Optic Flow With a Stereoscopic Display: Sustained Influence on Speed of Locomotion

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Abstract: Previous studies have shown that walking speeds can be modulated over short timescales by varying the rate of optic flow. This study investigated whether the modulating effect of optic flow on treadmill walking speed could be sustained for the longer time periods necessary for rehabilitation. An animated moving walkway was created in 3D Studio Max and rendered into a stereoscopic movie using Virtalis StereoWorks. The movie was projected (moving toward the subjects) onto a 5m wide screen in front of a self-paced treadmill. The movie was projected at three different speed conditions (0.75m/s, 1.5m/s and 3.0m/s) in counterbalanced order. Nine participants were instructed to maintain ‘comfortable walking speed’ throughout the 5-minute duration of each speed condition. A significant difference was found between the mean walking speeds of the participants at different animation speeds (ANOVA p<0.01); with lower animation speed associated with faster walking speeds and vice versa. This modulating effect was sustained for the duration of each 5-minute test, which suggests that it does have potential for use in rehabilitation and training. This study used healthy subjects, and further work is proposed to investigate the extent of this modulating effect on clinical groups.

INTRODUCTION

Pain and motor slowing in rehabilitation
Generalized psychomotor slowing and persistent slowing of movements are frequent consequences of injury, illness, pain, and aging, giving rise to an inability to function effectively in the community (Ada, Dean, Hall, Bampton, & Crompton, 2003). Slow movements are also associated with the fear of falling (Chamberlin, Fulwider, Sanders, & Medeiros, 2005). This adds to the physical burden, because slow movements are relatively inefficient both in terms of time taken and energy required (Simmonds, Goubert, Moseley, & Verbunt, 2006).

A study using regular ambulation on a treadmill without the use of Virtual Reality showed promising results, with significant increases in walking speed and walking capacity (Ada et al 2003). Moreover, Sullivan, Knowlton, & Dobkin (2002) found that post-stroke individuals achieved the greatest improvement in overground walking velocity (OWV) when trained at speeds above the patient’s typical OWV. This is supported by the findings of Lamontagne and Fung (2004), who also found that fast walking improved the overall walking pattern of stroke subjects.

Although rehabilitation approaches have targeted movement speed, an ongoing challenge is the need to engage and motivate patients to actively participate in their rehabilitation. Virtual Reality displays, as a tool for rehabilitation, have been demonstrated to help engage patients (Rizzo & Kim, 2005) and also improve movement (Merians et al., 2002). Boian, Burdea, Deutsch and Winter (2004) noted that most individuals do not fully recover their walking ability after stroke and proposed a system of training using Virtual Reality to enrich the rehabilitation environment. In addition, Hoffman et al. (2004) demonstrated that pain responses in the human brain can be significantly reduced by using Virtual Reality as a distraction. If this pain-reducing phenomenon can be combined with an environment which improves movement speed, and perhaps reduces the fear of falling, patients may be able to engage in rehabilitation at a higher functional level, leading to increased long-term gains in mobility.

Optic flow and movement
The image of an object on the retina enlarges as it comes nearer and shrinks as it moves...
away, and this optic flow phenomenon is used as a visual cue to assess both speed of movement and direction (Harris, 2002). Although the visual system can be used to determine the relative movement of different objects, in order to discriminate between movement of objects in the environment, and movement of self (egomotion), optic flow alone is insufficient, particularly when there is relatively little visual detail or richness.

A study by Prokop, Schubert, and Berger (1997) suggested that the rate of optic flow has a modulating effect on walking speed, demonstrating an inverse linear relationship between optic flow and walking velocity. This agreed with the findings of Pailhous, Ferrandez, Fluckiger, and Baumberger (1990), in which modulating the rate and direction of optic flow gave rise to modulations in stride length, cadence and velocity. Moreover, Durgin, Gigone, and Scott (2005) compared the perception of optic flow speed with and without the influence of self-motion and found that the rate of optic flow was perceived to be lower while walking, suggesting an internal calibration between locomotion and visual perception.

Thus, in addition to the visual stimuli, the brain receives regular information updating awareness of body position and movement, and this sensorimotor feedback is processed in combination with the optic flow to differentiate egomotion from object motion. However, it would seem that the interaction between these two systems is complex, and discrepancies between expected and actual rate of optic flow appear to stimulate a recalibration of the motion perception system. A study to determine visual-vestibular cortical interaction during visually-induced circular vection (illusory self-rotation) found that visual motion stimulation with circular vection not only activates the visual area of the cortex, but simultaneously deactivates the vestibular area of the cortex, suggesting that inhibitory visual-vestibular interaction may be a mechanism to protect visual perception of self-motion from vestibular mismatches (Brandt, Bartenstein, Janek, & Dieterich, 1998). Although this study used circular vection, it is conceivable that a similar mechanism may be brought into play during a mismatch between vestibular activation and linear optic flow, influencing the perception of the walking speed of the subject to be closer to that of the optic flow rather than physical speed. Indeed, a study investigating the effects of optic flow in a Virtual Environment found that a mismatch between walking speed and optic flow stimulated recalibration of visually directed motion in the real world (Mohler et al., 2004). This study also found that the speed at which the walk/run gait transition occurred was modulated by the speed of optic flow of the virtual environment, supporting the idea that visual information tends to dominate the calibration of human movement. Thus systematic manipulation of optic flow within a Virtual Environment could enable these modulating effects on locomotion to be applied to the rehabilitation domain.

Studies of this phenomenon to date have concentrated on modulations over short time scales, typically of a few seconds in duration. However, if there is to be a practical application for rehabilitation or training, then the effect needs to be sustained for longer time periods. The objective of this study was to investigate whether the manipulation of optic flow via a large-screen stereoscopic display could be used to sustain the modulating effect of optic flow on walking speed over several minutes, or whether the sensorimotor feedback would override any short-term effects.

**MATERIALS AND METHODS**

**Participants**
Nine healthy volunteers (5 men and 4 women) between the ages of 33 and 57 (mean age 45.6) participated in this study. Participants were from the University of Portsmouth staff, and all gave their informed consent prior to inclusion in the study.

**Apparatus**
The experimental system included a self-driven treadmill in front of a 5m x 2.5m stereoscopic display screen. To minimize visual distractions, the experimental room was dark, with the main light source being the display screen itself (Figure 1A).

Two equidistant reflective markers were placed on the treadmill belt (104 cm apart). Each test was recorded using a small video camera mounted behind the treadmill, with a local light
source focused on the treadmill belt to highlight the reflective markers. The footage was recorded at a rate of 25 frames per second, and by noting the frame number each time a marker appeared it was possible to accurately calculate the speed of the treadmill belt and thus the walking speed of the participants.

The animation was created using 3D Studio Max and rendered into a stereoscopic format using Virtalis StereoWorks. It consisted of two parallel rows of vertical columns on either side of a walkway (Figure 1B). A rolling ball was added in the middle distance to focus the participant’s attention on the screen.

The animation was designed to run at three different speeds, all approaching the subject. Condition B was set at 1.5m/s, which is the average overground walking speed for the general population under 65 years of age (Knoblauch, Pietrucha, & Nitzburg, 1996). In Knoblauch’s study, the walking speeds were found to be tightly clustered around the mean, suggesting that fixed animation condition speeds would be appropriate for all subjects. Condition A was half the speed of B, and condition C twice the speed, to provide high and low optic flow conditions. A fourth condition (D) was added as a control, and this involved a static display with no optic flow.

**Procedure**

Prior to the task, all participants were given the experimental instructions and spent a few minutes familiarizing themselves with the equipment and walking on the treadmill. They each participated in all four conditions in counterbalanced order. Each test required the participants to walk on the treadmill for five minutes at a self-selected comfortable pace, with a five-minute rest between each test. Participants were instructed to attempt to maintain the same pace throughout all the tests. During each test, participants wore earplugs to minimize the influence of external noise such as the treadmill belt. They also wore lightweight 3-D glasses to enable stereoscopic viewing.

**RESULTS**

An analysis of variance (ANOVA) was performed on the average walking speeds, and a significant difference between optic flow conditions was found ($F(3,24)=7.22, p<0.01$). Post-Hoc tests revealed that the walking speed in condition A was significantly faster than that in condition B ($p<0.05$), condition C ($p<0.01$), and condition D ($p<0.05$). In addition, the walking speed in condition B was significantly faster than that in condition C ($p<0.01$). There was little difference between the control condition (D) and the optic flow of 1.5m/s (B). The faster (C) and slower (A) conditions demonstrated a significant effect on the walking speed, such that walking speed was lower with a faster optic flow and higher with a slower optic flow (Figure 2).

The significant difference in walking speeds between the optic flow conditions was sustained
throughout the full five minutes. (Min1 $F(3,24) = 3.10, p<0.05$; Min2 $F(3,24)=4.77, p<0.01$; Min3 $F(3,24)=7.17, p<0.01$; Min4 $F(3,24)=6.91, p<0.01$; Min5 $F(3,24)=5.98, p<0.01$). Post-Hoc analysis of the minute-by-minute results confirmed that the pair-wise differences between the conditions were consistent throughout the 5-minute tests (Table 1).

**DISCUSSION**

The results of this study confirmed that treadmill walking-speed can be influenced by the speed of optic flow on a large-screen stereoscopic display, and demonstrated that the effect can be sustained over several minutes.

Although the experimental design based the optic flow speeds on multiples of the 'normal' overground walking speed of 1.5m/s, the subjects in this study walked on the treadmill at an average speed of 0.95 m/s (SD 0.21), which is similar to the steady treadmill walking speeds in Varraine, Bonnard, & Pailhous (2002). This might suggest a need for a slower optic flow (around 1m/s) for the matched condition (B), but previous studies have suggested that optic flow needs to be increased by as much as 50% to seem normal to subjects walking on a treadmill (Banton, Steve, Durgin, & Proffitt, 2000). The close matching of average walking speed in conditions B and D reported here confirms the previous finding. Thus the selected simulation speeds were appropriate to provide the desired high and low optic flow rates.

The decrease in walking speed with higher optic flow rates supports Durgin et al. (2005) who suggested that there may be a predetermined expectation of the visual effects associated with a particular walking speed.

If the actual rate of optic flow is different from the expected rate, the participants appear to adjust their rate of locomotion in an attempt to correct the optic flow rate to that expected (i.e. when the optic flow is too high, the speed of locomotion is reduced as this would reduce optic flow in normal circumstances, and vice versa). It appears that the visual information is overriding the other sensory input that would normally help to regulate the locomotor speed. This supports the findings of Brandt et al. (1998) of vestibular deactivation by visual stimulus. The modulation in walking speed was maintained for the full five minutes of each test, suggesting a recalibration of locomotion as observed by Mohler et al. (2004). Although this study was carried out on healthy participants and further work is needed to assess the extent of the effect on clinical groups, these preliminary results suggest that decreasing the rate of optic flow during treadmill walking may cause a significant increase in walking speed. Incorporating this effect into a Virtual Environment, where optic flow is geared up or down via a treadmill-to-environment interface, could enhance gait rehabilitation.
Table 1: Analysis of Variance and Post-Hoc analysis of mean participant walking speeds for each minute of the four optic flow conditions

<table>
<thead>
<tr>
<th>Minute</th>
<th>Walking speed m/s</th>
<th>Post-Hoc analysis - pairwise comparison of walking speeds in the four optic flow conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>1</td>
<td>A 0.99</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>B 0.93</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>C 0.89</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>D 0.90</td>
<td>0.22</td>
</tr>
<tr>
<td>2</td>
<td>A 1.08</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>B 0.99</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>C 0.94</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>D 0.97</td>
<td>0.25</td>
</tr>
<tr>
<td>3</td>
<td>A 1.11</td>
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</tr>
<tr>
<td></td>
<td>B 1.02</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>C 0.96</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>D 0.99</td>
<td>0.26</td>
</tr>
<tr>
<td>4</td>
<td>A 1.14</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>B 1.04</td>
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</tr>
<tr>
<td></td>
<td>C 0.98</td>
<td>0.19</td>
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<td></td>
<td>D 1.02</td>
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<tr>
<td>5</td>
<td>A 1.16</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>B 1.07</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>C 1.01</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>D 1.05</td>
<td>0.26</td>
</tr>
</tbody>
</table>

CONCLUSION

The findings of this study extend the work of Pailhous et al. (1990) and Prokop et al. (1997) by demonstrating that the modulating effect of optic flow on locomotion can be sustained for several minutes. This may be attributable to the suppression of the vestibular information by the visual cortex together with dominance of the visual input over the sensorimotor information in the recalibration of visual-motor feedback.

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REFERENCES


