EXPOSURE TO A ROTATING VIRTUAL ENVIRONMENT DURING TREADMILL LOCOMOTION CAUSES ADAPTATION IN HEADING DIRECTION

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ABSTRACT

The goal of the present study was to investigate the adaptive effects of variation in the direction of optic flow, experienced during linear treadmill walking, on modifying locomotor trajectory. Subjects (n = 30) walked on a motorized linear treadmill at 4.0 km/h for 24 minutes while viewing the interior of a 3D virtual scene projected onto a screen 1.5 m in front of them. The virtual scene depicted constant self-motion equivalent to either 1) walking around the perimeter of a room to one's left (Rotating Room group) 2) walking down the center of a hallway (Infinite Hallway group). The scene was static for the first 4 minutes, and then constant rate self-motion was simulated for the remaining 20 minutes. Before and after the treadmill locomotion adaptation period, subjects performed five stepping trials where in each trial they marched in place to the beat of a metronome at 90 steps/min while blindfolded in a quiet room. The subject's final heading direction (deg), final X (for-aft, cm) and final Y (medio-lateral, cm) positions were measured for each trial. During the treadmill locomotion adaptation period subject's 3D torso position was measured. We found that subjects in the Rotating Room group as compared to the Infinite Hallway group: 1) showed significantly greater deviation during post exposure testing in the heading direction and Y position opposite to the direction of optic flow experienced during treadmill walking 2) showed a significant monotonically increasing torso yaw angular rotation bias in the direction of optic flow during the treadmill adaptation exposure period. Subjects in both groups showed greater forward translation (in the +X direction) during the post treadmill stepping task that differed significantly from their pre exposure performance. Subjects in both groups reported no perceptual deviation in position during the stepping tasks. We infer that

viewing simulated rotary self-motion during treadmill locomotion causes adaptive modification of sensory-motor integration in the control of position and trajectory during locomotion which functionally reflects adaptive changes in the integration of visual, vestibular, and proprioceptive cues. Such an adaptation in the control of position and heading direction during locomotion due to the congruence of sensory information demonstrates the potential for adaptive transfer between sensorimotor systems and suggests a common neural site for the processing and self-motion perception and concurrent adaptation in motor output. This will result in lack of subjects' perception of deviation of position and trajectory during the post treadmill step test while blind folded.

INTRODUCTION

Vision, more precisely - optic flow, is a fundamental parameter that modulates motor output during locomotion (Gibson 1966). Optic flow, as an independent component of visual sensory input, is essential for controlling the estimation of distances, heading direction, dynamic balance and posture during locomotion (Warren et al. 1996; Bardy et al. 1999; Warren et al. 2001; Richards et al. 2004). Linear and rotating optic flow has been shown to cause directionally specific postural sway and positional deviations during treadmill and over ground walking (Warren et al. 1996; Keshner and Kenyon 2000). 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 (Prokop et al. 1997). Linear optic flow has also been shown to cause directionally specific postural sway and positional deviations during treadmill locomotion (Bardy et al. 1996; Bardy et al. 1999; Jahn et al. 2001; Warren et al. 1996; Warren et al. 2001). 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 (Duh et al. 2002). 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 (Keshner and Kenyon 2000).

Humans can rapidly readjust and recalibrate various characteristics of their gross movement activities depending on the interactions between optic flow and biomechanical factors during locomotion (Rieser et al. 1990; Rieser et al. 1995). Some of these characteristics include the estimation of distances to walk to reach a target and the direction of movement. Investigations on the directional control of locomotion have shown that blindfolded subjects, after walking in place on a counterrotating platform or circular treadmill, while maintaining visual stationarity by keeping the torso and head orientations in the straight ahead direction, veered from their straight ahead trajectory in the same direction of the preceding turntable rotation (Gordon et al. 1995a; Gordon et al. 1995b; Weber et al. 1998; Earhart et al. 2001; Earhart et al. 2002; Weber et al. 2002). These authors have hypothesized that reinterpretation of intersegmental proprioceptive cues, triggered by the conflict between stationary vision and the turning feet on the platform, induces veering of locomotor trajectory from the straight ahead direction. Further experiments with concomitant optokinetic stimulation while stepping on a counter rotating platform caused a proportional increase in turning during post treadmill stepping in place (Jurgens et al. 1999). Jurgens, et al. (Jurgens et al. 1999) suggest that the previous result of adaptive modification of locomotor trajectory was the outcome of an adaptation of the somatosensory channel and not by a visual-somatosensory mismatch. However, subjects that are exposed to prolonged optokinetic stimulation, seated in the center of a rotating drum and watching a striped pattern, also generate curved walking trajectories in the direction opposite to that of the optokinetic stimulus when asked to step in place with their eyes closed (Kato et al. 1977; Gordon et al. 2003). Thus, optokinetic stimulation alone can cause an adaptive modification in the locomotion heading direction. In a series of experiments, Rieser, et al. (Rieser et al. 1990; Rieser et al. 1995) demonstrated that humans can reliably estimate the distance to a target and walk to it without vision. Importantly, this capability can be re calibrated after being exposed to a new relationship between the rates of walking relative to that of the optical flow of the surrounding environment (Rieser et al. 1995). Thus, humans have a flexible perceptual motor system that has the ability to learn the covariation between the optical flow and the consequence of their walking in the environment (Rieser et al. 1995).

The goal of this study was to determine if plastic adaptive modification in locomotor trajectory, during a stepping task, could be achieved when exposed to a new relationship between the direction of optic flow, with matched optic flow rate, and that of walking during linear treadmill locomotion. Hence, subjects were tested using a stepping in place test pre and post exposure to optic flow that either rotated about the subjects' vertical axis (yaw optic flow rotation) or translated fore and aft in the direction of linear locomotion. Further, this study also aimed to investigate the underlying mechanisms of adaptation by measuring torso kinematics during the adaptive exposure period.

METHODS

Participants

30 healthy subjects of average ((± 1 SD) age = 32.0 (± 1.3) yr., height = 167.4 (± 4.4) cm, and weight = 67.2 ± 4.6 kg with normal or corrected-to-normal vision were recruited from the Human Test Subject Facility at Johnson Space Center (JSC) in Houston, TX. The experimental protocol was approved by the NASA-JSC Committee for the Protection of Human Subjects (CPHS), and informed consent was obtained prior to testing.

Visual Scene Adaptation Protocol

Prior to experimental trials, subjects walked on the treadmill until they were comfortable walking without holding onto the handrails (usually < 5 minutes). Subjects walked at 4.0 km/h while viewing either the Rotating Room (RR group, Fig 1A) or the Infinite Corridor

(IC group, Fig 1B) visual scene for 20 minutes continuously. An equal number of subjects were randomly assigned to the two groups. The scenes either rotated in yaw in the clockwise direction at a constant rate of 30 °/s for the RR group or translated from fore to aft at a rate of 4 km/h for the IC group. The rotation rate of the Rotating Room visual scene was chosen such that the forward translation component of optic flow was equivalent to that seen in the Infinite Corridor visual scene. Previous studies have shown rotation rates close to this to be effective in causing sensations of self-motion (Watt et al. 1993; Allison et al. 1999). Data were collected during 120-sec epochs of time uniformly distributed during the walk period. The first data take while subjects walked on the treadmill included data obtained 1 min. before the scene started rotating while the scene was static (static epoch) and 1 min. after the scene started rotating (rotating epoch). The remainder of the data collection was uniformly timed through the remaining walk period. Subjects were instructed to fixate on the scene for the entire trial and try to immerse themselves in it without paying attention to their position on the treadmill belt. A spotter provided guiding commands (e.g., "move left") when the subject approached the limits of the treadmill belt surface.

Visual Optic Flow Scenes

The monoscopic, passive-immersive 3D visual scenes were created using graphic modeling software (3ds max 4; Discreet, Montreal, Que.) and rendered using virtual environment software (VRUT v. 2.5, Python v. 2.0) on a PC computer (2.2 GHz, Intel Pentium 4 processor, nVIDIA Quadro2 EX graphics card). Scenes either constantly rotated in yaw or constantly translated along the anterior-posterior (AP) body axis. The