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Dynamic balance during walking adaptability tasks in individuals post-stroke

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Maintaining dynamic balance during community ambulation is a major challenge post-stroke. Community ambulation requires performance of steady-state level walking as well as tasks that require walking adaptability. Prior studies on balance control post-stroke have mainly focused on steady-state walking, but walking adaptability tasks have received little attention. The purpose of this study was to quantify and compare dynamic balance requirements during common walking adaptability tasks post-stroke and in healthy adults and identify differences in underlying mechanisms used for maintaining dynamic balance. Kinematic data were collected from fifteen individuals with post-stroke hemiparesis during steady-state forward and backward walking, obstacle negotiation, and step-up tasks. In addition, data from ten healthy adults provided the basis for comparison. Dynamic balance was quantified using the peak-to-peak range of whole-body angular-momentum in each anatomical plane during the paretic, nonparetic and healthy control single-leg-stance phase of the gait cycle. To understand differences in some of the key underlying mechanisms for maintaining dynamic balance, foot placement and plantarflexor muscle activation were examined. Individuals post-stroke had significant dynamic balance deficits in the frontal plane across most tasks, particularly during the paretic single-leg-stance. Frontal plane balance deficits were associated with wider paretic foot placement, elevated body center-of-mass, and lower soleus activity. Further, the obstacle negotiation task imposed a higher balance requirement, particularly during the trailing leg single-stance. Thus, improving paretic foot placement and ankle plantarflexor activity, particularly during obstacle negotiation, may be important rehabilitation targets to enhance dynamic balance during post-stroke community ambulation.

1. Introduction

Community ambulation is a major challenge post-stroke, with only 7% of those discharged from the hospital reporting the ability to walk independently in the community (e.g., Hill et al., 1997). Further, 73% of the community ambulators have been reported to fall within 6 months of discharge from the hospital, with most falls occurring during walking (Forster and Young, 1995). Thus, it is essential to design effective interventions to improve dynamic balance during post-stroke community ambulation. A crucial step in designing effective interventions is to understand and quantify dynamic balance during walking tasks essential to community ambulation.

Walking at home and in the community involves both steady-state walking on level terrains as well as tasks that require walking adaptability such as negotiating obstacles, stepping up on surfaces (e.g., curbs) and walking on uneven terrains. Walking adaptability is the ability to modify steady-state walking pattern to meet task goals and environmental demands (Balasubramanian et al., 2014). Although most studies of post-stroke walking function and dynamic balance have focused on steady-state walking (e.g., Allen et al., 2014; Hall et al., 2012; Nott et al., 2014), walking

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adaptability tasks have received little attention (Balasubramanian et al., 2014).

Analysis of whole-body angular-momentum (H) has provided an objective method for assessing dynamic balance in individuals post-stroke during steady-state walking (Nott et al., 2014; Vistamehr et al., 2016). This approach has also been used to quantify dynamic balance in adults with lower limb amputations during steady-state walking (Silverman and Neptune, 2011) and various adaptability tasks (e.g., Pickle et al., 2014; Sheehan et al., 2015), in older adults recovering from a trip (Pijnappels et al., 2005b), and in healthy younger adults (Herr and Popovic, 2008; Neptune and McGowan, 2011, 2016; Silverman et al., 2014, 2012; Yeates et al., 2016).

While the generation of H is essential to walking performance, H is highly regulated in order to maintain dynamic balance (Herr and Popovic, 2008). The regulation of H involves complex multi-level interactions between the central-nervous-system, the neuromechanics of muscle force generation and foot placement, and the resulting net external moment about the body center-of-mass (e.g., Neptune and McGowan, 2016; Pijnappels et al., 2005a, b; Robert et al., 2009). The net external moment, a function of foot placement and ground-reaction-forces (Fig. 1), is equal to the time rate of change of H. Thus, any adaptations in foot placement and generation of ground-reaction-forces can influence the rate of change of H and resulting peak-to-peak range of H (H_R) (e.g., Silverman and Neptune, 2011). Further, simulation studies of healthy adults during walking have shown that the ankle plantarflexors (soleus and gastrocnemius) are primary contributors to the ground-reaction-forces and the key regulators of H in both sagittal and frontal planes (Neptune and McGowan, 2011, 2016). However, it is not clear how foot placement and muscle activation adaptations post-stroke influence the regulation of H and the resulting H_R.

A higher H_R imposes higher balance control demands, which if not met properly during a perturbed condition, can lead to falls (Pijnappels et al., 2005a). Although certain tasks such as stair climbing may demand higher H_R generation than level walking (Silverman et al., 2014), a higher H_R can also result from poor H regulation in those with mobility impairments, suggesting presence of balance deficits. Prior studies of individuals post-stroke have shown that during steady-state walking, those with higher H_R in the frontal plane have poorer Berg Balance Scale (BBS) and Dynamic Gait Index (DGI) scores (Nott et al., 2014; Vistamehr et al., 2016). Further, those classified as fallers based on BBS and DGI scores, poorly regulated their H particularly during the paretic single-leg-stance (SLS), identifying this phase of the gait cycle as a period of higher instability (Nott et al., 2014). The assessment of dynamic balance through the analysis of H in individuals post-stroke has been limited to the frontal plane steady-state level walking. Thus, there are gaps in understanding the regulation of H in other anatomical planes and during tasks requiring adaptability.

The primary purpose of this study was to assess dynamic balance using three-dimensional H in individuals post-stroke and healthy adults across selected walking adaptability tasks and to identify the underlying mechanisms associated with the regulation of H. Our first hypothesis was that across all tasks, significant balance deficits would be evident during the paretic-SLS compared to the nonparetic- and healthy control-SLS. In our second hypothesis, we were most interested in anatomical planes (Fig. 1) where the largest differences in H were present between groups. We hypothesized that individuals post-stroke used different mechanisms for

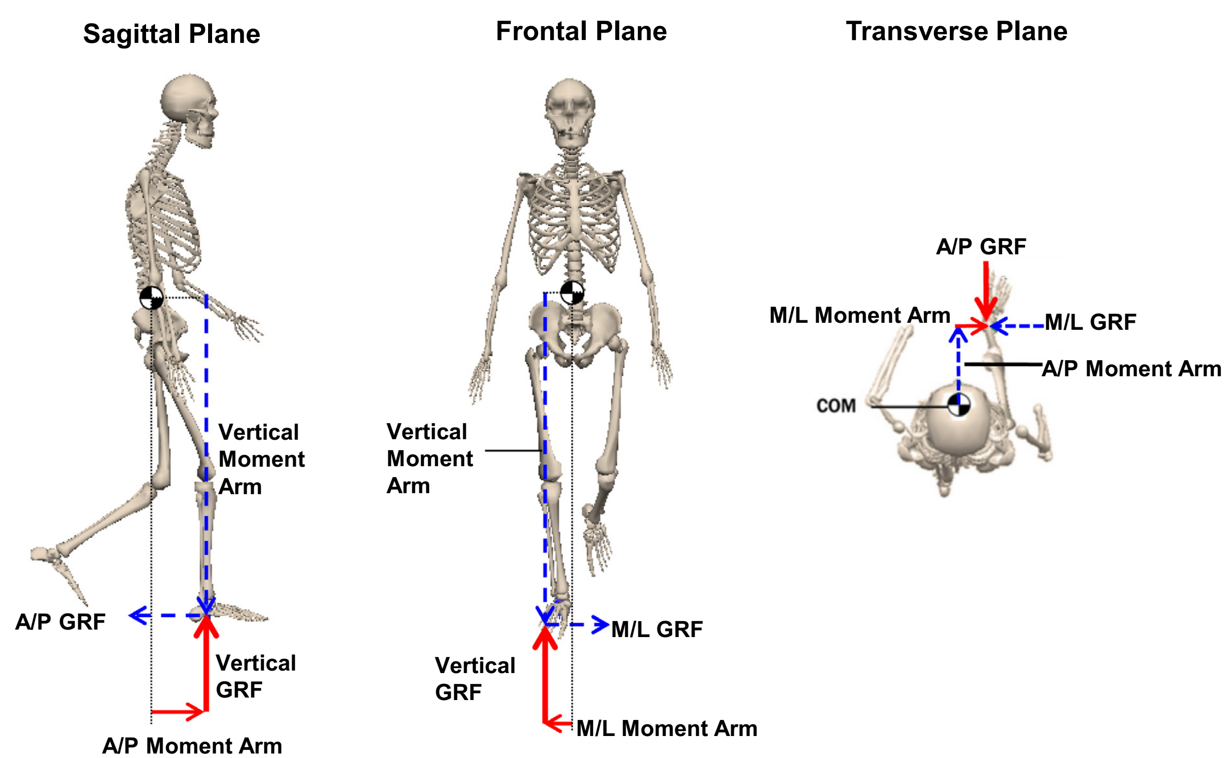

Fig. 1. The net external moment components are shown in the sagittal, frontal and transverse planes during single-leg-stance. Whole-body center-of-mass (CoM) is shown with '⊕'. The ground-reaction-force (GRF) vectors and their corresponding moment arms appear in the same color. During single-leg-stance, only the stance leg contributes to the net external moment about the body CoM. In each plane, the net external moment consists of two moment arm and GRF components. For instance, in the frontal plane, only the vertical and mediolateral moment arms and GRFs contribute to the net external moment and the regulation of whole-body angular-momentum. Here, we focus on analyzing the moment arms to further understand the regulation of whole-body angular-momentum. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)