Sensorimotor control of upright balance in walking

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I. Introduction

Humans must continuously regulate upright posture during walking to prevent loss of balance and falls. Controlling upright posture requires using different sensory systems to estimate the movement state of the body in space, detect deviations from the upright, and generate force against the ground to accelerate the body in a way that counters these deviations. This sensorimotor control loop is strongly nonlinear due to the gait cycle, since the effect of any particular muscle activation on the movement of the body is vastly different depending, e.g., on whether the relevant leg is in swing or in stance.

We use sensory perturbations to probe this sensorimotor control loop during walking. We provide artificial fall stimuli to induce the sensation of a lateral fall, targeting either the visual system by modifying the optical flow of a virtual reality environment [1], or the vestibular system using galvanic vestibular stimulation [2].

II. Results

We found evidence that humans actively modulate foot placement at each step for balance control to change the gravitational acceleration on the body, as previously discussed and predicted by robotics and human motor control studies [3], [4]. We also confirmed the hypothesis that humans use lateral ankle musculature along the stance leg during single stance to actively pull the body mass sideways. In addition to these two expected responses, we discovered a third mechanism for balance control, where humans modulate the plantar-dorsiflexion angle of the trailing leg to shift weight between the two stance legs during double stance.

Here we present results from a series of experiment showing that these observed changes in muscle activation, kinetics and kinematics correspond to three separate biomechanical mechanisms, and that the neural controller coordinates the activation of these three mechanisms throughout the gait cycle to create a unified balance response to accelerate the body based on the available sensory information. We show that the neural controller can flexibly shift response to fall stimuli to different mechanisms, depending on the time of perturbation during the gait cycle [2]. Differences in the timing of the gait cycle have a large effect on the relative magnitude with which each mechanism is used [5]. Differences in the stimulus amplitude, on the other hand, have similar but very small effects on each balance mechanism, while the combined effect on the whole body is comparatively large. When adding a secondary, more cognitive task in the form of a no-step zone on the ground, subjects show increased response magnitude for fall stimuli in the direction of the prohibited area.

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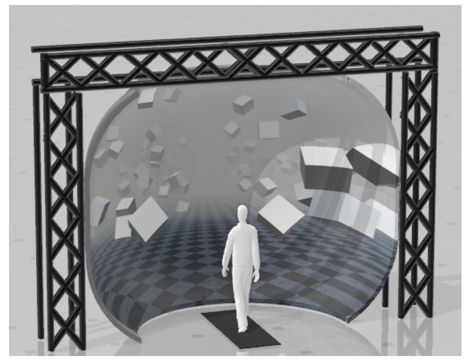

Fig. 1. Virtual Reality Walking Environment

III. Conclusions

These combined results are evidence for a dedicated neural control system that uses information from all relevant sensory systems to monitor the state of the body in space and modulate the rhythmic pattern of muscle activation in a precise, goal-oriented way to regulate upright balance during walking, and can be adapted to specific task constraints.

References

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