surface perturbation (Fig. C). We believe that integrating this additional feedback loop in the control of exoskeletons [6] or protheses will improve balance of the user.

References

[1] Welch, T. D. J. et al. J Neurophysiol 99, 1032–1038 (2007)
[2] Vlutters, M. et al. Sci. Rep. 8, 14621 (2018)
[3] Geyer, H. et al. IEEE Neural Syst. Rehabil. Eng. 18, 263–73 (2010)
[4] Moore, J. K. et al. PeerJ 3, e918 (2015)
[5] Afschrift, M. et al. Gait Posture 68, 575–582 (2019)
[6] Wu, A. R. et al. Front. Neurorobot 11, 1-14 (2017)

We acknowledge FWO fellowship: 12ZP120N