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Research Report

Optic flow dominates visual scene polarity in causing adaptive modification of locomotor trajectory

Y. Nomura[a], A.P. Mulavara[b,*], J.T. Richards[c], R. Brady[c], J.J. Bloomberg[d]

[a]*Nihon University School of Medicine, Tokyo 173-8610, Japan*
[b]*National Space Biomedical Research Institute, Houston, TX 77030, USA*
[c]*Wyle Life Sciences, Inc., Houston, TX 77058, USA*
[d]*NASA Johnson Space Center, Houston, TX 77058, USA*

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Abstract

Locomotion and posture are influenced and controlled by vestibular, visual and somatosensory information. Optic flow and scene polarity are two characteristics of a visual scene that have been identified as being critical in how they affect perceived body orientation and self motion. The goal of this study was to determine the role of optic flow and visual scene polarity on adaptive modification in locomotor trajectory. An object is said to have visual polarity, or to be "visually polarized", when it contains an identifiable principal axis with one end distinct from the other. Two computer-generated virtual reality scenes were shown to subjects during 20 min of treadmill walking. One scene was a highly polarized scene, while the other was composed of objects displayed in a non-polarized fashion. Both virtual scenes depicted constant rate self motion equivalent to walking counterclockwise around the perimeter of a room. Subjects performed Stepping Tests blindfolded before and after scene exposure to assess adaptive changes in locomotor trajectory. Subjects showed a significant difference in heading direction, between pre- and post-adaptation Stepping Tests, when exposed to either scene during treadmill walking. However, there was no significant difference in the subjects' heading direction between the two visual scene polarity conditions. Therefore, it was inferred from these data that optic flow has a greater role than visual polarity in influencing adaptive locomotor function.

Theme: Motor systems and sensorimotor integration
Topic: Control of posture and movement

Keywords: Optic flow; Visual polarity; Adaptation; Locomotion control

1. Introduction

Locomotion and posture are influenced and controlled by vestibular, visual and somatosensory information [18,22,24,27,40,50]. Visual input information consists of various factors including variation in type and distribution of the content of the scene. Several characteristics of patterned visual scenes have been identified as being critical in how they affect perceived body orientation and self motion [22]. These factors perceived from the visual scene are then integrated in the central nervous system and provide input for postural and locomotor control. Visual scene characteristics can be distinguished into two kinds of categories: those that contribute to optic flow and those that define polarity of the visual scene.

1.1. The role of optic flow in postural and locomotor control

Locomotion results from the output synergy of multiple sensory inputs, including vision. Visual inputs provide us with important cues for orientation and self-movement perception during locomotion. The patterned visual motion seen during self-movement constitutes the optic flow field that provides perceptual cues about self-movement and environmental structure [17].

* Corresponding author.
E-mail address: mulavara@bcm.tmc.edu (A.P. Mulavara).

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Artificially imposed optic flow can cause changes in perceived body orientation and the sense of self movement (vection), when it conflicts with information from other sensory inputs. Studies have shown that subjects who are sitting and are stationary experience illusory self-tilt when viewing a real rotating circular display of dots [20,23]. Astronauts have reported increased sensations of body-tilt and self rotation when viewing a rotating display of dots in microgravity. This is attributed to an increased reliance on vision resulting from the lack of gravity input that otherwise provides a reference for equilibrium information [34,35,49,51].

Other studies have directly measured the effects of optic flow on postural stability during locomotion. The rate at which people walk on a self-driven treadmill has been shown to depend on the velocity of an artificial optic flow pattern along the line of sight relative to their walking speed [37]. Linear optic flow has also been shown to cause directionally specific postural sway and positional deviations during treadmill locomotion [4,5,46,47]. The effects of rotational optic flow have also been demonstrated. When oscillated in roll and viewed during quiet stance, scenes containing complex realistic content caused more postural sway than scenes with simple radial patterns [14]. While walking over ground in a stereoscopic virtual environment that rotated in roll, subjects showed compensatory torso rotation in the direction of scene rotation that resulted in positional variation away from a desired linear path [26].

1.2. The role of visual scene polarity in postural and locomotor control

An object is said to have visual polarity, or to be "visually polarized", when it contains an identifiable principal axis with one end distinct from the other [22]. Most visually polarized objects, such as houses, tables and chairs, appear asymmetrical in the vertical plane and have distinct ends that are designated "top" and "bottom". Usually, we are familiar with the visual scene distribution being organized according to certain rules including the assumption that the ceiling of a room is located upward, the floor is located downward and the furniture is placed on the floor. This polarized scene distribution is never tilted unless we lean our head or body with respect to the gravity force axis. In this context, the vestibular, proprioceptive and tactile sensors inform the central nervous system that the body is indeed not vertical. However, the perception of subjective vertical and postural equilibrium can be influenced if the visual scene is distorted or displays tilted polarity [36]. For instance, entering a room consisting of an oblique wall, ceiling and floor would lead to the perception of standing obliquely [13]. Similar to pure optic flow, visual polarity cues can have compelling effects on an observer's perceived spatial orientation. If all polarized objects in view are statically tilted with respect to gravity by the same amount, static observers sitting upright with respect to the gravity vector feel as if they themselves are tilted [3].

There is also evidence that visual polarity can strengthen the sense of self motion one perceives while viewing a dynamic visual scene. Subjects who sat in a real room that constantly rotated around them reported more rotational self motion when that room was furnished with polarized objects than when it did not contain such objects [24]. Duh et al. reported that their subjects exhibited more balance disturbance and more difficulty in maintaining posture during viewing a rotating high resolution virtual reality scene containing polarized objects than when they viewed a simple radial pattern [14]. We have previously reported difference in the influence of a polarized furnished room scene and a random dot non-polarized scene moving about its different axes, with polarized scenes causing greater postural instability than the non-polarized scenes during treadmill walking [38].

1.3. Adaptive modification of locomotor trajectory

Humans can rapidly readjust and recalibrate various characteristics of gross movement activities such as walking to deal with variations in environmental constraints by using visual input [15,18,46,47]. Some of these characteristics include the estimation of distances to walk to reach a target and the direction of movement [39,40].

Rieser et al. demonstrated that the estimate of distance to a target, to which the subject has to walk, can be recalibrated by exposure to a disparity between visual flow and walking speed [40]. Subjects walked on a motorized treadmill and were exposed to linear visual flow that moved either faster or slower than their biomechanical walking speed. After 8 min of exposure to this stimulus, subjects were asked to walk in a straight line to a remembered target location with vision occluded. Subjects exposed to visual flow that was faster than their treadmill walking speed tended to overshoot the remembered target, while the converse was true for those subjects exposed to visual flow slower than their walking speed. This experiment showed that an adaptive recalibration occurred in subject's perception of forward translation after exposure to a brief period of adaptive visual stimuli.

Additionally, other studies have shown adaptive recalibration in locomotor trajectory. Subjects that were asked to step in place on a rotating disk with their head and torso aligned with their straight ahead direction inadvertently turned in circles when asked to step in place on a stationary surface with eyes closed after exposure to this stimulus. This is an adaptive effect called podokinetic after-rotation (PKAR) [18,50]. PKAR suggests a remodeling of the somatosensory signals regarding the relationship between trunk rotation with respect to the feet and the perception of trunk rotation relative to space [50]. Other investigators have reported changes in walking trajectory following exposure to even simple visual stimuli consisting of optokinetic black and white vertical stripe patterns when