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Cognitive-motor dual-task interference modulates mediolateral dynamic stability during gait in post-stroke individuals

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ABSTRACT

Gait asymmetry and dynamic balance impairments observed in post-stroke individuals increase their risk of fall. Moreover, walking while performing a cognitive task (*i.e.* dual-task) disturbs the control of balance in post-stroke individuals. Here we investigated the mediolateral dynamic stability in twenty-two community-dwelling participants (12 post-strokes and 10 healthy controls) while walking in single-task (normal gait) and four different dual-tasks (cognitive-motor interference). Positions of the extrapolated center of mass and mediolateral widths of both margin of stability and base of support were extracted from 35 marker trajectories. Post-stroke participants presented larger margin of stability and base of support than controls during single-task (both $p < 0.01$), with a larger margin of stability on the non-paretic side than on the paretic side at ipsilateral foot-strike ($p < 0.05$). No significant effect of the dual-task was found between groups. In post-stroke participants, dual-task induced slight modification of the mediolateral stability strategy, as the margin of stability was not different between the two limbs at foot-strike, and significantly reduced the performance in every cognitive task. Post-stroke participants increased their dynamic stability in the frontal plane in single-task by extending their base of support and mainly relying on their non-paretic limb. Under cognitive-motor interference (dual-task), post-stroke participants prioritized dynamic stability over cognitive performance to ensure a safe locomotion. Thus, rehabilitation programs should consider both dynamic balance and dual-task training, even at a chronic delay following stroke, to reduce the risk of fall in post-stroke individuals.

1. Introduction

Surviving stroke individuals usually come with balance impairments that may increase instability during locomotion. For

Abbreviations: BoS, Base of Support; CB, Counting Backward; CF, Counting Forward; CoM_{WB}, Whole-body Center of Mass; FAn, Verbal fluency (“Animals” category); FP, Verbal fluency (“P” first letter); MoS, Margin of Stability; XCoM, eXtrapolated Center of Mass

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instance, a reduced forward walking velocity (Hak et al., 2013), reduced lower-limb joints excursions (Lamontagne, Stephenson, & Fung, 2007) or a reduced whole-body angular momentum (Nott, Neptune, & Kautz, 2014) have been associated with increased instability in post-stroke individuals. Instability reflects the individuals' deficits (Hof, van Bockel, Schoppen, & Postema, 2007; Kao, Dingwell, Higginson, & Binder-Macleod, 2014) in his/her ability to prevent falling despite a perturbation (Bruijn, Meijer, Beek, & van Dieen, 2013; Hof, Gazendam, & Sinke, 2005). Dynamic (in)stability can be assessed by the margin of stability (MoS), defined as the shortest distance between the current position of the extrapolated center of mass (XCoM) and the edges of the base of support (BoS) (Hof et al., 2005). MoS is usually computed along the mediolateral axis (Hak et al., 2013; Hof et al., 2007; Kao et al., 2014; Vistamehr, Kautz, Bowden, & Neptune, 2016), because the frontal plane is critical during forward-propelled locomotion (Rosenblatt & Grabiner, 2010) and step initiation (Tisserand, Robert, Chabaud, Bonnefoy, & Chèze, 2016). In addition, control of balance along the mediolateral axis requires an active control during locomotion (Bauby & Kuo, 2000). Thus, investigating mediolateral dynamic stability during locomotion allows to better understand impairments in motor strategies used to control balance. This study focuses on how post-stroke hemiparetic individuals control their dynamic stability while walking.

Asymmetrical patterns and dynamic balance impairments characterize the locomotion of post-stroke individuals (Beyaert, Vasa, & Frykberg, 2015; Chen, Patten, Kothari, & Zajac, 2005; De Bujanda, Nadeau, & Bourbonnais, 2004; Hak et al., 2013; Hendrickson, Patterson, Inness, McIlroy, & Mansfield, 2014; Lewek, Bradley, Wutzke, & Zinder, 2014; Melzer, Goldring, Melzer, Green, & Tzedek, 2010; Olney & Richards, 1996; Patterson, Gage, Brooks, Black, & McIlroy, 2010) and may contribute to an increased risk of falling in the mediolateral direction (Kao et al., 2014; Vistamehr et al., 2016). Compared to healthy subjects during normal gait, post-stroke individuals had larger dynamic stability (Nott et al., 2014; Vistamehr et al., 2016), with a higher MoS variability (Kao et al., 2014), especially during the balance-challenging paretic single-leg stance phase (Nott et al., 2014). Post-stroke individuals also showed a reduced capacity to adapt their MoS during gait while performing concurrent motor tasks (Hak et al., 2013, 2015). These observations may arise from adaptations in their locomotor strategies: increased step width (Chen et al., 2005; De Bujanda et al., 2004; Hak et al., 2013; Kao et al., 2014; Vistamehr et al., 2016), frequency and length (Hak et al., 2015). However, the increase in mediolateral dynamic stability found in post-stroke individuals needs to be interpreted with caution, as it is also associated with reduced performance in clinical balance assessments (Nott et al., 2014; Vistamehr et al., 2016).

In addition to motor impairments, post-stroke hemiparetic individuals may have cognitive impairments, and especially attentional deficits (Plummer et al., 2013; Plummer-D'Amato et al., 2008). Situations where individuals need to provide attention to other tasks while walking are countless in daily living (*e.g.* conversing with someone, carrying objects, remembering an appointment, *etc.*). Consequently, performing a cognitive task while simultaneously walking (*i.e.* a dual-task) is more challenging for post-stroke than for healthy individuals (Hausdorff, 2005; Yang, Chen, Lee, Cheng, & Wang, 2007), resulting in modified spatiotemporal locomotor patterns such as reduced velocity and cadence coupled with increased stride time when compared to single-task (Beyaert et al., 2015; Cockburn, Haggard, Cock, & Fordham, 2003; Plummer et al., 2013; Plummer-D'Amato, Altmann, Behrman, & Marsiske, 2010). These locomotor adaptations may allow post-stroke individuals to maintain their balance (Bowen et al., 2001; Hyndman, Ashburn, Yardley, & Stack, 2006; Plummer-D'Amato et al., 2008) while attention is divided by the dual-task. However, no study has evaluated the influence of cognitive-motor dual-tasking on mediolateral dynamic stability in post-stroke individuals during gait.

Falls mainly occur during locomotion in post-stroke survivors, reducing their independence and life expectancy (Weerdesteyn, De Niet, Van Duijnhoven, & Geurts, 2008). Which is why identifying the critical biomechanical factors in dynamic balance control is of clinical and rehabilitative interests. The objective of this study was to quantify the mediolateral dynamic stability in chronic ambulatory hemiparetic post-stroke individuals while walking, in single-task and under various dual-task conditions of different cognitive loads. We hypothesized that the mediolateral dynamic stability in post-stroke individuals compared to controls will be (1) increased, especially on the non-paretic side, traducing a voluntary motor adaptation to increase their stability, and (2) reduced in dual-tasks compared to single-task, as a result of altered attention to locomotion.

2. Material and methods

2.1. Study design and population

Twenty-two community-dwelling individuals (58.2 ± 10 years old (mean ± SD), 11 women) participated in this cross-sectional study. Twelve hemiparetic post-stroke participants (Stroke group) were enrolled in the Neurorehabilitation department of Geneva University Hospitals, at a chronic delay of 27 ± 17.5 months following stroke. Inclusion criteria for post-stroke participants were: (1) a first ever supratentorial stroke, ischemic or hemorrhagic, confirmed by brain imagery, (2) he/she regained the ability to walk after having lost this skill due to the stroke and (3) he/she had a score ≥6 on the new Functional Ambulation Classification scale (Brun et al., 2000). Exclusion criteria included: a score ≤24 at the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975), spasticity treatment of the lower limbs in the 6 months preceding inclusion and/or surgical treatment of the lower limbs in the year preceding inclusion as well as any other medical or surgical conditions affecting locomotion. Ten healthy participants (Control group) matched for age and anthropometric parameters (see Table 1) were included at the Geneva University Hospitals. The local ethical committee approved this study (GE 15-227) and each participant signed a written informed consent form.

2.2. Experimental protocol

Gait assessments were performed barefoot at spontaneous speed on a 10-meter walkway in the Willy Taillard Laboratory of Kinesiology, Geneva University Hospitals. Subjects were equipped with 35 reflective markers, according to the Plug-In-Gait model