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## Wearable Haptic Devices for Long-Term Gait Re-education for Neurological Conditions

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**Abstract.** Many people with long-term neurological and neurodegenerative conditions such as stroke, brain injury, multiple sclerosis or Parkinson's disease suffer from an impaired walking gait pattern. Gait improvement can lead to better fluidity in walking, improved health outcomes, greater independence, and enhanced quality of life. Existing lab-based studies with wearable haptic devices have shown that rhythmic haptic cueing can cause immediate improvements to gait features such as temporal symmetry, stride length and walking speed. However, such wearable haptic devices are unsuitable for self-managed use, and to move this approach from out of the lab into long-term sustained usage, numerous design challenges need to be addressed. We are designing, developing, and testing a closed-loop system to provide adaptive haptic rhythmic cues for sustainable self-managed long-term use outside the lab by survivors of stroke, and other neurological conditions, in their everyday lives.

**Keywords:** Haptics, Long-term, Gait, Wearables, Adaptive, Rhythm, Health, Entrainment.

### 1 Introduction

Conditions such as Stroke, Parkinson's disease (PD), Multiple Sclerosis (MS), Traumatic Brain Injury (TBI), and Acquired Brain Injury (ABI) can all cause motor impairment, affecting basic tasks like walking, standing and reach. To improve individual health and well-being for patients it would be helpful to be able to both assess and treat their gait outside the clinic or lab. This would have the potential to allow researchers, clinicians, caregivers, and physiotherapists to devise and deliver more effective rehabilitation plans over the long-term [1]. Consequently, wearable sensing and feedback systems now offer considerable potential for the assessment and treatment of gait abnormalities over the long terms outside of clinical settings [2]. Many survivors with motor impairment develop gait abnormalities, such as hemi-paretic, hemiplegic, diplegic, neuropathic and Parkinsonian gait [3]. The exact nature and effects of such gait abnormalities are varied; however, common results include bone degeneration, joint pain, increase in higher vertical forces in the legs, loss of bone mineral density and

increased risk of falls and fractures [4]. Overall these factors cause reduced mobility, reduced quality of life, lack of confidence and independence. Gait re-education is a high priority for survivors of such conditions [5], though funding and availability for such therapy is often limited.

## 2 Biological Entrainment and Rhythmic Cueing

Gait re-education using rhythmic cueing can be performed via three sensory channels: auditory, visual and haptic [6]. These modalities have all shown improvements in gait features in the lab, especially auditory and haptic. The principle behind rhythmic auditory cueing and rhythmic haptic cueing is primarily biological entrainment [7], and its interaction with the Neural Central Pattern Generator [8]. In outline, the regular sequence of cues acts as a template for the brain to entrain with [9] typically leading to improvements in certain gait features, in particular increased temporal symmetry of steps, increased stride length and speed of walking [7].

Rhythmic cueing based on audio stimuli is a proven method for improving gait via entrainment [10], but in practice, its use is generally limited to the lab [7]. Haptic cueing is of particular interest because it offers an unobtrusive, invisible, sociable, safe alternative [11]. Other potential advantages of the haptic modality include the ability to deliver cues to the appropriate leg at the appropriate time, taking advantage of the proprioceptive and kinaesthetic senses [7,12]. However, existing systems that combine gait tracking and adaptive haptic cueing are unsuitable for long-term self-managed use outside the lab.

## 3 Longitudinal Pilot Study

We carried out what is to the best of our knowledge the first longitudinal pilot study on the self-managed use of wearable haptic devices for gait re-education via entrainment in outdoor settings. The study involved a brain injury survivor who had reduced ability on both sides of his body and therefore, significant gait impairments. On Day 1 of the study, we measured his baseline pre-intervention baseline measurements in the lab using x-OSC inertial measurement units [14] on both ankles. The measurements were taken while walking 10 metres in a straight line for about 6-8 times. The IMU data was logged wirelessly to a laptop for later analysis. While he was walking in the lab, he was also video recorded to later show it to physiotherapists to evaluate his gait. The participant was asked to walk in synchrony to the haptic rhythm at a suitable outdoor setting for at least five minutes for about 10 days within two weeks.

To provide the haptic cue for previous in-lab studies, we have used a family of wearable haptic devices developed in-house, generally known as the Haptic Bracelets [15], however, for this longitudinal pilot study we have provided a commercial off-the-shelf wearable haptic device that can provide rhythmic haptic cue only. In addition, the participant was also provided with an iPhone running the Health Kit [16] and Moves [17] applications, recording their step count, walking distance, duration and route. After the two-week period, he returned to the lab and gait measurements were taken again using

IMU sensors, similar to Day 1. He was also asked a number of interview questions related to usability, wearability, compliance, challenges he faced and perceived changes in his gait.

On comparing data from Day 1 pre-intervention with Day 16 post-intervention gait measurements, significant improvements in gait characteristics were observed. In addition, expert gait evaluation by a physiotherapist have also showed significant improvements on the following gait characteristics: stride length, temporal symmetry and walking speed.

## 4 Conclusion

This study also revealed numerous design challenges for users with characteristics such as reduced dexterity, hemiparesis, reduced sensitivity and limited proprioception.

Future design aims include simplicity, wearability, unobtrusiveness, low maintenance, low cost, oversight, where appropriate, by clinicians, accuracy and completeness of the longitudinal data.

For this pilot study, neither the participant nor the researchers had access to the data during the two-week period. As an extension to this study, we are planning to provide a customised wearable haptic device, that will provide the haptic rhythm and also be able to track activity and compliance over the long-term.

We believe that wearable haptic devices are able to both assess and, where appropriate, treat gait outside the clinic or lab over the long-term have the potential to make a substantial contribution to the gait re-education of survivors of neurological conditions. The design of these systems will need to be adapted to be suitable for a combination of self-management and therapist-overseen use. At present, most stroke survivors, for example, do not receive any rehabilitative therapy at all beyond a few months after their stroke, as continued gait training is very expensive.

Thus, such a system for community ambulators, where real time continuous gait data is collected over extended periods, in parallel with the provision of adaptive haptic rhythm, has potential to act as a highly desirable self-managed physiotherapy mechanism beyond care homes and indoor physiotherapy sessions.

Remote long-term gait tracking and training can lead to many benefits, most importantly improved confidence and independence, and improved quality of life and well-being, additionally reduction of costs associated with care and rehabilitation.

Such a system may be beneficial for post-operative progress tracking for knee and hip surgery patients and in addition, gait tracking of athletes, runners, and professional sportspersons.

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