

IMPROVING DYNAMIC STABILITY DURING THE COMPENSATORY STEPPING RESPONSE OF A TRANSFEMORAL AMPUTEE

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INTRODUCTION

Over one year, 66% of individuals with a transfemoral amputation (TFA) reported falling [1]. This high incidence of falls indicates a need for preventative interventions. For older adults, another population with a high incidence of falls, practicing a compensatory stepping response (CSR) has yielded beneficial results. After one training session, older adults improved recovery kinematics after a treadmill disturbance [2] and an overground trip [3]. To the best of our knowledge, CSR training has not been applied to individuals with a TFA.

We hypothesized that training would improve the CSR of a transfemoral, amputee subject by:

- decreasing the incidence of falls.
- limiting the use of a single-limb hopping strategy [4].
- increasing step length (L_{step}), decreasing step time (t_{step}), and decreasing trunk inclination angle (θ_{trunk}) at recovery step completion [2,3].
- increasing the anteroposterior (AP) margin of dynamic stability at foot strike (MOS_{AP}) [5].

METHODS

One female subject with a TFA (27 years, 165 cm, 62.5 kg, 3.5 years after traumatic TFA) and one female subject with intact limbs (21 years, 177 cm, 85.7 kg) participated in this study. The prosthesis consisted of a microprocessor knee (C-Leg®, Otto Bock, Minneapolis, MN) and a dynamic response foot. The amputee and non-amputee subjects participated in six and one days of CSR training, respectively.

The training protocol consisted of a progressively challenging sequence of CSR trials. For each trial, the subjects stood on a custom treadmill (Active Step™, Simbex, Lebanon, NH), and posteriorly-directed treadmill accelerations necessitated an anterior-directed CSR of multiple steps. The initial

belt accelerations lasted 0.5 sec, and ranged from 1.5 m/s² to 6.5 m/s². After the initial acceleration, the treadmill decelerated at a constant rate of -0.375 m/s². For small disturbances (≤ 2.25 m/s²), peak treadmill velocity was maintained so that the minimum belt displacement was 2 m.

The amputee subject performed two series of CSRs each day, once with the initial step with the non-prosthetic limb (NPL), and once with the initial step with the prosthetic limb (PL). The subject with no amputations performed one series of CSRs, stepping with the self-preferred limb. For all trials, three-dimensional position data were recorded by motion capture at 120 Hz. L_{step} , t_{step} , θ_{trunk} , and MOS_{AP} were calculated at foot strike of the first six steps following the disturbance. The equation for MOS_{AP} was modified from previous literature [5] to consider the treadmill belt velocity as follows:

$$MOS_{AP} = BOS_{AP} - \left(x_{COM} + \frac{(v_{COM} - v_{belt})}{\sqrt{\frac{g}{l}}} \right)$$

in which:

- BOS_{AP} : AP position of the base of support (toe marker) of the stepping foot
- x_{COM} , v_{COM} , and v_{belt} : AP position and velocity of the overall body center of mass and velocity of the treadmill belt, respectively.
- g : acceleration of gravity (9.81 m/s²)
- l : distance between the stepping ankle center to the body COM mass in the sagittal plane.

Trials of the amputee from the first and sixth day were compared to assess a training effect. Comparisons were made using disturbances common to both subjects and initial stepping limbs, i.e., those with an initial belt acceleration of 2.75-3.5 m/s².

RESULTS AND DISCUSSION

The CSRs of the amputee improved with training:

- The amputee fell on day 1 (initial acceleration of 4.5 m/s^2 , NPL initial step), but successfully recovered from the same disturbance on day 6.
- The amputee decreased the use of a hopping strategy from day 1 (5 of 25 trials) to day 6 (1 of 34 trials).
- MOS_{AP} improved with training, especially at the 2nd or 3rd step when performed with the PL (Figure 1).
 - 2nd step with PL
 - Day 1 = $-0.179 \pm 0.118 \text{ m}$
 - Day 6 = $-0.082 \pm 0.094 \text{ m}$
 - 3rd step with PL
 - Day 1 = $-0.220 \pm 0.147 \text{ m}$
 - Day 6 = $-0.049 \pm 0.021 \text{ m}$
- Improvements in MOS_{AP} coincided with increased L_{step} and decreased θ_{trunk} (Figure 1 & Table 1). These changes occurred without altering t_{step} .

Although the MOS_{AP} and kinematics of the trained amputee more closely approximated those of the non-amputee, the trained amputee demonstrated smaller MOS_{AP} after the 2nd step. This difference may be due to greater θ_{trunk} , despite greater L_{step} .

Table 1. Mean L_{step} and θ_{trunk} of the initial 3 steps.

	L_{step} (m)	θ_{trunk} (deg)
Day 1	0.759 ± 0.123	8.28 ± 7.63
Day 6	0.941 ± 0.096	4.03 ± 3.64
Non-Amputee	0.940 ± 0.152	1.03 ± 4.28

CONCLUSIONS

CSR training by a transfemoral amputee was associated with increased step length and decreased trunk flexion following large postural disturbances. The resulting improvements in dynamic stability may reduce trip-related fall-risk.

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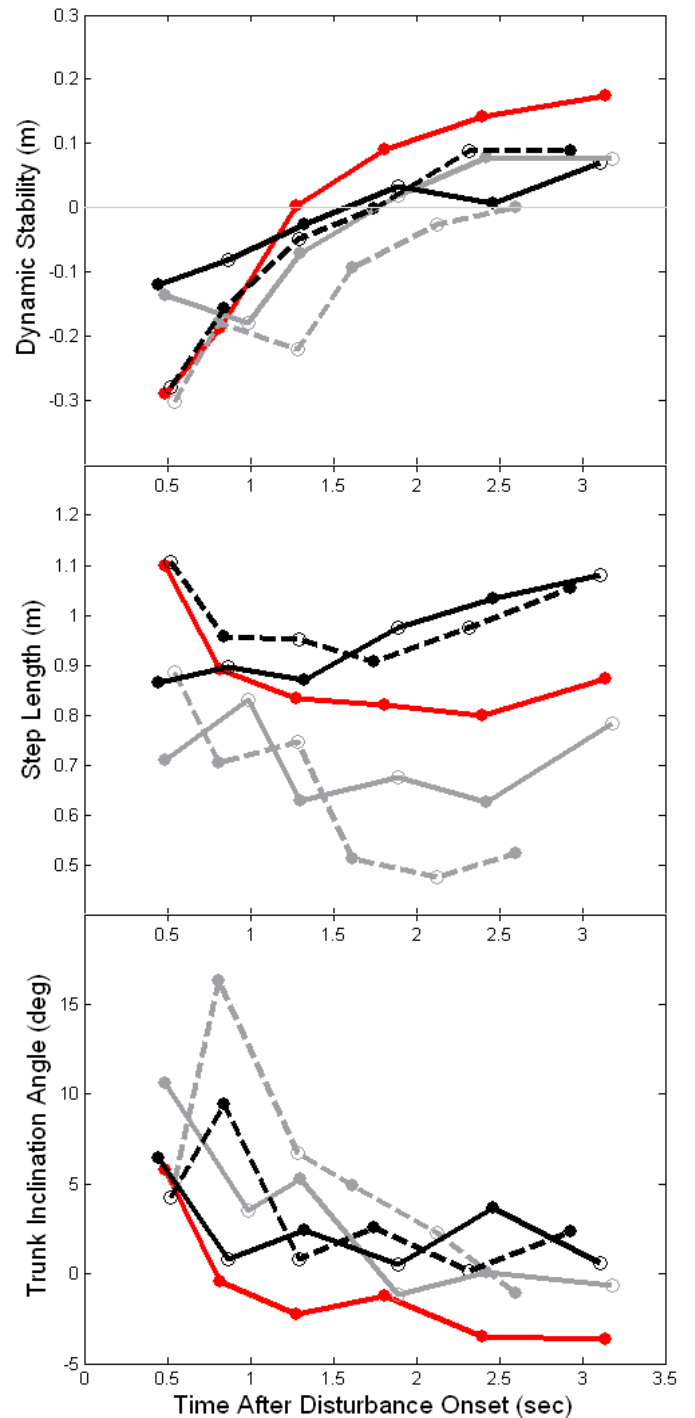


Figure 1. Mean MOS_{AP} , L_{step} , and θ_{trunk} (0° is upright, positive denotes forward tilt) for each heel strike after disturbance onset (initial belt acceleration of $2.75\text{-}3.5 \text{ m/s}^2$). Solid lines denote an initial step with the NPL, and dashed lines represent an initial step with the PL. Solid circles represent steps with the NPL, and hollow circles represent steps with the PL. Grey lines represent data from day 1. Black lines represent data from day 6. Red lines denote data from the non-amputee subject.