GaitWear: Haptic Cues for In-the-Wild Gait Normalization of Users with Parkinson's Disease

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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

Parkinson's patient's gait is one of the most affected motor characteristics of this disorder. The reduced efficiency regarding gait normalization of traditional therapies has introduced the concept of cueing. Many studies have been performed in order to assess the impact of these cues on patients' gait's parameters, and although the results are quite significant, we had found three major limitations: the assessment of cues usage only inside a controlled environment; the limited usage of information especially on Haptic cues; and the lack of investigations of its effects behind gait. To clarify these aspects, we had conducted a VR field study in order to safely assess the impact of visual and Haptic cues (with both temporal and spatial information) outside a laboratory, in participants' gait performance, usability, perceived cognitive load, and safety (i.e. awareness of their surroundings).

Due to Covid-19 pandemic and the major restrictions that were imposed, our study was performed by healthy participants (N=8). Although not suffering from any gait impairment, the results showed a positive effect of using haptic cues in regards to participants cadence, step length, and general awareness of their surroundings when compared to the visual cue. Other interesting outcome was the lack of significant difference between the usage of only temporal and temporal + spatial information in haptic cues. Besides this, in terms of usability and workload, haptic cues, were appointed to be participants' favourites and least demand, in contrast to visual cues.

Taking into account the results of this study, in addiction to the fact that many studies had observed long-term effects when using cues, we proposed an wearable app – GaitWear, that allowed participants' to display the best fit stimulus (Haptic 1P1W), whenever they felt the need to have it on.

CCS CONCEPTS

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

KEYWORDS

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

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1 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 [4]. 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 [16]. 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 [24].

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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 [26]. 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 [9]. 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 [3, 10, 23, 32, 34].

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) [3, 7, 20, 32, 37] and temporal parameters (velocity and cadence) [6, 10, 11, 17, 34] – 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 [31]. 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 [21, 22, 33]. These distractions have been proven to be even more problematic and difficult for Parkinson's patients [19, 29].

In this work 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 (i.e. only using temporal information, and lack of agreement on gait's parameters), demonstrating improvements in users' posture [38], balance [25], and gait [23, 28, 35].

Finally, additionally to all of these factors, there is still other issue that is important to discuss. The fact that all the described stimuli and previous studies, in order to improve gait, are only considered to be "always on", which may be too much and not needed for the patients. For instance, having a metronome beat constantly in the patients' ear is probably unbearable to deal during daily basis routine. Besides, it has already been proven that, these type of stimuli produce **carryover** effects, being not always necessary [3, 20, 30]. Therefore, finding the stimulus that most fit each patient needs without disturbance and having the patient choose when to have it on, may also beneficial.

Therefore, 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). Third, taking into account the results from the previous study, we will present a system that displays participants' best fit stimulus, whenever they feel the need to have it on.

In sum, the goal of our work is to, after assessing the effects of visual and haptic cues in participants' gait performance, usability, perceived cognitive load, and safety, propose a system that displays the best stimulus when taking into account the evaluated metrics - gait, usability and attention.

2 USER STUDY

2.1 Participants Selection

Due to Covid-19 major constraints, in addiction to the fact that gait disorders are more likely to be found in elderly people, which are considered to be the most vulnerable and high risk group to contract the virus, the access to this group was very restricted and not recommended.

Therefore, and since there are evidences that Parkinson's' patients and healthy participants are similarly affected by cues, when concerning gait [1], we had addressed this study to any person without gait impairments, regardless gender, age, or their experience with VR.

2.2 Experimental Setup

This study was performed in a room in TagusPark campus. 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.

2.3 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 [32] where bright transverse bars (20cm wide and 80cm long) 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 [3].

Haptic (one pattern, one watch [1P1W]). Another classic cue that uses a simple vibration pattern at specific intervals [36]. 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 correspond to -10% of the cadence measured during the baseline trial with no stimulus (we follow this rationale for the remaining 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.

2.4 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 (cm), 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. After each cue, participants completed the System Usability Scale (SUS) [5], a Raw Nasa-TLX [8] and a Stimulus usability questionnaire. In addition to this, and in order to have an overall perspective of the stimuli and experience, at the end of the study we asked the participants to fill a preference questionnaire, - where they had to pick and comment their favourite and least favourite cues - a Igroup presence questionnaire (IPQ) [27], and a simple questionnaire regarding their experience with our VR Scene.

Gaze. In order to assess participants' awareness of the three distractors and non distractors objects included in the scene, we measured the number of **gaze hits** - the number of times the participant looked at the object - and **dwell time** - the amount of time spent looking at each object - across cue conditions.

2.5 Procedure

The study was conducted in a empty and quiet room. Participants were asked to properly disinfect their hands with an 70% alcohol solution, to clean their face and wrists with disinfecting wipes, and to wear a mask during the entire session. Then, a brief introduction explaining the objectives of the study, and how the evaluation session was going to be conducted was presented to the user. This was followed by collecting participants' demographic information in addiction to to previous experience with VR and smartwatches, consent and an Immersive Tendencies Questionnaire (ITQ).

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.

Also, before the starting of the walks that were analyzed, it was allowed for the participant to have two moments of **familiarization** with the headset and the VE. Firstly, in the *VIVE Home*, the participant was encouraged to walk freely and to notice the **boundaries** that became visible when the end of the play area was closer. After the participant was confident that it was safe to walk without hitting a wall or an object, we let them explore the VR street without any external stimulus, for a maximum of five minutes.

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 fed into the system for personalized stimuli. Each of the following 4 trials had presented the previously described stimuli (in section 2.3) to the participant. Before each of the 5 trials, 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**; the **Nasa-TLX**; and the **Stimulus' Usability Survey**, and took a small break.

At the end of the study participants completed 3 more questionnaires: the **preference** questionnaire, the **IPQ**, and the **VR scene questionnaire**. The researcher completed the session by following thoroughly cleaning the headset and watches with disinfecting wipes with at least 70% alcohol.

3 RESULTS

Below we present our results from eight participants.

3.1 Participants

Our study was performed by 8 participants without any gait impairment. Except for one, these were aged between 18 and 25 years of age (M = 25.50; SD = 8.99); and the majority were students (75.0%). Using a 5-point Likert scale, participants reported being somewhat comfortable with VR technologies (M = 2.50; SD = 1.20), regarding the usage of smartwatches, participants declared being quite comfortable with them (M = 3.88, SD = 1.13). Apart from this, participants had also answered an ITQ, where it was observed an interesting susceptibility to be immersed (M = 105.40, 8.47).

Finally, all participants had granted us consent to collect and use their data anonymously, for scientific purposes.

3.2 Gait

We emphasize that our goal was 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). In order to understand whether this was accomplished, we should consider each of the gait parameters' differences – Step length, Cadence and velocity – across conditions. The analysis of each metric's result was evaluated in two different moments: Firstly, it was performed a comparison between baseline and each metric's results, through the usage of **paired-samples t-test**; Secondly, we had also performed a comparison between the results from each cue condition though the usage of an **one-way repeated measures ANOVA**.

During **visual condition** it was observed a significant decrease of **step length** (see Figure 2 – center), and a significant increase of cadence and velocity (see Figure 2 – left, right), when compared to the baseline walk.

On the other hand, during **Haptic conditions**, there was an increase of step length - observed during all haptic cues, but only statistically significant during Haptic 1P1W. In addiction to this, it was also observed a significant decrease of cadence and velocity (across all haptic conditions).

Regarding the comparison between the **two types of stimulus**, it was observed a significant decrease of step length, and an increase

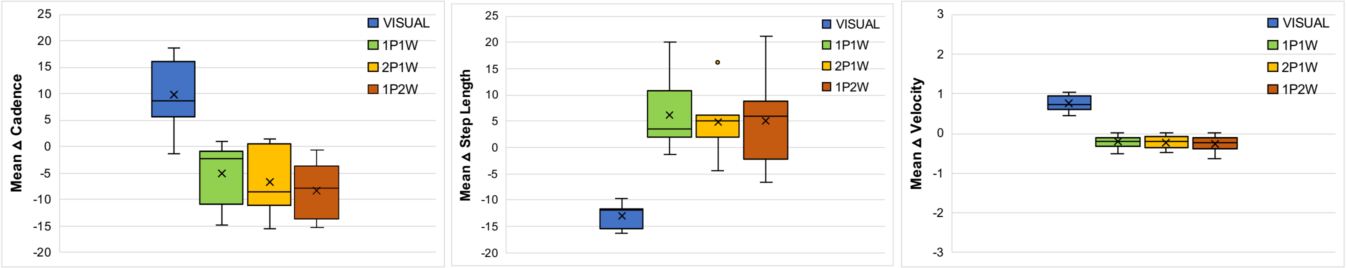

Figure 2: Results for cadence (lower is better, left), step length (higher is better, center), and velocity (right). These represent the mean delta to each participant's baseline results.

	Visual	Haptic [1P1W]	Haptic [1P2W]	Haptic [2P1W]
Steps	4.25 (0.71)	-0.25 (1.67)	-0.625 (1.06)	-0.75 (1.28)
Distance [m]	-0.09 (0.28)	-0.14 (0.26)	0.21 (0.42)	0.19 (0.36)
Time [s]	1.71 (3.52)	1.87 (3.79)	1.89 (3.64)	2.52 (2.82)

Table 1: Mean variation of number of steps, walked distance and time, between baseline and each tested condition. Standard error is presented in brackets. Negative values represent a decrease from the mean baseline value.

of cadence and velocity during visual condition, when compared to the haptic ones. However, it is important to highlight that no significant differences were found between haptic cues.

Beside these main metrics, we had also taken into account the **amount of steps**, **distance** and **time** required to perform each walk, since these factors were the ones influencing Step length, cadence and velocity. These results, presented in table 1, showed a statistically significant increase on the number of steps during visual condition, and no significant differences regarding the distance walked and the amount of time needed.

3.3 Gaze

The results regarding gaze can be seen in Figures 3 and 4.

In order to present and analyse these, we had divided them into two different subsections, depending on the type of element to which it referred - **Distractors** or **Non-distractors**. We had measured the number of hits and dwell time at each of those elements during the different conditions. And in order to determine whether these difference were statistically significant we had also used a one-way repeated measures ANOVA.

3.3.1 ***Distractors.*** From the plots presented in Figure 3, it is important to highlight that during visual condition it was not detected any look (hit) to the car nor to the pedestrian's crossing light, indicating that participants were not aware of these distractors at all.

Besides this, after conducting the one-way repeated measures ANOVA, in specific Post hoc analysis with a Bonferroni adjustment it was revealed that the count of hits and dwell time statistically **decreased from Baseline**, **Haptic 1P1W, Haptic 2P1W and Haptic 1P2W condition during visual condition** In other words, participants, during visual conditions looked significantly less times to the distractors elements, when compared to baseline or when using any other stimulus. In addiction to this, no significant difference was found when comparing haptic conditions with baseline.

3.3.2 ***Non-Distractors.*** Through those plots, it is observed that during visual cues, similarly to what happen with the distractors elements, participants did not noticed (i.e. looked) at some of these elements - buildings and trees. It was also quite noticed that floor's dwell time was much higher than the correspondent number of hits.

Besides these noticeable aspects, after conducting an one-way repeated measures ANOVA, in specific Post hoc analysis with a Bonferroni adjustment it was observed that hits' mean number had significant **decreased** from Baseline and Haptic 2P1W during visual condition. On the other hand, the mean dwell time had significant **increase** during visual cues when comparing to Baseline, Haptic 2P1W and Haptic 1P2W. This means that participants looked at the non-distractors elements significantly less but longer times during visual stimulus.

Besides this, no other significant differences was found, specifically regarding the comparison between haptic cues and baseline.

3.4 Usability

Regarding **SUS Final Score**, presented in the bottom of table 2, there was a clear preference for the haptic cues relying on a simple vibration pattern played over one or two smartwatches - 1P1W and 1P2W - (well above the average SUS score of 68). On the other hand, Visual cues and Haptic 2P1W's scores indicated the existence of an usability issue. In order to understand whether this differences were statistically significantly, we had conducted a **Friedman test**, which had identified this differences as significant, $\chi 2(3) = 21.911$, $p < .0005$.

These results were further corroborated by the preference rankings. 62.5% of participants had agreed that their favourite cue was Haptic [1P1W], mostly due to its simple nature requiring very little attention; 75% 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.

3.4.1 ***Workload.*** Regarding the **workload** experienced by participants during the usage of each stimulus, the results are presented in table 2. From these, it was observed an **higher level** of needed

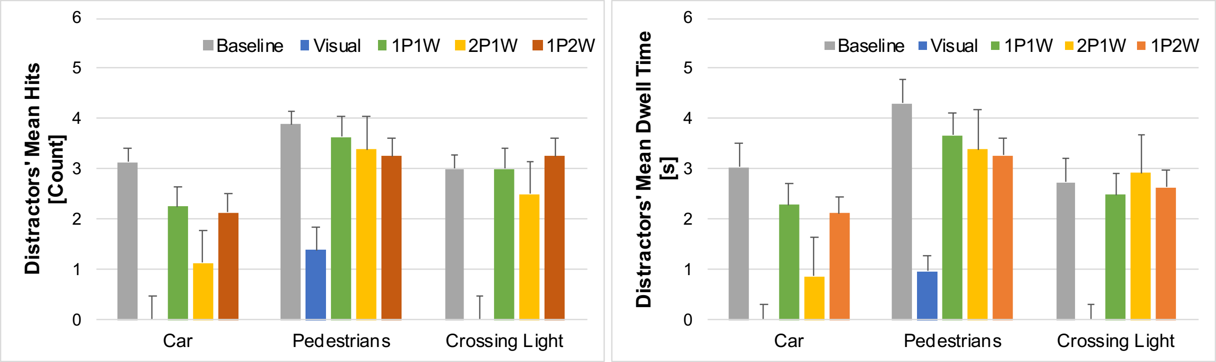

Figure 3: Left: mean gaze hits across conditions (and baseline) for each of the three distractors. Right: mean gaze dwell results.

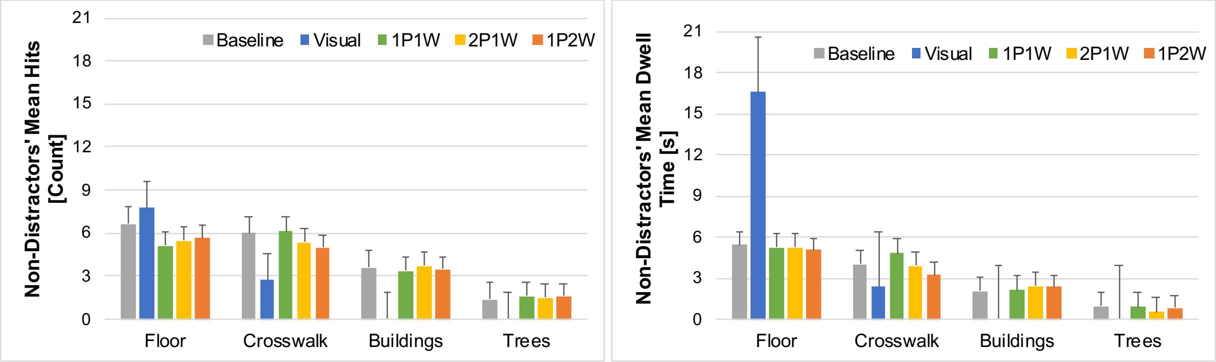

Figure 4: Left: mean gaze hits across conditions (and baseline) for each of the non-distractors elements. Right: mean gaze dwell results.

workload, during **visual** condition, and an **inferior value** during haptic cues, in particularly, during **Haptic 1P1W** and **Haptic 1P2W**. When comparing the results from these two Haptic conditions with visual, through the usage of **Friedman test**, there was a statistically significant increase during the last one ($p = 0.001$ and $p = 0.012$, respectively).

In fact, visual cues had statistically significantly higher values in Mental Demand, Performance, Effort and Frustration factors (Nasa-TLX subscales), when comparing with haptic stimulus.

3.4.2 ***VR Simulation***. Regarding the usage of **VR**, we had collected participants' opinions about it. As a result, we found out that, on a scale from 1 to 5 (where 1 is totally disagree and 5 is totally agree), participants found the street (M = 3.38; SD = 0.74) and the experience of walking in it (M = 3.63; SD = 0.52) quite real.

In addiction to these usability results, other factor that is related to the usage of VR, is the sense of **presence** in the Virtual Environment. This feeling was measured through the IPQ, resulting on a mean feeling of presence of 62.25 (SD = 7.07). These results were evaluated by the **Cronbach's alpha** test, in order to test the internal consistency and reliability of the data, resulting on an high internal consisting, α= 0.800.

	Visual	Haptic [1P1W]	Haptic [2P1W]	Haptic [1P2W]
SUS	40.00 (4.81)	80.31 (3.88)	58.75 (5.51)	81.88 (3.20)
Workload	41,98 (1,69)	11,77 (4,13)	18,96 (10,21)	12,71 (2,00)

Table 2: SUS and Workload results across conditions (std. dev. in brackets).

3.5 Results Discussion

From the performance of our VR field study we had evaluated the effects of different visual and haptic stimuli on participants' gait, attention and usability metrics. In order to understand those, we had compared them with similar previous works and, analyse and justify them in an auto-critical way. We will start with the gait results, followed by the attention results, and finalizing with the usability results.

3.5.1 ***Gait.*** During gait analysis we had evaluated the effects of using the different cues in participants' step length, cadence and velocity, across conditions.

Visual Cues.

During **visual condition** it was observed a significant decrease of **step length**, and a significant increase of cadence, when compared to the baseline walk, contrary to what was observed in previous works [3, 14, 20, 32]. On the other hand, it was observed a significant increase of velocity, similarly to what demonstrated in previous works [2, 14, 20]. Although all of these metrics are important in order to understand the impact of the cues, we should bare in mind that form the state of the art, visual cues, were appointed to be effective in improving patients' gait parameters in particularly the spatial ones (step and stride length). Therefore, although our cadence's results are quite important, we should particularly focus on the step length discrepancies observed.

In order to understand the reason behind this decrease we should take under consideration the formula that was used to compute this metric: $StepLength = distance/\#steps$. From the previous presented analysis we had observed that although the distance walked during visual cues was quite similar to the baseline walk, the **number of steps** taken in order to perform the walk did **significantly increase**. In fact, it was quite notorious during the conduction of the study that participants seemed to take more and shorter steps during the usage of visual cues. Therefore, this increase of the number of steps was the direct cause for this step length decrease.

Besides this deterioration of step length, **cadence** had also been negatively affected (i.e. increased) during the usage of visual cues, which was once again not expected when taking into consideration previous works related to Parkinson's' disease [3, 32]. In order to understand this, we should also take into account the formula that was used to calculate this value: $Cadence = 60 * \#steps/\Delta time$. Taking into account this equation, and the step, distance and time analysis, once again it was the increase of the number of steps that had influenced cadence's value (increasing it).

Regarding **velocity**, a significant increase (i.e. improve) was detected between visual condition and baseline, similarly to what demonstrated in previous works[2, 14, 20]. This metric is closely related to step length and cadence variation, in fact from the used formula ($velocity = Cadence/StepLength$) we can observe that velocity is positively correlated with cadence and negatively correlated with step length. Thus, since in our study it was observed a decrease of step length and an increase of cadence, this velocity increase was expected. In addiction to this, it is also important to reinforce the fact that no significant differences were observed regarding the time needed to perform the trial and the walked distance.

Taking all of this into account, and since one of our main objective for using visual cues was to have some kind of related work representation and comparison, we may conclude that, that was not accomplished. However, it is important to bare in mind that our study had diverged from previous ones in many factors: the participants (i.e. healthy), the usage of VR with different elements in it (different from the typical hallway from previous works), the usage of VR bars on the floor (opposed to the typical cardboard bars on the floor), and the distance between visual cues. These factors (one or more) may had had an influence in the performance of participants while using the visual cues

Haptic Cues.

Regarding **Haptic cues**, and before getting into any explanation and analysis regarding these results, we should remind that, up to our knowledge, the usage of haptic cues with the objective of gait regulation, had been **little explored** in the past, which makes it hard to find similar studies in order to compare results.

During this study, it was observed significant improvements regarding **step length** (i.e. increase) and **cadence** (i.e. decrease), when compared to baseline.

Firstly, regarding cadences' significant improvements (i.e. decrease), since we had used vibrations played at **-10% of participants' baseline** cadence, it was expected a decrease of this metric, similarly to what observed in previous literature [23, 36]. Besides this, we may also conclude that participants were able to match and adapt their cadence to the one presented by the smartwatches.

Regarding this, participants' **step length** had also been improved through the usage of haptic stimulus, significantly during Haptic 1P1W. Which is also in concordance with previous works [23, 36]. During the others two haptic cues (Haptic 2P1W and Haptic 1P2W), although it was also observed an improvement, it was not considered significant.

Finally, regarding **velocity**, it was detected a significant decrease between all haptic conditions and baseline. However, we should take into account two different aspects: firstly, it is important to refer that participants had walked similar distances within the same amount of time (no significant differences). Secondly, since, as explained before, this metric is closely related to cadence and step length,which means that with cadence's decrease and step length's increasing, it would be expected that velocity would decrease too.

Gait and VR Field study.

One important contribution of this study was the usage of a VR Field study approach. Taking into account all of these previously presented results, and the observed similarities and contrasts with the previous literature, we may infer that although it was quite successfully its usage during haptic cues, this approach may have had an impact on the perception of **visual cues**. This fact, may explain why participants had such a poor performance when comparing to similar state of the art studies.

On the other hand, little difference was noticed when using this study approach with **haptic cues**, when comparing to previous studies. In fact, as explained before, Haptic 1P1W did behave as expected (similarly to the previous works). Which lead us to conclude that in this case, the VR field study was successfully used.

However, this contrast between the success while using haptic and visual cues, and the uncertainty regarding what was the cause of the gait deterioration during visual cues, makes it quite difficult and unfair to establish a comparison between the obtained results during these two conditions. For that, we did not took into account comparisons between haptic and visual cues (only Haptic – Haptic, Haptic – Baseline and Visual – Baseline).

Temporal and Spatial Information.

Before the start of this study we had hypothesize that the usage of **spatial and temporal** information together in Haptic stimuli, would have a positive impact in almost every gait parameter, as observed by a previous work in the visual field [7]. However, this was not observed (Haptic 2P1W and 1P2W had not significantly improved step length nor velocity). In addiction to this, none of the comparisons regarding the two types of stimulus, (only temporal (i.e. Haptic 1P1W) and temporal + spatial (i.e. Haptic 1P2W and Haptic 2P1W), had led to significant differences, when gait regulation is concern.

Which may lead us to conclude that the impact on gait's parameters of the usage of an haptic stimulus with spatial and temporal information, does not differ from using only temporal information.

3.5.2 ***Attention.*** After this gait analysis, we should also take into account how did the stimuli influenced participants' **attention and awareness**, especially regarding the surroundings. For that we had used in our VR scene two different types of elements: distractors and non distractors, and measured the number of hits and dwell time at each of those elements.

During **visual cues** it was observed a significant decrease in the number of hits and dwell time at **distractors** elements, when comparing to baseline. In fact, it was not detected any look (hit) to the car nor to the pedestrian's crossing light, which indicates that participants were not aware of these distractors at all. In order to explain this decrease, we had appointed two main reasons. Firstly, the fact that as explained before, participants had some **struggles** coping with these cues, may had led to some extra focus on the visual stimulus. Secondly, the fact that, these cues were presented on the floor, forcing the participants to look down (to the floor), may had also led to a neglection of others events that were happen around them.

Consequently, since participants' attention was mainly directed towards the floor, **non-distractors**' mean dwell time had significantly increased, when comparing to baseline. However, the number of hits had decreased. Meaning that participants had looked less but longer times at the non-distractors elements (i.e. the floor).

Contrasting to this, during **Haptic cues** no significant differences were found, regarding participants' hits and dwell time at the **distractors** and **non distractors** elements, when comparing to baseline. Meaning that **no evidence** was found about an effect of haptic cues in participants' gaze and attention.

3.5.3 ***Usability.*** Finally, we also took into account the **usability** and **preference** of participants regarding each stimulus.

Although we had used several different questionnaires with the aim of evaluating participants' opinions, the answers were quite consistent when preferring the usage of **Haptic cues**, in particularly 1P1W stimulus, in contrast to the use of **visual cues**. These last ones were appointed by participants as their **least favourite**.

In addiction to this, regarding the **workload** needed by the participants' when using each stimulus, it was observed the requirement of **higher levels during visual cues** in contrast when using Haptic cues,in particularly, Haptic 1P1W and 1P2W. From this workload evaluation, we had identified that Mental Demand, Performance, Effort and Frustration were the factors that led to this increased during visual cues.

Once again, it is important to highlight that participants had some struggles during the usage of visual cues, which may had led to a decrease in terms of usability, preference and an increase of the required workload.

Finally, we had also taken into account how participants felt about the **usage of the VR street**. As an overall, participants' found the street and the experience of walking on it quite real, and felt present in the VE. Regarding this sense of presence, we did not found a correlation between that and the participants' tendency to be immersed (from the ITQ). One reason that can be appointed in order to justify this lack of significance, is the fact that the versions of these used questionnaires (ITQ and IPQ) were different. The ITQ's used version was the second one (with 29 items), however, the IPQ used was a short version of the second version (with only 14 items).

Thus, although there were some clear problems regarding the usage of visual cues, we may conclude that the usage of haptic cues, in particularly Haptic 1P1W, did improve participants' gait while not deteriorating their attention and usability.

4 GAITWEAR

After the performance of the VR field study, and understanding the effects of each of the studied cues in patients' gait, usability and attention, we had developed a **singleton android wear app** - GaitWear (Figure 5). The main reasons for this, relied on two different aspects. Firstly, as explained before, the fact that from previous works it was commonly observed a carryover (long-term) effect after the usage of the cues for a certain amount of time [3, 9, 12, 15, 18, 20, 30, 34], showing that in order to produce improvements in patients' gait, it is not necessary to have the cues always on.

Secondly, the fact that the usage of cues is normally just associated with controlled environments (i.e. laboratory, home), represents other aspect that we aimed to address with this application. In other words, although the results from the laboratory environments are quite important, the fact that when the effects from previous cues' usage disappear, patients need to go back there in order to reimprove gait, it is other aspect that should be taken into account. Besides this, since the amount of time that the effects efficiently last is quite uncertain - being observed effects from 15 minutes to 60 days - patients' become afraid to go out and to leave controlled environments, leading to a reduction of patients' mobility, independence and quality of life.

Therefore, this application aims to be like a "**pill**" that patients with gait impairments (i.e Parkinson's disease) can use, whenever they feel the need to, in order to safely and easily continue to perform their daily routine, as normal as possible. For that, the application has three main functionalities:

1. **Stimulus Presentation**. From the previous VR field study, we had identified Haptic 1P1W as the stimulus that most improved participants' gait without deteriorating their attention or usability. In fact, regarding gait, from the previous results we had observed that Haptic 1P1W, was the only stimulus that was able to significantly change (i.e. improve) participants' step length and cadence, without interfering with usability and attention, which was an important factor was an important factor for us to ensure users' safety while out in-the-wild.
   Therefore, taking into account all of these factors, that was the stimulus that was used in our application.
   - **Implementation:** This stimulus implementation was quite similar to the one used during the VR field study. However,

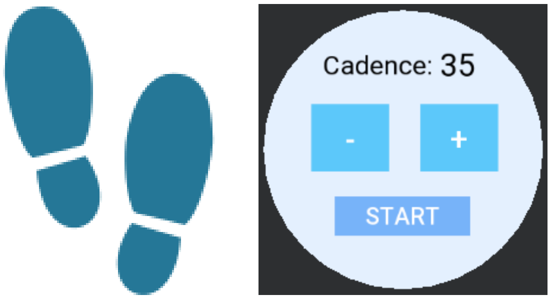

Figure 5: Left: GaitWear Logo; Right: GaitWear Screen

since the application run without the support of a mobile application, and there was no baseline value of cadence to be used to calculate the vibration frequency for each participant, we had established a default value for it. This value corresponded to less 10% of the mean cadence during our VR field study baseline walk. Therefore, since the cadence's mean value during baseline was 39 steps per minute, the used value as default was 35 steps per minute.

(2) **Stimulus' Frequency Regulation.** In order to allow users to adapt the vibrations frequency to their needs or preference, we had enabled the stimulus' frequency regulation. In other words, depending on the situation or the users' needs, the cadence imposed by the stimulus can be changed at any time.
   - **Implementation:** This feature implementation was accomplished trough the usage of two buttons (one to increase 1 unit, other to decrease 1 unit of the cadence value – represented in figure 5 as + and -). This regulation can be done at anytime, just by clicking on the correspondent button.

(3) **Start/Stop Stimulus.** Besides regulating the stimulus, the application allows users to start and stop the stimulus at anytime. This was an important feature, since as explained before, users may not always need or want the stimulus on, in order to have an improved gait.
   - **Implementation:** This was accomplished through two different ways. Firstly, users could start/stop the vibration through the usage of a simple button, that could be pressed at anytime (*Start Button* presented in figure 5). Secondly, and in order to introduce a different and simple type of input that did not need an interaction with the application screen, we had used a **flick wrist gesture** to toggle the stimulus' presentation. The choice of this gesture, relied on the fact that this is considered to be uncommon in daily life, quick and easy to execute and easily and reliably detectable [13].

5 LIMITATIONS AND FUTURE WORK

Our immediate future work includes expanding the number of participants in our VR field study, and following-up with participants with some form of gait impairment (particularly participants with Parkinson's disease) – the ultimate stakeholders of such a system. Secondly, an evaluation of the usage of GaitWear also with participants with some gait impairments, would also be interesting and important. Finally, we 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 Thesis explored popular (i.e. Visual) and new stimuli (i.e. Haptic) 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 laboratory environment (measured via gaze and awareness of several events).

The observed results were quite useful in order to clarify three different aspects: Firstly, not only did Haptic cues improved participants gait, but it was also observed that those did not had an impact on participant's' usability and attention factors; Secondly, it is important to highlight that when comparing our results with previous works, it was notorious a significant contrast regarding what was expected when using visual cues, particularly regarding the step length results. This may lead us to conclude that the usage of VR field study might have had some impact regarding participants perception of the visual cues. On the other hand, no evidence was found regarding this impact during the usage of haptic cues; Thirdly, no significant differences were found regarding the usage of only temporal information, and temporal and spatial information together in haptic cues;

After the performance of this study, and taken into account its results, we had proposed a smartwatch application: **GaitWear**. This application represents a form to face the fact that patients not always need the presence of stimulus in order to improve gait (due to Carryover effects). Therefore, GaitWear aims to be like a "pill" that users can use whenever they feel the need to. In order to do that, GaitWear enables the display and users' control of Haptic 1P1W stimulus – the stimulus that led to more improvements during the performance of the VR field study.

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