



Short communication

A portable visual biofeedback device can accurately measure and improve hip extension angle in individuals post-stroke

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ABSTRACT

Background: Visual biofeedback has shown success in improving gait mechanics in individuals post-stroke but has typically been restricted to use on a treadmill or a short walkway. Using real-time visual biofeedback during overground walking could increase the ease of clinical translation of this method. The objective was to investigate the reliability of a real-time hip extension feedback device during unconstrained, overground walking. We hypothesized that the peak hip extension angle outcome of our device would be comparable to peak hip extension angle measured from a common motion capture system. In addition, we hypothesized that individuals post-stroke would increase their hip extension angle after a single walking bout with visual biofeedback of their hip extension angle.

Methods: Fourteen individuals with chronic stroke walked for one six-minute walking bout with the visual biofeedback device. Before (pre-training) and after (post-training) the feedback walking bout, participants walked in a straight line at their self-selected speed for at least five steps per foot.

Findings: Our device was reliable in measuring peak hip extension angle when compared to 3D motion capture equipment ($R^2 = 0.99$). Individuals increased their hip extension angle after one session with the visual biofeedback ($+2.886 \pm 2.189$ deg) compared to a control walking bout ($+1.550 \pm 1.629$ deg) ($Z = -2.103$, $p = 0.035$).

Interpretation: Our novel and inexpensive biofeedback method may provide benefit for individuals post-stroke and expand the possibilities for feedback in rehabilitation.

1. Introduction

Individuals post-stroke typically have gait impairments, including a reduced walking speed and asymmetrical gait mechanics (Olney and Richards, 1996). Visual biofeedback is an effective method to help individuals post-stroke become aware of their impairment and enable them to improve their gait (Genthe et al., 2018; Spencer et al., 2021). While many biofeedback studies have shown positive results, they use methods and tools that require laboratory settings and are not available in a clinic for rehabilitation (Spencer et al., 2021). Most biofeedback settings do not use a portable display to provide the subject/user/individual with feedback and are restricted to treadmill or a short, straight walkway setting. Specifically, there are few biofeedback options that allow individuals to freely move in an environment. To address these issues, we designed a portable, visual biofeedback device reporting hip

extension angle that can be employed during continuous, overground walking. We selected the hip extension angle because it is a key gait variable reduced after stroke (Lewek et al., 2018; Olney and Richards, 1996; Tyrell et al., 2011) but can be increased with walking speed (Olney and Richards, 1996; Tyrell et al., 2011). If individuals are simply asked to increase walking speed, they may be able to do so, but may utilize undesirable compensations or gait mechanics. Furthermore, the hip extension angle can be measured in an environment outside of a laboratory, rendering it as an attractive option to overcome current barriers to clinical translation.

The purpose of this study was to validate our novel visual biofeedback device for use with individuals post-stroke. We hypothesized that the peak hip extension angle outcome of our device would be comparable to peak hip extension angle measured from a common motion capture system. In addition, we hypothesized that individuals post-

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stroke would increase their hip extension angle after a single walking bout with visual biofeedback of their hip extension angle.

2. Methods

2.1. Design of the device

We created a device that measured the absolute hip angle and displayed visual biofeedback of the hip angle on a miniaturized screen attached to a pair of glasses (Fig. 1A). The device is attached at the greater trochanter and is aligned with the thigh and lateral femoral condyle. A linear potentiometer with a customized Raspberry Pi script (version 4) was used to measure the hip angle (Fig. 1B) and convert voltage to a digital signal representing hip flexion and extension angle. A miniaturized screen was attached to glasses, which displayed the visual biofeedback (Fig. 1C). We have successfully used this visual display technology in previous research with young and older adults to modulate step timing (Vaz et al., 2019, 2020). The visual biofeedback displays a user's real-time hip angle along with a horizontal bar symbolizing the target hip extension angle that the participants were trying to reach during training (Fig. 1C). The target hip extension angle line was the highest hip extension angle the individual has been able to achieve during a six-minute walk. After five steps, the highest hip extension angle achieved in those steps was where the target bar started. If the individual was able to surpass their previous highest hip extension angle, the target bar would reset to the new highest hip extension angle reached.

2.2. Participants

Fourteen individuals completed this study (59.25 ± 12.77 yrs.; 9F/5M, 4.41 ± 4.67 years since stroke (0.52–16.10 range years), 7R/7L). To be eligible for participation, each participant was 19 to 80 years old and had a single stroke more than six months ago. Written consent was collected from all participants and the study was approved by the Institutional Review Board at the University of Nebraska Medical Center.

2.3. Procedures

Retro-reflective markers were attached to specific anatomical landmarks using a lower-body marker set. Kinematics from a motion capture system (Motion Analysis Corporation, Rohnert Park, CA, USA) collected marker data at 100 Hz. Before (pre-training) and after (post-training) the feedback walking bout, participants walked in a straight line at their self-selected speed for at least five steps per foot. No feedback was given during either the pre-training or post-training. However, the participant was told to remember the walking strategy they used in training and try to replicate it during the post-training session.

Individuals completed a control walking bout, before training, where they walked for six minutes with the device but received no feedback before the training bout. For the feedback training bout, participants walked around the perimeter of the laboratory (approximately 10 m $\times$ 9 m) for six minutes (Genthe et al., 2018) while wearing the custom-built hip extension device and the visual display glasses. The visual display was on a screen that was seen with one eye; therefore, the individual was

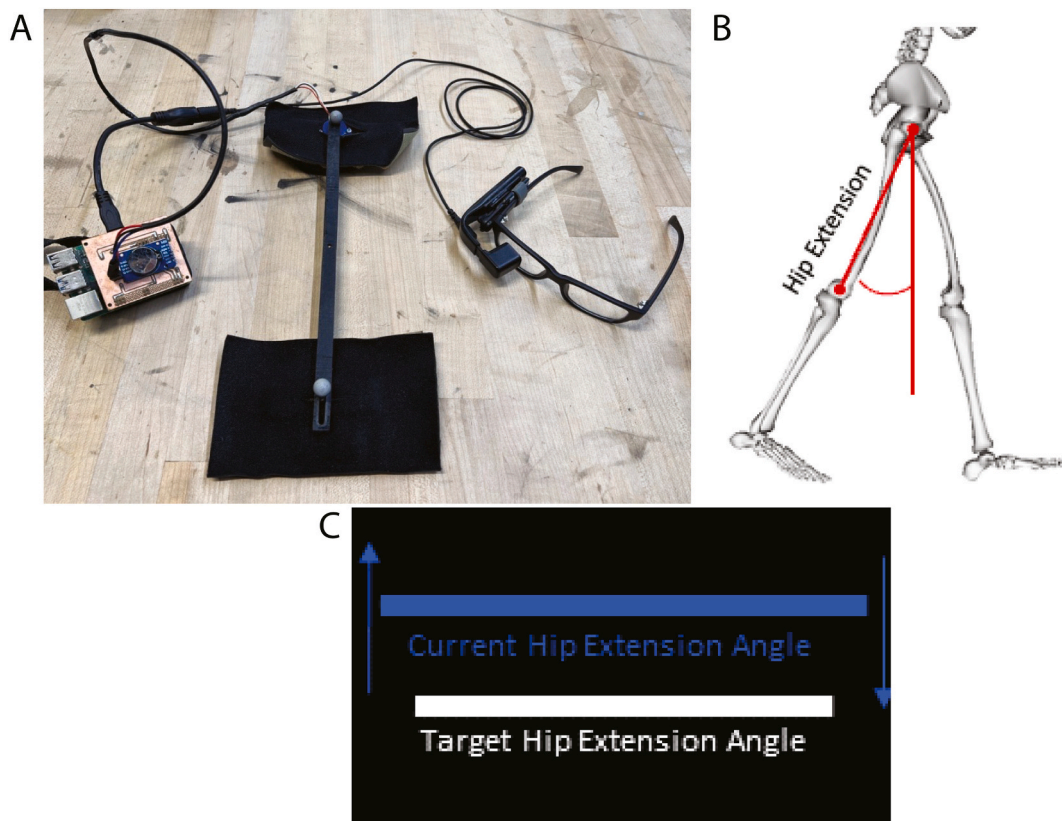


Fig. 1. The hip extension device. (A) A linear potentiometer was attached to a 3D printed piece that fit along the thigh. The raspberry pi was used to collect the data. The VuFine was attached to glasses and displayed the data and feedback. (B) The device was parallel to the individual's thigh and measured the angle of the thigh relative to the vertical. (C) Feedback seen by the participant on the screen. The blue bar represented their real-time hip extension angle, where moving up represented extension and moving down represented flexion. The white bar was the target hip extension angle. If the participant surpassed the target during a trial, the target bar moved to the new highest extension angle during that trial. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

still able to see the environment they were walking in, as well as the feedback. Biofeedback was intermittent, with one minute on and one minute off, to deter the individual from becoming dependent on feedback and to increase motor learning (Genthe et al., 2018; Winstein and Schmidt, 1990). Participants were told that the device measures the angle their leg is at, and as they moved their leg, the line on the screen moved. Participants were not given specific instructions on what walking strategies to employ to increase this hip extension angle.

2.4. Data processing

The hip angle was calculated using a linear potentiometer within the device. Kinematic data collected from all pre-training and post-training sessions were processed using Cortex (Motion Analysis Corporation, Rohnert Park, CA, USA) and Visual 3D (C-motion, Germantown, MD, USA). The difference in hip extension between before and after the six-minute control and training walking bouts were calculated. All processed data were exported to MATLAB (Mathworks, Natick, MA, USA) to determine peak hip extension. Walking speed was calculated as the average velocity of the sacral marker. To determine the accuracy of the feedback, the peak hip extension angle from the device and the peak hip extension angle from motion capture were calculated and compared using ten gait cycles from each participant during their self-selected walking.

Device usability was determined from the System Usability Scale survey (Bangor et al., 2009; Brooke, 1996). The survey is scored out of 100, with a score of 68 representing an above average score (Bangor et al., 2009). This survey data was important in evaluating the patient's comfort and ability to interpret the feedback given using the device.

2.5. Statistical analysis

An alpha value of $\alpha \leq 0.05$ was used to determine statistical significance. A linear correlation was used to determine the relationship between the hip extension angle peaks estimated from the device and the ones calculated from motion capture in MATLAB (Mathworks, Natick, MA, USA). Wilcoxon signed rank tests were performed for hip extension and walking speed between the difference in the control bout versus the training bout in MATLAB (Mathworks, Natick, MA, USA), and effect sizes (r) were calculated.

3. Results

The peak hip extension angle calculated from motion capture was strongly correlated with the peak hip extension angle calculated from the device ($R^2 = 0.99$) (Fig. 2). There was a significant increase in the improvement in median peak hip extension after one session with the visual biofeedback ($+2.886 \pm 2.189$ deg) compared to a control walking bout ($+1.550 \pm 1.629$ deg) ($Z = -2.103$, $p = 0.035$), with a large effect size ($r = -0.638$) (Fig. 3). There was an increase in the improvement in median walking speed after one session with the visual biofeedback ($+0.079 \pm 0.143$ m/s) compared to a control walking bout ($+0.033 \pm 0.033$ m/s), but it was not significant ($Z = -0.596$, $p = 0.583$), with a small effect size ($r = -0.181$).

Specifically, twelve out of fourteen participants increased their hip extension angle after one six-minute training with the device. The average System Usability Scale Score was 77.1, which is greater than the cutoff of 68 (Bangor et al., 2009). Individually, ten of the fourteen individuals rated the device greater than a 68.

4. Discussion

The purpose of this study was to validate a novel visual biofeedback device for individuals post-stroke. We found that our device reliably calculated and visually displayed the peak hip extension angle compared to the gold standard of 3D motion capture while walking. In addition, we

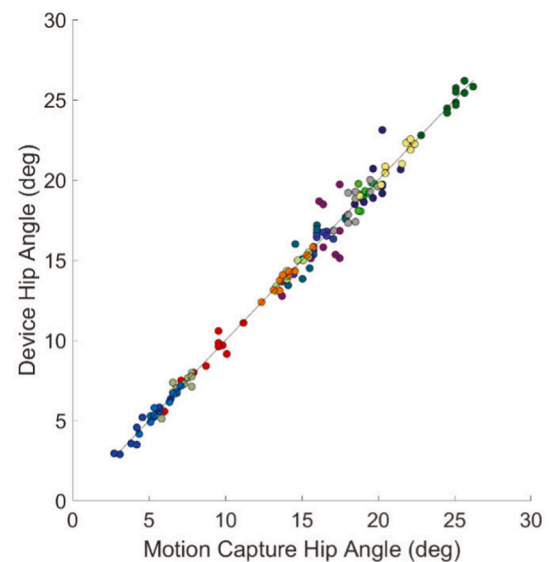


Fig. 2. Device validity while walking. The peak hip extension angle calculated from motion capture compared to the peak hip extension angle calculated from the device. Each dot represents the peak calculated from one gait cycle using both motion capture and the device. Each colour represents one participant.

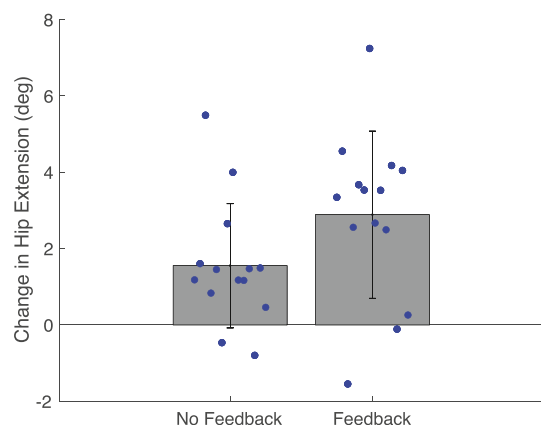


Fig. 3. The change in peak paretic hip extension angle between before and after one walking bout with the visual biofeedback (Feedback) and before and after one walking bout without the visual biofeedback (No Feedback). Each blue dot represents a single subject. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

found that after a single training bout, individuals significantly increased their hip extension angle. While their walking speed improved after one walking bout with the feedback, it was not significantly greater than one walking bout without feedback. However, this is limited to a single walking bout and an extended training and follow up study would be needed to make more concrete inferences about outcomes of a training paradigm. The motion capture results combined with the positive usability score, demonstrated that our participants seemed to improve their gait with the device and would use the device again. Clinicians could use the device to determine who has hip extension deficits and see if after using the device, they could improve their hip extension, and therefore use it for gait re-training.

4.1. Study limitations

Some limitations of the study were that participants were not screened for cognitive impairment and there was no measure of how

much attention the participant placed on the feedback. However, there was an average increase in peak hip extension angle, suggesting that if there was cognitive impairment, it did not negatively impact the results. Future studies can investigate how cognitive function and attention impacts this visual biofeedback system.

5. Conclusions

Many current biofeedback studies have been limited to treadmill walking, which makes the continuous, overground walking of this study a novel component. The feedback system requires minimal, inexpensive equipment, and is completely wearable and portable. The visual biofeedback could provide individuals a simple way to visualize a specific aspect of their walking deficit, enabling them to better understand their own gait patterns and how to change them. In addition, portable biofeedback for overground walking has the potential to be modified and target other gait deficits caused by a stroke or other types of central nervous system lesions.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.clinbiomech.2023.105967>.

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