Clinical Biomechanics 30 (2015) 507–512

Contents lists available at ScienceDirect

Clinical Biomechanics

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

Trunk control impairment is responsible for postural instability during quiet sitting in individuals with cervical spinal cord injury☆

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ARTICLE INFO

Article history:
Received 19 August 2014
Accepted 2 March 2015

Keywords:
Sitting balance
Postural sway
Centre of pressure (COP)
Spinal cord injury (SCI)
Foot support
Trunk control

ABSTRACT

Background: Individuals with cervical spinal cord injury usually sustain impairments to the trunk and upper and lower limbs, resulting in compromised sitting balance. The objectives of this study were to: 1) compare postural control of individuals with cervical spinal cord injury and able-bodied individuals; and 2) investigate the effects of foot support and trunk fluctuations on postural control during sitting balance.
Methods: Ten able-bodied individuals and six individuals with cervical spinal cord injury were asked to sit quietly during two 60 s trials. The forces exerted on the seat and the foot support surfaces were measured separately using two force plates. The global centre of pressure sway was obtained from the measurements on the two force plates, and the sway for each force plate was calculated individually.
Findings: Individuals with spinal cord injury had at least twice as large global and seat sways compared to able-bodied individuals, while foot support sway was not significantly different between the two groups. Comparison between global and seat sways showed that anterior–posterior velocity of global sway was larger compared to the seat sway in both groups.
Interpretation: Postural control of individuals with cervical spinal cord injury was worse than that of able-bodied individuals. The trunk swayed more in individuals with spinal cord injury, while the stabilization effect of the feet did not differ between the groups. Foot support affected anterior–posterior fluctuations in both groups equally. Thus, trunk control is the dominant mechanism contributing to sitting balance in both able-bodied and spinal cord injury individuals.

1. Introduction

Individuals with spinal cord injury (SCI) often experience motor and/or sensory impairment below the level of injury. Cervical injuries lead to impairment in upper limb, trunk, and lower limb muscles, while thoracic injuries lead to impairment in trunk and lower limb muscles (Seelen et al., 1998). Individuals with cervical or thoracic injuries often have impaired sitting balance (Chen et al., 2003; Grangeon et al., 2012). Impaired sitting balance after SCI causes an individual to alter his/her sitting strategy (e.g. individuals with SCI tilt their pelvis in order to achieve greater stability during sitting) and results in compromised sitting posture. Instability during sitting may affect performance of activities of daily living such as reaching and object manipulation (Chen et al., 2003), and could result in secondary health complications such as pressure sores (Minkel, 2000). Continuous, tonic activation of trunk muscles is required to maintain upright sitting posture, and phasic, feedback-driven activations are required to respond to balance disturbances (Masani et al., 2009). Therefore, paralysis of trunk muscles is one of the main reasons for compromised sitting balance after SCI (Minkel, 2000). Individuals with SCI often use innervated, non-postural muscles (e.g. shoulder and neck muscles), to compensate for the sitting impairment by voluntarily contracting these muscles to regulate sitting balance (Seelen et al., 1998). They also use their arms to increase the base of support during sitting, which can help improve their stability (Grangeon et al., 2012). Despite the compensatory methods

☆ Authors' contributions: MM, KM, MJK, MCV, and MRP designed the study. MRP and MCV obtained funding. MM and MJK collected the data. MM, KM, and HR analysed the data. MM, KM, HR, MCV, KMVM, and MRP interpreted the data. MM, KM, and MRP wrote the article. MJK, HR, MCV, KMVM revised the article. All authors reviewed, approved and provided input into the manuscript.

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http://dx.doi.org/10.1016/j.clinbiomech.2015.03.002
0268-0033/

that an individual with SCI may use, their sitting balance still remains and suboptimal.

Centre of pressure (COP) sway during quiet standing and quiet sitting has been utilized to assess postural stability during standing balance (Prieto et al., 1996; Vette et al., 2010) and sitting balance among able-bodied individuals (Gilsdorf et al., 1990; Dean et al., 1999; Kerr and Eng, 2002; Vette et al., 2010). Such assessments are relatively easy to perform in the laboratory, as they do not threaten the stability of the participants, and as such, can be applicable to evaluate sitting balance of individuals with trunk instability resulting from SCI. A small number of studies evaluated sitting balance of individuals with SCI using COP recordings (Chen et al., 2003; Shirado et al., 2004; Grangeon et al., 2012, 2013). These studies showed that postural sway is larger among individuals with SCI compared to able-bodied individuals, indicating worse postural stability and compromised sitting balance after a SCI (Shirado et al., 2004; Grangeon et al., 2012). Interestingly, the research indicates here that are no differences in postural sway between individuals with low and high thoracic SCI (Chen et al., 2003). However, in these studies the effect of foot support was either ignored (Chen et al., 2003; Shirado et al., 2004) or not analysed in detail (Grangeon et al., 2012, 2013).

It is recognized that foot support affects sitting balance. For example, in able-bodied individuals both COP displacement and velocity increased by as much as 70% during forward reaching when the subjects were allowed to use foot support compared to reaching without foot support (Kerr and Eng, 2002). Footrests also increased trunk displacement during forward reaching among individuals with thoracic SCI (Potten et al., 2002). However, the effect of foot support on postural stability of individuals with SCI during quiet sitting has yet to be examined in the literature. In prior studies, Chen et al. (2003) and Shirado et al. (2004) used one force plate positioned under the buttocks with both feet supported on the ground, but they did not account for the effects of foot support on COP.

Postural control is the ability to maintain balance. Various factors, including foot support and trunk control contribute to postural control during sitting balance. Trunk control is the ability to control the trunk, which can be evaluated by analysing the trunk fluctuations using COP measures obtained from a force plate placed under the buttocks. Similarly, foot support can be evaluated using postural sway fluctuations obtained using a force plate placed under the feet. Grangeon et al. (2012, 2013) used two force plates, one placed under the buttocks on the seat and the other one under the feet, to calculate the COP, but they did not analyse the separate contributions from the foot support and trunk fluctuations. This is likely because individuals with SCI typically do not have full voluntary control of lower limbs. Consequently, the utility of their foot support is often considered marginal despite the fact that it has been shown that foot support provides a significant contribution during transfers in individuals with SCI (Gagnon et al., 2008).

We hypothesized that individuals with cervical SCI will have worse sitting balance compared to able-bodied individuals, and that foot support will have a positive impact on postural stability. The objectives of this study were to: 1) compare postural control of individuals with SCI with able-bodied individuals; and 2) investigate the effects of foot support and trunk fluctuations on the postural control of the entire body during quiet sitting balance.

2. Methods

2.1. Participant recruitment

Able-bodied individuals and individuals with SCI were recruited to participate in this study. In order to participate, all participants had to have the ability to maintain unsupported sitting. Individuals were recruited in the able-bodied group if they had no history of neurological impairment or musculoskeletal injury that could affect their sitting balance. Individuals were recruited in the SCI group if they had either motor incomplete or complete, sensory incomplete or complete cervical SCI, and were minimum one year post injury. All participants gave written informed consent in accordance with the Declaration of Helsinki. The experimental procedures used in this study were approved by the local institutional research ethics board.

2.2. Experimental protocol

Participants were seated in upright sitting posture on a height-adjustable chair without back support and with their feet on the ground in all trials. The seating surface and the foot support surface were each instrumented with a force plate (AccuSway^{Plus}, Advanced Mechanical Technology Inc., Watertown, USA). A thin foam cover was placed over the seat surface to prevent risks of skin injury during data collection in both able-bodied and SCI groups. The height of the chair was adjusted such that the knee angle was at approximately 90°. Each participant was asked to keep a steady sitting balance with his or her arms crossed over their chest and with their eyes open, as illustrated in Fig. 1.

2.3. Measurements

Signals were recorded over two 60 s trials using two force plates (Fig. 1). Seat COP: $COP_S(x,y)$ was calculated from the force plate on the seating surface. Foot support COP: $COP_F(x,y)$ was calculated from the force plate on the ground. Global COP: $COP_G(x,y)$ was then computed from $COP_S(x,y)$ and $COP_F(x,y)$ as described in the next section. Moreover, force components measured using the seat

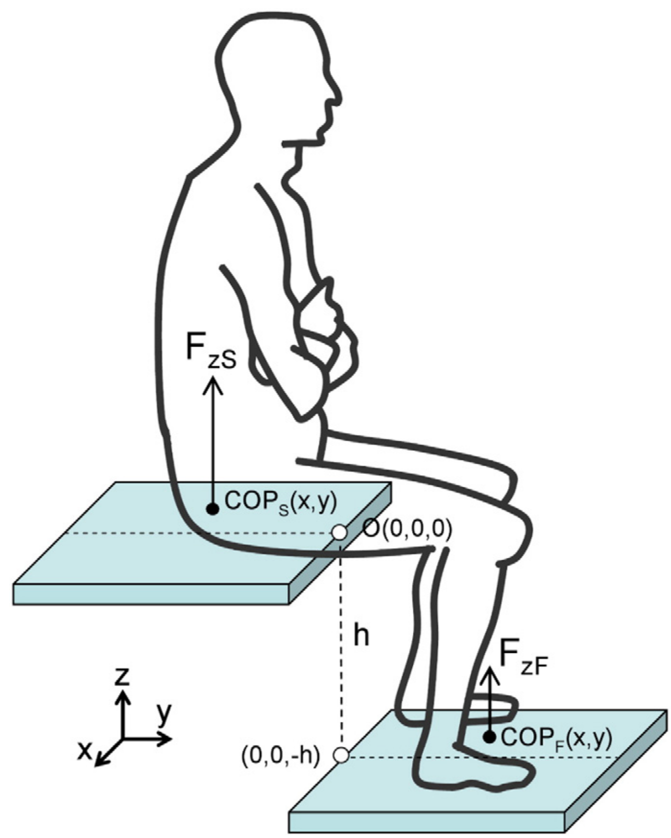

Fig. 1. Experimental setup for sitting balance utilizing two force plates. $COP_S(x,y)$ captured trunk sway on the seat surface and $COP_F(x,y)$ captured foot support sway on the ground. Vertical forces (F_{zS} and F_{zS}) and AP and ML forces (not shown) were also captured. The origin, O(0,0,0), of the global coordinate frame, which was used to calculate global COP was placed in the middle of the force plates, between the seat and foot support surface on the seat surface, where the seat and foot support surface were aligned along the x and y axes and only separated by distance *h* which was the height difference between the seat and foot support surface along the z axis.