Sounding Better: Fast Audio Cues Increase Walk Speed in Treadmill-Mediated Virtual Rehabilitation Environments

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Abstract. Music or sound effects are often used to enhance Virtual Environments, but it is not known how this audio may influence gait speed. This study investigated the influence of audio cue tempo on treadmill walking with and without visual flow. The walking speeds of 11 individuals were recorded during exposure to a range of audio cue rates. There was a significant effect of audio tempo without visual flow, with a 16% increase in walk speed with faster audio cue tempo. Audio with visual flow resulted in a smaller but still significant increase in walk speed (8%). The results suggest that the inclusion of faster rate audio cues may be of benefit in improving walk speed in virtual rehabilitation.

Keywords. Virtual reality, audio cues, gait speed, treadmill walking

Introduction

Music and sound effects are often added to Virtual Environments (VEs) in an attempt to enhance engagement or enjoyment. However, Virtual Reality (VR) is being used increasingly for motor rehabilitation, and it is not yet known whether audio input may not only enhance engagement but also influence the speed or quality of movement of individuals moving in VEs. Treadmill-mediated VR has the potential to be used for locomotor rehabilitation [e.g.1-4], but indiscriminate use of audio without understanding its effect on the desired outcomes could confound treatment goals. If audio is to be included in VR rehabilitation environments, it is important to understand whether, and how, it affects gait, and thus how audio cues can be utilised to facilitate the achievement of therapeutic goals.

There is evidence that music can influence cadence (step tempo) and effort in exercise [5, 6] and also that increased audio beat frequency can increase walk speed [7-9] and decrease gait variability [10,11]. However, music can also influence mood (affect) during exercise [6], and this altered affect can modulate gait kinematics [12]. Furthermore, the type of music also has a differential effect on gait kinematics [5, 6, 13]. Nevertheless, although it has been observed that walking with music is a rich multidisciplinary topic [8], it is also clear from a wide range of studies that there is an underlying effect of audio tempo on gait, whether delivered as music or as a simple metronome-type beat. Indeed a number of researchers suggest that the body has an

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intrinsic ability to synchronise to an external rhythmic cue [13-15], and this may have the potential to enhance walking rehabilitation.

However, to date there is little research into the effect of audio cues in Virtual Reality. Moreover, it has previously been noted that self-speed estimation is altered when walking in VR [4, 16, 17], and it is not known whether this visuo-motor modulation may interact with the effect of audio cues on walking speed. Thus it cannot be assumed that the results of previous 'real-world' studies can be generalised for application in Virtual rehabilitation. This paper reports a preliminary study investigating the influence of gait-referenced audio cue tempo on treadmill walking in Virtual Environments.

1. Method

Eleven healthy adults (4 male, 7 female, aged 23-54) participated in the study. All participants were familiarized with the self-paced motorized treadmill placed in front of a large (5mx3m) display screen. A virtual walkway lined with pillars was back-projected on the screen (Figure 1). During the test conditions the image of the walkway was either static on the screen (no visual flow) or linked to the treadmill via a virtual camera (VR condition - visual flow present). The VR condition was matched to the treadmill speed, such that each 1m walked on the treadmill advanced the participant 1m in the Virtual Environment.

Figure 1: Walking in treadmill-mediated VR

Previous work had demonstrated that baseline cadence (step frequency) differs between treadmill and over-ground walking [18], therefore a 3-min baseline walk test was conducted on the treadmill, during which average speed (m/s) and cadence (steps/s) were recorded. Participants then walked for 3 minutes in each of the test conditions (Table 1) in pre-randomised and counterbalanced order.

Table 1: The combination of audio cue rate and visual flow used in the experimental conditions

Audio Cue rate as % of baseline cadence	none (baseline)	75%	100%	125%	none	75%	100%	125%
Visual flow linked to treadmill motion	absent (no VR)				present (VR)			

2. Results

Table 2: Mean speed (m/s) and cadence (steps/s) for audio condition in the presence and absence of visual flow

Audio Cue rate as % of baseline cadence	Visual flow absent (no VR)		Visual flow present (VR)	
	Speed (m/s)	Cadence (steps/s)	Speed (m/s)	Cadence (steps/s)
no audio	1.12	1.76	1.16	1.77
75%	1.24	1.78	1.07	1.70
100%	1.20	1.77	1.13	1.75
125%	1.30	1.87	1.26	1.86

A two-way ANOVA (audio x visual) for gait velocity showed a significant main effect of audio cue tempo ($F_{3,30}$ = 4.69 p < 0.05). Participants walked fastest in the 125% audio-only condition, with a 16% increase in gait speed compared to baseline (p<0.01), and an 8% increase compared to matched audio cue tempo. There was no significant difference between the other conditions (Figure 2).

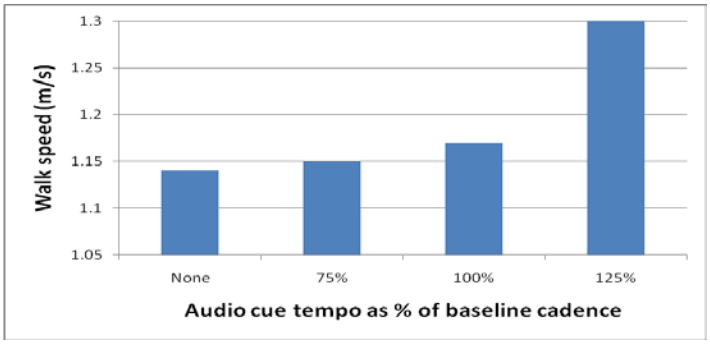

Figure 2: Modulating effect of audio cues on walk speed

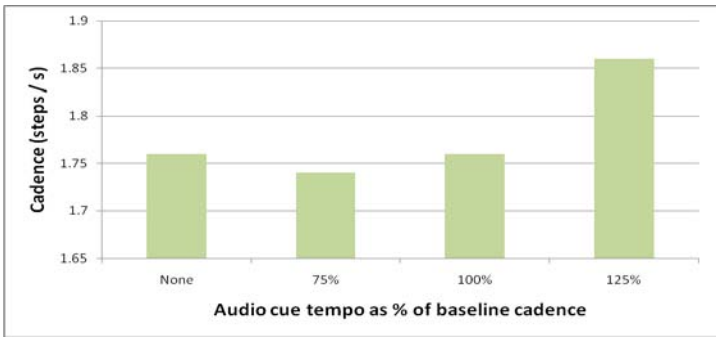

Figure 3: Modulating effect of audio cue tempo on cadence

There was however a significant interaction between the audio cues and visual flow ($F_{3,30}$ = 3.45 p <0.05). In both the fast and slow cue conditions, participants walked significantly slower in VR than with audio alone. However, the participants walked faster (8%) in the 125% VR condition, compared to baseline.

For cadence there was a significant effect for audio cues ($F_{3,30}$ = 2.89 p = 0.05), with a 6% increase in cadence in the 125% audio condition compared to baseline and

matched audio conditions. There was no significant difference between the other conditions (Figure 3). There was no significant effect of visual flow on gait cadence.

3. Discussion

This study demonstrated a clear effect of audio cue frequency on treadmill walk speed, with audio cues above baseline step frequency being associated with a significant increase in walk speed. This is consistent with the findings of previous studies [7-9]. Although there is a natural tendency for humans to synchronise movements to external audio rhythms [9, 13], the increased walk speed is achieved by a combination of increased cadence and increased stride length. This supports the observations of Durgin *et al*. [19], who note that step length/cadence is maintained at a relatively constant ratio across varying walk speeds.

This study extends previous work, by evaluating the effect of audio cues when the treadmill was linked interactively to a virtual environment. In the presence of visual flow there was still a significant effect of audio cue frequency on walk speed, although there was difference in the effect in the fast and slow audio conditions. It has previously been observed that perception of self-motion is altered in treadmill-mediated VR [e.g. 16, 17], leading to visuo-motor recalibration [20], and this may influence the magnitude of the effect of the audio cues. However, one would expect this to be consistent across all audio conditions, but it was observed that the VR only changed the effect of audio cues in the conditions where the cues were in conflict with the preferred cadence. This suggests that a different mechanism of action needs to be considered.

Auditory and visual stimuli both require attention, which can be considered to be a finite shared resource [21]. In the presence of audio cues alone, there is sufficient attention to respond to the cues, but by adding the visual cues the attention is divided between two cues [9]. Audio cues which are in conflict with the preferred cadence may disrupt the automatic synchronicity of walking, necessitating more conscious attention. The suppression of the effect of audio on walk speed by the addition of visual flow may therefore be attributable to a reduction of attention to the audio cues in the presence of a competing attentional load. It is notable that there is a marked difference in the effect of the slow audio cues between the two conditions. In the audio-only condition, the slow audio was associated with an increase in walk speed. Previous studies have noted the ability to 'double' a tempo [8], and this would be consistent with the speed increase seen with this cue frequency. However, in the VR condition the slow audio frequency was associated with a decrease in walk speed, which may be attributable to a decreased ability to double tempo with additional attentional demands.

4. Conclusion

This study demonstrated that the frequency of audio cues in treadmill-mediated VR can significantly influence walk speed. This supports and extends previous studies which have indicated that rhythmic audio cues may have a facilitating effect on the descending motor pathways, giving rise to an increased walk speed with increased tempo. The results suggest that the inclusion of faster rate audio cues may be of benefit

in improving walk speed in virtual rehabilitation., and further studies are underway to evaluate this effect in clinical populations.

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