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ADAPTIVE BALANCE RECOVERY RESPONSES TO REPEATED FORWARD FALLS IN OLDER ADULTS

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SUMMARY
The purpose of this study was to investigate the adaptive balance recovery response exhibited by older adults following exposure to repeated forward falls. Fifty-eight healthy older community-dwelling adults aged 65-80 participated in the study. Forward loss of balance was achieved by releasing participants from a static forward lean from which their balance could be regained by taking one or more rapid steps. The recovery response was quantified using a measure of dynamic stability computed from the difference between the velocity-adjusted position of the whole body centre of mass and the boundary of the base of support. Older adults did not exhibit anticipatory postural adjustments when exposed to repeated forward falls. However, improvements in the stepping response were observed. Increased dynamic stability across repeated trials occurred as a result of improved control of whole body centre of mass motion and trunk motion following foot contact and in the subsequent landing phase. Overall findings indicate that balance recovery responses improved with repeated perturbations and that the primary mechanism of improvement was related to greater control of trunk motion.

INTRODUCTION
Balance recovery studies to date indicate that older compared to young adults experience greater difficulty recovering from balance perturbations designed to simulate the conditions for trip related falls [1]. One particular experimental approach for studying balance recovery which was first used by Do et al. [2] is the tether-release method. To simulate a forward fall, this approach involves tilting the participant into a static forward lean position via the use of a horizontal tether, which is subsequently released after a random time delay. Participants were instructed to recover with a single step and performed 4 trials at cable forces of 15, 20, 25 and 30% of body weight in random order. Adaptive recovery responses were assessed at the 20% body weight cable force condition only.

METHODS
Participants consisted of 58 healthy community living older adults (35 male, 23 female). Each participant stood barefoot with their feet shoulder-width apart and were tilted forward by flexing their ankles until a predetermined percentage of their body weight was recorded on a force transducer placed in series with a restraining cable. One end of the cable was attached to a safety harness worn by the participant at the level of their sacrum and the other end to a rigid metal frame located behind the participant. The cable was released at a random time interval (2-10 s). Participants were instructed to recover with a single step and performed 4 trials at cable forces of 15, 20, 25 and 30% of body weight in random order. Adaptive recovery responses were assessed at the 20% body weight cable force condition only.

Trajectories of 57 reflective markers attached to the head, trunk, pelvis, and upper and lower limbs were recorded at 200 Hz using a 10-camera 3D motion analysis system. Ground reaction force data were simultaneously acquired at 1 kHz using two 900 x 600 mm piezoelectric force platforms. All kinematic analysis including estimation of antero-posterior whole body and trunk centre of mass motion was performed using OpenSim [4].

The Margin of Stability (MoS) in the anterior-posterior direction was calculated using MoS=BoS–XCoM, where BoS is displacement of the toe marker on the stepping foot from cable release until the event of interest. XCoM was obtained using equation 1.

\[ XCoM = PCoM + \frac{VCoM}{\sqrt{\ell^2}} \]  

Equation 1

PCoM is the antero-posterior distance from the toe marker at cable release and the vertical projection of the centre of
mass, VCoM is the anterior-posterior velocity of the centre of mass, g is the acceleration due to gravity and I is the distance between the whole body centre of mass and the ankle joint centre in the sagittal plane.

A repeated measures general linear model was used to assess the affect of trial (1-4) on the dependent measures (MoS parameters) at 4 events. These events were Cable Release (CR), Toe-Off (TO), Foot Contact (FC) and Maximum Knee Flexion Angle (KJM). A-priori (simple) contrasts were performed to assess differences between the first trial and subsequent trials (i.e. trials 2-4). Pearson product moment correlation coefficients were used to examine the relation between (1) changes in MoS and changes in trunk kinematics (i.e. displacement and velocity) computed between the first and last trial. Significance was accepted for p<0.05.

RESULTS
No significant main trial effects were detected for the durations from CR to TO, TO to FC or FC to KJM. Similarly, there were no significant differences across trials for any MoS parameters at CR or TO.

The proportion of participants that had a positive MoS across the 4 trials were 71, 86, 86 and 90% at FC and 57, 72, 79 and 84% at KJM. Adaptive balance recovery responses in MoS parameters to repeated trials are displayed in figure 1. Trial had a significant main effect on MoS, XCoM, PCoM and VCoM at FC and KJM. Planned contrasts revealed significant differences between the first and subsequent trials for MoS, XCoM, PCoM and VCoM at FC and KJM as depicted in figure 1.

Figure 1: Mean Margin of Stability (MoS) parameters for trials 1-4 at CR, TO, FC and KJM.

Trial also had a significant main effect on trunk displacement and trunk velocity at FC and KJM. Planned contrasts revealed significant differences between the first and subsequent trials for trunk displacement and velocity at FC and KJM as depicted in figure 2 (upper panels).

The change in MoS was significantly correlated with the change in linear trunk displacement and velocity at FC and KJM (r = -0.4 to -0.55, p<0.05, Figure 2, lower panels).

Figure 2: Upper panels show mean trunk displacement and velocity for trials 1-4 at CR, TO, FC and KJM. Scatterplots and linear regression lines for changes in Margin of Stability (MoS) versus changes in linear trunk displacement and velocity computed between the first and last trials are displayed in the four lower panels.

CONCLUSIONS
Dynamic stability at foot contact and at maximum knee flexion angle during landing was significantly improved following repeated forward falls. The primary mechanism underlying this improvement was a reduction in anterior displacement and velocity of the whole body centre of mass during recovery. Reductions were also observed for trunk displacement and velocity during recovery, suggesting that the observed improvements in whole body centre of mass motion were related to improved control of trunk motion. Given that real-world falls occur unexpectedly, the ecological validity associated with this experimental paradigm is greatest for the initial balance perturbation.

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