BRAIN RESEARCH 1625 (2015) 159–170

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Research report

Hemispheric specificity for proprioception: Postural control of standing following right or left hemisphere damage during ankle tendon vibration

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ARTICLE INFO

Article history:
Accepted 28 August 2015
Available online 8 September 2015

Keywords:
Postural control
Proprioception
Hemisphere
Stroke
Vibration
Non-paretic limb

ABSTRACT

Right brain damage (RBD) following stroke often causes significant postural instability. In standing (without vision), patients with RBD are more unstable than those with left brain damage (LBD). We hypothesised that this postural instability would relate to the cortical integration of proprioceptive afferents. The aim of this study was to use tendon vibration to investigate whether these changes were specific to the paretic or non-paretic limbs.

14 LBD, 12 RBD patients and 20 healthy subjects were included. Displacement of the Centre of Pressure (CoP) was recorded during quiet standing, then during 3 vibration conditions (80 Hz – 20 s): paretic limb, non-paretic limb (left and right limbs for control subjects) and bilateral. Vibration was applied separately to the peroneal and Achilles tendons. Mean antero-posterior position of the CoP, variability and velocity were calculated before (4 s), during and after (24 s) vibration.

For all parameters, the strongest perturbation was during Achilles vibrations. The Achilles non-paretic condition induced a larger backward displacement than the Achilles paretic condition. This condition caused specific behaviour on the velocity: the LBD group was perturbed at the onset of the vibrations, but gradually recovered their stability; the RBD group was significantly perturbed thereafter. After bilateral Achilles vibration, RBD patients required the most time to restore initial posture.

The reduction in use of information from the paretic limb may be a central strategy to deal with risk-of-fall situations such as during Achilles vibration. The postural behaviour is profoundly altered by lesions of the right hemisphere when proprioception is perturbed.

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http://dx.doi.org/10.1016/j.brainres.2015.08.043
0006-8993/

1. Introduction

Control of standing posture predominantly depends on proprioceptive information from the ankle joint (Fitzpatrick and McCloskey, 1994). Antero-posterior control of the musculoskeletal system is mostly based on the contribution of the Triceps Surae muscle (Gatev et al., 1999) to feedforward (Morasso and Schieppati, 1999) and feedback (Peterka, 2002) loops. In contrast, control of the medio-lateral direction is strongly related to the biomechanics of the musculoskeletal system (Silfies et al., 2003) and the base of support (Day et al., 1993; Henry et al., 2001). Although visual information is less precise than proprioceptive information for postural regulation (Fitzpatrick and McCloskey, 1994), it tends to be used to a greater extent in the regulation of standing posture (Chiari, 2000). When visual cues are lacking, antero-posterior oscillations increase (Berencsi et al., 2005). Some authors described this behaviour as a postural strategy to intensify proprioceptive information (De Haart et al., 2004; Horak et al., 1990).

Tendon vibration is a simple, non-invasive technique used to investigate the central integration of proprioceptive information (Romaiguère et al., 2003). The vibration principally activates primary (Ia) afferents in the muscle spindles, mimicking muscle stretch (Roll et al., 1989; Bergenheim et al., 2000). When vibration is applied to the ankle of a subject in quiet standing, a postural reaction occurs to 'restore' muscle length and avoid the illusory fall. The amplitude of the postural reaction reflects the extent to which proprioceptive information is important to control the position (Abrahámová et al., 2009; Kavounoudias et al., 2001). Moreover, the magnitude of the reaction depends on the tendon vibrated. Vibration of the peroneal tendon is known to induce a relatively small posterior displacement compared with vibration of the Achilles tendon (Duclos et al., 2014). One interpretation of this difference is that the Soleus muscle is dominant in the antero-posterior control of the standing position relative to the peroneal muscles.

Proprioceptive integration is greatly altered by stroke-related lesions of the cerebral hemispheres. Proprioceptive impairment at the ankle is one of the most common and most lasting somatosensory deficits following hemispheric lesions (Connell et al., 2008; Lee et al., 2005), leading to changes in postural control and regulatory sensory-motor loops (Jacobs and Horak, 2007). These lesions frequently impair postural control, leading to a loss of functional independence (Fong et al., 2001).

Postural impairments following stroke are strongly related to the side of the lesion (Pérennou et al., 2008). They occur particularly following lesions of the right hemisphere (Bohannon et al., 1986). Thirty-three percent of patients with right brain damage (RBD) do not recover independent sitting compared with only 5% following left brain damage (LBD). Equally, patients with LBD have 60% chance of recovering standing compared with only 37% of patients with RBD two months post stroke (Laufer et al., 2003). When standing capacity is restored, patients with RBD are generally more unstable (Manor et al., 2010). This postural instability is often related to deficits in environmental-perception. Changes in the subjective visual vertical occur more frequently following RBD than LBD (Bonan et al., 2007). However, in patients who have recovered upright standing, the relationship between subjective visual vertical and the side of lesion is no longer significant (Pérennou et al., 2008). Patients with RBD also frequently have an increased dependence on visual information (Bonan et al., 2004; Manor et al., 2010). This dependence may be related to a lack of use of other sources of sensory information, including proprioceptive information (Bonan et al., 2004; Marigold et al., 2004). Thus the regulation of sensory-motor loops for postural control may occur principally in the right hemisphere and may depend on one predominant form of sensory information. A paradigm involving tendon vibration has previously demonstrated hemispheric asymmetry for proprioceptive processes, independently from the subject's posture. Movement illusions induced by vibration only occur if cortical areas in the right hemisphere are activated (Cignetti et al., 2014). Activation of the right hemisphere during bilateral ankle vibration is correlated with the control of stable standing (Goble et al., 2011).

Following stroke, the functional role of each lower limb is altered (Mansfield et al., 2013). Postural control of the paretic lower limb remains impaired even if the spontaneous distribution of body-weight on each foot is symmetrical (Mansfield et al., 2013; Van Asseldonk et al., 2006). Bonan et al. (2013) showed that the majority of patients with hemiparesis respond to proprioceptive perturbations applied in standing, regardless of the degree of clinically-evaluated sensory impairment. Changes in posture during Achilles tendon vibration were not correlated with the degree of sensory deficit. However the stimulation was bilateral, therefore the postural reaction was based on information from both the paretic and non-paretic limbs. It is necessary to separately evaluate the paretic and non-paretic limbs and to consider the side of cortical lesion when evaluating the effects of proprioceptive perturbation on posture.

We therefore wished to apply the paradigm of tendon vibration separately to each limb in patients with LBD and RBD, in order to specify the role of unilateral proprioceptive integration in the global organisation of postural control. The integration of proprioceptive information to control the standing position depends on the mechanical context of instability (Ivanenko et al., 1999; McIlroy et al., 2003). Thus, two vibration sites which provoke different amplitudes of anteroposterior instability (Duclos et al., 2014) were chosen: the peroneal and Achilles tendons.

We hypothesised that:

(1) Since the right hemisphere is dominant for postural control and lack of vision requires increased integration of proprioceptive information, patients with RBD would be generally more perturbed by proprioceptive stimulation (bilateral tendon vibrations) than patients with LBD and healthy subjects of the same age.
(2) The different effects of vibration on the paretic and non-paretic limbs would help to define the main cause of ill-adapted postural behaviour.
(3) The difference in the magnitude of the responses to vibration of the paretic and non-paretic limbs would vary