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Increased sensory noise and not muscle weakness explains changes in non-stepping postural responses following stance perturbations in healthy elderly

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A R T I C L E I N F O

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A B S T R A C T

The response to stance perturbations changes with age. The shift from an ankle to a hip strategy with increasing perturbation magnitude occurs at lower accelerations in older than in young adults. This strategy shift has been related to age-related changes in muscle and sensory function. However, the effect of isolated changes in muscle or sensory function on the responses following stance perturbations cannot be determined experimentally since changes in muscle and sensory function occur simultaneously. Therefore, we used predictive simulations to estimate the effect of isolated changes in (rates of change in) maximal joint torques, functional base of support, and sensory noise on the response to backward platform translations. To evaluate whether these modeled changes in muscle and sensory function could explain the observed changes in strategy; simulated postural responses with a torque-driven double inverted pendulum model controlled using optimal state feedback were compared to measured postural responses in ten healthy young and ten healthy older adults. The experimentally observed peak hip angle during the response was significantly larger (5°) and the functional base of support was smaller (0.04 m) in the older than in the young adults but peak joint torques and rates of joint torque were similar during the recovery. The addition of noise to the sensed states in the predictive simulations could explain the observed increase in peak hip angle in the elderly, whereas changes in muscle function could not. Hence, our results suggest that strength training alone might be insufficient to improve postural control in elderly.

1. Introduction

In elderly, falls are the leading cause of accidental death and injury admissions to hospitals [1]. Postural control deficits contribute to the increased incidence of falls [2] but the influence of specific age-related changes in the neuro-muscular system on postural control is not well understood.

Healthy young and older adults use a different strategy in response to a perturbation of standing. With increasing perturbation magnitude, both young and older adults shift from an ankle to a hip strategy and eventually from a non-stepping to a stepping strategy [3,4]. But this shift in strategy occurs at lower perturbation magnitudes in older than in young healthy adults [2,3,5].

Age-related changes in perturbed standing balance have been related to changes in muscle function. First, overall muscle weakness has been correlated with impaired postural control, with especially weakness of distal lower limb muscles limiting non-stepping balance control [6]. In addition, muscular effort to control posture increases in elderly [7]. Second, the rate of force development decreases with age, however its effect on balance control is unclear [3,8]. Third, a decrease in functional base of support (FBOS) has been correlated with impaired postural control [3,9]. Older adults with a decreased FBOS use a heel-rise and stepping strategy for smaller perturbations of balance compared to healthy controls [3].

Age-related changes in perturbed standing balance have also been related to changes in sensory function. The decline of the somatosensory system in elderly causes a decrease in position and movement sense [10–13] and sensory loss has been related to declined postural control [14–17]. For example, individuals with peripheral nerve dysfunction, such as patients with diabetic peripheral neuropathy, are at greater risk of falling [14]; patients with somatosensory loss rely on a hip rather than an ankle strategy for postural corrections [15]; and the compensatory muscle activity in response to a perturbation decreases when plantar skin sensory input is inhibited by hypothermia [16].

Dynamic simulations of perturbed standing balance have been used to investigate the selection of an ankle or hip strategy. Kuo et al. have

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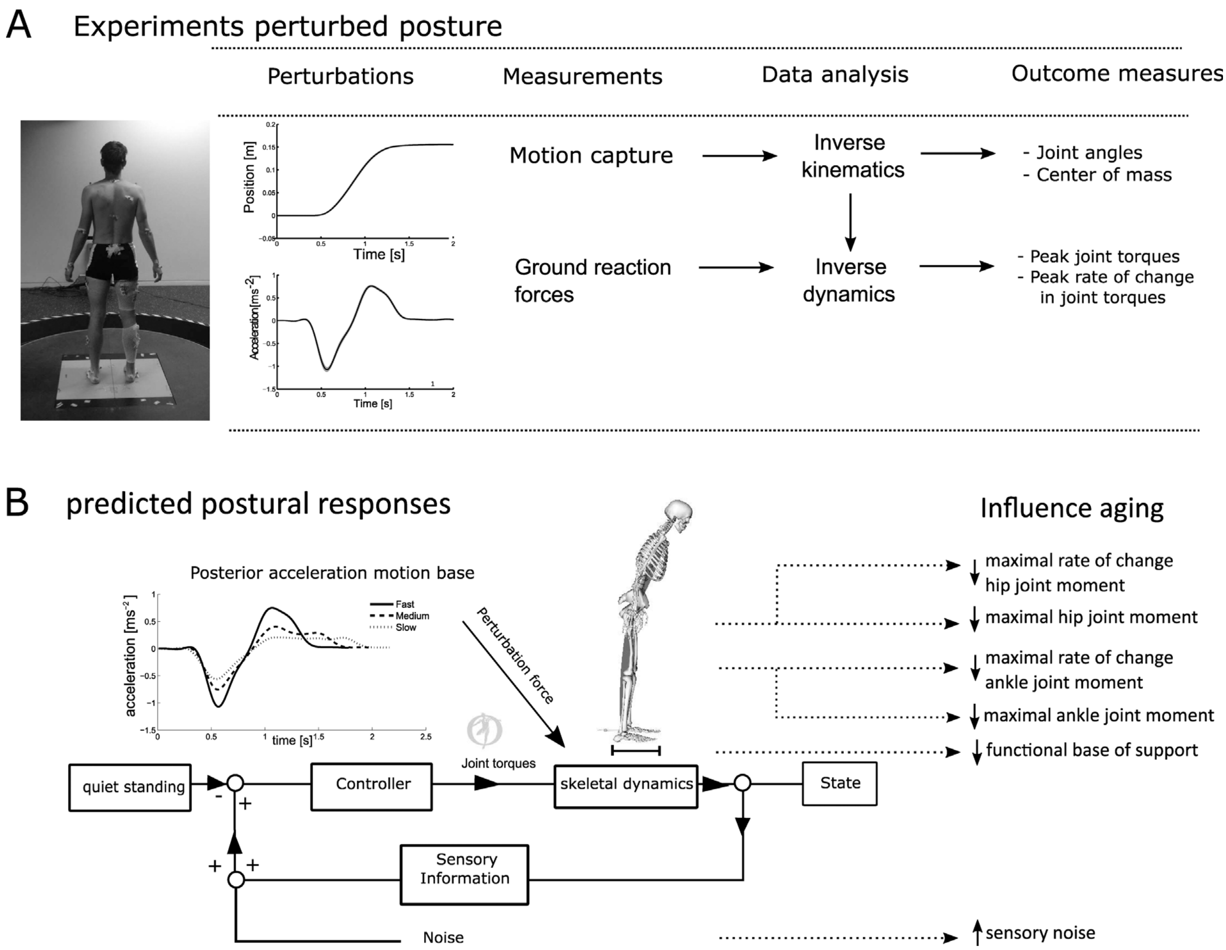

Fig. 1. Methods overview: Pane A: Processing workflow of experimental data collected during the response to a stance perturbation by means of a posterior platform translation with three different acceleration profiles. Joint angles and center of mass locations during the postural response were determined from the motion capture data. Joint kinematics were combined with ground reaction forces to compute joint torques. Pane B: neuromechanical model to simulate postural responses. The feedback control model is similar to the model of [26]. In the sensory information block returns the full state of the model (ankle and hip joint angles and angular velocities) with or without additive noise. The sensed state is compared to the desired state corresponding to quiet standing. The error on the desired state is multiplied by a feedback gain matrix (eight feedback gains) in the controller to compute the ankle and hip joint torques. The different acceleration profiles of the platform as a function of time were approximated by cubic splines and imposed as external forces acting on the skeletal model. Age-related changes were induced to the simulations by a stepwise decrease of (1) the FBOS, (2–3) the maximal ankle and hip joint torque, (4–5) the maximal rates of change in ankle and hip torque (6) and by a stepwise increase of the additive white Gaussian noise on the state (sensory information block).

shown that the capability to accelerate the center of mass, and hence to stabilize posture, is larger for hip versus ankle strategies and for stepping versus non-stepping strategies[18,19]. We recently found that hip strategies minimize center of mass movement whereas ankle strategies are energetically more efficient [20,21].

Since age-related changes in muscle and sensory function occur simultaneously, their individual contributions to postural control are hard to determine experimentally. In contrast, predictive simulations of balance allow investigating the effect of isolated changes in muscle or sensory function on postural control.

Here, we used our recently developed framework for predictive simulations of perturbed standing balance [20] to investigate the effect of isolated age-related changes in the neuro-musculoskeletal system on the postural response to a backward support surface translation. Specifically, we assessed how either a decrease in muscle function or an increase in sensory noise influenced the predicted postural response. Simulated responses were compared to measured responses in a group of healthy young and older adults without a history of falling to evaluate whether the modeled changes in muscle and sensory function could explain the increased occurrence of hip strategies in the older versus young adults.

2. Method

2.1. Experiments

Ten healthy young (21 ± 2 STD (standard deviation) years) and ten healthy older adults (67 ± 3 STD years) without history of falling participated in the study. KU Leuven's commission of medical ethics approved the experimental protocol. Participants provided written, informed consent prior to participating.

Subjects stood at stance width equal to their shoulder width on a moving platform (Caren-base, Motekforce Link, Netherlands). Subjects were informed that the platform would randomly move in multiple directions and were instructed to maintain stability without stepping. We analyzed perturbed standing in response to backward platform translations (0.16 m total excursion) administered within three blocks of randomized perturbations in anterior-posterior and medio-lateral directions with respectively fast, medium and slow acceleration profiles ($1.1\ m/s^2$, $0.8\ m/s^2$ and $0.6\ m/s^2$)peak acceleration). These acceleration profiles elicited a wide range of postural responses. Two trials per acceleration profile were analyzed, resulting in six trials per subject. In order to measure the FBOS, subjects were asked to lean maximally anteriorly and posteriorly with their trunk. The maximal excursion of the center of pressure (COP) with respect to the ankle defined the FBOS.