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Right cerebral hemisphere specialization for quiet and perturbed body balance control: Evidence from unilateral stroke

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ABSTRACT

Our aim in this investigation was to assess the relative importance of each cerebral hemisphere in quiet and perturbed balance, based on uni-hemispheric lesions by stroke. We tested the hypothesis of right cerebral hemisphere specialization for balance control. Groups of damage either to the right (RHD, n = 9) or the left (LHD, n = 7) cerebral hemisphere were compared across tasks requiring quiet balance or body balance recovery following a mechanical perturbation, comparing them to age-matched nondisabled individuals (controls, n = 24). They were evaluated in conditions of full and occluded vision. In Experiment 1, the groups were compared in the task of quiet standing on (A) rigid and (B) malleable surfaces, having as outcome measures center of pressure (CoP) amplitude and velocity sway. In Experiment 2, we evaluated the recovery of body balance following a perturbation inducing forward body oscillation, having as outcome measures CoP displacement, peak hip and ankle rotations and muscular activation of both legs. Results from Experiment 1 showed higher values of CoP sway velocity for RHD in comparison to LHD and controls in the anteroposterior (rigid surface) and mediolateral (malleable surface) directions, while LHD had lower balance stability than the controls only in the mediolateral direction when supported on the rigid surface. In Experiment 2 results showed that RHD led to increased values in comparison to LHD and controls for anteroposterior CoP displacement and velocity, time to CoP direction reversion, hip rotation, and magnitude of muscular activation in the paretic leg, while LHD was found to differ in comparison to controls in magnitude of muscular activation of the paretic leg and amplitude of mediolateral sway only. These results suggest that damage to the right as compared to the left cerebral hemisphere by stroke leads to poorer postural responses both in quiet and perturbed balance. That effect was not altered by manipulation of sensory information. Our findings suggest that the right cerebral hemisphere plays a more prominent role in efferent processes responsible for balance control.

1. Introduction

The conceptualization that each cerebral hemisphere is specialized for particular functions of movement control is consensual in the literature. Sainburg (2014) has proposed that in right handers while the left cerebral hemisphere is specialized for predicting the effects of the relationship between muscular and external forces (body-environment dynamics), the right hemisphere is specialized at mechanisms associated with impedance control. Impedance control has been conceptualized as neuromotor mechanisms leading to maintenance of a stable posture and to appropriate movement corrections when the body suffers unanticipated perturbations. Recent

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advancement of Sainburg's theoretical model has led to the conceptualization of a hybrid movement control, with both cerebral hemispheres participating in the regulation of each limb. From that perspective, hemispheric specialization should be more evident in the contralateral limbs but affecting also (to a lesser extent) the control of ipsilateral body segments as well (Yadav & Sainburg, 2011 2014). Evidence consistent with the notion of specialization of the right cerebral hemisphere for impedance control has been accumulated from investigation in nondisabled individuals by showing that the control of nondominant (left) arm movements is based predominantly on impedance mechanisms to compensate for self- or externally-induced errors in reaching (Schabowsky, Hidler, & Lum, 2007; Yadav & Sainburg, 2011, 2014). This conclusion has been corroborated in similar evaluation of individuals with unilateral cerebral damage (Schaefer, Haaland, & Sainburg, 2007, 2009; Schaefer, Mutha, Haaland, & Sainburg, 2012).

Information on hemisphere specialization for balance control has been provided by studies in individuals who suffered unilateral cerebral damage by stroke. Investigations comparing balance control following damage to the right versus left cerebral hemisphere have indicated a functional specialization of the right hemisphere for body balance control. Right hemisphere specialization for balance control has been inferred from assessment of quiet body balance, showing that damage to the right in comparison with the left cerebral hemisphere leads to reduced capacity to shift body weight between the legs (Ishii et al., 2010), poorer body vertical orientation (Perennou et al., 2008), lower scores in qualitative clinical evaluation (Perennou et al., 1999), delayed recovery of independent stance (Bohannon, Smith, & Larkin, 1986; Laufer, Sivan, Schwarzmann, & Sprecher, 2003), increased body sway (Peurala, Kononen, Pitkanen, Sivenius, & Tarkka, 2007; Rode, Tiliket, & Boisson, 1997), and poorer voluntary center of pressure displacement (Ioffe, Chernikova, Umarova, Katsuba, & Kulikov, 2010; Ustinova, Chernikova, Ioffe, & Sliva, 2001). Poor balance control resulting from right hemisphere damage is consistent with the conjecture that right cerebral hemisphere specialization for impedance control favors postural stabilization. Even though previous studies in individuals with unilateral stroke have suggested right cerebral hemisphere specialization for balance control in quiet stance, distinct critical issues have been left untouched thus far. First, a prevalent explanation for decreased balance control from right cerebral hemisphere damage is based on the notion that the right hemisphere is specialized for intersensory integration, leading to poor sensory reweighting when one or more sensory sources are disrupted. Support for this perspective has been provided by results showing that damage of areas in the right but not in the left cerebral hemisphere induced greater sway under visual occlusion in comparison with behavior of undamaged individuals, whereas under full vision balance was not significantly impaired by stroke (Manor et al., 2010). These findings suggest that lateral asymmetries in body balance control are detectable in conditions of vision deprivation, requiring increased weighting of other sensory sources signaling postural sway, while balance performance is similar to that seen in nondisabled individuals under full sensory information (see also Bensoussan et al., 2007; Bonan et al., 2004; Marigold & Eng, 2006b). From this perspective, hemisphere specialization might be associated with sensory processing, with deficit of intersensory reweighting in conditions of sensory deprivation. Then, a comprehensive analysis of right hemisphere specialization for balance control should include evaluation of the role played by sensory processing. Second, the most challenging situation for balance control is represented by unexpected perturbations to stance. This challenge is particularly evident in post-stroke patients (Di Fabio, 1987; Di Fabio, Badke, & Duncan, 1986; Marigold & Eng, 2006a; Pollock, Ivanova, Hunt, & Garland, 2015), with unexpected perturbations being possibly associated with several cases of falls in that population (Mansfield, Inness, Wong, Fraser, & McIlroy, 2013; Salot, Patel, & Bhatt, 2016). While balance control in quiet stance requires continuous low-magnitude postural adjustments, perturbed balance requires fast and strong muscular responses proportional to the magnitude of perturbation to recover balance stability (Azzi, Coelho, & Teixeira, 2017). From this observation, it might be conceived that specific neural mechanisms underlie quiet and perturbed body balance control, with the first relying on continuous feedback processing while the latter being implemented by a burst of activation of postural muscles triggered by different sources of sensory information signaling direction and magnitude of balance loss.

In the present study, the issue of cerebral hemisphere specialization for balance control in quiet and perturbed balance was assessed in two experiments, comparing performance between individuals who suffered a unilateral stroke either to the right or to the left cerebral hemisphere. Age-matched neurologically nondisabled individuals served as reference for comparison. In Experiment 1A, we evaluated balance control in quiet stance on a rigid surface, while in Experiment 1B balance was evaluated with participants standing on a malleable surface leading to distortion of tactile afference from the feet soles. In Experiment 2, we evaluated for the first time cerebral hemispheres specialization in reactive postural responses to an unanticipated mechanical perturbation. In the two experiments, the relevance of visual information was assessed by contrasting the conditions of full vision and visual occlusion. Thus, we originally provide here results allowing for evaluation of adequacy of the proposition of right cerebral hemisphere specialization for impedance control, in contrast to specialization of sensory processing, for balance regulation. The proposition of right cerebral hemisphere specialization for impedance control leads to the prediction of poorer performance both in quiet and perturbed balance in individuals with right cerebral hemisphere damage. Alternatively, if hemisphere specialization is associated with deficits in sensory processing, one would expect increased impairment of balance control from right hemisphere damage only in conditions of manipulation of sensory information.

2. Experiment 1: Quiet standing

In this experiment, we evaluated balance control in quiet standing while supported on a rigid (Experiment 1A) and on a malleable (Experiment 1B) surface. Results are presented separately due to the different periods of time participants were able to stand on each surface.