INTRODUCTION

The purpose of this study was to determine how trans-tibial amputation alters the ability to respond to small-amplitude continuous visual or mechanical perturbations during walking. Vision is crucial for maintaining balance during walking. So is somatosensory feedback, which is severely disrupted in patients with amputation [1]. However, to date there are no data defining how these patients use visual and/or somatosensory information to walk. Here, healthy individuals’ responses were compared to unilateral trans-tibial amputee patients’ responses during continuous mediolateral perturbations of the walking surface or visual field. This is the first study to determine how amputation affects global and local dynamic stability during exposure to external perturbations while walking.

METHODS

Thirteen healthy individuals (24.8±6.9yrs) and nine patients (30.7±6.8yrs) with a unilateral trans-tibial amputation provided written informed consent prior to participation. All subjects walked on a 2m x 3m treadmill embedded in a 4m dia. moveable platform in a Computer Assisted Rehabilitation Environment (CAREN) virtual reality system (Motek, Amsterdam, Netherlands). Subjects’ movements were tracked using 24 Vicon motion analysis cameras (Vicon, Oxford, UK).

Participants completed a 6-min warm-up followed by five 3-min trials under each of the following test conditions: no perturbation (NP), platform (PLAT) or visual field (VIS) perturbations. The order of the perturbation trials was randomized. All perturbations were applied as pseudo-random translations in the mediolateral direction [2,3]. The perturbation amplitudes used here were based on those used previously [3].

Orbital stability (maxFM) quantifies how purely periodic systems respond to perturbations discretely from one cycle to the next [2,4]. Local stability ($\lambda_s^\ast$) quantifies how the system responds to very small perturbations continuously in real time [2,5]. $\lambda_s^\ast > 0$ indicate instability. MaxFM > 1 indicate instability. For both $\lambda_s^\ast$ and maxFM, larger values indicate greater sensitivity to perturbations. We calculated these exponents using previously published methods [2,4,5] using velocity trajectories of mediolateral C7 marker movements [2,4]. Both variables were calculated using a 5-dimensional delay-embedded state space [5] of C7 velocity with a time delay of $\tau=30$ samples. For both maxFM and $\lambda_s^\ast$, a 2-way mixed repeated measures MANOVA with condition as the within factor and group as the between factor was used to determine the main effects for NP, PLAT and VIS perturbation trials.

RESULTS AND DISCUSSION

Consistent with previous work [2], orbital and short-term local instability both increased for platform and visual perturbed walking compared to unperturbed walking. In the mediolateral direction, patients exhibited slightly decreased maxFM during PLAT ($p<0.001$) and slightly increased $\lambda_s^\ast$ during NP ($p<0.025$) compared to controls (Fig. 1). During VIS, patients exhibited slightly lesser $\lambda_s^\ast$ than controls ($p<0.014$) (Fig. 1). While these differences were statistically significant, they were relatively small in magnitude.
Figure 1: Dynamic walking stability (mean±SD) for NP, PLAT and VIS conditions. The * indicates a significant difference between control and patient. The + indicates that the perturbed condition is significantly different from the unperturbed condition for both groups. The # indicates a significant difference between PLAT and VIS for patients.

For comparison, kinematic variability measured using the mediolateral C7 marker velocity (Fig. 2) was greater for patients during both the NP (p<0.008) and PLAT (p<0.000). The C7 velocity variability was also significantly different between conditions for both patients and controls (p<0.000).

Due to the lack of distal somatosensory feedback, we anticipated that the patients would rely more heavily on the visual feedback and therefore be more variable and less stable during VIS. Patients were, however, more stable during VIS (λ∗s), and PLAT (maxFM) than controls and more stable (λ∗s) during the VIS than PLAT (p < 0.00). Variability results were not consistent with stability analyses with patients being more variable during the PLAT.

Although significant, the between-group differences for all measures were quite small and not likely of functional relevance. The inconsistent results may be the product of a young, highly active and otherwise healthy population. This may be one reason we did not see larger differences in their dynamic stability during walking. The differing results for stability and variability measures further suggest that these measures do not quantify the same physiologic phenomenon.

CONCLUSIONS
Young, active patients with unilateral trans-tibial amputation were no less stable, locally or orbitally, than the controls when being mechanically or visually perturbed.

REFERENCES

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