Software Gearing in a Virtual Environment: The Effect on Perception of Optic Flow

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ABSTRACT
Immersing patients in a Virtual Reality environment whilst walking may engage and motivate them, stimulating a greater level of effort than exercise alone. Initial work has demonstrated that walking speed may be manipulated by controlling the rate of optic flow, which has potential for enhancing the recovery process for patients undergoing rehabilitation. However, it has been reported that there is a perceived mismatch between walking speed on a treadmill and the presented rate of optic flow when it is set to be equivalent to current walking speed. The consistency of this “gain mismatch” within and between participants is currently unclear and further clarification is needed if the beneficial effect of manipulating optic flow in a Virtual Rehabilitation setting is to be optimised. Preliminary findings of a study investigating this gain mismatch in a treadmill-mediated Virtual Environment indicate that substantial changes in optic flow are required before they are perceived as unmatched, and that slightly fast optic flow speeds are more likely to be perceived as normal than slightly slow optic flow speeds.

INTRODUCTION
Slow movements, and in particular slow walking, are a common consequence of illness and ageing, decreasing the ability to function effectively in the community. There have been some promising studies using treadmill training to improve walking speed (Ada, Dean, Hall, Bampton, & Crompton, 2003; Sullivan, Knowlton, & Dobkin, 2002), but there is a need to find ways to engage and motivate patients to actively participate in their rehabilitation.

Virtual Reality (VR) is a rapidly developing area of rehabilitation research, and early work in this field has demonstrated a range of benefits in a variety of clinical applications, including motor rehabilitation (Broeren, Rydmark, & Sunnerhagen, 2004; Gourlay, Lun, Lee, & Tay, 2000). An extensive review of the use of VR for motor rehabilitation (Holden, 2005) concluded that it is a promising therapeutic approach with results which are transferable to the real world. Moreover, the use of virtual environments has been shown to increase engagement with therapy (Rizzo & Kim, 2005) and have pain-reducing effects (Hoffman, 2004). However, previous studies have indicated that treadmill walking alters the perception of the speed of optic flow in a virtual environment (Distler, Pelah, Bell, & Thurrell, 1998; Durgin, Gigone, & Scott, 2005).

Gain mismatch
The altered perception of visual speed has implications for development of the rehabilitation environment, as a system designed to have a 1:1 gearing between the real and virtual worlds (i.e. 1m on the treadmill produces 1m of movement through the virtual environment) may actually be perceived by the participant as too slow. To correctly
calibrate a virtual rehabilitation system it will be necessary to establish the perceived normal for each participant. However, the level of this “gain mismatch” is not currently known, nor whether this is consistent within and between participants.

Motor Rehabilitation Interfaces
The potential of physically challenging interfaces (exertion interfaces) in the gaming industry has, in recent years, been recognized and commercially developed, for example the Nintendo Wii and the Sony Eyetoy (Nintendo, 2006; Sony, 2004). Exertion interfaces generally work in contrast to traditional human-computer interfaces, which are designed for ease of use. These more physically challenging interfaces provide the potential for significant motor rehabilitation opportunities, and rehabilitation researchers are becoming aware of the potential of exertion interfaces to enhance therapeutic interventions. Several centres are developing novel interfaces to virtual environments, which require a deliberate and focused physical effort (Boian, 2004; Fung et al., 2004; Mohler et al., 2004). However, there is a lack of data available for the design and optimisation of both the interface and environment in order to fully exploit the health benefits of the Virtual World.

A VR training program for locomotor rehabilitation at speeds above preferred walking speed may facilitate both short and long-term gains in walking speed. Furthermore, the benefits of engagement and motivation available with Virtual Reality can be used to great effect within such a program. Despite this, to date there has been no systematic evaluation of the interactions between exertion interface, user and the virtual world, and thus there is insufficient data to properly inform the development of such a rehabilitation system. It is not yet known how factors such as screen size, realism of the environment and interactive content will influence the rehabilitation experience. Indeed, even the baseline flow rate for perception of “normal” walking speed has not yet been established.

This study aims to investigate the phenomenon of gain-mismatch in order to inform the development and calibration of treadmill-mediated virtual rehabilitation environments. The extent of the gain-mismatch and the consistency within and between subjects will be analysed.

PRELIMINARY INVESTIGATION
A self-driven treadmill interface has been constructed that connects to a personal computer to accurately record participant walking speeds using a photoelectric sensor, which detects movement of the treadmill flywheel. The output from this sensor is routed through a measurement and automation peripheral (LabJack U12), which is then interfaced to the USB port of the computer. A C++ program processes the count and timestamp (in ms) from the sensor input and uses a software gearing ratio to alter the display speed of the virtual environment.

The environment consists of a virtual walkway flanked with columns spaced at 5m intervals (Figure 1). The model was created in 3D Studio Max and displayed using WorldToolKit. The scene is back projected onto a 5m wide and 2.5m high screen using a pair of polarising projectors to produce a stereoscopic view, and the treadmill input is
used to drive the movement of the viewpoint through the model, giving the illusion of walking through the virtual environment.

![Screenshot of Virtual Walkway](image)

**Figure 1: Screenshot of Virtual Walkway**

**Pilot-Study Design**

Results from a pilot study with three participants have been analyzed, although a larger study is currently taking place. These participants were healthy adults between the ages of 23 and 36. The full study will have 20 participants between the ages of 18 and 40, with normal or corrected to normal vision and no motor or cognitive deficits. All participants are drawn from students and staff at the University of Portsmouth, UK.

A within-subjects design was used, where the gearing between the speed of the treadmill and the display speed through the environment was altered in discrete steps. Two conditions were presented in counterbalanced order. Both conditions presented the participant with 40 gear changes in each trial, ranging from 0.1 (10m in real world moves 1m in the virtual world) to 2.0 (10m in real world moves 20m in the virtual world) in increments of 0.1. The first mode (stepwise) started at 0.1 and increased the gear by 0.1 at each gearing change, descending in the same manner once a gearing of 2 was reached. The second mode (random), generated two of each gearing level and randomised the order in which they were presented. The actual distance walked and timestamp was recorded 5 times per second, and the current software gearing was recorded each time a participant’s response was entered.

Participants were familiarised with the task using a demo program which presented very fast, normal and very slow gearings. They then walked steadily on the self-paced treadmill, observing their movement along the virtual walkway (Figure 2). The participants received both the step wise and random conditions, in counterbalanced order.
After each gearing change the participants gave a verbal judgement of the on-screen speed:

1. “Slow” (on-screen movement appears too slow)
2. “Normal” (on-screen movement appears to match walking speed)
3. “Fast” (on-screen movement appears too fast)
4. “Unsure” (after careful observation, the participant is still unable to decide)

After a short rest, the trial was repeated, and then the same process was carried out for the second experimental condition (four trials in total for each participant).

The participants were in control of how long they need to make a decision as the gearing changes were initiated by the recording of the previous response. Each trial took approximately 5 minutes to complete.

RESULTS
The study is ongoing but preliminary analysis, from three participants, suggest that there is indeed a mismatch in the perception of visual speed when compared to walking speed. For all participants across all conditions, there was a wide range of gearing which was perceived as matched (Fig 3), even though only the 1:1 gear was actually correctly matched to the walk speed. The ranges of “slow”, “normal” and “fast” appeared to be fairly consistent within participants, although there was generally overlap between the ranges. For example, in Fig 3 the participant was first presented with gear 1:1 as the 10th gear change, and perceived it as normal. When presented with the same gear as the 30th gear change, the participant perceived it as slow. These ambiguous responses tended to occur on the boundary between perceived slow/normal and perceived normal/fast.
Although there was some within-subject variation, there appeared to be a degree of consistency between the conditions for individual participants. Furthermore, the pattern of responses appeared similar whether the gearing changes were presented incrementally or in random order.

Between the subjects there was some variation, but again evidence of a pattern of response, with the range of gear values perceived as normal tending to be those above normal rather than below (Fig 5).
Participants were generally able to make a decision on the perceived speed within a few seconds, and were fairly certain of their judgements.

DISCUSSION

Early results indicate that substantial changes in visual flow are required before they are perceived as unmatched. This is consistent with the findings of Monen and Brener (1994) who observed that participants had considerable difficulty detecting changes in velocity based on visual information alone. Moreover, the perceived mismatch was also direction biased, as faster optic flow speeds were more likely to be perceived as normal than slower optic flow speeds. This would support the findings of Distler et al. (1998) of a perceived reduction in optic flow speed when treadmill walking. This shift appears so far to be fairly consistent both within and between participants, although at this preliminary stage no formal statistical analysis of the data can been undertaken.

The incidents of the same gear eliciting different responses typically occurred on the boundaries between perceived slow/normal and perceived normal/fast, suggesting that the participants had some difficulty in detecting small changes in visual velocity.

These preliminary findings tentatively suggest that the visual flow in a rehabilitation environment is likely to need setting slightly higher than the participant’s walking speed, to be perceived as matched, although further data collection and analysis is currently underway to enable identification of the range of mismatch which can be detected.

CONCLUSION

A treadmill interface to a virtual environment has been successfully developed to facilitate the study of the perception of visual speed and establish a perceived normal gearing level for a virtual rehabilitation environment.
Unlike a traditional gearing system, which requires an increase in physical effort to drive the treadmill as the gearing increases, this software gearing system allows the biomechanical effort to remain constant whilst altering the rate of progress through the virtual world. Incorporated into a rehabilitation program, increasing the perceived rate of progress could provide positive feedback and encouragement even at very low walking speeds, whilst also providing the potential to decrease the rate of flow to promote faster walk speeds (Powell, Hand, Stevens, & Simmonds, 2006). Further investigation of the gain-mismatch in such treadmill-mediated environments will enable correct calibration and optimisation of the rehabilitation potential.

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REFERENCES

