

# COMPENSATORY STEP TRAINING OF UNILATERAL, ABOVE-KNEE AMPUTEES: A POTENTIAL INTERVENTION FOR REDUCING TRIP-RELATED FALLS

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## INTRODUCTION

With a yearly fall incidence of 66% [1], above-knee (AK) amputees can benefit from rehabilitation methods aimed at fall prevention. For older, non-amputee adults, practicing a compensatory stepping response (CSR) on a modified treadmill improved the recovery response to treadmill disturbances [2] and overground trips [3]. Previously, we reported that, after six CSR training sessions, a unilateral, AK amputee demonstrated longer step lengths, decreased trunk flexion, and increased dynamic stability when responding to treadmill disturbances [4]. Unpublished data from our laboratory has identified low hip vertical height ( $z_{pelvis}$ ), short recovery step lengths ( $L_{step}$ ), delayed recovery step times, and large trunk flexion velocities ( $TFV$ ) as important mechanisms of failed trip recoveries by unilateral, AK amputees. The purpose of this study was to evaluate the ability of CSR training to improve these mechanisms. We hypothesized that, compared to the first training session, the sixth training session would be characterized by the following:

- Improved success in recovering from postural disturbances.
- A higher  $z_{pelvis}$  at the first recovery step completion.
- A longer first  $L_{step}$  and a shorter step time after disturbance onset ( $t_{step}$ ).
- Smaller trunk flexion angle ( $TFA$ ) and  $TFV$  at the first recovery step completion.

## METHODS

Three women and two men (age:  $43 \pm 10.7$  years, height:  $172 \pm 12$  cm, mass:  $79.7 \pm 22.3$  kg) with unilateral, AK amputations participated in this study. Four subjects used prostheses with a microcomputer controlled knee (C-Leg®, Otto Bock, Minneapolis, MN), and one subject used a

prosthesis with a hydraulic knee (Mauch SNS®, Ossur, Aliso Viejo, CA).

The training protocol consisted of a sequence of progressively challenging disturbances eliciting CSRs. For each trial, the subjects stood on a custom treadmill (Active Step™, Simbex, Lebanon, NH), and a posteriorly-directed treadmill acceleration necessitated the subject to execute an anterior-directed CSR of multiple steps to avoid falling. The initial belt accelerations lasted 0.5 sec, and ranged from  $1.5 \text{ m/s}^2$  to  $6.25 \text{ m/s}^2$ . After the initial acceleration, the treadmill decelerated at a constant rate of  $-0.375 \text{ m/s}^2$ . For small disturbances ( $\leq 2.25 \text{ m/s}^2$ ), peak treadmill velocity was maintained so that the minimum belt displacement was 2 m.

All subjects participated in six training sessions over the course of two to three weeks. For each session, the subjects performed two series of CSRs, once taking the initial step with the non-prosthetic limb (NPL), and once taking the initial step with the prosthetic limb (PL). Time permitting, each series progressed in difficulty until the subject could not recover from the disturbance or the subject recovered from the most challenging disturbance. For all trials, motion capture data was collected at 120 Hz. In order to determine the effects of training day (DAY) and stepping limb (LIMB) on each of the independent variables ( $z_{pelvis}$ ,  $L_{step}$ ,  $t_{step}$ ,  $TFA$ , and  $TFV$ ), a mixed model ANOVA was used with fixed (DAY & LIMB) and random (subject) factors. If significant correlations of the independent variable with the initial treadmill belt acceleration ( $a_{belt}$ ) existed,  $a_{belt}$  was included in the ANOVA as a covariate.

## RESULTS AND DISCUSSION

### Success of CSRs

During the sixth session, three of the five subjects successfully recovered from disturbances that had resulted in a fall during the first session. The two other subjects either had not progressed to failure on the first session, or successfully recovered from all disturbance magnitudes on the first day. Initially stepping with the PL resulted in falls at lower disturbance accelerations than when stepping with the NPL.

### Hip Elevation

$z_{pelvis}$  was not significantly correlated with  $a_{belt}$  ( $p < 0.05$ ). The main effect of DAY ( $p = 0.067$ ) and the DAY\*LIMB interaction ( $p = 0.390$ ) were not significant, suggesting no training effect. A significant main effect of LIMB ( $p < 0.001$ ) suggested that  $z_{pelvis}$  was higher when stepping with the PL (EMM  $\pm$  SE =  $52.4 \pm 0.012$  %BH) than when stepping with the NPL ( $50.4 \pm 0.012$  %BH).

### Step Kinematics

$t_{step}$  and  $L_{step}$  were significantly correlated with  $a_{belt}$  ( $p < 0.001$ ). A significant main effect of DAY ( $p < 0.001$ ) and LIMB ( $p < 0.001$ ) suggested a decrease in  $t_{step}$  with training, and an increase of  $t_{step}$  when stepping with the PL (Figure 1). A larger LIMB discrepancy in  $t_{step}$  was apparent at disturbances with low  $a_{belt}$  (LIMB\* $a_{belt}$   $p < 0.001$ ). The largest training improvement in  $L_{step}$  occurred when stepping with the PL in response to the most challenging disturbances (DAY\*LIMB\* $a_{belt}$   $p < 0.001$ , Figure 1).

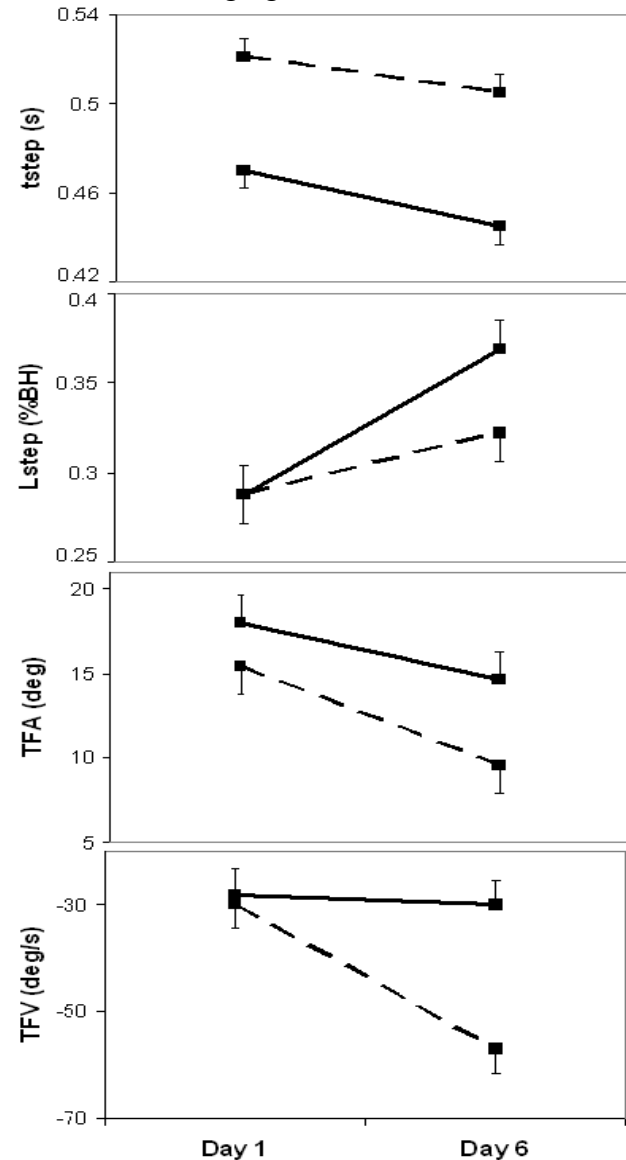
### Trunk Kinematics

TFA and TFV were significantly correlated with  $a_{belt}$  ( $p < 0.001$  &  $p = 0.039$ , respectively). For both stepping limbs, the largest training effect on TFA was apparent for large disturbances (DAY\* $a_{belt}$   $p < 0.001$ ). The largest training effect on TFV was observed when stepping with the PL in response to the most challenging disturbances (DAY\*LIMB\* $a_{belt}$   $p < 0.001$ ).

## CONCLUSIONS

With CSR training, unilateral, AK amputees improved their ability to recover from large postural disturbances. The subjects improved their CSR by taking longer initial steps in less time, and reducing their trunk flexion. The largest improvements were

observed when stepping with the PL in response to the most challenging disturbances.



**Figure 1:** Estimated marginal means ( $\pm$  SE, evaluated at  $a_{belt} = 3.6 \text{ m/s}^2$ ) of  $L_{step}$ ,  $t_{step}$ , TFA, and TFV for each combination of DAY and LIMB (NPL = solid, PL = dashed). Positive trunk angles denote flexion from upright (0 deg).

## REFERENCES

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