Biomedical Signal Processing and Control 39 (2018) 162–168

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Research Paper

Postural stability during long duration quiet standing in post stroke hemiplegia

Rakesh Pilkar[a,b,*], Nibal Arzouni[a], Karen J. Nolan[a,b]

[a] Kessler Foundation, Human Performance and Engineering Research, West Orange, NJ, USA
[b] Rutgers – New Jersey Medical School, Department of Physical Medicine and Rehabilitation, Newark, NJ, USA

ARTICLE INFO

Article history:
Received 25 August 2016
Received in revised form 20 March 2017
Accepted 20 July 2017
Available online 8 August 2017

Keywords:
Quiet standing
stroke
Sampling duration
Phase plane analysis
Postural stability

ABSTRACT

Background: Inter-limb center of pressure changes and stance asymmetry in individuals with hemiplegia secondary to stroke have previously been reported for short duration quiet standing (QS). The purpose of this investigation was to assess COP displacement, velocity, and loading forces during long duration (120 s) quiet standing. The investigation also aimed at performing an inter-limb stability assessment using COP distance and velocity dependent phase plane analysis during 120 s of quiet standing in healthy controls and individuals with hemiplegia post stroke.

Methods: Healthy adults ($n = 12$ control subjects) and individuals with hemiplegia secondary to stroke ($n = 10$) stood on a level floor with eyes open for 120 s while plantar pressure data was collected bilaterally. Main outcome variables included COP displacement, COP velocity, stability indices based on COP displacement and velocity variations, and the Berg Balance Assessment. In the stroke group, paired *t*-tests were used to perform inter-limb comparisons of the main COP outcome measures. Secondary analysis evaluated the inter-limb symmetry ratios for both groups, and independent sample t- tests were conducted to compare inter-limb ratios of COP, stability indices measures, and Berg Balance Assessment Scores between the two groups.

Results: In the stroke group, COP range, COP mean velocity, COP peak velocity, and stability indices were significantly asymmetrical and greater on non-paretic side in anterior-posterior (AP) direction. Individuals with stroke demonstrated symmetrical loading forces, COP range, RMS COP, COP velocity medial-lateral (ML) ratios and this was not significantly different from the healthy controls.

Conclusion: The majority of the weight bearing was imposed on the non-paretic side during 120 s of QS. As being the major contributor in maintaining balance, the non-paretic side may be over-utilized which may further lead to greater COP displacements, velocities, and potentially postural instability in AP direction. Such asymmetry in AP direction resulted in a compensatory weight “switching” strategy in ML direction.

1. Introduction

Balance is defined as the process of maintaining equilibrium and center of gravity (COG) within the body’s base of support while performing static or dynamic activities [1,2]. Control of balance is regulated within the central nervous system by a complex integration of various peripheral pathways including visual, somatosensory, vestibular and motor control substrates [1,3]. Even minor impairments in any of these systems can cause a significant decrease in effective balance performance resulting in substantial disability [4]. Forty percent of patients post stroke undergoing rehabilitation are able to stand independently for one minute, 20% can stand with help and 40% are not able to stand at all [5,6]. Post stroke hemiparesis is more detrimental to distal than to proximal limb muscles [7]. Hemiparetic patients with impaired function of the muscles controlling ankle movements are expected to have disrupted postural control pattern [7–9]. More specifically, the contribution of the paretic leg to generate corrective torque in the anterior-posterior (AP) direction is less than that of the non-paretic leg [10–12].

Another critical aspect of balance control in individuals post stroke is the weight loading strategy implemented between limbs. Many individuals with stroke and chronic hemiplegia stand with more weight on their non-paretic side. Favoring the non-paretic limb can reduce reliance on the more impaired limb for balance control [11,13]. Previous research, however, has shown that some

* Corresponding author at: Kessler Foundation, Human Performance and Engineering Research, West Orange, NJ, USA.
E-mail address: rpilkar@kesslerfoundation.org (R. Pilkar).

http://dx.doi.org/10.1016/j.bspc.2017.07.016
1746-8094/

patients with hemiplegia prefer standing over the paretic limb [11,14] which may result in increased instability [7].

Maintaining postural stability requires control of the center of gravity (COG) position and the resulting momentum [15]. Riley et al. [15] demonstrated that the phase plane analysis technique that incorporates both position and velocity of the center of pressure (COP) could be more useful in characterizing balance control than COP displacement measures alone. Stability analysis performed using this technique has not been fully explored for characterizing post stroke balance dysfunction. Phase plane analysis of the COP could add significant contribution in understanding inter-limb COP changes, stability and postural strategies during long duration quiet standing (QS).

Stability analysis during upright standing can also be influenced by the amount of time, or sampling duration, the data is recorded. Studies have shown that the magnitudes of COP related measures in the time and frequency domains are significantly influenced by sampling duration [16–18]. To the best of our knowledge, previous studies that have looked at inter-limb COP changes, synchronization and weight bearing during standing in individuals with hemiplegia have used COP related measures with sampling duration up to 40 s [7,11,19,20]. Research by Kooij et al. to evaluate the effects of sampling duration on COP recommends a standardized sample duration of at least 60 s (for eyes open condition) in order to compare outcomes between groups or individuals who are unable to stand for long periods of time [17]. Studies have shown that the magnitudes of COP measures are significantly influenced by sampling duration [16,18]. These studies were limited to sample durations of less than 120 s, which may not be sufficient to capture the very low frequency, and unique characteristics of postural sway observed during more extended periods of quiet stance [16,21]. In the cases of postural assessment during standing in hemiplegic populations, the sampling duration is even smaller [7,11,19,20] which may only include the higher frequency components of the COP and may not contain the lower frequency bands characterized by the low-frequency high-amplitude drifts in the time domain. Therefore, it is important to collect the quiet standing (QS) data for a longer duration in order to more comprehensively evaluate inter-limb synchronization, balance control strategies and loading strategies in healthy as well as neurologically impaired population.

The purpose of this investigation is to 1) compare inter-limb COP (displacement and velocity) and loading force measures and 2) perform inter-limb stability assessment using COP distance and velocity dependent phase plane analysis during long duration (120 s) of upright standing in individuals with hemiplegia post stroke and compare these measures to age-matched healthy controls.

2. Methods

2.1. Participants

Ten individuals with hemiplegia secondary to stroke (>4 months) and twelve healthy controls were recruited for participation. All presented outcomes represent analyses of quiet standing data collected as a part of a larger multi-site clinical trial. All individuals with stroke were able to stand independently for at least 2 min without any assistance. All healthy controls had no significant neurological or orthopedic impairment that would affect their ability to walk or stand.

2.2. Testing procedures

Participants completed the 14 items of the Berg Balance Assessment and received standard instructions. The Berg Balance Scale (BBS) is a standard clinical assessment used to measure balance. The BBS includes 14 items related to functional activities including sitting, standing, single leg standing and postural transitions with eyes open and closed. The maximum score is 56 and a score of less than 45 is associated with an increased risk of falling.

Data collected during the *standing unsupported for two minutes* subtask of the Berg Balance Assessment was used for all subsequent analysis. During this subtask, participants were instructed to stand upright with their natural stance, facing forward with their eyes open without holding on anything for two minutes. All participants completed the task and were able to stand without assistance for two minutes.

Wireless plantar pressure data was collected bilaterally using the pedar®-x (novelGmbH, Munich, Germany) during the entire Berg Balance Assessment. The pedar®-x is an objective, quantifiable pressure distribution measuring system for monitoring magnitude and timing of plantar loading. The system consists of a portable data collection device attached to the participant's waist, and two thin sensor insoles are inserted bilaterally directly below the plantar surface of the foot inside the shoe. Plantar pressure data for all participants was collected at 100 Hz during two minutes of quiet standing for individuals with stroke and healthy control subjects. Members of the study team provided supervision and non-contact guarding during all standing trials for safety. All procedures performed in this investigation were approved by the Human Subjects Review Board and informed consent was obtained prior to study participation.

2.3. Data processing

Demographic information including age, gender, and time since stroke was collected and verified with medical records. Data from all assessments are represented as mean ± standard deviation. Pedar®-x force data was calculated by multiplying the recorded pressure by the sensor area resulting in a force "normal" to each sensor in the matrix [22]. Using pressure data from all 99 sensors, the centroid of the pressure distribution is provided in terms of x and y insole coordinates for each foot independently. The origin was defined as the point most medial and posterior with reference to the insole regardless of foot orientation and line of progression [23]. Increased x-coordinate indicated a movement toward the lateral border of the insole and increased y-coordinate indicated a movement toward the anterior border. Plantar pressure data was exported using the Novel pedar-x Recorder Software (novelGmbH, Munich Germany) and all data was imported into Matlab (The Mathworks, Inc, Natick, MA, USA) for custom analysis. A low pass IIR Butterworth filter of 6 Hz cutoff frequency was used to eliminate high frequency noise contributions in the COP data. The filtered COP data was then normalized by the insole length in AP direction and insole width in ML direction for each foot.

3. Calculations

3.1. COP displacement, COP velocity and loading force

The description of COP variables and loading forces are presented in Table 1.

3.2. Phase plane analysis

The phase plane index (PPI) [15] is calculated by using the standard deviations of the position and velocity components of COP in both AP and ML directions using Eq. (1)–(3) [15]. The position index (PI) which considered only displacements was calculated using the COP position in both AP and ML directions using Eq. (4). The velocity index (VI) was calculated using the COP velocity in both directions