Wearable Haptic Devices For Post-Stroke Gait Rehabilitation

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Author's accepted Manuscript.
Ubicomp/ISWC'16 Adjunct , September 12-16, 2016, Heidelberg, Germany.

Abstract

Wearable technologies, in the form of small, light and inconspicuous devices, can be designed to help individuals suffering from neurological conditions carry out regular rehabilitation exercises. Current research has shown that walking to a rhythm can lead to significant improvements in various aspects of gait.

Our primary aim is to provide a suitable, technology based intervention to enhance gait rehabilitation of people with chronic and degenerative neurological health conditions (such as stroke). This intervention will be in the form of small, lightweight, wireless, wearable devices the user can take out of the clinic, extending their rehabilitation to their own home setting. The devices can deliver a series of vibrations at a steady rhythm giving the patient a more stable and symmetric pace of walking.

The simplest version of this approach typically comprise of a very small network of just two nodes and a central controller. The existing prototypes (called the *Haptic Bracelets*) capture and analyse motion data in real time to provide adaptive haptic (through vibrations) cueing. In the future and after more refinement, the system could allow a single therapist to monitor and advise groups of stroke survivors undergoing therapy sessions.

Figure 1: A Haptic Bracelet device strapped on user's leg.

Figure 2: Participant using the Haptic Bracelet devices.

Figure 3: Vibrotactiles used for delivering the rhythmic haptic cue.

Author Keywords
Stroke; gait rehabilitation; hemiparetic gait; wearables; Haptic Bracelets; rhythmic haptic cueing

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

H.5.2 User Interfaces: Haptic I/O; Prototyping

Introduction
Wearable technologies, in the form of small, light and inconspicuous devices, can be designed to help individuals carry out regular rehabilitation exercises.

One of the key aims of this research is the design, implementation, testing and evaluation of a multi-limb wireless device, with appropriate software to capture motion data in real time and deliver flexible, adaptive rhythmic haptic cues to its wearers to assist with gait rehabilitation and the restoration of mobility.

Rhythmic cueing has real promise for improving the gait of stroke survivors, with auditory metronomic cueing demonstrating immediate (though not necessarily lasting) improvements to gait [1]. Audio, on the other hand, may not be the best medium for gait rehabilitation outside a controlled environment (i.e. lab or rehabilitation gym), as it is important to keep the audio channel clear, helping people to remain aware of the surrounding environment, have conversations with other people and avoid dangers from traffic.

The devices we are designing are capable of monitoring and analysing gait characteristics in real time and automatically provide rhythmic haptic cueing (through vibrations) whenever it is needed, leaving the audio channel clear and free of distractions.

The design and development of our prototypes is based around the needs of stroke survivors and their physiotherapists [2]. Survivors can then continue to work on gait improvements in the leisure and privacy of their home or while going about with their day-to-day activities, without the need of constant medical supervision. In the future, the system could be developed further to allow a single therapist to monitor and advise groups of stroke survivors undergoing therapy sessions remotely.

Background
Stroke is a serious, sudden and devastating illness, affecting approximately seventeen million people worldwide each year [3]. Four out of five stroke victims survive their stroke [3] but over half stroke survivors are left with a disability, making stroke one of the leading causes of complex adult disabilities [4]. Post-stroke disabilities have a higher impact on an individual than any other chronic disease [4] with more than half of all stroke survivors left dependent on others for everyday activities.

Stroke survivors commonly experience what is called *hemiparetic gait*. Hemiparetic gait is characterised variously by temporal [5], and spatial [6] asymmetries between left and right steps. Many health problems are associated with this disorder, for example the non-paretic (stronger) limb may be exposed to higher vertical forces [7] which can lead to joint pains [8], and increased risk of fractures. Hemiparetic gait is directly linked to an increased risk of falling observed after stroke, doubling the risk of hip fracture [9]. Besides the physical health issues, gait rehabilitation is also of paramount importance for the restoration of independence and thus an overall better quality of life.

Carrying out rehabilitation exercises regularly can significantly improve a person's recovery both in in the early days after a stroke and long after they return home [10]. Research in rehabilitation techniques strongly suggest that home-based rehabilitation is more beneficial to the patients [11]. The approach of self-managed rehabilitation also has the potential to offer substantial cost savings for health services, considering that the current stroke care provision plan in the UK is estimated to cost an average of £24,855 per patient [12]. On the other hand, exercising in the home setting is not always easy as patients may have difficulty carrying out exercises effectively without suitable guidance.

Advances in technology mean that we are now in a position where it can be employed to assist individuals with day-to-day rehabilitation exercises. The field of research for improving gait rehabilitation is still open for further exploration, with strong evidence suggesting that metronomic cueing and entrainment (discussed below) are very effective in the rehabilitation and re-training after a stroke [13].

Entrainment

In physics, entrainment is a natural phenomenon where two or more periodic processes interact with each other to adjust to a common or related period. However, it was only recently (early 1990s) that the human capacity for biological entrainment became better understood and applications for movement rehabilitation of neurological conditions were studied. Applications included the use of auditory cues to synchronise human motor responses into stable time relationships. In such cases, entrainment mechanisms act between the external rhythm and the motor response to stabilise and regulate gait patterns [14].

Rhythmic cueing for gait rehabilitation

Use of an auditory rhythm provided by a metronome has been investigated and successfully demonstrated as a means of improving hemiparetic gait with immediate effects [14].

Studies with stroke survivors walking to an audio rhythm showed improvements in spatial [15] and temporal symmetry [16]. The step time asymmetry and the paretic (affected leg) step time variability of participants also improved significantly [1], as did the ability to make gait adjustments in response to changes in the cue [17]. Rhythmic cueing is therefore a promising approach, but the use of audio may not be the best medium for in-home or out-and-about scenarios for rehabilitation, where it is important to keep the audio channel clear for reasons of safety, sociability, and to remain aware of the environment. In addition, with audio cues alone it is difficult to differentiate which cue is for which leg [1], thus missing out on some potentially beneficial aspects of attention and proprioception in gait rehabilitation.

Rhythmic Haptic Cueing

Haptics is a term used when referring to any form of communication involving the sense of touch. This can provide another mode for mediating rhythmic cueing for entrainment and motor movement rehabilitation. Rhythmic haptic cueing has shown promising results and great potential of offering similar and immediate

The Haptic Bracelets

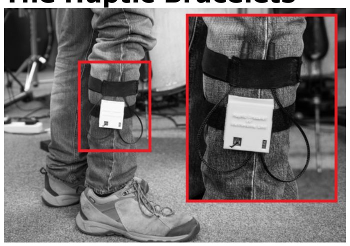

Figure 4: The Haptic Bracelets device strapped on user's leg.

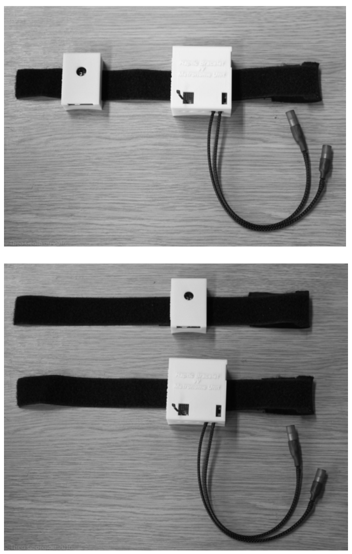

Figure 5: The Haptic Bracelets are designed to be modular. The metronome and gait monitoring unit can be strapped on different parts of the body, depending on user preferences and/or needs.

benefits similar to auditory cue [18]. Though, there is still not much literature exploring how it can be used for motor movement rehabilitation. The literature concerning haptic cueing mostly focuses on stimulus response mechanism for conveying messages and notifications (e.g. [19]). One possible reason for this apparent underuse of rhythmic haptic cueing may be the evident tension that exists between the notion of stimulus-response and the notion of entrainment [2]. It is often not clearly understood that due to physiological delays, stimulus response is not a viable way to consciously synchronise to rhythm [20]. Entrainment, on the other hand (as discussed above), can provide the fine-grained synchronisation that allows one's movement to synchronise to an external rhythm both physically and mentally.

Technology resources

In order to deliver this haptic cueing for assisting gait rehabilitation we designed and developed the *Haptic Bracelets*. The Haptic Bracelets are lightweight wearable devices, capable of monitoring and analyse gait in real time and provide rhythmic haptic cueing (RHC) in the form of vibrations on alternating legs.

Gait related data can be recorded and reviewed by a physiotherapist, who can then advice or adjust the walking tempo set by the RHC.

The Haptic Bracelet system is designed to be modular (see figure 5), allowing the the user to alter the position where RHC is received based on personal preferences (e.g. some users preferred to have the RHC delivered on their wrists instead of their ankles).

At the moment, the system comprises of two nodes for gait recording and delivering the RHC, and a laptop acting as a central controller for analysing the data and producing the required response (starting/stopping the RHC, adjusting the RHC tempo, etc.).

Summary & future work

Advances in technology mean that wearable technologies, in the form of small, light and inconspicuous devices, can be designed to help individuals suffering from neurological conditions carry out regular rehabilitation exercises. Current research has shown that walking to a rhythm can lead to significant improvements in various aspects of gait.

For this reason, we designed and developed the *Haptic Bracelets.* The Haptic Bracelets are wearable devices capable of recording and analysing gait in real time and provide a gait rehabilitation intervention whenever needed. This intervention is in the form of rhythmic haptic cueing on alternating legs; however, this position can be customised based on the user's personal preferences. This is a mobile solution, allowing patients and sufferers of chronic neurologic diseases (i.e. stroke) to take their rehabilitation in their own hands, while remaining under inconspicuous remote supervision of their physiotherapists.

In the future and after more refinement, the system could allow a single therapist to monitor and advise groups of stroke survivors undergoing therapy sessions.

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