Adaptive modifications in dynamic stability to unilateral change in lower limb dynamics in older and younger adults while walking

1Kiros Karamanidis, 1Florian Süptitz, 1Maria Moreno Catalá, 2Juuli Piironen, 2Janne Avela and 1Gert-Peter Brüggemann.
1 1Institute of Biomechanics and Orthopaedics, German Sport University Cologne, Germany;
2Department of Biology of Physical Activity, Neuromuscular Research Center, University of Jyväskylä, Finland;
email: karamanidis@dshs-koeln.de

SUMMARY
The aim of this study was to examine the reactive responses and adaptive modifications in dynamic stability resulting from a unilateral change in lower limb dynamics in older and younger adults while walking. Eleven older (62-76yrs) and eleven younger (22-30yrs) subjects walked on a treadmill and performed different gait conditions using an external resistance against lower limb movement. The margin of stability (MoS) at touchdown was calculated as the difference between base of support (BoS) and extrapolated centre of mass. After the resistance was turned on unexpectedly, older adults needed more steps to get back to the MoS baseline level due to a lower increase of the BoS. In the following protocol, a continuous resistance was applied over 11 consecutive steps. Adaptation level in MoS and BoS was lower in the early adaptation phase but not in the late adaptation phase for the older compared to the younger adults. After removing the resistance, both groups showed similar aftereffects. Our results indicate that elderly preserve their ability to recalibrate their feedforward motor commands to control dynamic stability during perturbed walking. However, the rate of adaptive improvements and feedback driven postural modifications is diminished in the elderly, increasing the risk of falling.

INTRODUCTION
Human gait is a mechanically complex task and the patterns must be flexible enough to accommodate changing environmental demands and task constraints. As a consequence, effective postural modifications are required to produce successful and safe gait patterns without loss of stability. Such modifications in motor task execution take place on different time scales; while some are immediate reactions to a novel situation, others are slower adaptive changes that last longer. Reactive or feedback-driven movement corrections occur quickly, using ongoing afferent feedback information. Slower adaptive modifications require practice of the novel situation and result in storage of the new movement pattern. They result in new calibration of feedforward motor commands, seen as aftereffects that persist upon return to the original condition [1].

Previous work has documented that cognitive [2], and skeletal muscle-tendon [3] functions gradually decline with advancing age, and it would, therefore, not be surprising if the ability to use appropriate feedback corrections and the ability to adapt also decline. Accordingly, a number of studies have shown that, in general, older adults have a slower motor learning process and reduced adaptive improvement under a novel task constraint [4, 5]. However, most studies analyzing adaptation potential in the elderly are based on discrete upper-limb tasks and such findings do not necessarily apply to postural tasks such as gait. Falls during ongoing gait after a sudden postural perturbation are a major health threat in the elderly and, therefore, analyzing the motor learning processes during walking may be important for the implementation of early effective intervention to reduce the risk of falls in the elderly population. Based on upper-limb tasks, it is known that changes in the dynamics of the limb due to the application of an external resistance against limb movement will result in movement errors due to changes in the sensory input from the limb [1]. In the current study we used similar task constraints for the lower limbs, aimed at examining the reactive response and adaptive modifications in dynamic stability resulting from a unilateral change in lower limb dynamics in older and younger adults while walking. We hypothesized that older compared to younger adults will show (i) a less effective feedback-driven postural adjustment after an unexpected change in lower limb dynamics and (ii) a slower motor learning process and reduced magnitude of adaptive improvement in dynamic stability as a result of a sustained change in walking condition.

METHODS
Eleven older women aged between 62 and 76 years and eleven younger women aged between 22 and 30 years with similar anthropometric data participated in the study. All subjects had to walk on a motor driven treadmill with a belt speed of 1.4 m/s. A custom-built device including an electric driven brake-and-release system was used in order to unexpectedly apply and remove a resistance of 2.1 kg on the lower right limb during the swing phase while walking. For this reason a Teflon rope connected with the brake-and-release system was secured with Velcro straps around the right leg of the subjects just above the ankle joint. The gait protocol consisted of three Blocks starting with the baseline trials (Block 1: resistance was turned off while walking), followed by the reactive response trials (Block 2: resistance was turned on during the swing phase of the right leg for one step) and finally the adaptation trials (Block 3: resistance was turned on during the swing phase of the right leg for 11 consecutive steps followed by an additional step without resistance in order to examine aftereffects). Between Blocks 2 and 3, the resistance was always turned off and sufficient time was given for each subject to provide a “wash-out” effect of the postural adjustments experienced due to the applied resistance. Subjects were not warned about the application or removal of the resistance.

Kinematic data while walking were recorded with a Vicon motion capture system using eight cameras operating at 120 Hz. Twenty-six reflective markers were fixed on anatomical landmarks on the skin to track a twelve segment full body model. The margin of stability (MoS) in anteroposterior direction while walking was determined using the “extrapolated centre of mass” concept provided by Hof et al. [5] and was calculated as the difference between the anterior boundary of the base of support (BoS, i.e. horizontal component of the projection of the toe from the corresponding
limb to the ground) and the extrapolated center of mass \( (X_{CM}) \) in the anteroposterior direction. \( X_{CM} \) was defined as follows [5]:

\[
X_{CM} = P_{\text{XCM}} + \frac{V_{\text{XCM}} + V_{\text{BoS}}}{\sqrt{g/l}}
\]

where \( P_{\text{XCM}} \) is the horizontal (anteroposterior) component of the projection of the centre of mass \( (\text{CM}) \) to the ground, \( V_{\text{XCM}} \) is the horizontal (anteroposterior) CM velocity, \( V_{\text{BoS}} \) is the horizontal (anteroposterior) BoS velocity (approximately equal to the velocity of the treadmill), \( g \) is the acceleration of gravity, and \( l \) is the distance between CM and the centre of the ankle joint in the sagittal plane. Postural stability is maintained in circumstances where the position of the \( X_{CM} \) is within the BoS (positive values of MoS) while stability is lost in cases where the \( X_{CM} \) exceeds the anterior boundary of the BoS. All components of the dynamic stability were analyzed at the instants of touchdown (TD). TD was identified by the acceleration of the tibia determined by 2D accelerometers (1080 Hz). All events were further visually checked by the same examiner using a video camera (60 Hz). The mean values of eight consecutive baseline trials were used to determine the baseline level. For the reactive response condition in Block 2, the disturbed right leg and the following six consecutive steps (left and right) were analyzed in order to determine the reactive response in dynamic stability during ongoing gait. For the adaptation trials in Block 3, resistance trials 1-3 as well as resistance trials 9-11 were pooled together as representative of the early and late adaptive adjustments in dynamic stability, respectively. A one way repeated-measures analysis of variance was used in order to examine the age and trial-related differences in the analyzed dynamic stability parameters. Post-hoc testing (Duncan’s Test) was applied for the pairwise comparison.

RESULTS AND DISCUSSION

Compared to the baseline level, the MoS at TD of the right leg after the resistance was turned on unexpectedly decreased in both age groups significantly \((p<0.05)\) with no significant differences \((p>0.05)\) between older and younger adults (Figure: Block 2). This means that the consequence of the applied perturbation on dynamic stability was similar for both age groups, leading to a clear unstable body configuration at TD (i.e. negative values of MoS). However, the analysis of the following consecutive steps revealed that the older adults needed significantly more steps in order to get back to the baseline level (on average three more steps; Figure: Block 2), showing that the feedback corrections were less effective in the elderly. The main reason for this was the reduced ability of the elderly to increase their BoS following the unexpected change in lower limb dynamics \((p<0.05)\). During the following adaptation trials (Figure: Block 3), the MoS as well as the BoS at TD of the weighted right leg showed lower values in both the early and late adaptation phases compared to the baseline value \((p<0.05)\) independent of the subject’s age (no age-effect). However, a continuous increase in the MoS and BoS at TD from the first perturbation in Block 2 (reactive response trial), to the early until the late adaptation phase was present for the younger adults \((p<0.05)\) but not for the older adults (i.e. no significant differences in MoS or BoS between the first unexpected perturbation and the early adaptation phase for the elderly; \(p>0.05\)). Accordingly, there was a significant \((p<0.05)\) age-effect in the MoS and BoS at TD for the early adaptation phase (lower values for the elderly) but not for the late adaptation phase \((p>0.05)\). The above findings demonstrate that the older subjects achieved the same adaptation level as the younger ones after performing all 11 weighted gait trials; however, they adapted more slowly than the younger ones. After removing the resistance from the limb, both age groups showed clear aftereffects manifested in a significant increase \((p<0.05)\) of the BoS at TD compared to the baseline level with a similar magnitude between age groups.

CONCLUSIONS

Our results provide evidence that older adults preserve their ability to recalibrate their feedforward motor commands to control dynamic stability during perturbed walking. However, the rate of adaptive improvements to a sustained change in lower limb dynamics and feedback-driven compensatory adjustments in dynamic stability are diminished in the elderly population, increasing the risk of falling while walking.

![Figure: Margin of stability (MoS) at touchdown (TD) for the older and younger adults for the three gait conditions (mean and standard error of mean). Block 1: resistance was turned off while walking; Block 2: resistance was turned on for one step of the right leg; Block 3: resistance was turned on for 11 consecutive steps of the right leg. Note that for Block 2, in addition to the single step with the disturbed right leg, the following six consecutive recovery steps (left and right) were analyzed.](image)

REFERENCES