A Hypothetical Perspective on the Relative Contributions of Strategic and Adaptive Control Mechanisms in Plastic Recalibration of Locomotor Heading Direction

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We have previously shown that viewing simulated rotary self-motion during treadmill locomotion causes adaptive modification of the control of position and trajectory during over-ground locomotion, which functionally reflects adaptive changes in the sensorimotor integration of visual, vestibular, and proprioceptive cues (Mulavara et al., 2005). The objective of this study was to investigate how strategic changes in torso control during exposure to simulated rotary self-motion during treadmill walking influences adaptive modification of locomotor heading direction during over-ground stepping.

Methods

Treadmill Locomotion Adaptation Protocol

Subjects (n = 10) walked on a motorized linear treadmill while viewing a wide field-of-view virtual scene for 24 minutes. The scene was static for the first 4 minutes and then, for the last 20 minutes, depicted constant rate self-motion equivalent to walking around the perimeter of a room to one's left. During treadmill walking, subjects' three-dimensional torso positions and angles were recorded at 60 Hz using a video-based motion measurement system, and gait cycle timing data were collected at 1000 Hz using foot-switches with force-sensing resistors attached to the heel and toe of each shoe. 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 for a total of 100 steps while blindfolded in a quiet room. At the end of each stepping trial, the subject's final position and heading direction were measured relative to his or her initial position and heading direction, respectively. Subjects never received post-test feedback of their performance and final heading direction.

Data Analysis

To characterize the positional and angular variation of the torso over the 20-min treadmill locomotion adaptation period, we calculated the root mean square (RMS) and sum of standard deviations (SSD) variation, respectively, for every 60 seconds of kinematic data collected during adaptation. Normalized variability data were then calculated for each subject as the ratios, R_P and R_O, of RMS position and SSD orientation values during scene rotation to RMS and SSD means during static scene presentation, respectively, for each body axis. These ratio means were measures of the relative *magnitude* of torso variation during scene motion. The 95% confidence intervals, CI_P and CI_O, for R_P and R_O, respectively, were considered measures of the variability in the magnitude, or the *volatility*, of torso variation during scene motion. Repeated measures ANOVAs were used to test for changes in magnitude and volatility of torso variation over the 20-min adaptation period. Post hoc contrasts were used to test for differences between individual

Epochs for those parameters who showed a significant main effect of Epoch. We then used regression analyses over all subject data to confirm the direction (increasing or decreasing) and significance of trends revealed by post hoc contrasts. We also ran separate regression analyses on each individual subject's variability data over time. To investigate whether a relationship existed between the observed change in heading direction following adaptation and the rate at which the magnitude or volatility of torso variation changed during adaptation, Pearson correlation tests were used with regression fit slopes and heading direction differences as variables.

Results
Repeated measures ANOVAs showed significant main effects of Epoch for both magnitude and volatility of variation in both torso X position and torso Yaw orientation. Post hoc contrasts between individual Epochs further indicated that changes in both magnitude and volatility of variation in torso X position and torso Yaw orientation were decreasing in nature. Regression analyses confirmed that decreasing trends over the 20-min adaptation period were significant, but only for the volatility in torso X variation and the magnitude of torso Yaw variation. Interestingly, Pearson correlation tests further showed that the rate at which the volatility in torso X variation decreased was negatively correlated with the heading direction bias observed during post-adaptation stepping trials ($R^2 = 0.45$, $p < 0.05$). The rate at which the magnitude in torso Yaw variation decreased was also negatively correlated with the heading direction bias, but was only marginally significant ($R^2 = 0.37$, $p = 0.06$).

Conclusions
Results indicate that the faster one can formulate and subconsciously implement a locomotor strategy for coping with a given visuo-motor disturbance, the more complete the sensorimotor reorganization is for a given visuo-motor disturbance, and consequently, the larger the magnitude of the adaptive aftereffect. We infer that adaptive recalibration of locomotor trajectory using optic flow stimuli depends on the rate at which strategic intervention is reduced.