Sensory integration training improves balance in older individuals

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***Abstract*—With the massive growth of the aging population worldwide, of utmost importance is reducing falls. Critical to reducing fall risk is one's ability to weight incoming sensory information towards maintaining balance. The purpose of this research was to investigate if simple, targeted sensory training on aging individuals (50 – 80 years old), including twelve healthy and eight individuals with chronic stroke, could improve their balance. Repeated sensory training targeted visual (via eyes-open/closed) and somatosensory inputs (via light touch to the fingertip as well as hard, soft foam, and hard foam support surfaces to the feet) during standing and dynamic base-of-support (BOS) exercises. Study participants underwent six weeks of training. Prior to and post training, standing balance was assessed via a simple, clinical measure: the balance error scoring system (BESS). Following several weeks of training, participants showed significant improvements in BESS errors: healthy participants for small BOS with limited somatosensory information (i.e., tandem and single-leg standing on foam) and participants with stroke in all conditions.**

***Clinical Relevance*— This research study demonstrated that simple, accessible exercises, can positively impact balance in the aging population, a pressing need.**

I. Introduction

In 2015, the total medical costs for falls in the United States was approximately $50 billion [1], and the number of falls is likely to rise. With increases in average life expectancy (43 million Americans over 65 years old in 2012 and 72 million projected in 2030) the importance of improving and maintaining balance parallels preventing falls [2]. In adults over 65 years old, it is well-known that stroke is considered the largest risk factor for falls [3]. When patients that had suffered stroke are discharged from the hospital, fall-risk still persists in that highest fall-rates are reported immediately after discharge from the hospital or rehabilitation clinic. This finding suggests that rehabilitation and training needs to continue once released to their home environment. Further, despite common misperceptions, falling is not an inevitable result of aging.

According to the National Council on Aging (NCOA) [4], through practical lifestyle adjustments and evidence-based falls prevention programs, the number of falls among seniors may be substantially reduced. For these reasons, straight-forward training methodologies that are accessible and safe to perform in one's home must be investigated, such as those that target sensorimotor integration (e.g., sensory balance training).

Balance control requires the integration of sensory information from visual, vestibular, and somatosensory systems; consequently, the lack or dysfunction of central integration of sensory information causes imbalance leading to falls. The vestibular system provides angular and linear (head) orientation information while the visual system provides us information on our environment and the world around us. Vestibular and visual systems provide us essential information on our motion and spatial orientation [5]. The somatosensory system provides information (via mechanoreceptors in the skin and pressure receptors) on the quality of a support surface (e.g., compliance and texture), and orientation and motion can be inferred through sensing of shear forces, or pressure, induced by these movements between one's body and the support area or support surface [6, 7]. Proprioceptors (muscle spindles, Golgi tendon organs, and joint receptors) provide critical information about one's orientation and the relative movements of one's body segments.

The central nervous system (CNS) integrates and weighs information from the different systems in order to generate an appropriate feedback command and postural response [8, 9]. Sensory reweighting is a term which is defined as an ability for the CNS to choose (or weigh) sensory information in order to maintain postural stability, and ultimately, to prevent falls [8, 10]. Further, it has been shown that sensory information in feedback control of trunk posture is reweighed depending on the stability of an environment [9]. If multisensory integration is functioning normally, the sensory usage increases in one system in order to compensate for the other sensory channel with decreased or inaccurate sensory information. For example, if vision is unavailable or unreliable, a person without impairment can properly maintain posture by integrating information from vestibular and somatosensory sensory systems [11]. Moreover, if the somatosensory information of lower limb is unreliable (e.g., as one stands on

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a compliant surface instead of solid ground) other sensory system inputs will be weighed higher [12]. Further, when the quality of the input from one system decreases due to for example aging or injury, an advantage of this reweighting may be that the CNS can adjust (increase) gains of sensory inputs from other locations (e.g., [9]).

Deficient sensorimotor integration was acknowledged as a major factor in balance disability after stroke [12]. Patients with stroke have different etiologies which can present very different types of deficits and symptoms; somatosensory and proprioceptive issues, as well as visual dependence, in patients with stroke varies. It had been previously reported that, unlike healthy subjects, during standing, patients with stroke tended to rely upon vision rather than somatosensory inputs (e.g., [12, 13]). Previous studies have reported that patients that had suffered stroke rely on ("weigh") vision heavily [14] and this is perhaps due to their inability to make accurate use of somatosensation or proprioception. Patients that had suffered stroke have damaged somatosensory information (e.g., from the foot pressure and ankle joint receptors, as well as muscle proprioceptors) and [15] reported that the proprioception recovery (sensing the relative positioning of body segments to one another) of patients that had suffered stroke is impaired.

There is general agreement that decreased postural ability in older individuals, even those that had not suffered a stroke, is linked to/could reflect pathologies associated with one or more sensory system components, as well as age-related changes and deterioration of motor and higher-level adaptive mechanisms [16, 17, 18]. This leads to difficulty weighing and comparing appropriate sensory inputs, thus leading to potential balance problems. However, sensory integration of aging populations, including patients that had suffered stroke, may be enhanced with the use of the use of balance training focusing on the sensory integration component.

For example, Jang et. al [19] investigated the impact of sensory integration training on the balance recovery of stroke survivors. One group underwent physical therapy training while the other group underwent physical therapy training with sensory integration training (SIT), in addition. In terms of assessing balance, they focused solely on muscle activity and limits of stability (LOS) measurements. They found that LOS, or the maximum limit of stability (i.e., how far back-forward, side-to-side one can sway in the standing position without stepping; or, in other words, how far one can shift their weight toward the boundary of stability without lifting their feet from the ground) was increased (or improved) in the SIT group. However, setbacks of this study were the lack of measures to concretely quantify standing balance. More specifically, the lack of use tools designed to measure sensory contribution to postural control especially after training focusing on sensory integration; sensory inputs to the participants during the training needed to be identified and implemented.

The goal of the present study was to examine if training older individuals under diverse sensory conflict situations targeting vision and somatosensory inputs, as well as BOS and dynamic & static conditions, could impact (improve) their standing balance. We hypothesized that our sensory-training would be an effective tool for enhancing balance ability in older participants that had not suffered stroke, as well as those that were at least one-year post-stroke.

II. Methods

All study activities were conducted within the Center for Biomechanical & Rehabilitation Engineering (CBRE) at the University of the District of Columbia, the protocol was approved by the Institutional Review Board (979744-1), and all participants gave their informed consent prior to participating in the study. Eight chronic stroke survivors and 12 healthy participants enrolled in this study. Inclusion criteria included a score greater than 25 on the Mini-Mental State Examination (all participants scored above 28). Further inclusion criteria for stroke survivors were: they were at least one-year post-stroke, able to maintain standing position free of aids for at least 5 minutes, able to walk without external assistance for at least 15 meters. One stroke participant and one healthy participant withdrew from the study due to follow-up tied to the 6-week training commitment. The results presented here include 7 participants with stroke (2 females and 5 males; 66.1 +/- 8.6 years old) and 11 healthy participants (2 males and 9 females; 68.5 +/- 4.8 years old).

A. Training Assessment

Participants underwent a specific training program aimed at increasing their sensorimotor integration and balance. During the sessions, the participants worked with the principal investigator and research assistants which also served as spotters to prevent them from falling. Exercises, during several weeks of training, required healthy and participants with stroke to make use of diverse sensory information while attempting to maintain their balance. Vision was modified to make conditions more or less challenging (eyes-closed/eyes-open, respectively). Further, BOS was modified between large and small (i.e., double-leg, tandem, and single-leg stances) to increase task difficulty. In order to maintain static equilibrium (e.g., during standing), one's projected center of mass (COM) must lie within the BOS. The COM is the location at which the entire mass of one's body is balanced, and typically, during standing the BOS is the region bounded by the points of contact between body segments and the support surface [20]. A larger BOS allows for greater stability while a smaller one leads to lesser stability. During dynamic equilibrium (e.g., walking) the COM rarely lies within the BOS and is continuously regulated. During training, if needed to stabilize themselves, participants were allowed to place their index and middle fingers on the spotter for (light) fingertip touch information (e.g., [21]) but were not allowed to grab for support nor place a significant amount of weight and/or lean on the spotters.

Participants completed a 6-week exercise routine which consisted of two, 30-minute sessions/week. Every 2 weeks, the training progressively increased in difficulty: Training I. Walking; Training II. Foam Exercises; Training III. Walking over obstacles and more foam exercises. The training is described in detail within Thompson [22].

B. Assessment

In order to assess participant balance, pre and post-assessments were conducted on standing balance. Static tests are relevant to functional stability in daily life for two reasons: 1) a sizable proportion (nearly half) of falls occur during near-static movements and activities and 2) static test results may provide information that is relevant to the many falls that occur during gait [23]. We acquired kinematic measures using motion capture, as well as center-of-pressure (COP) using a forceplate walkway. However, for this paper, a particular emphasis was placed on a simple, clinical static test: the Balance Error Scoring System (BESS). The BESS assessment is a straightforward, standard assessment that requires little to no equipment; the BESS utilized double-leg, single-leg, and tandem stances as the participant stood on either hard or foam surfaces, all with eyes closed with hands on their hips. Further, because of the nature of the sensory training, the sensory conditions (eyes-closed balancing while standing on hard or foam surfaces) achieved by using BESS was of particular interest to us. The stance conditions were presented in a latin squares fashion to reduce learning effects. The number of deviations from upright were counted as 'errors' for six, 20 second trials per condition. Examples of errors were the following: moving the hands away from one's sides/off of the iliac crests, opening one's eyes, stepping or stumbling, hip abduction or flexion beyond roughly 30° (crouching), remaining out of the proper testing position for over 5 seconds. Each error was given a point of 1, and errors were counted throughout each trial. The maximum number of BESS errors for each trial, for each condition, was set at 10; if the maximum number of errors was reached within a 20 second trial, or if the participant could not perform the particular stance condition, the experimenter stopped and moved on to the next trial. The number of BESS errors for each condition was determined; also, a total BESS error (sum of errors for all conditions) was computed. A higher score could be interpreted as lesser ability to balance, and conversely, a lower score (i.e., fewer deviations) could be interpreted as a better ability to balance.

B. *Statistical Analysis*

In terms of statistical analysis, for each group, for each test condition, trials were pooled from which means and standard errors were computed for the above parameters. For pre and post-results, average values for each above were computed. Differences were compared by using statistical analysis between the pre and post assessments. Significant differences were observed as p-values < 0.05 and assessed using t-tests for equal sample size, unequal variance. Further, a two-way analysis of variance (ANOVA) was conducted for each group for the BESS data using SAS Software (SAS Institute Inc., Version 9.4) to determine if there were significant interactions between stance (or BOS) and support surface.

III. Results

Fig. 1 displays the BESS pre and post errors for healthy participants and participants with stroke. Test conditions from easiest to most difficult were: double-leg stance/hard surface (DL/firm), double-leg stance/foam surface (DL/foam), tandem stance/hard surface (T/firm), tandem stance/foam surface (T/foam), single-leg stance/hard surface (SL/firm), and single-leg stance/foam surface (SL/foam). As previously stated, for all BESS conditions vision was limited (eyes closed).

For the healthy participants, there were no significant decreases (improvements in balance) pre versus post for the test conditions, with the exception of the most challenging condition (single-leg stand/foam surface: t = -3.65, df = 12, p<0.05). For the participants with stroke, there were significant decreases in several conditions post versus pre observed as an increase in balance ability (i.e., double-leg/firm surface: t = -5.70, df = 10, p<0.001; double-leg/foam surface:

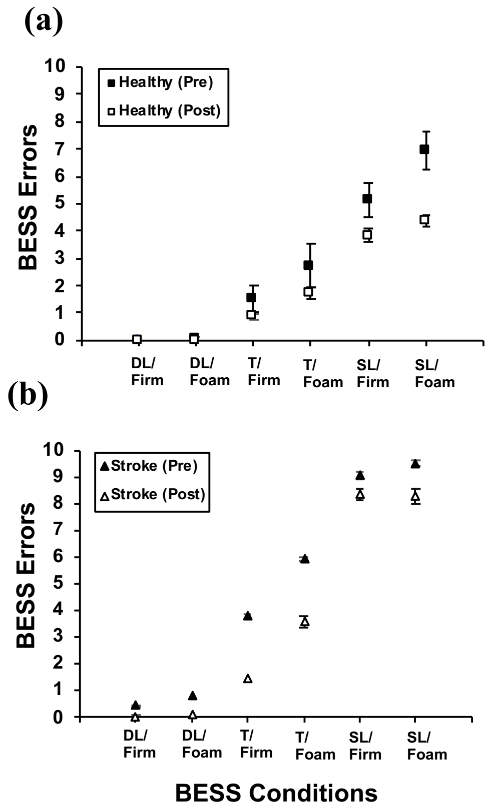

Figure 1. BESS errors as a function of BESS test conditions for **a)** 11 healthy and **b)** 7 chronic participants with stroke' pre (filled circle) versus post (open circle); means and standard errors are shown.

t = -3.11, df = 6, p<0.02; tandem/firm surface: t = -8.31, df = 10, p<0.001; tandem/foam surface: t = -4.59, df = 7, p<0.01; single-leg/foam surface: t = -3.15, df = 12, p <0.02). It is of note that their performance improved for the three most difficult standing conditions (i.e., standing on the foam surface). Also, the general shapes of curves saturate at low and high ends (easier and more difficult conditions).

The interaction between stance (BOS) and support surface were meaningful to interpret the BESS error differences between test conditions. For both healthy and participants with stroke, there were no significant interactions between stance and support surface prior to training. However, post-training there were significant effects for surface, stance, and surface*stance. For healthy individuals pre-training: surface (df = 1, F = 10.72, P = 0.0013) and stance (df = 2, F = 173.03, P <0.0001) had significant effects, however, there was an insignificant interaction between surface and stance. For healthy individuals post-training: surface (df = 1, F = 19.65, P = 0.001), stance (df = 2, F = 189.43, P <0.0001), and surface*stance (df = 2, F = 5.07, P = 0.0072) all had significant effects. For stroke individuals pre-training: surface (df = 1, F = 7.91, P = 0.0054) and stance (df = 2, F = 216.6, P <0.0001) had significant effects, however, there was an insignificant interaction between surface and stance. For healthy individuals post-training, surface (df = 1, F = 5.51, P = 0.02), stance (df = 2, F = 459.82, P <0.0001), and surface*stance (df = 2, F = 11.25, P = 0.001) all had significant effects.

IV. Discussion

The present study displays the effects of sensory-type balance training on standing balance and postural control. Following several weeks of training, participants displayed significant improvements in their balance observed as decreases in BESS errors. We propose that the improvements in our participants' balance could be ascribed to a change in sensory strategies for postural control.

For the BESS assessment, all conditions involved eyes being closed (no visual cues). Eyes-closed is standard for the BESS assessment and also makes the conditions more challenging to perform for healthy, and especially stroke, participants. However, the participants were able to perform better on the limited BOS (e.g., tandem and single-leg stances) and limited somatosensory (foam) conditions post-training. This leads us to believe that perhaps the dominance of visual influence for survivors of stroke was reversible, as described in previous studies [12, 14, 24]. And further, that healthy older individuals were able to also place less of a dominance on vision during challenging standing tasks. In fact, repeated sensory trainings in our work, introduced new stimuli to the somatosensory system and encouraged the CNS to employ new strategies to maintain balance. In other words, the adaptation ability of CNS to new test conditions reinforces the balance in elderly through putting more emphasis relying on non-visual sensory information cues. Another factor could relate to study subjects gaining confidence and having less fear while doing the tasks. However, our Activities-specific Balance Confidence (ABC) results, not shown nor described here, showed no significant difference pre versus post-training for each respective group. For future work, comparisons with other "conventional" rehabilitation programs may be needed to determine relative effectiveness.

With older participants encountering fall incidents, programs must be rigorously tested under close supervision in a large population prior to prior to the translation to home-based training. Despite its smaller sample size, the significance of this work cannot be understated. Encouragingly, this study shows that simple-targeted sensory-type training can have an impact on older individuals' balance.

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