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Gait & Posture



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

The effects of muscle strength on center of pressure-based measures of postural sway in obese and heavy athletic individuals

Grant A. Handrigan ^{a,*}, Felix Berrigan ^b, Olivier Hue ^c, Martin Simoneau ^{a,d}, Philippe Corbeil ^{a,d}, Angelo Tremblay ^a, Normand Teasdale ^{a,d}

^a Faculty of Medicine, Kinesiology division, Laval University, Québec, Canada

^b Faculty of Physical Education and Sports, Sherbrooke University, Sherbrooke, Canada

^c Department of Science and Physical Activity, University of Québec at Trois-Rivières, Québec, Canada

^d Vieillissement, Centre de recherche FRSQ du Centre hospitalier affilié universitaire de Québec, Québec, Canada

ARTICLE INFO

Article history: Received 6 October 2010 Received in revised form 25 March 2011 Accepted 10 August 2011

Keywords: Obesity Body mass index Posture Force Athletes Balance control

ABSTRACT

Introduction: Obesity affects postural sway during normal quiet standing; however, the reasons for the increased postural sway are unknown. Improving muscular strength is regarded as a potential way to improve postural control, particularly for obese and overweight subjects. The purpose of this investigation is to evaluate the role of muscular strength on postural sway in obese and overweight individuals.

Methods: Fifteen healthy weight (control group), seventeen obese (obese group) subjects and nine football players (heavy athletic group) participated in this investigation. Isometric knee extension force and postural sway were measured. Muscular strength was calculated in absolute measures as well as relative to body mass (muscular strength to body mass).

Results: The heavy athletic group demonstrated significantly stronger (absolute) lower limb strength (1593.9 N (95% CI 1425.5, 1762.3)) than both the obese (796.2 N (95% CI 673.8, 824.5)) and control (694.1 N (95% CI 563.7, 824.5)) groups. As well, when muscular strength was expressed as a ratio to body mass the heavy athletic group had significantly higher values (1.27 (95% CI 1.11, 1.43)) than obese (0.78 (95% CI 0.66, 0.89) and control (1.00 (95% CI (0.88, 1.12)) individuals. Despite this, they swayed similarly to the obese (mean center of pressure speed of 0.83 cm s⁻¹ (95% CI 0.72, 0.93) vs. 0.87 cm s⁻¹ (95% CI 0.80, 0.95)), that is, significantly more than the controls (0.60 cm s⁻¹ (95% CI 0.52, 0.68)).

Conclusion: Isometric knee extensor strength has a minimal effect on postural sway in heavier athletic individuals during normal quiet stance.

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1. Introduction

Obese persons have a body mass index (BMI) greater than or equal to 30 kg m⁻². These individuals sway more than persons with a lower BMI (<25 kg m⁻²) during normal quiet standing [1– 3] and weight loss has been shown to reduce the magnitude and speed of their postural sway [4]. Why these individuals oscillate more than normal weight individuals remains unknown. For this behaviour, two hypotheses are proposed. The first is a reduced plantar sensitivity from a hyper activation of the plantar mechanoreceptors due to the continuous pressure of supporting a large mass [4]. The second hypothesis is a greater mechanical

* Corresponding author at: Groupe de Recherche en Analyse de Mouvement et Ergonomie Division de kinésiologie Université Laval PEPS, 2300 Rue de la Terrasse Québec, QC, Canada G1K 7P4. Tel.: +1 418 656 2131x4920; fax: +1 418 656 2441. *E-mail address:* grant-a.handrigan.1@ulaval.ca (G.A. Handrigan).

0966-6362/\$ - see front matter © 2011 Elsevier B.V. All rights reserved. doi:10.1016/j.gaitpost.2011.08.012

demand due to a whole body center of mass further away from the axis of rotation (i.e., ankle joint assuming an inverted pendulum model) that causes a greater gravitational torque. Consequently, to maintain upright stance, this gravitational torque that accelerates the body must be countered by a large muscular torque [5,6]. The physiological basis for this explanation is that individuals who are heavier have less strength relative to body mass [7] and subsequently have a reduced capacity to control postural sways. Generally, a minimal muscular activity is necessary for balance control during quiet standing [8]. However, a larger force, and rate of development, is necessary when dealing with larger body masses, such as in overweight and heavier individuals when recovering from forward destabilisations [9,10]. We have demonstrated the limited effect of reduced muscular strength proportional to body mass elsewhere on postural sway [5]. We are now interested in the effect of an increased muscular strength proportional to body mass on postural sway.



Experimentally separating the contributions of body mass and muscular strength on postural sway is difficult [9], in general, larger individuals have greater muscle mass and are stronger, and smaller individuals have less muscular mass and are less strong. Comparisons between groups that have a similar mass but different strength levels are a method to single out the potential confounding roles or contributions of muscular strength on postural sway in overweight persons.

Therefore, the objective of this study was to examine the effect that an increased amount of muscular strength has on postural sway in heavy athletic individuals. We reasoned that if lower limb muscular strength is crucial, heavy athletic individuals that demonstrate greater strength (absolute and relative) would oscillate less than sedentary obese individuals.

2. Methods

2.1. Subject characteristics

In this cross-sectional study the subjects included three groups of Caucasian male adults: control, obese and heavy athletic (see Table 1 for anthropometric characteristics). Individuals in the control group (BMI between 20 and 25 kg m⁻²) and the obese group reported no regular participation in physical activity. The heavy athletic group were football linemen and reported via a questionnaire regular participation in six weekly training sessions; three cardiovascular and three-resistance training. Postural sway and muscular strength were measured for the control, obese and heavy athletic groups. All participants gave their written informed consent to participate in this study, which was approved by the local IRB.

2.2. Lower limb maximum strength protocol

While seated comfortably in an experimental chair the subjects performed isometric right quadriceps contraction with the hip angle fixed at 100° and knee angle set at 90° of flexion. Isometric quadriceps extension was selected as representative of total lower body strength. A padded cuff (15-cm wide) was secured above the ankle malleolus on the dominant leg and attached to a load cell (Inter-Technology model 9363-DI-500) fixed to the chair. The subjects held a rigid armchair and were asked to maintain their back and their buttock in contact with the chair. Moreover, they were verbally directed to produce their maximal strength and strongly encouraged to maintain this force level for about 3 s. For this measure, three trials were performed with a 1-min rest between trials. The strength signal was amplified and conditioned (Ectron model 563H, Intertechnology, Toronto, Canada) before digitizing at 500 Hz (12-bit A/D conversion). All data were imported into the Matlab environment for analysis. The strength signal was filtered with a dual-pass Butterworth low-pass fourth order filter with a 10-Hz cut-off frequency. All strength time series were automatically marked (custom software) and visually inspected to identify maximal peak strength. The mean of the three trials was taken. The relative strength measure (ratio of maximal strength to body mass) was also considered.

2.3. Postural sway protocol

Postural sway was evaluated with a force platform (AMTI Model OR-6). Subjects stood barefoot on the platform with their feet 10 cm apart. Subjects were asked to stand as still as possible with arms alongside their body while fixing a reference point located at eye level (5 m in front of them). They performed four trials with vision and four trials without vision (eves closed). Visual conditions were randomly presented. Subjects were able to rest midway through the experiment. An assistant was present for each session to ensure that procedures were adequately followed and that foot position was constant across all trials and subjects. Anterior-posterior and medio-lateral coordinates of the center of pressure (CoP) were determined from the ground reaction force and moments recorded at 200 Hz (12-bit A/D conversion). Prior to computing the CoP displacement, the moments and force data were digitally filtered (Butterworth fourth-order, 7 Hz low-pass cut-off frequency with dual-pass to remove phase shift). Mean CoP speed, the cumulative distance over the sampling period and the anterior-posterior and medio-lateral range values were used to evaluate the ability of the participants to control their balance. All trials within each condition lasted 30 s and the averages of the four trials were used for data analysis. Postural data for some subjects from both the control and the obese group have been published elsewhere [1,6].

2.4. Statistical analysis

Lower limb maximum strength comparisons between the three groups (control, obese and heavy athletic) were performed using the Analysis of Variance test

Table 1

Subject characteristics (mean \pm SD).

Characteristic	Control group (<i>n</i> =15)	ontrol groupObese group $n = 15$) $(n = 17)$	
Age (years)	$\textbf{38.5} \pm \textbf{9.7}$	$\textbf{36.9}\pm\textbf{7.7}$	$23.4 \pm 1.3^{*}$
Height (cm)	176.9 ± 5.8	176.1 ± 6.7	189.9 ± 4.4
Weight (kg)	$\textbf{70.5} \pm \textbf{7.8}$	$106.1 \pm 19.6^{\circ}$	$127.2 \pm 12.4^{*}$
BMI (kg m $^{-2}$)	$\textbf{22.5} \pm \textbf{2.2}^{*}$	$\textbf{34.0} \pm \textbf{4.7}$	$\textbf{35.3}\pm\textbf{3.1}$

* Significant difference between the other groups (p < 0.01).

(ANOVA). Postural sway measures were analyzed with a Group (three groups) × Vision (vision/no vision) design with repeated measures on the last factor. All results were considered to be significant at the 5% critical level (p < 0.05). Statistica Software 7.1 (Statsoft, Inc., Tulsa, OK) was used for all analyses. A priori planned comparisons were performed using orthogonal contrasts.

3. Results

3.1. Anthropometrics

In terms of age and height and mass, the heavy athletic group were significantly younger (F(2,38) = 11.99, p < 0.001) and taller (F(2,38) = 17.89, p < 0.001) and heavier F(2, 38) = 46.45, p < 0.001) than both other groups of subjects. However, in terms of BMI, the control group has a lower BMI and is significantly different (F(2,38) = 52.21, p < 0.0001) from the heavy athletic and obese. There were no differences between obese and heavy athletic (F(1,38) = 0.71, p = 0.402) for the measure of BMI.

3.2. Lower limb absolute force

As one would expect, in terms of maximum force, the heavy athletic group was significantly stronger than both the obese group and the control group (F(2,38) = 40.98, p < 0.001). A priori planned comparisons indicate that the heavy athletic group was significantly stronger than the obese (F(1,38) = 60.10, p < 0.001) with a mean value of 1593.9 N (\pm 95% CI 1425.5, 1762.3) vs. 796.2 N (\pm 95% CI 673.8, 824.5). As well, the heavy athletic group was significantly stronger than the control group (F(1,38) = 73.13, p < 0.001) with a mean value of 694.1 N (\pm 95% CI 563.7, 824.5) (see Table 2 for actual values). No significant difference existed between the obese and the control group (F(1,38) = 1.34, p = 0.255).

3.3. Lower limb relative force

In terms of lower limb relative force, the heavy athletic group was significantly stronger than both the obese group and the control group (F(2,38) = 13.34, p < 0.001). A priori planned comparisons indicate that the heavy athletic group had a greater force to mass ratio (approximately 68%) than the obese (F(1,38) = 26.13, p < 0.001). The heavy athletic group was also significantly stronger than the control group (F(1,38) = 7.27, p < 0.01) with a force to mass ratio approximately 27% greater (see Table 2 for actual values). The obese group was approximately 22% relatively weaker than the control group (F(1,38) = 7.51, p < 0.01).

Table 2		
Absolute strength and relative strength for all three groups (mean,	$\pm 95\%$ C	I).

Group	Absolute strength $(N \ (\pm 95\% \ \text{Cl}))$	Relative strength (<i>N</i> /kg)
Control $(n = 15)$ Obese $(n = 17)$	694.1 (563.7, 824.5) 796.2 (673.8, 824.5)	1.00 (0.85,1.16) 0.78 (0.70, 0.85)
Heavy athletic (n=9)	1593.9 (1425.5, 1762.3)	1.27 (1.05, 1.5



Fig. 1. Vision and no vision center of pressure speed (cm s⁻¹) for all three groups.

3.4. Postural sway measures

The heavy athletic group swayed as fast as the obese group, both swaying more quickly than the control group (Fig. 1). For the CoP speed a significant interaction effect was present between vision and group (F(2,38) = 3.81, p = 0.031). Planned comparisons indicate that the control group CoP speed was significantly slower than the heavy athletic group (F(1,38) = 4.15, p < 0.05) and the heavy athletic group swayed as fast as the obese group (F(1,38) = 0.016, p = 0.89).

Anterior–posterior range values showed a Group effect (F(2,38) = 12.41, p < 0.001) and a priori planned comparisons indicated that the control group swayed within a smaller range than the heavy athletic group (F(1,38) = 18.18, p < 0.001) and the heavy athletic group swayed as much as the obese group (F(1,38) = 0.56, p = 0.46). Medio-lateral range values showed a group effect (F(2,38) = 4.17, p < 0.05) and a priori planned comparisons indicated that the control group swayed within a smaller range than the heavy athletic group (F(1,38) = 0.56), p < 0.05) and the heavy athletic group swayed within a smaller range than the heavy athletic group (F(1,38) = 5.9, p < 0.05) and the heavy athletic group swayed within a similar range as the obese group (F(1,38) = 0.12, p = 0.73). For actual range values (vision condition, mean \pm SD and \pm 95% confidence intervals) (see Table 3).

4. Discussion

Our study used a heavy athletic group and an obese group that had similar BMI values, but different strength levels and training habits. This allows the experimental examination of strength contributions to reducing postural sway. Our results indicate that despite the heavy athletic group having a significantly stronger lower limb muscular strength capacity (absolute and relative strength); they swayed similarly to the obese sedentary group and more than the control group. These results suggest the increased sway observed in obese and heavier individuals is not related to a lower relative muscular strength compared to healthy mass individuals. Furthermore, these results revealed that removing vision increased the postural sway speed of the obese and heavy athletic groups to a greater extent than controls.

Other research in this area has concluded that mass is a primary factor that affects postural sway in heavier individuals [4,11,12]. Our results reinforce that muscular strength is of less importance for postural sway than body mass in heavy (BMI \geq 30 kg m⁻²) individuals. Some related modeling and experimental work suggest that muscular strength and its rate of development are thought to become more important in balance situations that are challenging [9,10,12–15]. As it is, here we have tested the contribution in tasks that are less demanding, but important

Table 3

Medio-lateral and anterior–posterior (vision condition) range values for all three groups (mean, $\pm 95\%$ CI, $\pm SD$).

Group	ML range (cm)		AP range (cm)			
	Mean	±95% CI	SD	Mean	±95% CI	SD
Control Heavy Athletic Obese	0.76 1.11 1.11	(0.60,0.91) (0.77,1.45) (0.90,1.32)	0.28 0.44 0.41	1.42 2.34 2.2	(1.22,1.62) (2.00,2.68) (1.91,2.49)	0.36 0.44 0.56

and interesting in light of emphasis placed on muscular strength training as a measure to improve balance control [16]. It appears that the role of muscular strength in balance recovery situations could be different than during normal quiet standing [9].

We feel that it is necessary to clarify that muscular strength is not the only factor important in guiet postural sway; there are also significant coordinated contributions from the vestibular, proprioceptive and plantar sole mechanoreceptors, none of which are evaluated here. While we assume that the visual and vestibular senses are similar between our three groups of subjects, it may be possible that plantar mechanoreceptor sensitivities differ. It has been suggested that because of a body mass surplus in heavier individuals, these individuals might have a reduced plantar sensitivity due to the hyper activation of the plantar mechanoreceptors [4]. When removing vision, the greater increase in postural sway speed for obese and heavy athletic groups compared to controls may indirectly support this suggestion. According to the idea that balance control results from active feedback-control mechanisms [17], in the absence of vision the brain must rely on the remaining sensory inputs to generate a corrective torque to counter the gravitational torque and reduce postural sway. In such circumstances, alterations of visual cues cause transient increases in postural sway which is attributed to a reduced ability to reconfigure the postural position using the other sensory modalities [18-20].

Our statistical analyses reveal that some of the anthropometric characteristics do indeed differ between groups. Our athletic group are taller and heavier than the obese and control groups. Despite these differences, the BMI values for the obese group and the heavy athletic group are similar and this is what our analysis is based on. We recognize that some parameters quantifying the amount of postural sway depend on height [21]. However, in our data a multiple stepwise forward regression analysis (mass $r^2 = 26\%$, height $r^2 = 6\%$ and age $r^2 = 2\%$) and an analysis of covariance (ANCOVA) failed to significantly identify height as a factor for our tested subjects. In addition, the heavy athletic group is also younger than the other two groups; however, previous research demonstrates through a multiple regression model the limited role that age has on measures of balance control in these subjects [4], adding only 3% to the variance of the CoP speed for subjects aged 24-61 years of age. This age related effect is supported elsewhere [22-24].

It must be noted that there are some limitations and assumptions with the conclusions of this cross-sectional study. For instance, we did not measure adipose distribution in our subjects. It is possible that the mass distribution is different in obese and heavy athletic groups, for example, in the sedentary population we would expect a larger concentration of adiposity on the abdomen, while in the athletic group we would expect a greater distribution of the mass (muscular and adipose) over the entire body [6]. It remains, however, that despite this possibility the heavy athletic group swayed similarly to the obese group. A second limitation is that we used BMI as a measure of similar anthropometrics between the heavy athletic group and the obese group. It is often suggested that BMI is an inappropriate measure for body mass in athletes because of differences in body composition [25], for this reason some may suggest it is incorrect to compare these two groups. We note that our heavy athletic group had average BMI values of 35.3 kg m^{-2} , these are similar to research reported elsewhere that determined an 'optimal' BMI cut point of 34.1 kg m^{-2} for classifying obesity in football athletes [25].

In summary, our results suggest that muscular strength has a minimal relationship with postural sway in obese and heavy athletic individuals during normal quiet standing.

Acknowledgments

The authors would like to thank all subjects for graciously donating their time. Special thanks to Marcel Kaszap for his programming expertise. This study was supported by a Collaborative Health Research Project (CHRP) of NSERC, NSERC Discovery grants of Canada and a FQRNT team grant (NT, AT, MS and PC).

Conflict of interest

The authors state that there are no conflicts of interest with this work.

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