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Differential Effects of Haptic Biofeedback on Gait Performance in Older Adults

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***Abstract* -** Older adults have poorer gait performance, leading to diminished mobility and increased risk of mortality. They walk with shorter stride length and lower gait speed, which are key determinants of gait performance. They also have reduced hip range of motion which leads to shorter steps and higher cadence. Wearable biofeedback systems are a potential solution to enhance walking ability in older adults, however, providing biofeedback to multiple gait variables is challenging. Yet, it is unknown if by providing biofeedback to one parameter only, all users display the same movement strategies resulting in the same gait pattern. This pilot study investigated if healthy older adults presented different gait patterns when a wearable biofeedback system prompted users to increase their swing time only. Four participants aged over 65 years used the device in an outdoor flat surface and received haptic biofeedback during 10-minutes. Two conditions were evaluated, with (Biofeedback) and without biofeedback (Control). Gait trials analysis suggested that in this pilot test, all participants increased swing time and reduced cadence, however, two walking patterns were characterized among participants. Participant 3 (P3) and participant 4 (P4) increased their stride length and speed, whereas participant 1 (P1) and participant 2 (P2) behaved the opposite. While P3 and P4 used their hip extension to produce larger strides to propel the body forward, P1 and P2 increased their knee flexion but lacked substantial increments in hip extension. This pilot test demonstrated that while all users followed the clues from the biofeedback, their entire gait could be very different. This pilot study provides insights into differential gait patterns and serves as a foundation to guide further experiments aiming to improve gait performance in healthy older adults.

***Keywords*:** wearable device, biofeedback, older adults, healthy older adults, gait performance, gait pattern

1. Introduction

More than 60% of older adults experience a reduction in their ability to walk which affects their mobility, reduces independence and increases mortality [1]. Stride length has been an important factor to maintain good gait performance, however, adults over 65 commonly walk with shorter steps [2]. This reduction in stride length has been observed in combination with a slower gait , which is a strong predictor of mortality, falls and disability [3]. The literature has found that reductions in the gait speed and stride length are associated with changes in the muscle strength [4], particularly in hip extensors and plantar flexors [5]. To compensate and to cover the same distance over a similar frame of time, healthy older adults increase the number of steps per minute, however greater cadence and reduced strength could lead to higher levels of fatigue [6].

Older adults also present reductions in the range of motion of the lower limb [7]. The hip flexion at late-swing and the hip extension during early swing are reduced. Such reduction in the range of motion lowers the forward displacement of the lower limb, which in turn decreases the stride length and speed [3]. Studies have shown that peak hip extension is reduced across older adults and such reduction is more obvious among fallers [4]. The literature also reports that hip flexor tightness can produce a forward pelvis tilt which limits the functional hip extension and leads to smaller steps [8]. However, larger motion in hip and ankle have been proven to improve the step length [3]. Meanwhile, swing time is a critical temporal parameter. Changes in the swing phase can lead to modifications in the stride duration which affects the stride length and the cadence.

Wearable devices equipped with a sensor that quantify gait parameters and provide real-time biofeedback via actuators have improved gait performance across multiple populations [9]. These devices have shown increments in the proprioception and walking ability of older adults [10] and provide opportunities to identify gait changes in healthy older adults, especially in those situations where subtle changes are unnoticed by the human eye.

Despite the initial benefits found in the literature associated with wearable devices and healthy older adults, this population present changes in multiple gait parameters. However, it is challenging to provide biofeedback to more than one variable at the same time. Based on the current literature, it remains unclear if by providing biofeedback to one variable, the user always employs the same movement strategies to achieve the desired gait pattern once the biofeedback is provided. Therefore, in this study we aim to investigate if older adults display different gait patterns to achieve the same target, after using a wearable biofeedback system such as a shoe-embedded device that prompted users to increase their swing time to enhance a longer stride length.

2. Methods

In this pilot study four healthy older adults (three men and a woman, mean age: 79.75± 2.48 years, mean height: 1.63m± 0.07), with no history of lower limb surgeries or fractures during the last 2 years, were recruited and given consent to participated. The study was approved by University of Wollongong Research Ethics Committee (reference number 2017/473).

A prototype of a wearable biofeedback device has been developed in a larger study [11] to promote gait performance in older adults. The devices were attached to each leg simultaneously. They had a sensing unit as well as a biofeedback unit, which communicated with a microcontroller (ATmega328P). Each sensing unit included two piezoresistive force sensitive resistor sensors (FSR Interlink Electronics, Irvine, CA, USA) and each biofeedback unit included a motorised vibrating actuator (1027 Flat Coreless Vibrating Motor, Baolong Electronic Group, Yueqing, China). While the FSR were placed under an insole at the first metatarsal and the calcaneus bone, the actuators were placed in the back of the tights and the microcontroller communicated wirelessly with a computer that analysed and processed the raw data.

The sensing unit acted as a foot switch collecting the gait events of heel strike and toe off. A customized Labview program (National Instruments Corporation, Austin, TX 2018) processed the raw data and calculated the user's swing phrase. The program also calculated a 5% increment of the baseline swing time, setting a target swing time 105% of the baseline. If the target was not achieved, the microcontroller sent a 3.5v signal to activate the biofeedback unit in a continuous vibration mode.

During the experiment, participants initially walked for 5-min on a flat pathway at their preferred speed with the prototype turned on, however the biofeedback unit was turned off while their initial customised swing time target was calculated. This period also served as a control condition. Then, during the biofeedback condition, participants walked for 10-min on the same pathway with the biofeedback unit turned on. They received instantaneous biofeedback about their swing time and were instructed to maintain the speed while increasing the duration of the leg swing when a vibration was felt. The biofeedback signal lasted until they reached the target, or the following step was calculated. Participants had 5-min rest between conditions to avoid fatigue.

Multiple gait trials were collected at the end of both conditions using Xsens MVN BIOMECH 3D motion capture system (version 2019.0.0.0, Xsens Technologies B.V) and the standardized GaitRite mat system (CIR Systems Inc. Clifton, NJ, USA). Both systems were synchronized, and data collection frequency was set at 60Hz. Participants were unaware of the exact gait recording time and GaitRite was placed in the middle of the 10-meter pathway to avoid capturing any gait acceleration and deacceleration. A total of 140 steps were analysed, swing time, stride length was processed for each footfall with the software Gaitrite as well as cadence and velocity of the walking trial. Sagittal joint angles of the lower limb were processed and filtered by a customized MATLAB code (MATLAB R2021b) to identify joint peak angle.

3. Results and Discussion

The pilot test results have shown that all four participants effectively increased their average swing time above 5% after using the wearable device which prompted them to increase their swing time to promote a longer stride length. For instance, the swing time increased in participant 1 (P1) by 5%, participant 2 (P2) by 16%, participant 3 (P3) by 6% and participant 4 (P4) by 11%. Conversely, cadence decreased across all participants with greater values in P2. While P1, P3 and P4 reduced their cadence by 7%, 5% and 6% respectively, P2 had a reduction of 16% (Figure 1).

While everyone was able to achieve the target swing time, differences across participants were demonstrated in the following variables. Data analysis demonstrated that P1 and P2 were unable to increase the stride length while P3 and P4 effectively increased it. P1 and P2 reduced their stride length by 6% and 7% while P3 and P4 increased it by 11% and 4%, respectively. Likewise, while P1 and P2 had a slower gait, P3 and P4 increased their speed. Specifically, the normalized velocity of P1 and P2 was reduced by 12% and 21%, whereas P3 and P4 increased it by 6% and 3%, respectively (Figure 1).

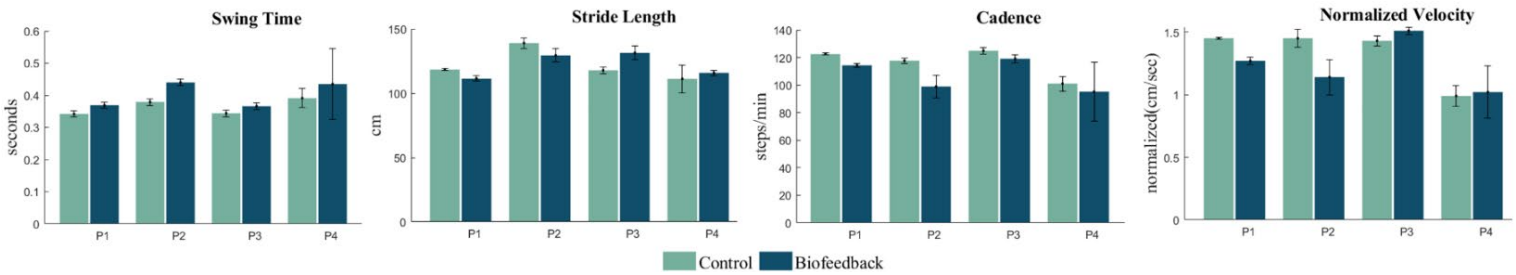

Fig 1. Changes in spatio-temporal parameters in 4 subjects (P1 to P4). Error bars represent SD.

The kinematic analysis of joint angles demonstrated that there was an increment in hip flexion for all participants. P1 increased by 3%, P2 by 23%, P3 by 15% and P4 by 17%. Similarly, hip extension also increased for everyone however a greater increment was observed for P3 and P4 than P1 and P2. P1 increased their hip extension by 0.01%, P2 by 8%, P3 by 16% and P4 by 30%. The opposite scenario was demonstrated for knee flexion, where P1 and P2 had greater knee flexion compared to P3 and P4. Specifically, P1 and P2 increased by 9 and 4% respectively, whereas P3 and P4 reduced their knee flexion by 3% (Figure 2). Interestingly, knee extension decreased for P2 and P4 by 0.1% and 3%, respectively, whereas it increased for P2 and P3 by 3% and 1%, respectively. Finally, there were small changes in the range of motion of the ankle compared with hip and knee. The dorsiflexion increased across all subjects, P1 increased by 7%, P2 by 8%, P3 by 1% and P4 by 9%. Plantarflexion decreased in P1 and P2 by 0.5% and 11%, respectively, whereas it increased for P3 and P4 by 14% (Figure 2).

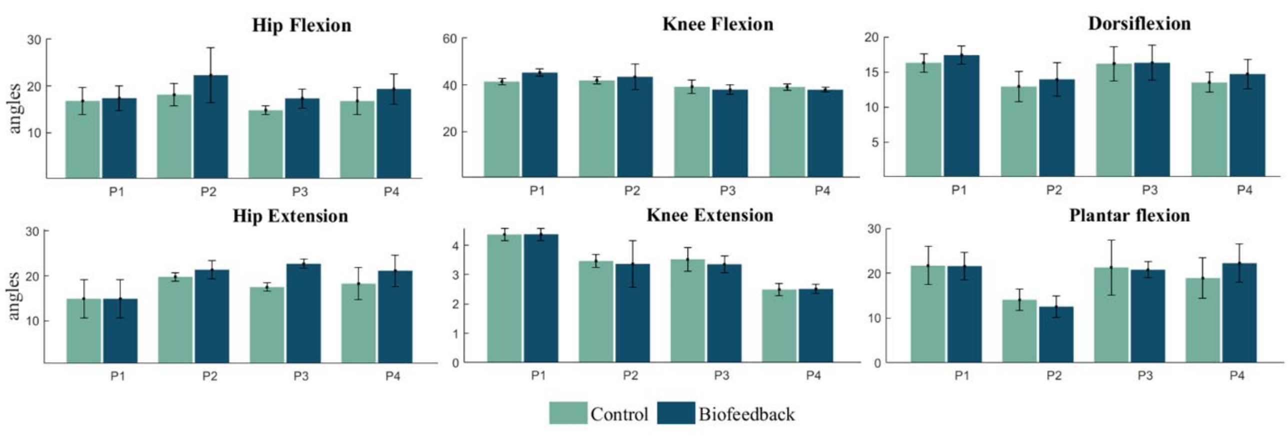

Fig 2. Comparison of changes in peak joint angles at hip, knee and ankle among participants before and after the use of the wearable biofeedback device. Error bars represent SD.

In summary, our study identified that although all four participants reached the swing time target following the clues from the biofeedback, P1 and P2 were unable to adapt to the biofeedback protocol and as a result, their steps were shorter. P2 was the slower participant with the greatest reduction in cadence. These values correspond to the changes observed in joint angles where P2 had the greatest increment in peak hip flexion, which is required to improve toe clearance, but not sufficient to propel the leg. In contrast while P3 and P4 increased at least twice the values reached by P1 and P2 in peak hip extension, P1 and P2 increased at least three times the values reached by P3 and P4 in peak knee flexion. These findings which are in agreement with the literature highlight the importance of the hip extension to modify the distance between steps. Although the literature suggests that plantarflexion is also a factor to improve stride length, the results in this pilot study were not consistent among P1-P2 and P3-P4 to support this remark.

4. Conclusions

This study found that while the biofeedback target was achieved, the walking strategies used among participants were varied. As a result, the gait improvements were observed in some participants while others presented a worsen gait pattern. These findings offer insights to guide further experiments that aim to improve gait in healthy older adults using wearable biofeedback devices.

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