International Journal of Physical Medicine & Rehabilitation

Massenzo and Pidcoe, Int J Phys Med Rehabil 2015, 3:3
http://dx.doi.org/10.4172/2329-9096.1000275

Research Article Open Access

Investigating the Impact of Visual Biofeedback on Postural Control Via Informative Dynamic Balance Training in Healthy Individuals

Trisha Massenzo[1*] **and Peter E Pidcoe**[2]

[1]*Virginia Commonwealth University, Department of Biomedical Engineering, Richmond, VA 23298-0224, USA*

[2]*Virginia Commonwealth University, Department of Physical Therapy, Richmond, VA 23298-0224, USA*

*__Corresponding author:__ Trisha Massenzo, Virginia Commonwealth University, Department of Biomedical Engineering, Richmond, VA 23298-0224, USA, Tel: (804) 828-9778; E-mail: massenzotj@vcu.edu

Received date: March 20, 2015; **Accepted date:** April 29, 2015; **Published date:** May 02, 2015

Abstract

Objective: After traumatic brain injury (TBI), postural instability often results. This can effect ambulation and, subsequently, activities of daily living. Various forms of rehabilitation have been developed, but few offer engaging activities that provide informative dynamic balance training. The goal of this pilot study was to build a goal-based system that provided visual biofeedback to create an enriched environment for dynamic postural rehabilitation. The study aimed to determine if visual biofeedback had an effect on posture and balance during training for healthy participants; as well as determine the optimal man-machine visual-biofeedback interface.

Method: A modified elliptical trainer was developed that incorporated visual-biofeedback from measured left and right lower extremity loads. Four visual displays were constructed and tested on a sample of 15 healthy participants. These displays provided targeted feedback to aid in symmetric performance. The displays differed in the amount of information provided and in the extent of algorithmic pre-processing. Data were evaluated by calculating the index of symmetry (IOS) and statistically comparing display types.

Results: Participants performed significantly better with the introduction of visual biofeedback than baseline measurements with no display based on index of symmetry values. The data suggests that the feedback display that incorporated both temporal historical data and differential pre-processing performed the best. This display was called the differential-temporal display.

Conclusion: Our results reflect that performance is enhanced with the introduction of visual biofeedback during dynamic postural training. We also established that the differential-temporal display was the optimal feedback system to reduce IOS values during elliptical trainer use. From our results, it became apparent that incorporating visual biofeedback during postural training is a sophisticated approach to improve baseline asymmetries inherent in healthy participants. It is anticipated that similar results are likely to occur in a cohort of TBI patients due to the reduction of cognitive demand.

Keywords: Brain injury; Balance training; Biofeedback; Man-machine interface; Cognitive load; Postural control; Informative dynamic balance training

Introduction

The occurrence of a traumatic brain injury (TBI) can negatively impact a person's well-being not only cognitively but also physically and emotionally. Common cognitive impairments include reduced intellectual function, memory, processing speed, attention and language [1], whereas physical impairments include decreased balance, impaired proprioception, and dizziness [2,3]. These physical issues often impact the ability to ambulate and contribute to emotional impairments like depression. In order to combat these impairments, early detection and treatment is recommended.

Several disruptions can occur during a TBI to cause both cognitive and physical impairments that influence mobility. Postural control is often affected due to disturbances in the vestibular system or to the motor cortex [2]. In a study by Geurts et al., static and dynamic postural control was compared in a TBI cohort against healthy controls [4,5]. This study measured postural sway on dual-plate force platforms in a sample of post-TBI participants (months to years) who complained of postural instability and impaired gross-motor skills. They found that TBI patients tended to show 50-70% greater center-of-pressure velocities for both anterior-posterior and lateral sway than controls. One of the most noteworthy findings of this study showed that although measured neurological signs may normalize post mild-TBI there are often still associated postural problems present that result in an overall reduction in static as well as dynamic control therefore influencing functional mobility [5]. In order to improve postural control, rehabilitation intervention is essential for recovery. In traditional rehabilitation, force platforms, weight measurement scales, and mirrors are often used to provide the patient with weight distribution biofeedback during stance [2,5,6]. With the incorporation of the biofeedback, the patient is able to visually determine if his or her weight is distributed asymmetrically and adjust accordingly.

Although this form of rehabilitation has been successful for static stance, often TBI patients lose motivation during training, mostly due to impairments with attention [5,6]. To increase motivation and adherence to rehabilitation, several systems have been commercially developed [5-7]. In Gil-Gomez et al., comparisons were made between traditional therapy and therapy with their developed eBaViR (easy balance virtual reality) system. They found that both therapy techniques were equally successful for static balance, but suggested that participants were more motivated to perform the tasks from the virtual reality system. One interesting note was their additional suggestion for incorporating virtual reality training for dynamic balance systems to promote symmetric gait parameters [5].

Recently, other studies have implemented such therapies during dynamic balance by applying virtual reality systems to treadmills and found success with training. For example, Tirosh et al. found that toe clearance in healthy participants could be manipulated based on visual feedback during treadmill use [8]. This study coupled feedback from measured toe height to create a target-based visual display. They measured both baseline results and results from training and found that both mean and median minimum toe clearance increased due to the visual biofeedback. With the incorporation of visual biofeedback, participants were more engaged during the activity resulting in improved goal-based training [8]. Other examples of goal-based visual biofeedback training include studies by Dingwell et al. and Crowell et al., who used visual displays to represent kinetic measurements during treadmill use [9-11]. Dingwell et al. employed differential, temporal and comparison visual displays to represent measurements from push-off forces and center of pressure [9,10]. The incorporation of visual biofeedback, stance time decreased by 26% and push-off forces and center or pressure improved from 2.47% to 1.38% and -1.58% to 0.56%, respectively. Crowell et al. measured running mechanics with attached accelerometers, and represented measurements through a temporal display to reduce impact loading [11]. This technique resulted in reduced amplitude of peak acceleration, impact peaks, average loading rates and instantaneous loading rates, during training and ten minutes following removal of feedback. These elements are all beneficial to improved gait mechanics.

Our study aimed to test if visual biofeedback during dynamic gait training on an instrumented elliptical trainer influenced posture and balance in a healthy population prior to application in TBI patients. This system differs from overland training in that the foot is guided through the entire gait cycle. This design allows earlier intervention and may be beneficial in rehabilitation following a brain injury. Another study aim was to determine the best man-machine visual-feedback interface to optimize participant performance during dynamic gait training. Four different visual displays were developed using kinetic biofeedback from vertical load measurements on each pedal of the elliptical. These displays were adapted from previous research studies that measured the effect of visual biofeedback during instrumented treadmill use [9-11]. They featured differential, temporal, and comparative measures. Visual biofeedback was used to supplement the participant's internal memory. Since memory and retention are common impairments in patients with TBI and may affect ambulation, supplementing (or enhancing) this information through visual biofeedback, thereby decreasing cognitive load, may improve performance. With the incorporation of visual biofeedback, the participant has the ability to offload internal memory storage onto perceptual processes and pattern recognition of the external source, making this an attractive mechanism for implementing informative dynamic balance training [12].

Methods

To assess the effects of informative balance training, a study was conducted on healthy participants. A modified elliptical trainer (NordicTrack®, Logan, UT) was developed, incorporating visual biofeedback for kinetic postural training. Kinetic measurements from both left and right pedals were obtained through embedded strain gages (350 Ω) organized in a Wheatstone bridge configuration. Four visual displays were created based on previous literature incorporating kinetic biofeedback. Corresponding descriptive labels were given for each display based on their appearance and function. These labels were the "Tanks display", the "Temporal display", the "Differential-Temporal display", and the "Differential display". These displays differed in four ways: (1) the number of display elements presented, (2) whether or not a temporal history was provided to the participant, (3) how much data pre-processing was performed prior to display, and (4) the amount of displayed data (either from one limb or both). Each display is described in the following paragraphs and is illustrated in Figure 1.

The tanks display presented 4 different display elements including two filler tanks and two goal lines (Figure 1a). Weight displacement was depicted as the filler in each tank and two horizontal target lines were placed on each tank for reference. Feedback was updated with no temporal history and included measurements for both limbs.

The temporal display only displayed measurements from the participant's non-dominant limb for postural balance (Figure 1b). This display derived the label temporal since temporal history of past data samples was displayed to the user. Data was represented as a white dot with red lines connecting each data sample. A solid blue line was displayed for user reference as a target goal. Since the display incorporated both data samples and a single target line, this particular display was noted to have two display elements.

The differential display incorporated a single pointer on a numberless gauge to represent pre-processed comparison data between the left and right limbs (Figure 1c). This display did not utilize temporal history or a reference line.

The differential-temporal display incorporated basic features from both the Temporal and differential displays (Figure 1d). It utilized pre-processed data which was presented in the same fashion as the data samples in the temporal display. A solid blue line was used as a reference goal for the user to achieve. A single graph was divided by the vertical blue line, splitting the graph into one half representing right values and the other representing left.

Before visually presenting any measurement, the kinetic data were low-pass filtered (10Hz). LabVIEW (National Instruments™, Austin, TX) was used in constructing the displays. Averaged vertical load measurements were taken for each cycle and used as input for each display. A 200 point encoder with quadrature and index outputs was attached to the elliptical trainer to index the position of the flywheel so that the left heel-strike position was the beginning of each cycle. The data update rate was a function of the encoder speed and 200 samples represented a total cycle. Left and right arrays were captured 180° out of phase and compared continuously on the display. Display refresh rates were set to 3 kHz so that any change in kinetic data would be reflected with minimal delay. For off-line performance analysis, data was down-sampled to 300 Hz. Each display presented averaged values either directly in the display (Tanks and Temporal) or indirectly through pre-processed comparison values (Differential and Differential-Temporal). Both MATLAB (The MathWorks, Inc., Natick, MA) and Excel (Microsoft, Redmund, WA) were used in data analysis.

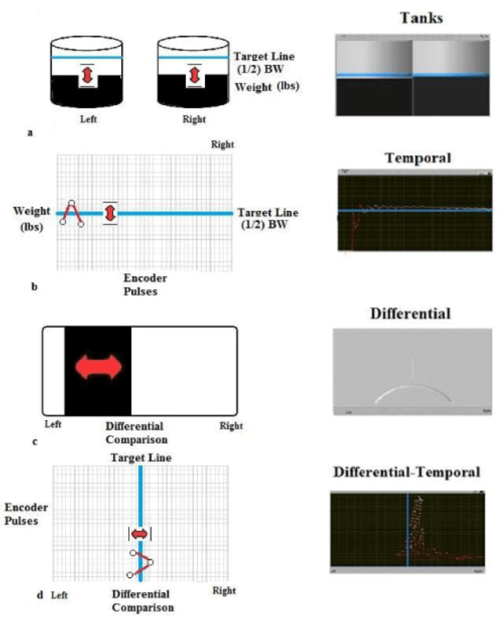

Figure 1: Visual displays of biofeedback. From top to bottom, left images are a schematic of the screen shots of each display on the right, the displays are the following: a) Tanks; b) Temporal; c) Differential; d) Differential-temporal.

This study was approved through Virginia Commonwealth University's institutional review board. All participants were approved prior to participation based on inclusion criteria, specifically as healthy participants who have not acquired a lower limb injury within the past year. Fifteen participants (7 male, 8 female) with average age of 25.47 (4.88) participated in the study and were recruited by a sample of convenience in the surrounding Richmond area through public advertisements. Participant performance was tested during 4 sessions, with at least 24 hours in between each session. Order of displays for the 4 sessions was random, based on blind selections from the participants. Prior to testing, participants warmed up on the elliptical trainer for five minutes and were provided instructions on how to interpret the data presented on the randomly drawn session for that day. Participants then ran on the modified elliptical for five minutes while reacting to feedback from the display. Data were recorded with each session. The first no-feedback session was used as a baseline comparison. Robinson's index of symmetry (IOS) was used to compare the averaged vertical load from right and left pedals.

$$IOS = \frac{|Xright - Xleft|}{\frac{Xright + Xleft}{2}} \times 100\%$$

IOS values can range from 0 to 100%, with perfect symmetry between both limbs as 0%. IOS values were found for baseline and visual biofeedback recordings and were used to compare performance across all measures. Preferred limb for stability and balance was found during baseline analysis corresponding to the limb that presented the largest cumulative load. Differences in the dataset were found through a one-way analysis of variance. Student t-tests (α=0.05) were performed to test significance of IOS values in comparisons between baseline and each display. Differences in speed for each session were analyzed through student t-tests (α=0.05). Correlation coefficients comparing speed to IOS values and day each display type was performed to IOS values, to test the effect of learning, were also found. Box plots were constructed to screen for outliers. Through this screening, one of the participants was removed from the post-analysis since their IOS metric was found to be larger than two standard deviations from the mean of the population results.

Results

Baseline measurements reflected a general trend in the sample group as all except one participant presented more weight on their left limb (Table 1). Participant 13 presented more vertical load towards the right limb and was identified as nearly symmetric compared to other participants in the study.

Subject	Dominant weight-bearing side	Baseline IOS (%)
P1	Left	11.79
P2	Left	11.38
P3	Left	11.98
P4	Left	11.13
P5	Left	8.82
P6	Left	5.52
P7	Left	12.67
P8	Left	6.18
P9	Left	8.71
P10	Left	9.58
P11	Left	6.14
P12	Left	9.78
P13	Right	1.21
P14	Left	14.99

Table 1: Baseline values for preferred leg for balance and Robinson's index of symmetry (IOS) for all participants.

A value of 0% represents perfect symmetry. Weight-bearing dominance was determined from baseline measurements as the limb that had the largest cumulative load during each session users maintained a self-selected pace for the five minute recording period. Speed was measured for each session and t-tests were performed to determine differences in speed. There were no significant differences in speed (0.83 ± 0.14 cycles/sec) from day-to-day (p-value>0.05). Speed was also compared to the IOS values. No correlation was found between the two variables ($R2<0.20$). The effect of learning was tested by comparing values from subsequent days for each display. No correlation was found between day of performance and IOS values ($R2<0.1$).

One-way analysis of variance test showed a significant difference in the dataset for baseline and all display types (p-value<0.05). Subsequently, student t-tests revealed a significant difference between baseline (9.28 ± 3.56) IOS values and IOS values for each display (Figure 2) (p-value<0.05). The IOS value for the Differential-Temporal display (0.90 ± 0.67) was significantly smaller than all other displays (p-value<0.05). Whereas the Temporal display (3.77 ± 3.16) had the largest IOS value compared to the other displays. Although, only with a significant difference between the Differential-Temporal display and baseline.

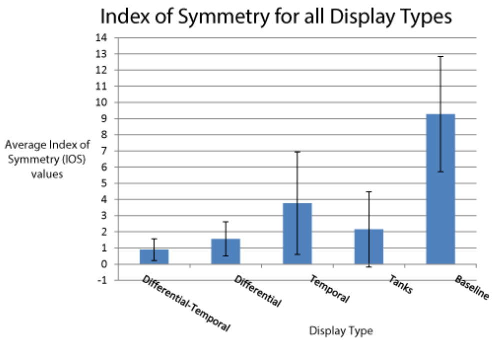

Figure 2: Index of symmetry for all display types. Robinson's index of symmetry (IOS) values averaged across the sample set for all displays and baseline. Error bars indicate standard deviation of IOS values within the dataset.

Discussion

The two goals of the study were to test if visual biofeedback had an effect on dynamic postural control via informative dynamic balance training and to determine which of the displays promoted the best symmetric performance in healthy participants. Kinetic visual biofeedback was implemented to supplement user internal memory and decrease cognitive load. Current rehabilitation techniques for balance training depend greatly on a patient's spatial interpretation of body position by viewing weight shifts on bathroom scales or a reflected mirror image. This approach, though cost effective, places a large demand on patients to accurately interpret results and make adjustments accordingly. The system employed in this study provided weight bearing feedback during dynamic movement in a gait-like environment. The feedback was designed to decrease the cognitive demand on the participant. This decrease in cognitive demand is likely to play a pivotal role in treating patients who have suffered a TBI resulting in impaired static and dynamic balance.

When comparing baseline measurements to measurements taken during performance with each display, we found a significant difference with the incorporation of visual biofeedback, specifically improvement in IOS values. We can associate this trend to decreased cognitive demand during activity since users could apply inherent pattern recognition processes, thereby offsetting demand for attention and interpretation. This enabled the participant to visually sense load distribution and make corrections based on task-oriented and goal-driven activities. Our results are similar to those found in Tirosh et al. in that we saw a significant improvement from baseline measurements to measurements while using the visual biofeedback [8].

Based on the IOS comparisons, we concluded that the Differential-Temporal display was the most suitable man-machine interface. In comparison to all displays, the Differential-Temporal had significantly smaller IOS values, leading toward perfect symmetry. We equated this result as an impact of both data pre-processing and the representation of the data to the user. The representation allowed users to follow adjustments during both right and left weight transitions continuously while also considering past performance since their temporal history was provided. This allowed users to execute adjustments without requiring pre-planning. The participants appeared to continuously make weight-bearing adjustments until they reached the goal. This performance method has been illustrated in other task-oriented experiments. Kirsh and Maglio's study found that experienced gamers were more successful at geometrically constrained pick-and-place tasks when they rotated the object to be placed more frequently as opposed to pre-planning the movement [13]. From these observations, we conclude that a continuous adjustment of load allowed users to visually perceive results during use without making constrained cognitive calculations. Pre-processing the data proved to be a critical approach when delivering information to the user. By incorporating this piece, users no longer had to make the arduous process of interpreting results and comparing between both limbs to make adjustments. Alternatively, we found that the Temporal display recorded the most unfavorable results among all displays. We can attribute this to the increased cognitive demand placed on the user to receive results from a single limb and interpret a suitable outcome for both limbs.

Our findings suggest that visual biofeedback influences gait symmetry during dynamic postural activity on an elliptical trainer. We also found the optimal visual biofeedback representation among the four displays adapted from previous research. We concluded that with improvement from baseline activity to visual biofeedback, users were able to offload interpretation and attention demand onto perceptual processes allowing easy manipulation of spatial parameters. Our future endeavors will be to expand on these findings in determining the effects of manipulating scaled values to cause hyper-symmetry, asymmetry towards non-dominant balance limb, while using an elliptical trainer and apply these methods to participants who have suffered TBI and stroke to determine its efficacy in these populations. Potential limitations in the study may be the effect of learning from each day of exposure, since order of display was randomized and corresponding correlation coefficients revealed no correlation this is not expected to have occurred.

References

1. Tsaousides T, Gordon WA (2009) Cognitive rehabilitation following traumatic brain injury: assessment to treatment. Mt Sinai J Med 76: 173-181.
2. Walker WC, Pickett TC (2007) Motor impairment after severe traumatic brain injury: A longitudinal multicenter study. J Rehabil Res Dev 44: 975-982.
3. Pickett TC, Radfar-Baublitz LS, McDonald SD, Walker WC, Cifu DX (2007) Objectively assessing balance deficits after TBI: Role of computerized posturography. J Rehabil Res Dev 44: 983-990.
4. Geurts AC, Ribbers GM, Knoop JA, van Limbeek J (1996) Identification of static and dynamic postural instability following traumatic brain injury. Arch Phys Med Rehabil 77: 639-644.
5. Gil-Gómez JA, Lloréns R, Alcañiz M, Colomer C (2011) Effectiveness of a wii balance board-based system (eBaViR) for balance rehabilitation: a pilot randomized clinical trial in patients with acquired brain injury. J Neuroeng Rehabil 8: 30.
6. Betker AL, Desai A, Nett C, Kapadia N, Szturm T (2007) Game-based exercises for dynamic short-sitting balance rehabilitation of people with chronic spinal cord and traumatic brain injuries. Phys Ther 87: 1389-1398.

7. Lange B, Chang CY, Suma E, Newman B, Rizzo AS et al. (2011) Development of low cost game-based balance rehabilitation tool using the Microsoft Kinect sensor. Conf Proc IEEE Eng Med Biol Soc 2011: 1831-1834.

8. Tirosh O, Cambell A, Begg RK, Sparrow WA (2013) Biofeedback training effects on minimum toe clearance variability during treadmill walking. Ann Biomed Eng 41: 1661-1669.

9. Dingwell JB, Davis BL, Frazier DM (1996) Use of an instrumented treadmill for real-time gait symmetry evaluation and feedback in normal and trans-tibial amputee subjects. Prosthet Orthot Int 20: 101-110.

10. Dingwell JB, Davis BL (1996) A rehabilitation treadmill with software for providing real-time gait analysis and visual feedback. J Biomech Eng 118: 253-255.

11. Crowell HP, Milner CE, Hamill J, Davis IS (2010) Reducing impact loading during running with the use of real-time visual feedback. J Orthop Sports Phys Ther 40: 206-213.

12. Hegarty M (2011) The cognitive science of visual-spatial displays: implications for design. Top Cogn Sci 3: 446-474.

13. Maglio PP, Wenger MJ, Copeland AM (2008) Evidence for the role of self-priming in epistemic action: expertise and the effective use of memory. Acta Psychol (Amst) 127: 72-88.