Neuroscience Letters 642 (2017) 91–96

Contents lists available at ScienceDirect

Neuroscience Letters

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

Research article

Effect of haptic input on standing balance among individuals with incomplete spinal cord injury

Tarun Arora [a,*], Kristin E. Musselman [a,b,c,d], Joel Lanovaz [e], Alison Oates [e]

[a] College of Medicine, University of Saskatchewan, Saskatoon, Canada
[b] Toronto Rehabilitation Institute-University Health Network, Toronto, Canada
[c] Dept. of Physical Therapy, Faculty of Medicine, University of Toronto, Canada
[d] School of Physical Therapy, University of Saskatchewan, Saskatoon, Canada
[e] College of Kinesiology, University of Saskatchewan, Saskatchewan, Canada

HIGHLIGHTS

- Haptic input in form of light touch can reduce COP sway in people with iSCI.
- The effect of haptic input is greater in people with more intact UE cutaneous pressure.
- The effect of haptic input is greater in people with less intact LE proprioception.

ARTICLE INFO

Article history:
Received 31 July 2016
Received in revised form 31 January 2017
Accepted 1 February 2017
Available online 3 February 2017

Keywords:
Incomplete spinal cord injury
Standing balance
Center of pressure
Light touch

ABSTRACT

The present study investigated the effect of haptic input via light touch on standing balance of individuals with incomplete spinal cord injury (iSCI). Centre of pressure (COP) measures during standing were assessed in 16 participants with iSCI (13 males; 61.1 ± 19.9 years; C1-L4; AIS C and D) and 13 able-bodied (AB) participants (10 males; 59.4 ± 19.7 years). The effects of light touch (touch/no touch), vision (eyes open/closed), and group (iSCI/AB) on COP measures were assessed using a two-way mixed design MANOVA. Correlations were examined between changes in COP measures with touch (ΔCOP), and clinical measures of cutaneous pressure and proprioception in the upper (UE) and lower (LE) extremities in participants with iSCI. Significant main effects for touch ($p < 0.001$), vision ($p < 0.001$), and group ($p = 0.01$) for all COP measures were found. There was a significant interaction between vision and group ($p = 0.01$) for a subset of COP measures. With eyes closed, ΔCOP was positively correlated with UE cutaneous pressure sensation and negatively correlated with LE proprioception. Compared with AB adults, individuals with iSCI show a greater increase in postural sway when standing with eyes closed than with eyes open. Individuals with iSCI can use light touch to reduce postural sway, and the effect is greater in those with more intact UE cutaneous pressure sensation and more impaired LE proprioception.

1. Introduction

Seventy-five percent of individuals with incomplete spinal cord injury (iSCI) report at least one fall a year [1] and most of the falls in this population are reported while standing and walking [2]. Falls can lead to health complications, such as fractures, soft tissue injuries, a fear of falling, and subsequent restriction of activities and community participation [1,2]. Standing balance is also one of the major determinants of walking function in this population [3]; therefore, discovering effective strategies to improve standing balance in individuals with iSCI is important.

Standing balance is maintained by keeping the center of mass within one's base of support (BOS) by voluntarily moving the center of pressure (COP) [4]. Characteristics of COP movement are commonly used measures of standing balance [5] and represent the complex interactions between visual, somatosensory, vestibular, and motor functions to maintain balance. Impairment in one system can lead to more reliance on the other systems. For example, individuals with iSCI show a greater reliance on vision for maintaining standing balance likely because of somatosensory impairments [6].

* Correspondence to: Biomechanics of Balance and Movement Laboratory, College of Kinesiology, University of Saskatchewan, 87 Campus Drive, Saskatoon SK S7N 5B2, Canada.

E-mail addresses: tarun17arora@gmail.com, taa043@mail.usask.ca (T. Arora).

http://dx.doi.org/10.1016/j.neulet.2017.02.001
0304-3940/

One mechanism to improve standing balance can be through haptic input, which refers to the perception of sensory inputs from fingertip contact forces and proprioceptors in the arms while touching a stable object fixed in the environment (e.g., railing) [7]. During postural sway, mechanoreceptors located in the fingertip sense the shear forces between the finger and the touched object, whereas proprioceptors sense the change in configuration of the arm relative to the torso. The CNS uses this added sensory information to reduce the postural sway. The amount of mechanical support using light touch (<1N) can reduce body sway by only about 2.3% [7], which is considerably less than the reductions in body sway seen with light touch in AB individuals, individuals with balance disorders due to aging [8], Parkinson's disease [9] and stroke [10]. These findings suggest that the improvements in postural control are due to mechanisms other than mechanical support. In fact, the spatial information provided by the light touch can improve postural stability by as much as vision [7].

In individuals with iSCI, haptic input in form of light touch may improve standing balance by compensating for the sensory deficits in the lower extremities (LE); however, the extent of improvement may depend on the magnitude of somatosensory impairments in the upper extremities (UE) and LE. Loss of cutaneous and/or proprioceptive information in the UE may negate the effect of added haptic input as the individual will not perceive relevant information; whereas, individuals with greater sensory loss in the LE may benefit more from additional sensory information in the form of light touch as the added UE sensory input can be used in place of the reduced LE input. The effect of light touch on standing balance of individuals with iSCI has not been studied. Furthermore, the relationship between the extent of impairment in somatic sensation and the effect of light touch has not been studied; therefore, the objectives of this study were to: (a) investigate the effect of light touch on the standing balance of individuals with iSCI; (b) understand the relationship between the effect of light touch and UE and LE proprioception, and cutaneous pressure sensation. We hypothesize that individuals with iSCI will: (a) show a reduction in quiet standing postural sway with light touch, and; (b) show a significant correlation between the effect of light touch and clinical measures of cutaneous pressure and proprioception in LE and UE.

2. Methods

2.1. Participants

Participants with iSCI were recruited from regional health centres and advertisements within the province. Individuals who were at least one-year post iSCI, classified as American Spinal Injury Association Impairment Scale (AIS) C or D, and who were able to stand independently for sixty seconds were included in the study. Participants were excluded if they had any other disease, injury, or condition that could have affected standing balance. Age (±3 years) and gender matched healthy AB participants were recruited from the local community through advertisements. This study was approved by the University of Saskatchewan Biomedical Research Ethics Board.

2.2. Experimental procedure

Participants were asked to stand for 60 s on a force platform mounted flush with the floor (18.25 × 20 inches, AMTI OR6-7, Advanced Mechanical Technology, Inc., Watertown, MA) under each of the four conditions in the following order: (i) eyes open no touch, (ii) eyes closed no touch, (iii) eyes open touch, (iv) eyes closed touch. The eyes closed condition is more challenging and discriminating than eyes open condition, and also it can affect the validity and reliability of COP measures [11], therefore the eyes closed condition was included in this study. Participants stood with their shoes on and with their feet at a self-selected comfortable position. For the touch conditions, participants lightly touched a rail with the tip of their dominant index finger (self-reported). The rail was set on the same side as their dominant hand at a standard height of 85 cm above and parallel to the walking surface such that the participants received haptic input from the lateral side. The rail was instrumented with force sensors (Futek LRF400, Advanced Sensor Technology, Inc., Irvine, CA) to measure the amount of vertical touch force in Newtons (N). Before each trial, participants were instructed to use less force if they were applying more than 1N of force during the previous trial. If a participant had UE sensory and/or motor impairments, he/she used the index finger of the less affected side to touch the railing, as determined by their cutaneous pressure sensation and proprioception scores (iSCI only).

Kinematic data were obtained using a 3D motion capture system (Vicon Nexus, Vicon Motion Systems, Centennial, CO). Base of support (BOS) was calculated from markers at three locations on each foot–heels, tips of first toe, and the most lateral part of the foot at the base of the fifth metatarsals. Cutaneous pressure sensation was tested using monofilaments (Baseline® Tactile™ Monofilaments) of six different thicknesses for the palmar surface of the index finger on the touch side, and for the plantar surface of the first toe bilaterally. The monofilaments were applied in order of descending thickness. With the participant's eyes closed, a researcher applied each monofilament six times. Participants were instructed to say 'yes' if they could feel pressure being applied. A score of one was assigned for each correct 'yes' response, leading to a total possible cutaneous pressure score of 36 for the UE and 72 for both LE combined. Proprioception was measured in the touch side upper extremity in the following order – metacarpo-phalangeal, wrist, elbow, and then shoulder joints on the touch side, and in both lower extremities at the first metatarso-phalangeal and ankle joints. The same researcher moved each joint slowly through approximately 10° of extension (plantarflexion) or flexion (dorsiflexion) six times. Participants were asked to state the direction of movement (up or down) with their eyes closed [12]. A maximum score of six for each joint was recorded, leading to a total possible proprioception score of 24 for the UE, and 24 for both LE combined. To describe ambulatory status, scores on the Walking Index for Spinal Cord Injury (WISCI II) were also obtained. The WISCI II is a 21-item scale of walking capacity that ranks walking according to the amount of physical assistance, braces and walking aids required [13].

2.3. Data analysis

The force platform and 3D kinematic data were collected at sampling rates of 2000 Hz and 100 Hz, respectively. The force platform data was filtered at 10 Hz using a 4th order low pass Butterworth digital filter [5]. Custom MATLAB (R2006b for PC, MathWorks, Natick, MA) routines were used to obtain COP and BOS data. The following measures of COP sway were used as indicators of standing balance: (1) medio-lateral root mean square (RMS_{ML}), (2) antero-posterior root mean square (RMS_{AP}), (3) medio-lateral mean velocity (Vel_{ML}), (4) antero-posterior mean velocity (Vel_{AP}), (5) area of an ellipse, centered at the mean, encompassing ninety percent of COP samples (Area90%), (6) length of medio-lateral radius of the ellipse (Rad_{ML}), and (7) length of antero-posterior radius of the ellipse (Rad_{AP}). Root mean square measures are indicators of variability of COP distribution, whereas velocity and area measures are indicators of change in COP position with time and the amount of sway, respectively. Since, the feet position was determined by the comfort level of the participants and was not fixed, the COP measures were normalized to the individual's BOS: RMS_{ML} and Rad_{ML} measures were normalized to the width of BOS, and