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Two kinds of entrainment in gait rehabilitation using haptic metronomic cues

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There are currently over 1.2 million stroke survivors in the UK, and with more than 100,000 new incidents each year, stroke is a leading cause of adult disability [1]. Almost three quarters of stroke survivors suffer from gait deficiencies [2].
In the case of hemiparetic stroke and related brain injuries, gait deficiencies typically take the form of bilateral spatial and temporal asymmetries. This can lead to overuse of the non-paretic (unaffected) leg, exposing it to higher vertical forces [3], [4], and underuse of the paretic (affected) leg leading to loss of muscle tone and reduction of bone mineral density. This increases the risk of knee and joint problems together with hip and bone fractures, and the likelihood of falls [5]. Restoring mobility and rehabilitation of gait are thus high priorities for post-stroke rehabilitation.

Walking following an external metronomic rhythm has been shown to improve gait, leading stroke survivors to walk more symmetrically [6] and to neglect their affected leg less. Audio metronomes are used for gait rehabilitation and therapy – though mostly only in the lab –with documented results in aiding the recovery of functional stable and adaptive walking patterns [7]. Entrainment can help to promote desired movement patterns and to retrain motor programs through anticipatory cuing of functional movement patterns [7].
In a series of recent case studies, we have investigated delivering metronomic cues haptically (referred to as "*rhythmic haptic cueing*" or RHC) as opposed to via audio, leaving the sense of hearing free for socialising, situation awareness and safety while walking. Metronomic cueing is delivered by vibrations to alternating legs. Control of the vibrations and their synchronisation was achieved using the Haptic Bracelets, a system of wearable devices and sensors we developed at The Open University [8], [9], [10].

Two participants in the most recent case study highlighted two contrasting ways in which entrainment can enhance gait. The first participant, a 50-year-old fully independent male community ambulator suffering from hemiparesis after brain injury, showed immediate improvement in both his temporal step asymmetries and variability both during and immediately after haptic cueing.
The second participant was a 60-year-old male hemiparetic stroke survivor who had his stroke 2 years ago, leaving him with severe attention deficits. This meant he could not walk and attend to external cues at the same time. However, when asked to walk following the rhythm from memory, this participant became more symmetric and his steps less variable.

These two cases demonstrate, in the haptic case, two contrasting ways in which entrainment can be exploited for gait rehabilitation:

a) External rhythmic cues provided *during* movement.
b) Mental entrainment retained *after* application of an external cue.

This distinction has been noted in the general case by Thaut [7], but this appears to be the first explicit documentation of this distinction in practical use when using haptics for gait rehabilitation.

References

[1] The Stroke Association, 'State of the Nation: Stroke Statistics 2017, 2017.
[2] E. S. Lawrence, C. Coshall, R. Dundas, J. Stewart, A. G. Rudd, R. Howard, and C. D. Wolfe, 'Estimates of the prevalence of acute stroke impairments and disability in a multiethnic population.', *Stroke.*, vol. 32, no. 6, pp. 1279–1284, 2001.
[3] V. S. Mercer, J. K. Freburger, S.-H. Chang, and J. L. Purser, 'Measurement of paretic-lower-extremity loading and weight transfer after stroke.', *Phys. Ther.*, vol. 89, no. 7, pp. 653–64, 2009.
[4] R. W. Bohannon and P. A. Larkin, 'Lower extremity weight bearing under various standing conditions in independently ambulatory patients with hemiparesis', *Phys. Ther.*, vol. 65, no. 9, pp. 1323–1325, 1985.
[5] B. Wen, J. N. Lampe, A. G. Roberts, W. M. Atkins, A. D. Rodrigues, and S. D. Nelson, 'Neurological Gait Abnormalities And Risk Of Falls In Older Adults', *J. Neurol.*, vol. 257, no. 3, pp. 392–398, 2010.
[6] M. H. Thaut, G. C. McIntosh, and R. R. Rice, 'Rhythmic facilitation of gait training in hemiparetic stroke rehabilitation', *J. Neurol. Sci.*, vol. 151, pp. 207–212, 1997.

[7] M. H. Thaut, *Rhythm, Music, and the Brain: Scientific Foundations and Clinical Applications*. Routledge, 2007.

[8] S. Holland, R. L. Wright, A. Wing, T. Crevoisier, O. Hödl, and M. Canelli, 'A Gait Rehabilitation pilot study using tactile cueing following Hemiparetic Stroke', in *Proceedings of the 8th International Conference on Pervasive Computing Technologies for Healthcare*, 2014, pp. 402–405.

[9] T. Georgiou, S. Holland, and J. Van Der Linden, 'Rhythmic Haptic Cueing for Entrainment : Assisting Post-stroke Gait Rehabilitation'.

[10] T. Georgiou, S. Holland, and J. Van Der Linden, 'Wearable Haptic Devices For Post- Stroke Gait Rehabilitation', in *International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*, 2016.