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Research Report

The effect of age on coordination of stabilization during changing environmental dynamics

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Coordination as part of the stabilization process of joints is compromised in older adults. We addressed changes in neuromuscular control and force output during a ballistic force production task influenced by different environmental dynamics. Aged participants (AP) and young participants (YP) were asked to perform a unilateral maximal leg extension against a movable sled in a reaction-time task. The task was performed in a sitting posture and involved a stable (1 degree of freedom; DoF) or an unstable (3 DoF) condition of the sled. Electromyographic and dynamometric recordings were made and analyzed using the cross-correlation-function, assessment of peak EMG-activity and peak force. Initial motor strategies (i.e. motor system adjustments in order to meet the demands of the particular task while respecting individual constraints) were assessed by analyzing total reaction times (TRT), premotor time (PMT) and electromechanical delay (EMD). The AP group showed motor control strategies governed by prolonged TRT in both conditions. However, the change of mechanical interactions (i.e. the interaction between the participant and the sled in its particular mechanical state) caused group specific motor system adjustments in PMT and EMD. Force measures showed reduced peak forces in AP accompanied by less loss of force between conditions compared to YP. Inter- and intramuscular coordination strategies differed between YP and AP reflected in changes in CCF and peak EMG values. We conclude that change in environmental dynamics is associated with specific adjustments of control properties of the motor system. These adjustments were sensitive to age and mechanical condition (1 or 3 DoF) and might contribute to declines in motor output seen in AP. However, due to the nature of the task, our results do not allow a direct transfer to situations involving whole body balance.

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1. Introduction

In most everyday activities accurate neuromuscular control is essential in order to avoid injuries or to precisely execute functional motor acts that involve rapid force production (e.g. stair climbing, sit-to-stand-maneuver). Ample evidence supports the idea that with age neuromuscular control is altered. This connection was shown amongst others in non-ballistic single leg tasks (Madhavan et al., 2009) and tasks involving the upper extremities (Gorniak and Alberts, 2013). Facing increased risks of injuries in the elderly, such changes might contribute to injuries during everyday tasks. Changes in numerous aspects of motor control add to natural consequences of aging like sarcopenia and, consequently, loss of strength (Visser, 2012; Reid et al., 2014) and explosive voluntary strength (Mau-Moeller et al., 2013). Neural effects of aging affecting motor control strategies include e.g. decreased number of motoneurons or decreased motoneuronal firing rates (Kamen et al., 1995; Christie and Kamen, 2006). Additionally, aging is believed to cause changes in intrinsic properties of the motoneurons (Christie and Kamen, 2006) causing altered motor unit drive during force production tasks (Kamen et al., 1995; Mau-Moeller et al., 2013). As a consequence of the age related neuronal changes, motor unit recruitment is adjusted in order to meet the altered demands for adequate force production (Madhavan et al., 2009). However, the neuromuscular effects associated with aging, the altered body composition (muscle mass) and control modalities can lead to frailty syndrome, which is believed to include (amongst others) modifications of motor control aspects (Fried and Walston, 2003).

In a study on upper extremity movements, Barry et al. (2005) provided evidence that aged participants (AP) react slower and show reduced capabilities of rapid force production as compared to young participants (YP). The authors attributed these differences to dysfunctions in muscular coordination. However, considering the fact, that coordination deficiencies are present in multiple facets of motor control, including lower extremity movements, we assume that active (i.e. muscle driven) stabilization of movement is also compromised. Consequently, a change in the capability of rapid force production might be associated with impaired balance in connection with a reduced ability for neuromuscular responses for postural sway control (Izquierdo et al., 1999). Hence, these findings support the idea that aging causes alterations in motor control modalities which in turn might contribute to higher risks of injury when interacting with the environment. The effects occurring with age must be seen within the context of motor unit reorganization and, subsequently, changes in neural drive. Regarding movement orchestration, Darling et al. (1989) showed a decoupling of activation patterns during upper extremity movements in the elderly. These findings are supported by Stelmach et al. (1989) who reported less tight coupling of muscular activity during balance-recovery tasks. Additionally, Thelen et al. (2000) attributed deficiencies in balance recovery performances during forward falls in the elderly to differences in muscle activation timing. In fact, these studies have demonstrated that performance deficits occurring with age are evident during a variety of movements involving whole body perturbations and hence input from multiple sensory sources (visual, vestibular, somatosensory) possibly contributing to the basic muscular activity profiles.

In studies from our laboratory, we have previously shown that muscular coordination (temporal & EMG magnitude) and motoneuronal control modalities change with varying environmental dynamics during a force production task while sitting (Holl and Zschorlich, 2011; Wuebbenhorst and Zschorlich, 2011, 2012, 2013). More precisely, exerting force against stable and unstable objects leads to context-specific adjustments in inter- and intramuscular coordination schemes. We reasoned that these adjustments resemble motor strategies in order to counteract movement instability created by the environment and to minimize the destabilizing potential of an inordinate muscle activity. The latter may in part be achieved by timing muscular activity bursts or by altering Ia-afferent and corticospinal transmission in response to changes in biomechanical task demands. However, given the complexity of neural organization, the documented changes have to be seen as contributive to other neural processes.

We now ask for the changes occurring with age in motor control strategies during execution of a ballistic force production task under changing stability conditions. We exposed our participants to either stable (1 degree of freedom; DoF) or unstable (3 DoF) conditions while they created force against an external device. In earlier studies we reasoned that changing environmental dynamics causes alterations in motor control modalities in order to counteract the instability created by the environment. Here, we extent previous findings by evaluating age-related performance differences.

2. Results

2.1. *AP and YP use different initial motor strategies in dependence of DoF-condition*

Both groups revealed individual strategies regarding initiation of task execution. These different strategies became manifest in differences in total reaction time (TRT), electromechanical delay (EMD) and premotor time (PMT).

The TRT was considerably slower for the elderly resulting in group differences of 44 ms for 3 DoF (Man–Whitney: $p=0.055$) (Fig. 1A). Regarding the 1 DoF condition the AP-group exhibited significantly longer TRT as compared to YP reaching between group-differences of 61 ms (Man–Whitney: $p=.019$). As seen in Fig. 1A, when changing the mechanical interaction properties from stable dynamic (1 DoF) to unstable dynamic (3 DoF) the two groups showed incongruent changes. More specifically, the elderly tended to slightly decrease TRT, while young participants tended to slightly increase TRT. However, the within group changes between 1 & 3 DoF were not significantly different for both groups (YP: Wilcoxon: $p=.508$; AP: Wilcoxon: $p=.333$).

We further addressed premotor time (PMT), i.e. the interval between the onset of the light signal and the muscle response, assessed by TRT minus EMD (Fig. 1B). The young participants showed significantly shorter PMT as compared to the elderly in the 1 DoF condition (Man–Whitney: $p=.0058$) but not in the 3 DoF condition (Man–Whitney: $p=.473$). No significant changes between DoF-conditions were observed for within group analyses.

In opposite to TRT and PMT, the electromechanical delay (EMD) revealed longer delays in the 1 DoF condition for YP as compared to the elderly (Fig. 1C). Changing the mechanical