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Error augmentation feedback for lateral weight shifting

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ABSTRACT

This study examines the effect of error augmentation of center of pressure (CoP) visual feedback on the performance of a lateral weight shifting task. Error augmentation emphasizes deviations from a standard CoP trajectory generated from existing data of over 2000 weight shifts collected with young, healthy subjects. Thirty-six subjects completed nine lateral weight shifting sessions, of which four were training sessions between each of the five testing sessions. Half of the subjects received error augmentation feedback during the training sessions, while the other half received the unaltered, control feedback. The change in visual feedback did not affect the final steady state weight shifting performance. Instead, error augmentation feedback was found to drive subjects to their steady-state performance sooner than unaltered visual feedback. The emphasis on deviations from the standard trajectory with error augmentation appears to lead to reduced variation in shifting. This finding may be useful in generating novel therapies that improve the efficiency of balance rehabilitation.

1. Introduction

Visual, vestibular, and somatosensory feedback all contribute to maintaining balance while standing upright [1]. Visual feedback in particular is useful for evaluating balance performance and can improve static balance through use of a force plate [2,3]. Functional balance, though, often involves tasks beyond quiet standing [4], such as weight transfer between legs in walking. This motivates analyzing balance performance during lateral weight shifting tasks, wherein visual feedback is critical for shifting weight to specified targets.

Much research has shown that feedback in simple motor training tasks improves performance, but less work has sought the optimal feedback within individual tasks [5]. There is evidence, though, that altering visual feedback affects balance performance [6,7]. In arm reaching tasks, augmenting the visual feedback position error promotes temporary performance effects for new tasks [8,9]. Error was measured as the distance from a straight-line path between the starting point and target and was visually augmented to encourage elimination of deviations from this path. Error augmentation helped speed subjects' adaptation to a rotation in the visual feedback [8,9]. The effects of altering biofeedback in this manner are unknown for mobility and balance tasks [10]. Application of error augmentation to quiet standing balance has been inconclusive [11,12], requiring large augmentation to improve performance. Effects on lateral weight shifting may be more pronounced, though, since it is typically more difficult and relies more heavily on visual feedback.

A primary metric in dynamic balance is time-to-target – the time required for the center of pressure (CoP) feedback to move to the target [13]. Therefore, error augmentation must consider CoP motion over time, as opposed to previous methods in static balance that depend entirely on spatial CoP parameters. Most weight shifting research emphasizes controlled shifts because of their functional utility for walking and preventing falls. This study constrained shifts in two ways that restricted the speed of shifting – a shift could not be initiated until a new target appeared and the CoP marker had to remain in the target for a specified duration after the shift.

This paper aims to determine whether error augmentation in visual feedback can improve balance performance during a relatively simple, visually guided lateral weight shifting task. In arm reaching experiments, error augmentation promoted temporary performance effects for new tasks, but not improved overall steady state performance [14]. Hypothesizing that error argumentation offers the same benefits here as in arm reaching, we expect subjects presented with augmented error feedback to exhibit temporary performance improvement but reach the same steady state level of balance performance.

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2. Methods

2.1. Subjects

Thirty-six healthy subjects, 13 males and 23 females, ages 17–21 (18.9 ± 1.0) years, participated in this study. All subjects (or guardians) gave their informed consent prior to the study, and this research received approval from the appropriate Institutional Review Board. Evaluating the effects of augmented error feedback on weight shifting tasks required an experiment duration of roughly 40 min. To avoid fatigue effects, exclusively young, healthy subjects were recruited.

2.2. Experimental system

The WeHab system [15] employs an open-source program that uses the Nintendo Wii Balance Board to provide biofeedback during standard balance sessions. The system functions by connecting, via Bluetooth, one or two balance boards to a computer running the custom software. The position of the CoP of an individual standing on the balance board(s) is calculated from the force data and displayed as a green circle on an LCD screen (Fig. 1). The balance board has been shown to perform comparably to sophisticated force plates for balance biofeedback [16,17].

As shown in Fig. 1, two balance boards were placed side-by-side to isolate each foot. Each subject stood with one foot centered on each board, facing a 27″ monitor that displayed the 2-dimensional position of the subject's CoP over an image of the balance board, as in [6]. The target was displayed as a vertical rectangle in a center, left, or right location. The center location corresponded to a 50–50% weight distribution, while the left and right locations corresponded to 70–30% weight distributions. A chair placed behind the subject allowed for a short rest between each session. The researcher sat nearby to run the software and ensure that the subject followed the protocol.

2.3. Error augmentation design

For lateral weight shifting, the standard CoP trajectory is unlikely to be a monotonic progression along a straight line. The CoP typically exhibits a non-minimum phase (NMP) behavior, moving away from the target due to the initial forces that ultimately drive it toward the target [18]. Therefore, the error must be calculated relative to a time trajectory of the CoP position, whereas for error augmentation in reaching [8], a time-independent path is sufficient. Additionally, it is beneficial to display the anterior–posterior movements of the CoP even when they are not relevant to the task [6]. Since it is not task-relevant, though, no error augmentation was applied in the anterior–posterior direction. A standard CoP time trajectory was generated by averaging data from 2287 shifts made by 27 young, healthy subjects [6] (Fig. 2A). The lateral CoP trajectory does not vary with left/right direction, so these results average all shifts. There is little variation across the interquartile trajectories, particularly in the subjects' reaction time from when a target appears until the CoP first moves away from that target in its initial NMP behavior. The standard shift generated from previous studies may be different from those of a new subject pool, but it is reasonable to use a standard CoP trajectory that most young, healthy subjects employ, including the relatively static portion during the reaction time due to the small amount of variability for most shifts.

A subject's instantaneous error was computed as the difference between the true CoP position and the standard CoP position at the same instant. (The standard trajectory was taken to have a

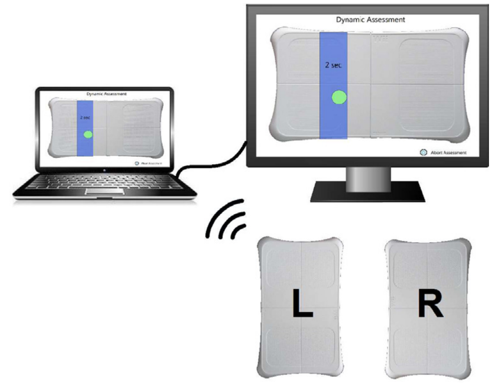

Fig. 1. Experimental setup. Each subject places one foot on each board, facing the large monitor. The boards connect wirelessly to the laptop running the software, which is not visible to the subject.

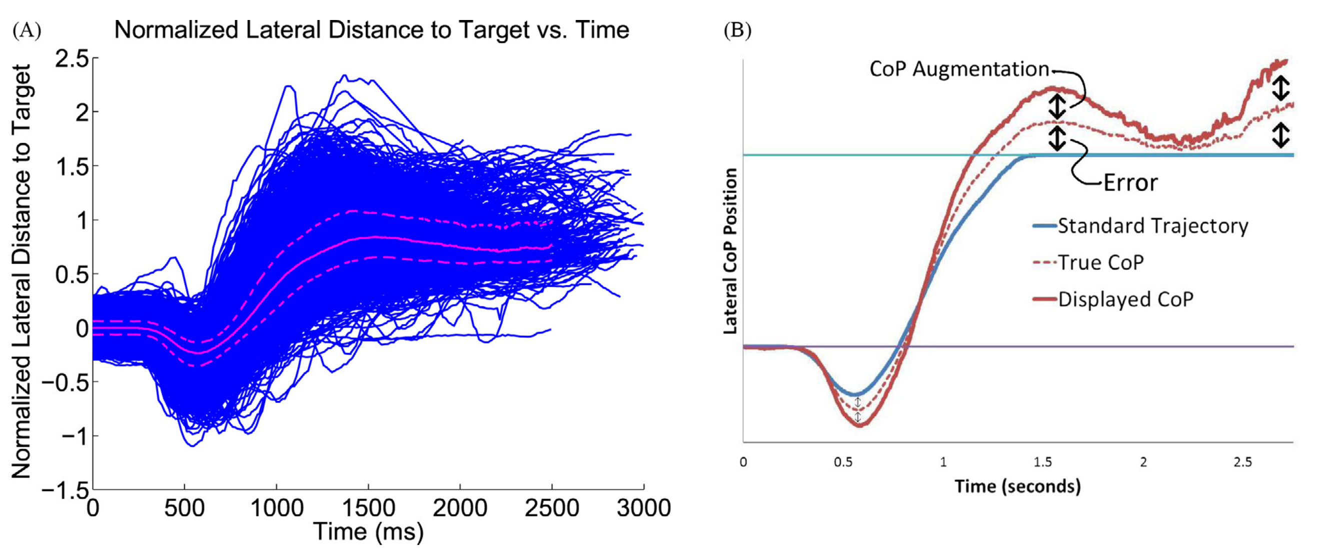

Fig. 2. Error augmentation feedback generation. (A) Trajectory data from a total of 2287 lateral shifts that 27 young, healthy subjects performed in a previous study [6]. Each blue line represents an individual shift. The pink trajectories represent the analysis from all of the individual trajectories combined. The median trajectory is solid, while the interquartile positions are indicated by the dotted lines. These results demonstrate that there is a standard trajectory that most subjects follow while shifting to the target. (B) Error augmentation calculation. Using the standard trajectory, the error of the true CoP is calculated. A gain is then applied to the error and added to the true CoP to generate the displayed CoP feedback in real time. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)