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Rapid processing of haptic cues for postural control in blind subjects

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HIGHLIGHTS

- Vision or touch stabilizes standing posture in sighted subjects: is touch-induced stabilization more rapid or more efficient in total blinds?
- Blinds exhibited a faster balance control than sighted when granted haptic reference.
- Vision loss favours the fast processing of a posture-stabilizing haptic cue.

ABSTRACT

Objectives: Vision and touch rapidly lead to postural stabilization in sighted subjects. Is touch-induced stabilization more rapid in blind than in sighted subjects, owing to cross-modal reorganization of function in the blind?
Methods: We estimated the time-period elapsing from onset of availability of haptic support to onset of lateral stabilization in a group of early- and late-onset blinds. Eleven blind (age 39.4 years ± 11.7 SD) and eleven sighted subjects (age 30.0 years ± 10.0 SD), standing eyes closed with feet in tandem position, touched a pad with their index finger and withdrew the finger from the pad in sequence. EMG of postural muscles and displacement of centre of foot pressure were recorded. The task was repeated fifty times, to allow statistical evaluation of the latency of EMG and sway changes following the haptic shift.
Results: Steady-state sway (with or without contact with pad, no haptic shift) did not differ between blind and sighted. On adding the haptic stimulus, EMG and sway diminished in both groups, but at an earlier latency (by about 0.5 s) in the blinds (p <0.01). Latencies were still shorter in the early-than late-blinds. When the haptic stimulus was withdrawn, both groups increased EMG and sway at equally short delays.
Conclusions: Blinds are rapid in implementing adaptive postural modifications when granted an external haptic reference. Fast processing of the stabilizing haptic spatial-orientation cues may be favoured by cortical plasticity in blinds.
Significance: These findings add new information to the field of sensory-guided dynamic control of equilibrium in man.

1. Introduction

Visual impairment increases the risk of falling in otherwise healthy populations (Lamoureux et al., 2010). Beyond the likely event of encountering an unseen obstacle, visually-impaired persons might react to it in inappropriate ways in spite of their cautious walking strategy (Nakamura, 1997; Hallemans et al., 2010), since vision assists the coding and processing of other sensory information (Paulus et al., 1984). Transients in sensory inflow, particularly vision and proprioception that are normally of paramount importance for body orientation in space (Peterka and Loughlin, 2004; Mergner et al., 2005; Mergner, 2007; De Nunzio et al., 2005), require well-timed and coordinated responses for successful control of balance. How loss of vision modifies the treatment of information from a changing environment and modifies the stabilizing responses in the blind has not received much attention to date.

Abbreviations: CoP, Centre of Pressure; nT, no-touch; PER, Peroneus Longus; SOL, Soleus; T, touch; TA, Tibialis Anterior.

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In sighted subjects, under both quiet stance and dynamic conditions, vision is not readily replaced by other sensory inputs: with eyes closed, body stability is reduced during stance (Dichgans et al., 1976; Schieppati et al., 1999) as well as in dynamic postural tasks (Corna et al., 1999; Schieppati et al., 2002). In people with impaired visual function, minor differences in quiet stance control compared to sighted people have been reported (Rougier and Farenc, 2000). However, when exposed to sudden stance perturbation, the automatic postural responses of the blind were not different from those of sighted persons (Nakata and Yabe, 2001). Diminished visual acuity clearly affects the motor behaviour during a balancing task consisting in a series of repeated, predictable perturbations of stance produced by a moving platform, pointing to the paramount role of vision in selecting and modulating the balancing strategy (Schmid et al., 2008). During the same type of balance perturbation, blind subjects behave very much as sighted people eyes-closed, and the displacement of the body's centre of mass while counteracting the perturbation is larger than that of sighted people eyes-open (Schmid et al., 2007). These findings indicate no superior capacity of coping with perturbations in blind people as a result of long-term plasticity (Pascual-Leone et al., 2005), suggesting that proprioception does not compensate for permanent vision loss by providing a safer balancing strategy during dynamic tasks. Others have recently found superior proprioceptive acuity in the blind, which however does not translate into improved balance control (Ozdemir et al., 2013). In sighted subjects, body stabilization can be definitely achieved by haptic referencing to stationary surroundings (Nardone et al., 1990; Schieppati and Nardone, 1991), even when the applied force is insufficient to provide mechanical stabilization (Jeka and Lackner, 1994). Stabilization also occurs in blind subjects with additional sensory information provided by a cane, even if no superior abilities with respect to blindfolded sighted subjects were demonstrated (Jeka et al., 1996).

In the blind, tactile activation occurs in cortical areas that normally subserve vision (Sadato et al., 2002; Noppeney, 2007), even if the ultimate function of the enhanced tactile acuity remains controversial (see Sathian and Stilla, 2010). Experiments in congenital and late-onset blind people suggest that early visual experience may play a role in facilitating haptic shape discrimination (Burton, 2003; Goldreich and Kanics, 2003). However, the precise haptic task administered to the blind subjects can make a difference in the degree to which they outperform sighted (Alary et al., 2009).

The mentioned studies may not have addressed all aspects of balance control in the blind, since balance relies on time-consuming neural processes of sensorimotor integration of tactile, proprioceptive or haptic cues (Schieppati and Nardone, 1995; Rabin et al., 1999). In sighted subjects riding the continuously moving platform, adding or removing vision during the ongoing balancing task modifies the behaviour from head fixed-in-space (eyes open) to head-translating-with-the-platform (eyes closed) at time-delays as short as 1 s (De Nunzio et al., 2007), indicating the operation of a sensorimotor integration process able to affect the postural set within a short delay. Recently, the delay has been estimated in sighted subjects freely standing on a stable base following addition or withdrawal of visual or haptic information (Sozzi et al., 2012). The results confirmed that the changes in postural behaviour in response to a stabilizing sensory cue require a finite amount of time. In particular, this delay from the sensory shift to the change in postural control mode was longer than reflexes or voluntary responses, signifying the operation of a central integration process, and it was longer for haptic than visual cues, indicating a modality-dependence.

No studies have addressed the speed of the neural process whereby a given haptic cue translates into an appropriate balance-stabilizing response in the blind. In the present investigation, we tested a group of blind subjects with the same sensorimotor integration task previously administered to sighted subjects. Our aim was to assess whether, in spite of known deficits in the processing speed of visual stimuli in the intact visual field of patients with visual system damage (Bola et al., 2013), blind subjects are more prompt than sighted subjects eyes-closed in reducing body sway in response to a haptic cue, based on their past experience and acquired skill in the use of their remaining senses (Pascual-Leone et al., 2005; Cattaneo and Vecchi, 2011). The variable considered for this analysis was the delay from the moment of lightly touching a touch-pad to the onset of reduction of the random body oscillations and related EMG activity of the postural leg muscles. In addition, we addressed the issue whether late-blind behave like congenitally-blind subjects, in whom the plasticity process would be differently structured (Cohen et al., 1999; Sadato et al., 2002).

2. Methods

2.1. Participants

Eleven blind subjects (age 39.4 years ± 11.7 SD, height 161.7 cm ± 12.4, weight 61.9 kg ± 15.6, foot length 24.1 cm ± 2.2) and eleven sighted subjects (age 30.0 years ± 10.0 SD, height 174.2 cm ± 8.7, weight 68.3 kg ± 11.1, foot length 25.6 cm ± 1.7) participated in the experiments. All subjects were free of otological, neurological, or orthopaedic abnormalities except for visual function. All blind subjects had either no perception of light or light perception, but with vision in the best eye of less than 20/500. All were included in the diagnosis H54.0 of the WHO 'blindness, binocular' classification (ICD-10 WHO 2010). Four of the blind subjects were early-blind (i.e., onset of blindness at age <5 years), seven had lost vision later in life (age >5 years, late-blind). The blindness was of variedaetiology. Some late-blind participants were born visually impaired and had gradually become blind; others became blind as a result of an accident (Table 1). Based on the interview, all blind and sighted subjects were right handed; all blind subjects were familiar with Braille reading, for which they used the right hand. All were naïve to the experimental task and had not participated previously in balance control investigations. However, all of them had received at some point in their life an orienteering and training course, in a rehabilitation setting, comprising approximately 35–40 h over an average 6- to 8-week program. All procedures were carried out in accordance with the Declaration of Helsinki with the adequate understanding and written informed consent of the subjects. The research protocol had been approved by the local review board and ethical committee.

2.2. Task and procedure

The experiments took place in a normally lit room. All subjects stood in tandem position (heel of one foot placed directly in front of the toes of the other foot) with eyes closed on a force platform. Subjects chose which foot was the front foot (it was the right foot in 8 blind and in 11 sighted subjects). In this position, subjects were asked to gently lower the right hand (<5 cm) so as to lightly touch with the fingertip a touch-pad, or to withdraw the finger from the pad, after a verbal go-signal given by the operator at intervals of about 20 s (the actual duration of the interval varied pseudo-randomly between 15 s and 25 s). The touch-pad was horizontally oriented and positioned in front of the subject's right hemi-body at about the height of the flexed forearm. The height of the touch-pad was adjusted prior to testing for each subject, so that the light contact was maintained easily during the touch period. Subjects were asked to not move the hand in a reaction-time mode on hearing the verbal signal, but to self-pace the finger