DYNAMIC STABILITY OF WALKING DURING ANTERIOR-POSTERIOR AND MEDIO-LATERAL SUPPORT SURFACE AND VISUAL FIELD TRANSLATIONS

Patricia M. McAndrew, Jonathan B. Dingwell, Jason M. Wilken

INTRODUCTION

Improving the ability to react to perturbations during daily activities like walking is a key to effective fall prevention training. Quantifying how walking stability changes in response to destabilizing events is critical for assessing how effective gait training interventions are. When small perturbations of increasing amplitude were applied to a dynamic model of walking, the model did not become orbitally more unstable, but did become locally more unstable [1]. In humans, healthy elderly were both orbitally and locally more unstable than healthy young adult subjects during unperturbed walking [2]. However, changes in orbital and local stability have not been assessed in humans during perturbed walking.

Virtual reality (VR) environments such as the Computer Assisted Rehabilitation ENvironment (CAREN) system (Fig. 1) provide a unique opportunity to understand how humans control gait stability. In such a system, we can apply well-controlled and repeatable visual and mechanical perturbations during gait. This study determined how continuous pseudo-random horizontal oscillations of the walking surface and visual field affected (local and orbital) dynamic gait stability.

METHODS

Twelve young healthy subjects participated with informed consent. Each subject completed five 3-min walking trials in the CAREN under each of 5 conditions: no perturbations (NOP), anterior-posterior platform (APP) or visual (APV) translations or mediolateral platform (MLP) or visual (MLV) translations. All translations were applied as a pseudo-random sum of sines with incommensurate frequencies of 0.16, 0.21, 0.24 and 0.49 Hz. Kinematic data for the head, trunk, pelvis and feet were collected using Vicon at 60 Hz.

Motions of a single marker placed on the seventh cervical (C7) vertebra were analyzed. Power spectral analyses confirmed that subjects responded to the applied perturbations [3].

Fig. 1. The CAREN is an immersive VR system with a six degree of freedom platform with a built-in instrumented treadmill.

To quantify stability, maximum Floquet multipliers (FM) and short-term ($\lambda*$) and long-term ($\lambda^*$) local divergence exponents were calculated using standard techniques. State-spaces were generated using 3-D velocities and accelerations of the C7 marker. Maximum FM defines the amount by which small perturbations away from the mean reference trajectory grow or decay after one cycle. If the maximum FM has magnitude < 1, perturbations decay after successive strides, and the system is orbitally stable. Smaller FM indicate greater stability. Local divergence exponents quantify sensitivity to small perturbations in real time with larger values indicating increased instability. The results were analyzed using 2-factor ANOVA.
RESULTS AND DISCUSSION

The applied perturbations significantly altered each subjects’ kinematics [3]. Conversely, subjects remained orbitally stable throughout the gait cycle for all experimental conditions. Maximum FM magnitudes did not increase significantly (p \geq 0.104; Fig. 2) for any perturbation condition. \( \lambda^* \) indicated increased local instability (\( \lambda > 0 \)) during experimental conditions while \( \lambda^* \) indicated no changes in long-term local instability (Fig. 3). These results confirm previous modeling predictions [1].

Fig. 2. Summary of average maximum FM by condition. Blue markers indicate AP perturbation conditions, red markers indicate ML perturbation conditions and the black marker indications the no perturbation condition. Note that all values are <1, indicating that subjects remained stable for all experimental conditions.

Even with substantial perturbations, subjects still maintained orbitally stable gait for all conditions. FMs theoretically reflect the inherent stability of the system, which should not depend strongly on the specifics of the perturbations applied [1] and this was reflected in these stable FM values.

Interestingly, there was a trend for subjects to be slightly less orbitally and locally stable during platform translations in the AP direction, whereas subjects were slightly less orbitally and locally stable during visual field translations in the ML direction.

CONCLUSIONS

Our results indicate that inducing greater movement, and thus greater movement variability [3] does not necessarily induce greater orbital instability (Fig. 2) but does induce greater local instability (Fig. 3). What the FMs do not reflect is how people achieved stability, and while these FM appear to represent overall gait “stability”, they may not in fact be sensitive enough to predict risk of falling. Despite no changes in orbital stability, subjects exhibited short-term local instability for all experimental conditions. This is consistent with the modeling results of Su and Dingwell [1].

ACKNOWLEDGEMENTS

Support provided by the Military Amputee Research Program (to JMW) and by National Institutes of Health Grant 1-R21-EB007638-01A1 (to JBD).

REFERENCE

