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Cognitive demand and predictive adaptational responses in dynamic stability control

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ABSTRACT

We studied the effects of a concurrent cognitive task on predictive motor control, a feedforward mechanism of dynamic stability control, during disturbed gait in young and old adults.

Thirty-two young and 27 elderly male healthy subjects participated and were randomly assigned to either control or dual task groups. By means of a covered exchangeable element the surface condition on a gangway could be altered to induce gait perturbations. The experimental protocol included a baseline on hard surface and an adaptation phase with twelve trials on soft surface. After the first, sixth and last soft surface trial, the surface condition was changed to hard (H1–3), to examine after-effects and, thus, to quantify predictive motor control. Dynamic stability was assessed using the 'margin of stability (MoS)' as a criterion for the stability state of the human body (extrapolated center of mass concept).

In H1–3 the young participants significantly increased the MoS at touchdown of the disturbed leg compared to baseline. The magnitude and the rate of these after-effects were unaffected by the dual task condition. The old participants presented a *trend* to after-effects (i.e., increase of MoS) in H3 but only under the dual task condition.In conclusion, the additional cognitive demand did not compromise predictive motor control during disturbed walking in the young and old participants. In contrast to the control group, the old dual task group featured a *trend* to predictive motor adjustments, which may be a result of a higher state of attention or arousal due to the dual task paradigm.

1. Introduction

Postural stability is crucial for safe and efficient locomotion (Patla, 2003; Al-Yahya et al., 2009). Considering an increased fall incidence in the elderly population (Nevitt et al., 1989; Talbot et al., 2005), mainly following gait perturbations (Berg et al., 1997; Blake, 1988), the understanding of mechanisms regarding dynamic stability control becomes important in the prevention of falls.

Motor adaptive behavior including feedback (reactive, anticipatory) and feedforward (predictive) mechanisms is necessary for an appropriate control of the stability state during daily locomotion (Marigold and Patla, 2002; Bierbaum et al., 2010, 2011). Whereas feedback responses depend on online sensory input, predictive motor control is based on prior experiences and leads to new and adapted movement patterns which are identifiable by after-effects (Bronstein, 2007; Morton and Bastian, 2006; Shadmehr and Mussa-Ivaldi, 1994). Following gait disturbances, predictive motor control occurs prior the potential perturbation in order to reduce its consequences and to prevent a fall (Bierbaum et al., 2010; Marigold and Patla, 2002). Recent work demonstrated that although old adults show deficits in the reactive adaptation during disturbed walking compared to young (Bierbaum et al., 2011), the predictive adaptational potential does not decline with age (Bierbaum et al., 2010; Pavol et al., 2004).

Scientific work of the past decade provides evidence that both postural (Jacobs and Horak, 2007; Maki and McIlroy, 2007) and gait control (Abbud et al., 2009; Lajoie et al., 1993) involve cognitive resources and high-level processing. Dual task studies indicate that in the context of a postural threat evoked by an unexpected perturbation stability control requires increased cognitive resources and processing capacity (Brauer et al., 2002; Brown et al., 1999; Norrie et al., 2002). Due to the limitation of available cognitive capacities this increase may induce task-interferences, represented by a decreased performance on the postural, cognitive or both tasks (Pashler, 1994; Woollacott and Shumway-Cook, 2002). It is reported that these interferences are more pronounced within the elderly population (Brauer et al., 2002; Brown et al., 1999; Rankin et al., 2000). However, it is yet unknown whether these findings are attributed to the age-related decline of cognitive resources (Bishop et al., 2010) and processing

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capacity (e.g. ability to allocate attention (Siu et al., 2008, 2009)) or an increased demand for postural control or a combination (Woollacott and Shumway-Cook, 2002).

Whereas the involvement of cognitive resources and processing capacity in feedback based mechanisms (i.e., reactive, anticipatory) (Maki and McIlroy, 2007; Brown et al., 1999; Harley et al., 2009) are well examined, the relevance for predictive motor control during gait, especially in the elderly, has currently not been investigated. Predictive control is associated with supraspinal structures and the cerebellum in particular (Bastian, 2006; Jayaram et al., 2011; Morton and Bastian, 2006) which in turn seems to be involved in cognitive processes (e.g. attention, working memory) (Strick, 2009). Therefore, a concurrent cognitive demand could interfere with the motor task, impairing the formation or execution of predictive control. In this regard, Taylor and Thoroughman (2007) found that predictive control in young adults was affected by a secondary cognitive task. Since cognitive resources and processing capacity in older adults are decreased or altered compared to young, interferences may occur to a greater extent in the elderly population.

Thus, the purpose of the present investigation was to examine the influence of a concurrent cognitive demand on the predictive adaptational potential during disturbed walking in young and old adults. We hypothesized that (a) a concurrent cognitive task would impair predictive adaptational responses regarding dynamic stability control in both young and old adults and (b) the observed impairments would be more pronounced in the elderly.

2. Methods

2.1. Experimental design

Thirty-two young and 27 elderly male subjects participated in the study after giving informed consent to the experimental procedure according to the rules of the local scientific board and were randomly assigned to either control (young: $n=15$, 26.2 ± 3.2 yr, 183.5 ± 6.7 cm, 75.3 ± 8.3 kg; old: $n=14$, 70.1 ± 4 yr, 177.4 ± 7.8 cm, 80 ± 8.5 kg) or dual task groups (young: $n=17$, 27.9 ± 1.8 yr, 180.6 ± 7.5 cm, 75.8 ± 8.7 kg; old: $n=13$, 68.8 ± 3.1 yr, 173.7 ± 6.1 cm, 76.8 ± 8.3 kg). All subjects were physically active (sport activities at least twice a week) and without neurological or musculoskeletal impairments.

An exchangeable element was placed halfway along a gangway and covered with an elastic sheet. Gait perturbations were induced by changing the surface condition from hard to soft without the knowledge of the subjects (Fig. 1), who were secured by means of a safety harness. The force deformation characteristic of the soft surface (total height 17 cm) was non-linear, featuring an average deformation of 12 cm within the experiment.

The subjects were instructed to walk constantly at self-selected (brisk) pace (young: 2.0 ± 0.15 m/s; old: 1.85 ± 0.13 m/s). Starting position and gait velocity were monitored throughout the experiment by means of three pairs of light barriers, so that the participants would always step with their right leg onto the exchangeable element (Fig. 1).

The gait protocol consisted of 18 walking trials according to Bierbaum et al. (2010) (Fig. 1). Before starting the experiment, the participants were briefed that the surface characteristics could change without further warnings. The protocol started with three baseline trials on the hard surface followed by an unexpected perturbation on the soft surface (s1). Subsequently, it was announced that the surface in all following trials would stay "soft". Since it is crucial to restore baseline conditions to examine after-effects (Shadmehr and Mussa-Ivaldi, 1994) and, thus, to quantify the rate and the magnitude of predictive motor control (Bierbaum et al., 2010), the trial following s1 and the trials after the sixth and twelfth soft surface trial (adaptation phase) were performed on hard surface (H1–3) (Fig. 1).

The kinematic data were recorded with an infrared motion capture system (Vicon Nexus, Version 1.4.1., Vicon Motion Systems, Oxford, UK) integrating 11 cameras operating at 250 Hz. For capturing whole body kinematics, 17 reflective markers (diameter of 14 mm) were fixed at the following anatomical landmarks: left and right acromion, 7th cervical vertebra, joint line of elbow and wrist, greater trochanter, joint line of the knee, lateral malleolus, tuber calcanei, caput ossis metatarsalis II and two at the front as well as at the back of the cranial bone. The foot markers located at the tuber calcanei and caput ossis metatarsalis II were plotted in individual sketches of the shoes to calculate the boundaries of the base of support. The marker trajectories were smoothed using a fourth-order bidirectional Butterworth low-pass filter (6 Hz cut-off frequency). Segmental masses and the locations of the segment center of mass were calculated based on the data reported by Dempster et al. (1959).

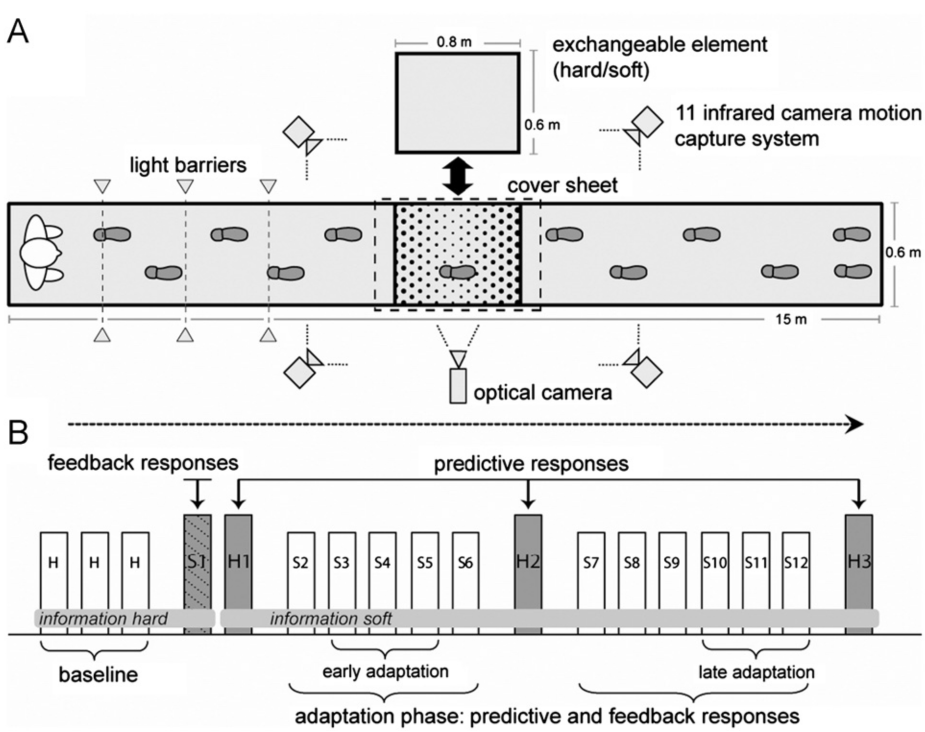

Fig. 1. Experimental protocol. Gait perturbations were induced by using an exchangeable element in a gangway which allowed altering the surface condition without the knowledge of the participants (A). Baseline trials on hard surface were followed by an unexpected perturbation (s1) on soft surface. After this disturbance the participants continued with the information that there would stay the soft surface. The consecutive unannounced hard surface trial (H1) and the hard surface trials after six (H2) and twelve (H3) soft surface trials (adaptation phase) were used to estimate after-effects and, thus, predictive motor control. The early and late soft surface trials documented the adaptation phase (B).