Applied Ergonomics 66 (2018) 64–69

Contents lists available at ScienceDirect

Applied Ergonomics

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

Effects of external loads on postural sway during quiet stance in adults aged 20–80 years

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ARTICLE INFO

Article history:
Received 25 January 2017
Received in revised form
28 July 2017
Accepted 7 August 2017
Available online 21 August 2017

Keywords:
Functional balance
External loads
Grocery bags
Postural stability
Age-related changes

ABSTRACT

The purpose of this study was to investigate the effects of holding external loads on postural sway during upright stance across age decades. Sixty-five healthy adults (females, $n = 35$), aged 18–80 years were assessed in four conditions; (1) standing without holding a load, holding a load corresponding to 5% body mass in the (2) left hand, (3) right hand and (4) both hands. The centre of pressure (COP) path length and anteroposterior and mediolateral COP displacement were used to indirectly assess postural sway. External loading elicited reductions in COP measures of postural sway in older age groups only ($P < 0.05$). No changes were observed in younger or intermediate aged adults ($P > 0.05$). Holding external loads during standing is relevant to many activities of daily living (i.e. holding groceries). The reduction in postural sway may suggest this type of loading has a stabilising effect during quiet standing among older adults.

1. Introduction

Postural control in quiet standing is a complex function that involves maintaining the vertical position of the centre of mass (COM) within the base of support (Paillard, 2012). The ability to maintain an upright stance is an essential pre-requisite for gait, initiation of voluntary movement and for activities of daily living (Vuillerme et al., 2002). In order to perform a postural task, the central nervous system must continuously integrate and re-weigh information from different sensory systems (vision, vestibular and somatosensory) and modulate commands to the neuromuscular system (Gurfinkel et al., 1995). The performance of the postural control system can be quantitatively estimated by measuring the ability to minimise postural sway during quiet stance (Paillard and Noé, 2015). By using centre of pressure (COP) measures, it has been shown that postural sway increases when the difficulty of the task increases, for example, by altering the support surface size and shape (Era et al., 2006), decreasing the quality of sensory input (Cornilleau-Pérès et al., 2005), or diminishing neuromuscular control with muscle fatigue (Paillard, 2012).

Postural sway during quiet standing can additionally be affected by external loading (Rosker et al., 2011). Load bearing during standing is an important aspect of many daily and occupational activities (Rugelj and Sevšek, 2011). The existing literature has suggested that holding external loads at or above the COM (e.g. weights positioned at the waist, back or shoulders) alters the mass-inertia characteristics of the body, since the application of the load increased postural sway during quiet standing (Heller et al., 2009; Qu and Nussbaum, 2009; Rugelj and Sevšek, 2011; Schiffman et al., 2006). For example, carrying a backpack elicits a posterior shift in the COM, which is compensated for by forward trunk lean to move the COM anteriorly (Palumbo et al., 2003). The inverted pendulum model states that the stability of a rigid body is inversely related to the height of its COM above the base of support (Winter et al., 1998). Thus, when the position of the COM is elevated (i.e. carrying a backpack), the body has less stability and an increase in postural sway is observed.

Despite the prevalence of holding loads in the hands (i.e., grocery bags), little is known about the extent to which carrying asymmetrical loading affects postural sway parameters. Carrying a load in the hand, such as a grocery bag, could be expected to affect the COM differently to how a backpack would. Indeed, Zultowski & Aruin (2008) reported an increase in mediolateral COP as a result of holding an asymmetrical load (20% body mass) among young individuals. Holding asymmetrical loads may consequently have important implications for older people because mediolateral

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http://dx.doi.org/10.1016/j.apergo.2017.08.007
0003-6870/

aspects of postural sway have predictive value for fall incidence (Era et al., 2006; Maki et al., 1994). More recently, it has been shown that holding a relatively light load in the hand (1.5 and 3.0 kg) did not alter postural sway in young or older females (Bampouras and Dewhurst, 2016). The above study assessed symmetrical load and asymmetrical load in the preferred hand and included only young and older females, limiting the generalisability of their findings to both genders across the entire adult age spectrum. When carrying or holding loads, individuals are likely to interchange between the preferred and non-preferred hand, to offset fatigue effects of prolonged load carriage and to allow the opposite hand to be free for other activities (Wang and Gillette, 2017). From this perspective, it is important to consider postural sway while holding loads with the preferred and non-preferred hand.

Given the limitations in the existing scientific literature, the purpose of this study was to determine the effects of external loads carried symmetrically and asymmetrically (in the preferred and non-preferred hand) on postural sway in males and females aged 20–80 years. Considering that this type of loading comprises an important activity of daily life and is frequently practiced by adults of all ages, examining the effects of holding external loads across the lifespan has clear relevance. We hypothesised that postural sway without holding a load (control condition) would systemically increase from 30 to 80 years (Era et al., 2006). We also hypothesised, that asymmetrical loading would increase postural sway (Zultowski and Aruin, 2008), particularly among older adults (60–80 years).

2. Methods

2.1. Participants

Sixty-five healthy adults (females, $n = 35$) gave their written informed consent to participate in this study. Recruitment continued until a minimum of ten participants were obtained for each decade from 20 to 80 years (Table 1). All participants were healthy with no previous history of neurological, orthopaedic, musculoskeletal and/or cardiovascular, pulmonary or metabolic diseases. All participants could walk without the use of an assistive device and were independently living and engaging in recreational daily activities. The procedures of the study were approved by the ethics committee of Coventry University, and experiments were carried out according to the Declaration or Helsinki (1964).

2.2. Postural sway measures

To examine postural sway each participant performed quiet standing tasks on a force platform (AMTI, AccuGait, Watertown, MA) for 30 s. The force platform was calibrated in accordance with the manufacturer's recommendations. Data were sampled at 100 Hz (AMTI, Netforce, Watertown, MA) and the total displacement of centre of pressure (COP) in the anteroposterior (COP_{AP}) and mediolateral (COP_{ML}) directions, and COP path length (COP_L) (all cm) were subsequently calculated (AMTI, BioAnalysis, Version 2.2, Watertown, MA) and served as measure of postural sway. All forces were filtered with a 4th order low-pass Butterworth filter with a cut off frequency of 6 Hz. To ensure continuity between bipedal trials, unshod foot position was standardised at a distance of 3 cm between the medial extremities of the posterior side of the calcaneus with feet at a self-selected angle. In an attempt to reduce within-session variability a tracing of the participant's feet was made on A3 paper for use in subsequent trials.

Following a single familiarisation trial for each task, participants performed four standing postural tasks: (1) bipedal stance while holding a grocery bag in the right hand, (2) bipedal stance while holding a grocery bag in the left hand, (3) bipedal stance while holding a grocery bag in both hands, (4) bipedal stance without holding bags (CON). All tasks were performed with the eyes open. The order of task conditions were randomly assigned. Randomisation was done using Research Randomizer, a program published on a publicly accessible official website (www.randomizer.org/). A total of three trials were recorded consecutively for each condition and the mean of these trials was used in subsequent analysis. Participants could step off the plate and rest between tests. In order to avoid unnatural postural sway, internal focus of attention and restriction of exploratory behaviour, participants were not asked to stand as still as possible (Lajoie et al., 2016). Instead, participants were asked to minimise movements of the grocery bag (i.e. external focus). Participants' arms were left to hang freely by their sides during unloaded trials. When standing quietly participants were instructed to gaze at a target 1.5 m away, which was adjusted to the eye level of each individual. The load used consisted of circular metal weights of varying dimensions (~12 × 2 cm), held in a reusable grocery bag made from woven synthetic fibres (dimension; 34 cm × 38 cm × 16 cm; volume; 21.89 L). All participants held the same grocery bag. We chose to normalise bag mass to a percentage of total body mass to allow comparisons to be made with previous studies (i.e., Zultowski and Aruin, 2008). Throughout all tests, the investigator stayed close to the participants to prevent falling but without interfering with postural sway.

2.3. Data analysis

Statistical analyses were carried out using SPSS version 20.0 software (IBM Inc., Chicago, IL). For all analyses, normality (Shapiro–Wilk test) and homogeneity of variance/sphericity (Levene test) were performed and confirmed prior to parametric tests. Differences between age groups when holding bags were examined using a two-way (age × condition) repeated measures analysis of variance (ANOVA). Where significant differences were detected, post hoc analyses with Bonferroni-adjusted α were conducted to determine the location of these differences. Cohen's D effect sizes (ES) are reported for post hoc comparisons with an effect size of 0.2, 0.6, 1.2 and 2.0 indicating small, medium, large and very large effects, respectively. Associations between COP outcome measures and anthropometrics (height, mass, BMI) were assessed using

Table 1
Participant demographics for each decade for 20–80 years.

Decade (Years)	Sample (n)	Gender (M/F)	Age (Years) (Range)	Height (cm)	Mass (kg)	Bag Mass (kg)	BMI
20–29	13	5/8	25.5 ± 2.3 (20–28)	170.6 ± 8.7	72.0 ± 14.4	3.6 ± 0.7	24.2 ± 3.4
30–39	10	6/4	33.8 ± 2.7 (33–38)	173.8 ± 4.1	73.6 ± 7.1	3.7 ± 0.4	24.9 ± 2.8
40–49	11	5/6	43.4 ± 2.9 (42–49)	172.4 ± 7.4	72.7 ± 13.0	3.6 ± 0.7	24.3 ± 3.1
50–59	10	5/5	53.0 ± 2.0 (52–56)	170.3 ± 7.6	74.9 ± 6.8	3.7 ± 0.3	27.3 ± 4.8
60–69	10	4/6	63.8 ± 1.9 (62–67)	163.1 ± 7.5	67.1 ± 14.4	3.4 ± 0.7	26.3 ± 5.8
70–80	11	5/6	74.7 ± 4.3 (73–80)	161.8 ± 9.8	73.6 ± 10.5	3.7 ± 0.5	30.6 ± 9.0