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The effect of differing optic flow on steering behaviours during goal-oriented locomotion

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Abstract—**The ability of healthy young individuals to accurately steer toward a virtual target while experiencing different foci of expansion (FOE) and target positions was examined with the use of a virtual reality task. Ten participants steered toward the virtual target with the use of mouse displacements while sitting or while changing their body orientation during over-ground walking. Net virtual errors showed that participants were able to accurately align themselves with the target despite having confounding visual information regarding FOE location and heading direction. Participants performed better in the mouse-driven task than the walking task. This may be attributed to the nature of the tasks that employ different degrees of freedom. Altogether, results support the use of this virtual reality-based paradigm to further investigate the contribution of altered visual self-motion processing and gait-related impairments on steering abilities in stroke and in the elderly.**

Keywords-visual motion; virtual reality; gait; heading; healthy young

I. INTRODUCTION

Accurate goal-oriented locomotion relies on a correct perception and control of heading direction. During goal-oriented locomotion, vision serves to inform the person about his or her self-motion and surroundings. Optic flow (OF) is a source of visual information that is described as a pattern of motion of objects or edges in one's visual field that causes the perception of self-motion (1). The focus of expansion (FOE) describes the point of radial expansion of the OF. According to the OF theory, the control of steering or heading direction occurs by aligning the FOE of the OF with the desired goal. As a result, modifying the FOE during locomotion may induce changes in the trajectory taken to accurately arrive at the required goal (2). It has previously been shown that when virtual reality is used to offset the FOE of the OF, healthy individuals veer from their original trajectory in the physical world when attempting to exhibit a straight trajectory in the virtual world (3). However, the effect of different OF directions and target locations on goal-oriented locomotion has not yet been examined. Recent studies have also shown that heading responses to changes in optic flow directions can be altered by ageing (4) and stroke (5). Whether such alterations result from gait-related difficulties or an altered perception/integration of heading information remains unclear. In this context, virtual reality provides a unique opportunity to look into those factors by implementing a steering task that can be executed both in sitting and while walking. The purpose of this study is two-fold: first, to study steering strategies of young healthy individuals while walking to different targets in a virtual environment (VE) describing translational OFs expanding from different locations; second, to provide normative data and demonstrate the feasibility of the sitting and walking steering tasks.

II. METHODS

A. Participants

A convenience sample of 10 healthy young (19-29 yrs) persons participated in the study. Participants' vision was corrected to normal by eyewear if needed and they were free of neurological or orthopedic conditions that could interfere with locomotion. All participants signed an informed consent form and the project was approved by the Montreal Center for Interdisciplinary Research in Rehabilitation (CRIR) establishments' Research Ethics Board.

B. Setup and Procedures

The study consisted of 2 experiments that were completed in the same testing session. Both experiments were performed in identical virtual environments (VE) created with Softimage XSI. The VE represented an open room (40m X 25m) with a centrally located target at eye level and was 7m away from the participant. Target and FOE locations, initially at 0°, remained unchanged or shifted to ±20° after 1.5m of forward displacement.

In experiment A, participants were evaluated in a seated position while performing a mouse-driven steering task, with their dominant hand, in the VE which was rear-projected onto a large screen. Subject's anterior-posterior (A-P) displacement within the scene was set at 1.0 m/s and the trials ended after 5m of forward displacement. Subjects were instructed to 'head toward the target so as to align yourself with it', by controlling their medio-lateral (M-L) displacement within the VE with mouse M-L displacements. Participants performed 108 trials that were randomly presented in 5 blocks of 18 trials each.

In experiment B, participants were evaluated during an over-ground walking task in which the VE was displayed in a helmet-mounted display (NVisor™) (Fig. 1). Three-dimensional body coordinates were acquired with reflective markers placed on body landmarks and a 12-camera Vicon™ system. Participants performed 36 trials (4 blocks of 9 trials). Subjects' camera view was updated in real time based either on head coordinates (experiment B) or mouse M-L position (experiment A) using the CAREN-3 (Motek BV) software.

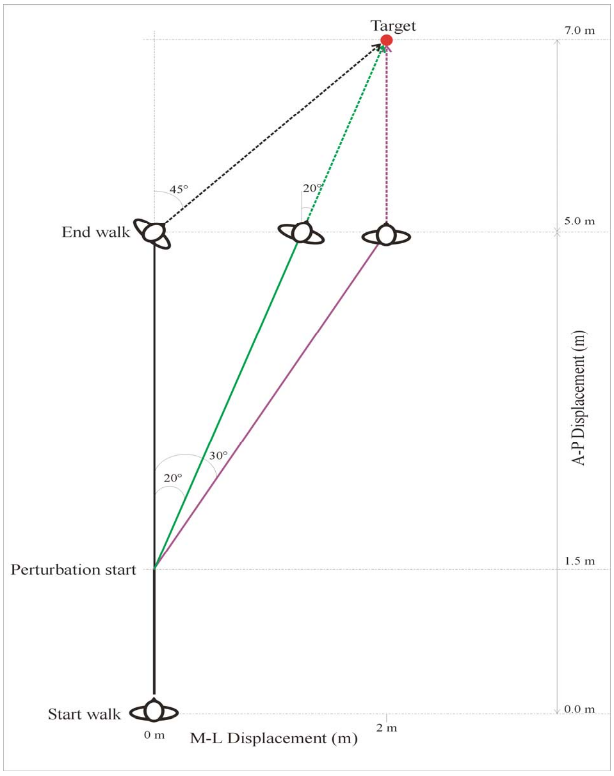

Figure 1. Representation of different scenarios illustrating the relationship between medio-lateral (M-L) body displacement and head rotation as a function of antero-posterior (A-P) progression while walking toward a target located to the right (Exp. B).

C. Data Analysis

Virtual heading and net virtual heading errors (NVE) were examined. Virtual heading was calculated as the instantaneous angular orientation of the participants' virtual trajectory along the M-L (x-axis) versus the A-P direction (y-axis) in the VE.

As the participants' alignment with the target could be achieved only with changes in M-L position with the mouse but through changes in both M-L position and head rotation in walking, NVE were calculated differently for experiment A and B. For experiment A, the net virtual error (NVE) was calculated first by subtracting the participants' M-L position and target position in the virtual world and then by converting this displacement error into the rotational domain, yielding a NVE value in degrees. For experiment B, the NVE was calculated as the angular difference between the actual and the ideal head rotation required to be perfectly aligned with the virtual target, given the participant's M-L position in the virtual world. NVE values at 5m of A-P displacement were averaged and contrasted across conditions. Positive and negative values of NVE refer to an overshooting or undershooting of the target, respectively.

III. Results

A. Experiment A

Examples of virtual heading traces in response to different FOE and target positions are shown for one participant (S1) in Fig. 2. Subjects used lateral mouse displacements, in the physical world, to align themselves with the targets in the VE. Participants required approximately 0.5s to react and begin adjusting their heading in response to the change in target and FOE locations. Upon beginning to adjust their heading, participants tended to make the majority of their adjustments within 2m from perturbation onset and then made little or no adjustments for the last 1.5m of their path. At 5m of forward walking, the participants exhibited virtual heading values of -22.2°, 0.0°, and 22.0° when FOE was centered and the target was positioned at -20°, 0°, and 20°, respectively.

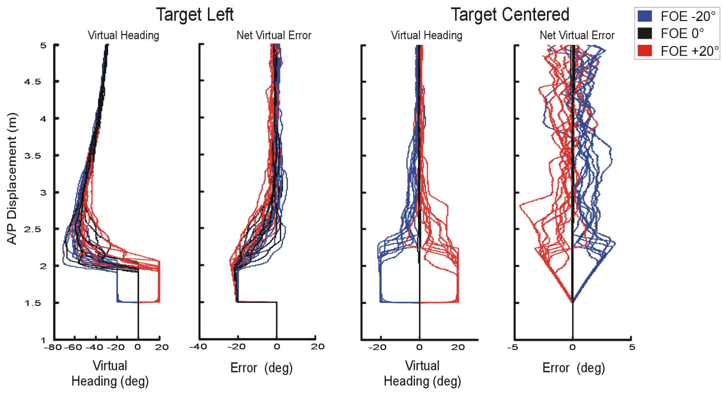

Figure 2. Virtual heading and net virtual errors for the target left and target centered conditions for participant S1 in experiment A.

As illustrated in Fig. 3, participants accurately aligned themselves with the targets, displaying mean NVEs between 2.5° and -1.5°. Although the NVEs were small, subjects overshot the target when target and FOE position were situated ipsilaterally while they undershot when the target and FOE were situated contralaterally.

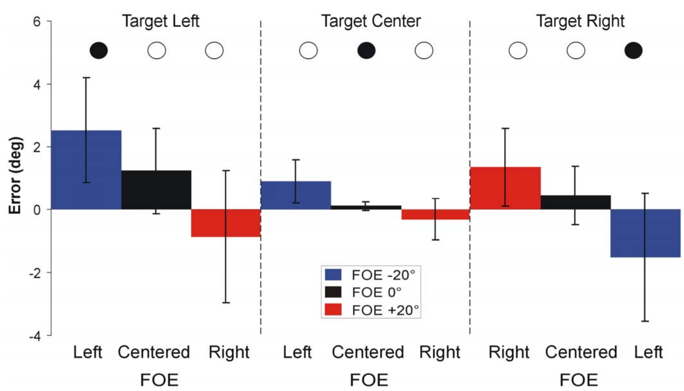

Figure 3. Mean net virtual errors (± 1SD) across all conditions for experiment A.

B. *Experiment B*

Examples of heading trajectories walked by participant S1 for target left and center in response to changing FOEs are shown in Fig. 4. As for the mouse trials, participants also made the majority of their corrections within 1.5m of onset of perturbation and then continued along the same path, making minimal or no corrections within the last 2m of their walk.

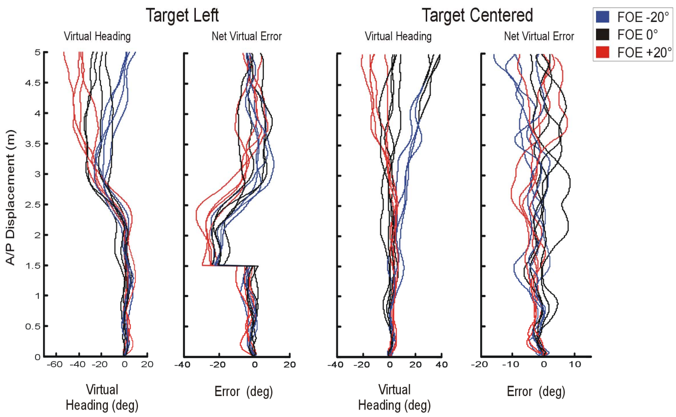

Figure 4. Virtual heading and net virtual errors for the target left and target centered conditions for participant S1 in experiment B.

It can be seen from Fig. 5 that the participants performed quite accurately, yet less than in experiment A, with NVEs between 5.7° and -2.2°. As in experiment A, participants overshoot the target when targets and FOEs were ipsilaterally located. However, unlike the mouse trials, participants did not undershoot the target when the target and FOE were located contralaterally.

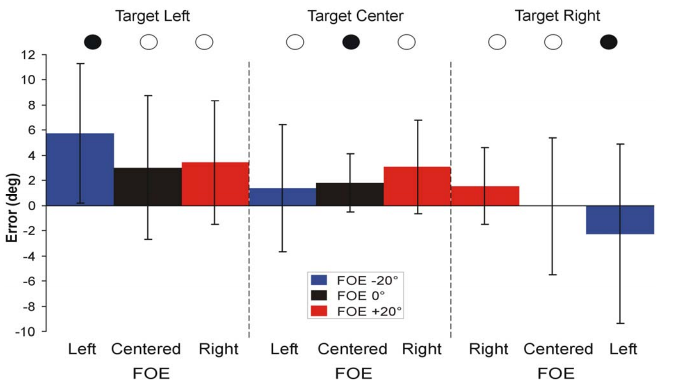

Figure 5. Mean net virtual errors (± 1 SD) across all conditions for experiment B.

IV. DISCUSSION

This study is the first to describe changes in steering strategy and performance as a function changes in optic flow direction and target location in a virtual reality-based paradigm that included both a mouse-driven and a walking steering task. The small performance errors exhibited by the participants indicate that healthy young individuals can accurately perceive and adjust for different OF directions and target locations. In the mouse-driven steering task, this was achieved in the absence of vestibular and proprioceptive information signaling changes in self-motion. Participants' performance did not seem to be affected by the use of rule-based information, which was needed to transpose the small mouse movements carried out with the hand into large perceived displacements in the VE. The ability to guide movements based on rule-based information can be altered by ageing and is an indicator of early Alzheimer's disease (6). The high accuracy of corrective motions by the participants may also have been facilitated by the nature of the mouse task, which limited the participants' interaction with the VE to changes in the M-L position, therefore preventing the use of multiple degrees of freedom. Such behaviour is reminiscent of the "crab-walk" strategy adopted by healthy young adults when exposed to translational optic flow, which consist of walking to the side while limiting body reorientation (2, 3).

In the walking steering tasks, participants also achieved relatively accurate heading performances despite the presence of conflicting sensory information caused by the shifts in FOE locations that altered the visual perception of self-motion direction. Accuracy, however, was less than in the mouse-driven task and strategies differed. In fact, there exist an infinite number of solutions, combining various amplitudes of head reorientation and body lateral displacement, to steer accurately towards a goal while walking (see Fig. 1). For instance, one can be aligned with the target using either a large M-L displacement and a small (or absent) head rotation or a small (or absent) M-L displacement and a large head rotation. Results indicate that most of the participants showed a hybrid strategy that falls in between the two extremes, with simultaneous M-L displacement and head reorientation. The systematically larger errors in the walking condition as compared to the mouse-driven condition may be a consequence of the increased degrees of freedom available to perform the task as a result of the body's multiple joints and the possibility for adjustments in the translational and rotational domains.

V. CONCLUSIONS AND FUTURE DIRECTIONS

The overall goal of this study was to demonstrate the feasibility of using a mouse-driven task in sitting and a walking task to characterize steering strategies and provide normative data for future comparisons with patient populations. Larger performance errors in the walking task compared to the mouse-driven steering task may be attributed to the nature of the tasks that employ different degrees of freedom. Altogether, results support the use of this virtual reality-based paradigm to further investigate the contribution of altered visual self-motion processing and gait-related impairments on steering abilities in stroke and in the elderly.

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