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Self-motion perception and vestibulo-ocular reflex during whole body yaw rotation in standing subjects: The role of head position and neck proprioception

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A B S T R A C T

Self-motion perception and vestibulo-ocular reflex (VOR) were studied during whole body yaw rotation in the dark at different static head positions. Rotations consisted of four cycles of symmetric sinusoidal and asymmetric oscillations. Self-motion perception was evaluated by measuring the ability of subjects to manually track a static remembered target. VOR was recorded separately and the slow phase eye position (SPEP) was computed. Three different head static yaw deviations (active and passive) relative to the trunk (0°, 45° to right and 45° to left) were examined. Active head deviations had a significant effect during asymmetric oscillation: the movement perception was enhanced when the head was kept turned toward the side of body rotation and decreased in the opposite direction. Conversely, passive head deviations had no effect on movement perception. Further, vibration (100 Hz) of the neck muscles splenius capitis and sternocleidomastoideus remarkably influenced perceived rotation during asymmetric oscillation. On the other hand, SPEP of VOR was modulated by active head deviation, but was not influenced by neck muscle vibration. Through its effects on motion perception and reflex gain, head position improved gaze stability and enhanced self-motion perception in the direction of the head deviation.

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1. Introduction

The vestibular system requires visual and proprioceptive information for stabilizing eyes and head in space and for assuring adequate self-motion perception. Integration from accelerative to positional signals occurs in the vestibular circuitry for adjusting reflex and perceptive responses to functional needs (Mergner, Nasios, Maurer, & Becker, 1991; Mergner, Rottler, Kimming, & Becker, 1992; Robinson, 1981; Wilson & Melvill Jones, 1979). However, this transformation is not sufficient to guarantee correct gain and phase of movement perception and of VOR in the low velocity-range of movement. To this aim, the combination of visual, proprioceptive and vestibular signals is necessary. In case of poor visual information, the role of proprioception becomes of fundamental importance for both motion perception and VOR.

The dynamics of perceptive and reflex responses have been systematically investigated by Mergner and co-workers, who described how proprioceptive and vestibular signals interact with each other to provide information about body movement perception (Mergner et al., 1991, 1992; Mergner & Rosemeier, 1998; Mergner, Schweigart, Botti, & Lehmann 1998; Schweigart, Chien, & Mergner, 2002). They demonstrated different transfer properties of proprioception compared to the vestibular system in perceptive and ocular reflexes during horizontal sinusoidal rotation. During rotation of the head on the fixed trunk, vestibular and neck muscle receptors are activated conjointly. In this condition perceptive responses and ocular reflexes reach near optimal gain and phase over a wide range of frequencies, showing a complementary role of proprioceptive and vestibular signals, compatible with a linear summation mechanism (Collewijn, 1977; Mergner & Rosemeier, 1998).

While combinations of dynamic vestibular and neck proprioception activity have been widely analyzed, scarce information is available on the influence of *tonic* proprioceptive signals on the vestibulo-ocular reflex and body movement perception in humans. Position signals, as those arising from eye, neck or otolithic receptors sensitive to eye-head-trunk position and gravity, might influence the perceptive and reflex responses to dynamic body movements (Anastasopoulos et al., 1998; Botti, Anastasopoulos, Kostadima, Bambagioni, & Pettorossi, 2001; Bottini et al., 2001; Courtine, De Nunzio, Schmid, Beretta, & Schieppati, 2007; Müller et al., 2005 Pettorossi, Errico, & Ferraresi, 1997; Pettorossi, Manni, Errico, Ferraresi, & Bortolami, 1997; Pettorossi, Panichi, Bambagioni, Grassi, & Botti, 2004; Sugita-Kitajima & Koizuma, 2009). Therefore, tonic signals may provide positional information to that generated by the dynamic signals, and interfere with reflex and perceptive responses.

Attention to the issue is justified by the observation that head position is out of the primary position during curvilinear locomotion (Courtine & Schieppati, 2003) or can be so in several everyday activities like driving a car. Subjects tend to hold the head rotated toward the side they are turning to, and in general the head tends to anticipate the body movement (Grasso, Glasauer, Takei, & Berthoz, 1996; Grasso, Prévost, Ivanenko, & Berthoz, 1998; Hicheur, Vieilledent, & Berthoz, 2005). The influence of static gaze deviation on motion perception has already been demonstrated (Mergner et al., 1991; Pettorossi et al., 2004), indicating that the reproduction of a remembered target was influenced by the retinal and gaze eccentricity. Conversely, the effects of the static head displacement and neck proprioception on vestibular dynamic signals for movement perception and VOR have not been investigated yet. Therefore, the main target of the present study was to verify the hypothesis that the dynamics of both motion perception and VOR are influenced by horizontal head tonic deviation from the primary position and to dissect out the role of the central and peripheral signals.

To this aim, we studied the effect of different horizontal (yaw) head postures relative to the trunk on motion perception during whole-body yaw rotation in the dark. Since motion perception of whole-body rotation likely stems from vestibular receptor activation (Fernandez & Goldberg, 1971; Mergner et al., 1991), we analyzed also the vestibulo-ocular reflex (VOR) that shares, at least at the level of the vestibular nuclei, a common pathway with movement perception. If all body segments are kept in the primary position, both perception and VOR show characteristics that have been attributed to the high-pass transfer properties of the vestibular system (Mergner et al., 1991, 1992): the gain of both perceptive and reflex responses increases and phase decreases by increasing stimulation frequency. However, we do not know whether and to what extent the characteristics of these responses are maintained when the head is not in primary position. A 'new' interaction between the tonic neck