# Step in time: exploration of synchrony and timing correction in response to virtual reality avatars for gait re-training

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## ABSTRACT

This study investigates the use of virtual reality avatars as exercise cues for retraining gait. A feasibility test was conducted by asking participants to step in time with the avatar viewed through a virtual reality headset. We observed that a temporal perturbation (a speeding up or slowing down of one step cycle) applied to the avatar resulted in a significant corrective response in participants' own step timing. If this response can extend to spatial perturbations, we suggest that virtual reality avatars have the potential to assist in the targeted rehabilitation of neuromuscular or other disorders and retraining of gait post-surgery.

## 1. INTRODUCTION

Gait retraining is often required as an intense part of a physiotherapy or rehabilitation process, following neurological disease (e.g., Stroke) or serious musculoskeletal injuries. Using an auditory metronome to provide a regular beat has been found to be a simple and effective method for retraining the timing and coordination of gait following Stroke (Pelton et al., 2010). Similarly, the use of regularly timed visual stepping stones on a treadmill can be used to influence gait coordination (Bank et al., 2011). A key goal of retraining gait is to improve adaptability so individuals can quickly correct movements in response to a sudden perturbation or obstacle (Fonteyn et al., 2014). Gait adaptability training involves random phase perturbations inserted into otherwise regular auditory or visual rhythmic cues to force an adaptive response in the form of timing correction (Wright and Elliott, 2014). While this demonstrates the effectiveness of using sensory cueing for retraining gait, the abstract nature of the cues currently used limits the scope of their effect.

Evidence from research into social imitation (Rizzolatti and Craighero, 2004) and the phenomenon of spontaneous synchrony in gait (Zivotofsky and Hausdorff, 2007) highlights the potential for using the movements of a humanoid avatar to guide and influence user motion during rehabilitation but the effects of avatars in fully immersive 3D environments on the timing characteristics of gait have yet to be explored. Here, we describe the development of a novel method of visually cued training in the form of a full-body virtual partner in an immersive environment. We investigate whether participants are able to correct their steps to stay in time with the avatar following a perturbation to the avatar's gait and suggest it will be possible to develop more sensitive and targeted gait retraining methods using this virtual partner approach.

## 2. CLINICAL SIGNIFICANCE

The development of this method along with the proof of concept study opens up the possibility of using virtual partners to retrain gait in individuals following neurological disease or musculoskeletal injury. Having a representative partner to guide exercises could improve adherence to rehabilitation programmes and subsequently reduce long-term reliance on physiotherapy services. Importantly, we use a low cost consumer system that will allow it to be used in the home or community, as well as clinical environments.

## 3. METHODS

A volunteer (Male, age 37 years, height 1.8m) was recorded stepping on the spot using a 12-camera Vicon motion capture system. To set the tempo for each condition, the volunteer stepped in time with an auditory metronome with a beat interval of 450ms (Fast) and 800ms (Slow), at least 20% faster or slower than the normal male, self-selected inter-step interval of 543.4ms (Pietraszewski et al., 2012). Captured marker trajectories were mapped onto an avatar using Unity3D software (see Figure 1). The trajectory of one of the avatar step cycles was subsequently accelerated or decelerated by 15% to create a perturbation (Figure 2). Stepping in place was chosen as it allowed participants to naturally match their tempo to the avatar without external influences such as the speed of a treadmill or limited space within a gait lab. It is also a standard intervention to improve step height and speed in gait rehabilitation.

**Figure 1.** *An example of the virtual environment and avatar presented to the participant during the trial (left), and an image of one participant taking part in the trial wearing the Oculus Rift head mounted display and reflective Vicon markers for motion capture (right).*

In the main experiment, participants wore an Oculus Rift DK2 virtual reality headset to view the avatar, eliminating distractions and presenting a three dimensional 1:1 scale humanoid. They further wore reflective markers to capture their movements using a Vicon motion capture system. Participants (N=11, healthy males, age 23-39, right handed) were instructed to step on the spot in time with the avatar, unaware of the perturbation that took place in one of the step cycles. Participants completed 4 trials for each of the four conditions (Tempo [Slow, Fast] x Perturbation [+15%, -15%]). Trials included 30 steps each, resulting in a length of approximately 24 seconds for the slow condition and 13.5 seconds for the fast condition. The timing of the Oculus system was synchronized with the Vicon system using a hardware trigger. Heel step times of both the avatar and participant were extracted from movement trajectories to measure the timing errors (asynchronies).

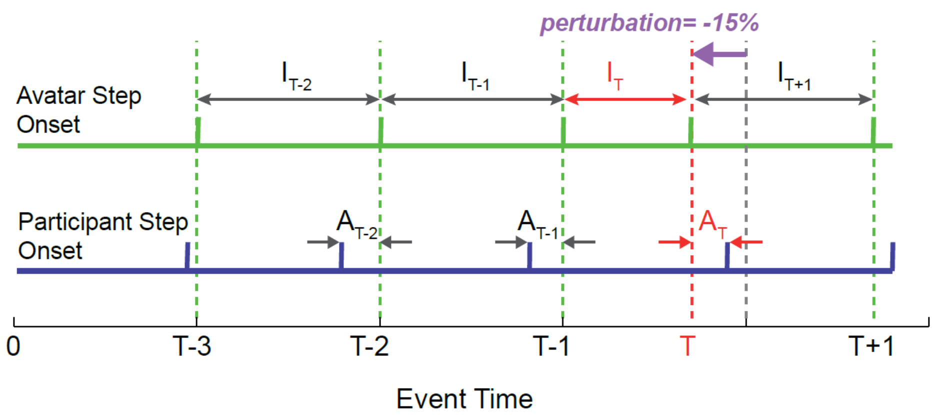


**Figure 2.** *A timing diagram illustrating the avatar steps (I) including a perturbed (speeded) step ($I_T$) and the measured asynchronies (A) between the participant's heel onsets and the corresponding onsets for the avatar.*


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## 4. RESULTS

### 4.1 *Hypothesis 1: Participants would be able to match the tempo of their steps with the Avatar's*

For the Slow condition, participants' mean step intervals were found to accurately match those of the avatar. However, on average, participants stepped significantly slower than the avatar in the Fast condition (p<.001) (Figure 3), the difficulty in synchronising with the fast condition was commented on by some participants during the trial. We suspect synchronising to the fast rhythmic cue was difficult for the participants as the avatar had not been augmented with any auditory cues, such as stepping sounds, which have been found to lead to better synchronisation when compared to visual-only cues (Wright and Elliott, 2014).

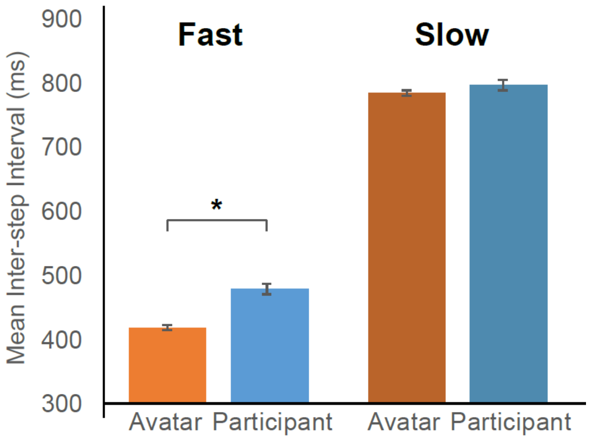


**Figure 3.** *Plot of mean Inter-Step Interval (ISI) of participants compared to the avatar cue for the Fast and Slow conditions, *A significant (p<.001) difference between avatar and participant step intervals indicated participants were unable to step in time with the fast condition. Therefore, these results have been excluded from the corrective response analysis.*

### 4.2 *Hypothesis 2: Participants would be able to synchronise their steps with the Avatar's*

Asynchronies, measured as the time between heel onsets of the participants and the corresponding onsets for the avatar, for the Slow condition were not significantly different from zero (Figure 4), suggesting good synchrony. However, variability (standard deviation) was high, indicating instability.

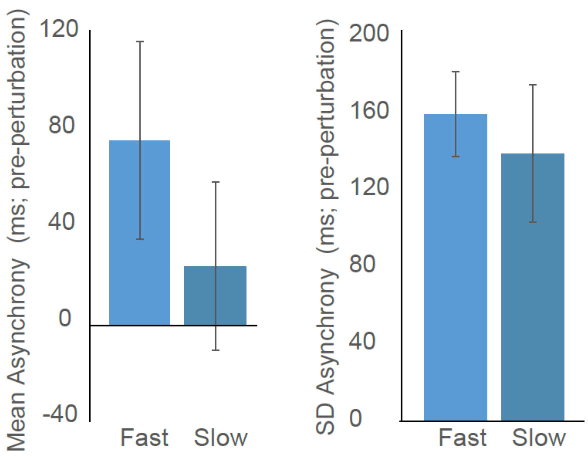


**Figure 4.** *Plots of mean asynchrony measured before the perturbed step (left), and the variability in synchronisation (right) for both fast and slow conditions.*

### 4.3 *Hypothesis 3: Participants would correct their step timing to regain synchrony following a perturbation*

Only the Slow condition was analysed. Relative mean asynchronies were calculated by subtracting the mean asynchrony pre-perturbation (T-5 to T-1) from all asynchronies in each trial to eliminate the baseline differences in step synchrony between participants. The post-perturbation response clearly shows participants corrected their step timing to regain synchrony (0 ms) with the avatar (Figure 5) even though the perturbation itself was imperceptible to participants. Recovery from a shortened interval was found to take longer (3 steps), on average across participants, compared to a lengthened interval (<2 steps).

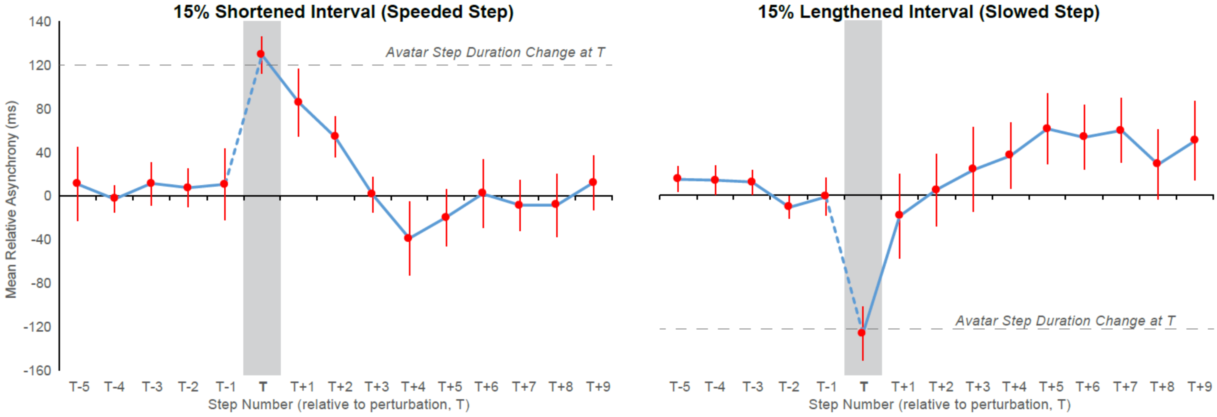


**Figure 5.** *Plots showing mean asynchrony across participants before and after the perturbation (step T). Participants corrected their step timing to gain synchrony with the avatar for both speeded (left) and slowed (right) steps.*

## 5. CONCLUSIONS

We have shown that an avatar's gait pattern in an immersive virtual environment (a head mounted display encompassing the user's vision) can be used to influence a person's temporal gait characteristics. When instructed to step in time with an avatar, participants are able to match the tempo of an avatar for slow exercises and, when a perturbation is made to the avatar's step timing, participants corrected their own timing to regain synchrony. Some issues remain, with participants unable to synchronise in the Fast condition. Future studies will investigate multisensory cues (e.g. auditory foot strikes) for improving accuracy.

Overall, this study highlights the potential of virtual partners, within immersive environments, to retrain gait timing and step coordination. If similar corrective responses can be elicited for spatial and complex perturbations, avatars could potentially be used to present personalised, targeted exercises, for the rehabilitation disorders affecting gait.

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