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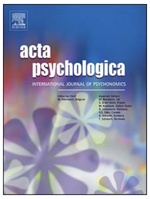

Inducing circular vection with tactile stimulation encircling the waist

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ABSTRACT

In general, moving sensory stimuli (visual and auditory) can induce illusory sensations of self-motion (i.e. vection) in the direction opposite of the sensory stimulation. The aim of the current study was to examine whether tactile stimulation encircling the waist could induce circular vection (around the body's yaw axis) and to examine whether this type of stimulation would influence participants' walking trajectory and balance. We assessed the strength and direction of perceived self-motion while vision was blocked and while either receiving tactile stimulation encircling the waist clockwise or counterclockwise or no tactile stimulation. Additionally, we assessed participants' walking trajectory and balance while receiving these different stimulations. Tactile stimulation encircling the waist was found to lead to self-reported circular vection in a subset of participants. In this subset of participants, circular vection was on average experienced in the same direction as the tactile stimulation. Additionally, perceived rotatory self-motion in participants that reported circular vection correlated with balance (i.e., sway velocity and the standard error of the mean in the medio-lateral dimension). The fact that, in this subset of participants, subjective reports of vection correlated with objective outcome measures indicates that tactile stimulation encircling the waist might indeed be able to induced circular vection.

PsycINFO classification

2300 Human Experimental Psychology
2320 Sensory Perception

1. Introduction

An illusory experience of self-motion (i.e. vection) can be induced by moving stimuli, even in absence of physical movement of the body (e.g. Lestienne, Soechting, and Berthoz, 1977; Riecke, Feuereissen, and Rieser, 2008). Several slightly different definitions of vection exist. In this article vection is defined as the sensation of self-motion induced by moving sensory stimulation not corresponding to the veridical self-motion. Self-motion illusions occurring in a linear fashion (i.e. translation along one or more of the three body axes) are referred to as *linear vection*. The illusion of rotation about one or more of the three body axes is referred to as *circular vection* (Väljamäe, 2009). In general, vection is experienced in the direction opposite to the sensory stimulation (Andersen, 1986; Riecke, Väljamäe, and Schulte-Pelkum, 2009; Väljamäe, 2009). However, a few studies have demonstrated that vection can be experienced in the same direction as the sensory stimulation (Nakamura & Shimojo, 2000 and 2003; Seno, Ito, and Sunaga, 2009).

Vection can be induced by stimulation in different (combinations of) sensory modalities. Visually-induced vection is the most studied type, with visual stimulation being able to induce both linear and circular vection (Andersen, 1986). Visually-induced vection can be modified by vestibular stimulation (Lepecq et al., 2006). Vestibular stimulation by itself (through electrical stimulation of the vestibular system) can also induce vection, with longer stimulation (at least 400 ms) and with higher currents (when tested with currents ranging from 0.5–4 mA) being more likely to induce an illusion of continuous movement (Fitzpatrick, Burke, and Gandevia, 1994; Wardman, Taylor, and Fitzpatrick, 2003). Auditory stimulation can enhance visually-induced vection as well (Riecke et al., 2009) and it can induce linear and circular vection by itself (Väljamäe, 2005 and 2009).

In addition to the subjective reports of vection, vection can influence the spatial reference frame as for example reflected in its influence on balance and walking. These effects are often interpreted as a

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correction to compensate for the perceived self-motion (e.g. Fitzpatrick et al., 1994; Wardman et al., 2003). In general, visually-induced linear and circular vection induce body displacements in the same direction as that of the moving visual stimulus (Bronstein and Buckwell, 1997; Fushiki, Kobayashi, Asai, and Watanabe, 2005; Kapteyn and Bles, 1977; Reason, Wagner, and Dewhurst, 1981) and when movement of the visual stimulus stops, participants return to an upright position and there after lean in the opposite direction (Reason et al., 1981). However, participants may report vection without a balance shift, or change their balance without reporting vection (Guerraz and Bronstein, 2008) or before vection is reported (Fushiki et al., 2005). Moving sounds from side to side or rotating around the participant's head induce vection and elicit lateral sway (Al'tman, Varyagina, and Levik, 2005; Soames and Raper, 1992; Tanaka, Kojima, Takeda, Ino, and Ifukube, 2001), yet not in a systematic direction. Regarding stimulation of the vestibular system, postural and locomotor deviations toward the stimulated side have been reported (Fitzpatrick et al., 1994; Bent, McFadyen, French Merkley, Kennedy, and Inglis, 2000; Cauquil, Martinez, Ouaknine, and Tardy-Gervet, 2000).

Thus, there is considerable evidence for vection induced by auditory, vestibular, and especially visual stimulation. Yet, research on tactile stimulation and vection is rather scarce and has generally focused on whether tactile stimulation can facilitate vection induced by stimulation of another sensory modality. For example, the addition of vibrations on an area of the body can enhance both visually-induced linear and circular vection (Riecke, Schulte-Pelkum, Caniard, and Bulthoff, 2005) and auditorily induced linear (Väljamäe, 2005) and circular (Riecke et al., 2008) vection. However, inhibition of vection by tactile stimulation has also been reported in a few participants (Riecke et al., 2005). Additionally, self-motion illusions induced by non-moving tactile stimulation on the supporting areas of the feet in standing participants are reported in three studies (Nilsson, Nordahl, Sikström, Turchet, and Serafin, 2012; Nordahl, Nilsson, Turchet, and Serafin, 2012; Roll, Kavounoudias, and Roll, 2002). Roll et al. (2002) first reported that ten seconds of stimulation on the supporting areas of both feet could induce illusions of linear self-motion (orthogonally directed and ipsilateral to the vibrated area of the feet) in 7 out of 10 blindfolded and restrained (to prevent real movement) participants. Nordahl et al. (2012) and Nilsson et al. (2012) continued this work by presenting participants different virtual environments (an elevator (Nordahl et al., 2012) or an elevator, train, bathroom, and darkness (Nilsson et al., 2012)). Identical tactile stimulation on the supporting areas of both feet could induce horizontal and vertical illusory linear self-motion, depending on the virtual environment. Notably, all studies examining the effect of tactile stimulation on the illusion of self-motion did not present moving tactile stimulation but rather examined whether tactile stimulation can induce uncertainty to the vestibular system and therefore increase the weighting of signals of other sensory modalities or whether it can increase the convincingness of motion simulation. Therefore, to our knowledge, vection induced predominantly by moving tactile stimulation and its effects on walking and balance have not been reported yet. The role of visual, vestibular and auditory information in determining (illusory) self-motion might appear more straightforward than the role of tactile information. Yet, tactile cues appear to play an important role in determining self-motion as well, as for example, air that flows over the skin during movement appears to play an important role in determining self-motion (Seno, Ogawa, Ito, and Sunaga, 2011). Additionally, tactile cues can influence orientation, especially when more weight is given to these cues compared to other sensory cues (van Erp and van Veen, 2006). Therefore, tactile-induced vection might be expected to influence walking and balance.

In earlier studies in our lab (Bos, van Erp, Groen, and van Veen, 2005; van Erp, Groen, Bos, and van Veen, 2006) several participants anecdotally reported circular vection as a result of receiving tactile stimulation encircling the torso. In these experiments, densely spaced vibrating elements were used to create a sensation of smooth apparent motion. However, these studies did not systematically measure circular vection. The aim of the current study was to (1) verify whether comparable tactile stimulation encircling the waist could induce circular vection around the body's yaw axis and (2) examine whether this type of stimulation would influence walking and balance. To this end, we assessed participants' subjective strength and direction of perceived self-motion while their vision was blocked and while they received tactile stimulation encircling the waist clockwise or counterclockwise or no tactile stimulation. Additionally, we assessed participants' walking trajectory and balance while their vision was blocked and while receiving these different stimulations.

It was expected that participants would experience clockwise circular vection with counterclockwise tactile stimulation and counterclockwise circular vection with clockwise tactile stimulation. In addition, it was expected that tactile stimulation would lead to the participants' walking trajectory and balance to be shifted in the same direction as the tactile stimulation. Specifically, participants' walking trajectory was expected to deviate and participants' balance was expected to shift to the right with clockwise and to the left with counterclockwise tactile stimulation.

2. Method

2.1. Participants

A total of 40 participants gave written and verbal consent and participated in this study, 20 female and 20 male. The participants were aged in between 40 and 60 years (*Mean* = 52.30 ± *SD* = 6.13). The criteria for exclusion were: (1) history of orthopedic disorders; (2) usage of medication that is known to influence the vestibular system; (3) usage of assistive devices for standing; and (4) not being able to stand in the Romberg position (an upright position with legs stretched, feet together and arms held next to the body) with the eyes closed for 30 s (assessed when participants arrived in the lab). Participants received 30 euros for their participation. The study was approved by the TNO Institutional Review Board (Ethical Application Ref: TNO-IRB-2013-12-31) and was conducted according to the principles expressed in the Declaration of Helsinki.

2.2. Apparatus, stimuli and measures

2.2.1. Tactile stimulation

Tactile stimulation was presented by means of a ‘belt’ consisting of a string of 13 vibration elements (i.e. tactors) mounted on elastic textile, developed by Elitac, Amsterdam, the Netherlands. This belt was worn around the waist at approximately 6 cm above the participant's navel over one layer of thin clothing. The tactors were lightly pressed on the skin by the elastic textile. The tactors had a contact area of 28 by 9 mm and generated a 158 Hz oscillation. The optimal temporal parameters for the tactile stimulation were determined in a pilot study in which 10 research interns of TNO Human Factors participated. Participants in the pilot study indicated for 6 different stimulations how strongly they experienced self-rotation while they were seated with their eyes closed. A sequential oscillation of each tactor for 308 milliseconds with an overlap of 154 milliseconds elicited the strongest self-reported circular vection in the pilot study and these parameters were used in the current study. In this way the vibration travelled the whole waist (clockwise or counterclockwise) in about 2 s. This stimulation elicited weak self-reported circular vection (*M* = 3, *SD* = 1.78, on a scale from 1 to 10, ranging from ‘not strong at all’ to ‘absolutely strong’) in the pilot study and is within the range of optimal tactile apparent motion (van Erp, 2007). The tactile stimulation was demonstrated before starting the experiment. The expected effects of the tactile stimulation on the study's outcome measures were not disclosed at any time during the study.