

Direction-Dependent Weighting of Walking Balance

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SUMMARY

While walking has previously been described as controlled “falling”, computational models suggest that the fore-aft dynamics may be self-stabilizing, whereas lateral motion remains unstable and requires active control. Humans might then rely less on vision for antero-posterior (A-P) balance than mediolateral (M-L). We tested whether healthy humans ($N = 10$) exhibit such direction-dependent control by applying low-frequency perturbations to the visual field through a projected virtual hallway and measuring foot placement during treadmill walking. We found step variability to be nearly ten times more sensitive to ML perturbations than AP. This direction-dependent sensitivity suggests that the central nervous system may gain stability in the AP direction through an uncontrolled series of falls.

INTRODUCTION

Three-dimensional walking models indicate that the fore-aft component of walking may be passively stable from step to step, whereas the lateral motion remains unstable and requires control, as through active foot placement. Humans might then rely less on integrative sensory feedback, such as vision, for antero-posterior (A-P) balance than mediolateral (M-L). We used a virtual reality environment to test whether perturbations added to the visual field in either the M-L or A-P directions would have a differential impact on the variability of foot placement during walking.

METHODS

Ten healthy subjects (aged 24.3 ± 4.1 yrs., mean \pm s.d.) provided consent and participated in this study. Subjects walked at 1.25 m/s on an instrumented force treadmill and received visual information through a wide field-of-view virtual reality display. The visual field consisted of movement through a virtual dark hallway tiled with randomly placed white rectangles (Warren 1996). After a training period, subjects were exposed to continuous 0.25 Hz perturbations of the visual flow in the M-L and A-P directions at amplitudes of 0, 0.05, 0.15, 0.25, and 0.35m. The effect of the perturbations was assessed by measuring root-mean-square (RMS) variability in step length and step width recorded from individual limb COP estimated at mid-step over at least 300 steps.

RESULTS AND DISCUSSION

To test whether oscillations added to the visual field in either the M-L or A-P directions would have a differential impact on the variability of foot placement we calculated the slopes of the step placement variability vs oscillation amplitude trends (Figure 1).

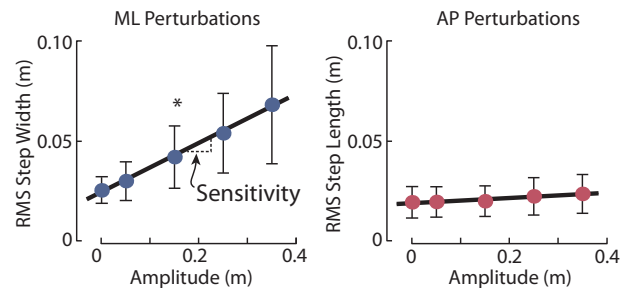


Figure 1: Comparison of M-L and A-P visual perturbations with increasing amplitude on step width and step length variability.

We found step variability to be nearly ten times more sensitive to ML perturbations than AP. Root-mean-square step width variability increased approximately linearly with ML perturbation amplitude ($R^2 = 0.81$, $P = 5.7e-4$), with the slope defining the ML sensitivity, which was 9.4 times the AP sensitivity ($P = 0.0005$, ANCOVA). This result indicates that visual information pertaining to side-to-side movement may be more useful for controlling balance during walking than information about fore-aft movement. This trend persisted even when the average forward motion through the hallway was removed, suggesting that bulk optic flow associated with forward movement cannot account for the low A-P sensitivity.

To verify that this M-L sensitivity is due to walking dynamics rather than the effect of the virtual environment or the amount of visual information contained in the M-L or A-P directions, similar perturbations were applied during quiet standing. We expected standing to be actively controlled in all directions, but less so in directions with large base of support (BOS). We measured variability of center of pressure as an indicator of active control, and found normal standing to have a reversed direction dependence compared to walking. The AP sensitivity was 2.3 times greater than ML ($P = 0.039$), suggesting that the low AP sensitivity of walking was not simply due to physiological limitations of visual processing. Tandem (heel-to-toe) standing yielded ML sensitivity 3.0 times greater than AP ($P = 0.005$), suggesting that the BOS indeed influences the degree of instability.

REFERENCES

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