Using a VR Field Study to Assess the Effects of Visual and Haptic Cues in "In-the-Wild" Locomotion

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Figure 1: Two screenshots from our VR scene. On the left we have highlighted the several distractors put in place to assess participants awareness of them across the cue conditions: (a) a passing car; (b) a pedestrian; and (c) a crossing light. On the right we present a closer look to stimulus in the visual cue condition.

ABSTRACT

This work aims to assess the effect of visual and haptic cues in users with gait impairments; not only in performance, but also in terms of usability, perceived cognitive load, and safety. These haptic cues were delivered via wrist-worn devices, with the goal of supporting these users while out in-the-wild – three types of haptic cues were tested. To further assess the impact of haptic and visual cues outside of a laboratory environment, we used a Virtual Reality Field Study to safely assess the impact of these cues in users' awareness of their surroundings (measured via gaze hits and dwell). Despite conducting a preliminary study with participants not suffering from gait impairments (N=6), our results seem to indicate a positive effect of the haptic cues in regards to participant cadence, step length, and general awareness of their surroundings when compared to the visual cue. One of the simpler haptic cues was also the preferred stimulus by all participants.

CCS CONCEPTS

• **Applied computing** → **Health informatics**; • **Human-centered computing** → *Empirical studies in accessibility*; Ubiquitous and mobile computing systems and tools.

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KEYWORDS

Parkinson's Disease, Gait, Visual cues, Haptic Cues, Virtual-reality, Virtual Field Study, Usability, Attention, Eye-tracking

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1 CROSS-REALITY INTERACTION

We agree with Speicher et al.'s expectation that the distinctions between AR and VR will fade away in time [24]. In that sense, we see Cross-Reality Interaction not so much as a system-centred series of in-app transitions across the Reality-Virtuality continuum [12], but as user- or experience-centred transitions. That is, how can we build mixed-reality systems that enable users to seamlessly transition their attention between digital content and the physical world? How can they transition from ready-at-hand and present-at-hand operations when interacting with mixed-reality tools [4]? How can users offload cognitive processes to a blend of digital and physical spaces? In that regard, the work we present in this paper focuses on a small subset of those transitions: how can we model and study real world behavior via a VR experience? How can we transition abstractions, data, observations, and ultimately knowledge across these realities? We use this premise to study the effect of various cues in users' gait, relying on VR to safely simulate a variety of competing stimulus that can affect users' performance with these during in-the-wild locomotion.

2 INTRODUCTION AND RELATED WORK

Gait disorders, which greatly contribute to a decrease in quality of life and increased mortality, are common and often devastating companions of the ageing process [2]. These disorders increase from around 10% between the ages of 60 and 69 years, to more than 60% in those over 80 years of age [10]. Age is not the only source of these impairments, as strokes, Parkinson's disease, myelopathy, or sensory ataxia are some of the most known and studied neurological conditions with repercussions in patients' gait [18].

Our work was primary motivated by Parkinson's disease, the second most common neurodegenerative disorder that affects over 10 million people all over the world [20]. As the disease progresses many are the effects in patients' ability to walk: their gait pattern becomes usually characterized by a shortened gait stride, their walking speed is reduced, their gait variance is increased, and they can be affected by what is known as festinating gait [7]. As there is no cure or treatment that completely addresses the effect of Parkinson's disease on gait, these symptoms can be minimized with lifestyle changes and physiotherapy. Another approach is what is known as *cueing*.

Cueing consists of sensory spatial and temporal stimulus that have been shown to minimize the effect of Parkinson's disease in users' gait [1, 8, 17, 25, 27]. Visual and auditory stimuli are the most used and studied types of cues to this effect. And although many studies have demonstrated that these two types of cues are quite effective in normalizing patient's gait parameters – respectively, spatial (step length and stride length) [1, 6, 14, 25, 30] and temporal parameters (velocity and cadence) [5, 8, 9, 11, 27] – very few studies exist that demonstrate the effect and usability of these systems outside of a controlled environment (i.e., a research laboratory). That is, very few studies explore these cues while the users are out in-the-wild, where they need to engage in simple tasks such as walking through a crosswalk – a task that requires undivided attention and concentration [23]. In fact, recent studies show that texting, talking on a smartphone, surfing the web, or playing games negatively affects the safety of pedestrians while crossing the road [15, 16, 26]. These distractions have been proven to be even more problematic and difficult for Parkinson's patients [13, 22].

In this paper we propose to focus particularly on haptic cues. These types of cues have been demonstrated to be less cognitively taxing than visual stimuli in navigation tasks, and can be provided to users in the less distracting and more private form factor of a wrist-worn device such as a smartwatch or fitness tracker; ultimately leading to a system that is more feasible for continued use out in-the-wild. Haptic cues have been explored briefly in the past, demonstrating improvements in users' posture [31], balance [19], and gait [17, 21, 28]. We propose to expand this work in the following ways. First, we propose the study of three distinct haptic cues against a visual baseline. These were designed to explore both temporal and spatial properties of these cues – the latter using two wrist-worn devices mapped to left and right steps. Second, we will conduct our study in a simulated street environment in virtual-reality (VR), enabling us to measure participants' engagement with various points-of-interest in the scene via gaze data (hits and dwell). In sum, the goal of our work is to assess the effect of visual and haptic cues not only in participants' gait performance, but the usability, perceived cognitive load, and safety of these types of systems.

3 USER STUDY

3.1 Participants

Mostly due to COVID-19 constraints, our preliminary study relies on six patients without any gait impairments. Except for one, these were aged between 18 and 25 years of age (M = 27.0; SD = 11.52); and the majority were students (66.6%). Using a 5-point Likert scale, participants reported being somewhat comfortable with VR technologies (M = 2.00; SD = 1.10). All participants had experience with smartwatches prior to this study.

3.2 Experimental Setup

This study was performed in a hallway 1m wide and 6.5m long. We relied on VR to simulate a street environment where participant walked in a straight line along a 5m long sidewalk. Several events were included (described as *distractors*) such as a passing car, a pedestrian that would start walking, and crossing light that would change from red to green (see Figure 1 – left). These events took place after participants walked 1.5, 2.5, and 3.5m, respectively. This was developed using the Unity Game Engine, and deployed on an HCT Vive Pro Eye head-mounted display (combined resolution of 2880×1600 px, 615 PPI, 90Hz, 110° FoV) and eye-tracker (120Hz, 0.5° 1.1° accuracy). Finally, the haptic cues were played on two Huawei Watch 2 and controlled through an Android application where the researcher started and stopped the cues and the VR simulation. The communication between these devices was done via the Open Sound Control (OSC) protocol, and the study complied with the ethics guidelines and COVID-19 regulations in our institution.

3.3 Experimental Design

Our study followed a within participants design counterbalanced using a Latin square. It included four cue conditions:

Visual. This followed a classic approach [25] where bright transverse bars 45cm wide were displayed on the floor covering the entire scene (see Figure 1 – right). The distance between bars varied between participants to match 150% of their baseline step length [1].

Haptic (one pattern, one watch [1P1W]). Another classic cue that uses a simple vibration pattern at specific intervals [29]. This was played on the participant's wrist, and provided them with a rhythmic stimulus. The *temporal* property of this stimulus varied between participants in order to match the cadence measured during the baseline trial with no stimulus (we follow this rationale for the remaning two haptic cues).

Haptic (one pattern, two watches [1P2W]). This designed this cue to explore the idea of playing the haptic pattern above alternatively over two smartwatches, placed on participants' left and right wrists. This would provide participants with a rhythm with *temporal* and *spatial* properties (left and right).

Haptic (two patterns, one watch [2P1W]). Two distinct vibration patterns were played in sequence on a single smartwatch, attempting to explore the *temporal* and *spatial* properties of [1P2W] using a single device.

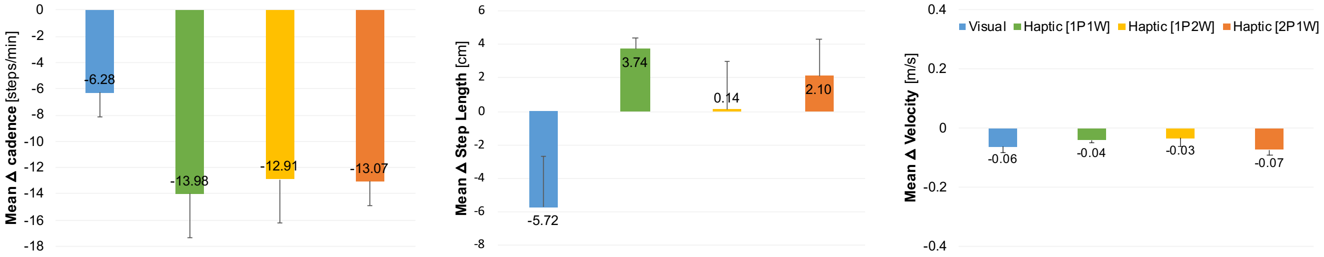

Figure 2: Results for cadence (lower is better, left), step length (higher is better, center), and velocity (right). These represent the mean delta to each participant's baseline results.

3.4 Metrics

In order to understand the effects of the cues and distractors on participants' gait and experience, we measured:

Performance. This included participants' cadence (steps per min.), step length, and velocity (meters per second). This was calculated by visually counting the number of steps in a trial, and by automatically recording how long it took participants to reach the end of the trial (five meters).

Usability. Participants completed the System Usability Scale (SUS) [3] for each cue, and a preference questionnaire at the end of the study. In the latter they were asked to comment on they favourite and least favourite cues.

Gaze. In order to assess participants' awareness of the three distractors included in the scene, we measured the number of gaze hits and dwell time on these across cue conditions.

3.5 Procedure

The study was conducted in a empty and quiet hallway. Participants were asked to properly disinfect their hands with an 70% alcohol solution, and to clean their face and wrists with disinfecting wipes. This was followed by collecting participants' demographic information in addiction to to previous experience with VR and smartwatches.

Afterwards, we asked participants to put on both smartwatches, one on each wrist, and to adjust them so they were tight and comfortable. This was followed by the setup and calibration of the VR headset and eye-tracker. The study started by a trial with no stimuli, where baseline measures of participants' gait parameters were captured (i.e., cadence, step length, and velocity) and feed into the system for personalized stimuli. Participants were asked to walk in a straight line towards the crossing light at the end of the scene (5m), and that the trial would stop when they were close to reaching it. Finally, at the end of each condition participants completed the SUS and took a small break.

At the end of the study participants completed the preference questionnaire. The researcher completed the session by following thoroughly cleaning the headset and watches with disinfecting wipes with at least 70% alcohol.

4 RESULTS

Below we present our preliminary results from six participants.

Table 1: SUS results across conditions (std. dev. in brackets).

Visual	Haptic [1P1W]	Haptic [1P2W]	Haptic [2P1W]
49.16 (3.76)	85.41 (4.59)	91.66 (6.07)	62.50 (3.02)

4.1 Performance

We emphasize that our goal is to improve users' gait, i.e., have them produce less but longer steps (as opposed to, e.g., the small shuffling steps seen with Parkinsonian gait). Despite not having any gait impairments, our participants' seem to have been able to improve their cadence and step length in the majority of the haptic conditions (see Figure 2 – left and center), while completing the trial in the approximately same amount of time as with no stimuli (see Figure 2 – right).

4.2 Usability

The SUS results for each of the conditions is seen in Table 1. This highlights a preference for the haptic cues relying on a simple vibration pattern played over one or two smartwatches (well above the average SUS score of 68). These results are further corroborated by the preference rankings. All participants' agreed their favourite cue was the Haptic [1P1W], mostly due to its simple nature requiring very little attention; and all agreed the visual cue to be their least favourite as it required them to continuously look at the floor, often loosing track of their surroundings.

4.3 Gaze

The gaze results can be seen in Figure 3. These seem to suggest participants were quite aware of their surroundings in both the baseline (no stimuli) and haptic conditions. As expected, the visual condition wielded a potentially lower number of gaze hits and dwell times across distractors – some of these are zero or close to zero, indicating some participants were not aware of some of these distractors at all. While further studies are required, this highlights how impractical and potentially dangerous is this well-studied cue outside of a controlled laboratory environment.

5 LIMITATIONS AND FUTURE WORK

Our immediate future work includes expanding the number of participants in our study, and following-up with participants with some form of gait impairment (particularly participants with Parkinson's

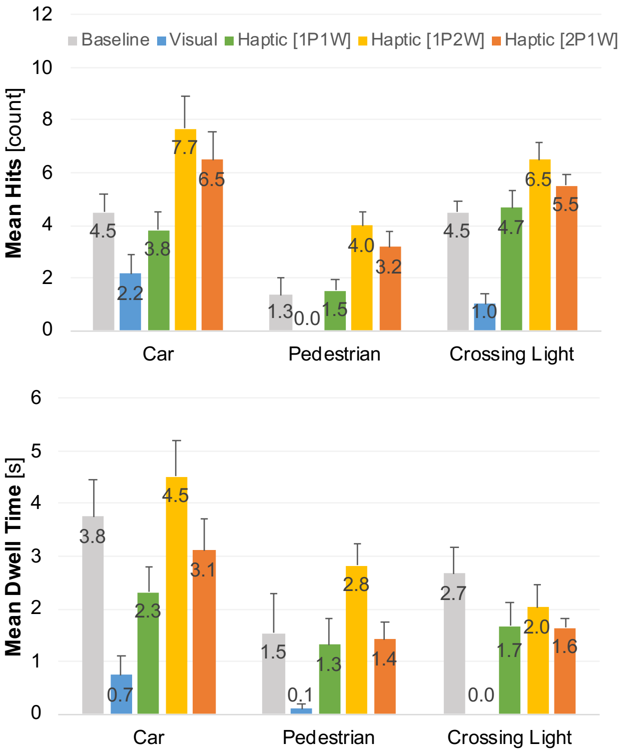

Figure 3: Top: mean gaze hits across conditions (and baseline) for each of the three distractors. Bottom: mean gaze dwell results.

disease) – the ultimate stakeholders of such a system. We will consider running these studies in a wider space, as we suspect our narrow hallway might have affected participants' gait at points (for fear of hitting a wall). Ultimately, we aim to develop a smartwatch application for in-the-wild haptic cues that not only aims to normalize users' gait but is comfortable and safe to use outside of a laboratory. We also suggest a replication of our study via a standard field study in order to compare findings. This would enable us to further validate virtual field studies as a novel research paradigm, particularly in the context of locomotion and mobility tasks.

6 CONCLUSION

This paper presented a work-in-progress where we explored popular and new stimuli to normalize users' gait in the context of a VR Field Study. The latter was employed so that we could explore the impact of these cues while walking in a simulated sidewalk; allowing us to start to assess not only the impact of these cues in the overall user experience, but their safety outside of a controlled lab. environment (measured via gaze and awareness of several events). We aim to expand this work via a wearable application that can help address gait disorders in a comfortable, usable, and safe way.

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