Sensory integration and response to balance perturbation in overweight physically active individuals

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Abstract

The purpose of this study was to compare sensory integration and response to balance perturbation between physically active normal weight and overweight adults. Physically active young adults were grouped into normal weight (N=45) or overweight (N=17) according to the WHO body mass index classification for Asian adults. Participants underwent two balance tests: sensory organization and motor control. Overweight participants presented marginally lower somatosensory score compared to normal weight participants. However, they scored significantly higher in response to balance perturbation. There was no difference in the onset of participants' active response to balance perturbation. Physical activity might have contributed to improved muscle strength and improved the ability of overweight individuals to maintain balance.

Introduction

There is large amount of evidence supporting the association between obesity and several conditions such as: type II diabetes, cardiovascular disease, cancer, osteoarthritis, and musculoskeletal disorders (Visscher & Seidell, 2001). It is also known that obesity is associated with postural deficits (Greve, Alonso, Bordini, & Camanho, 2007), which can impact gait and daily living (Capodaglio et al., 2010), as well as increase the risk of falling (Fjeldstad, Fjeldstad, Acree, Nickel, & Gardner, 2008). Body weight can contribute to more than 50% of the variance in balance stability (i.e., measured by the mean speed of the center of pressure), even when this variable is controlled by age, body height, and foot length (Hue et al., 2007).

Few studies have focused on the effect of weight loss and balance (Handrigan et al., 2010; Sartorio, Lafortuna, Conte, Faglia, & Narici, 2001; Teasdale et al., 2007). Balance control measured by the centre of pressure speed was directly associated with the amount of weight loss (Teasdale et al., 2007). Likewise, weight loss was associated with improvement in balance control despite a decrease in absolute muscle strength (Handrigan et al., 2010). Finally, improvement in the ability to stand on one leg was observed after obese individuals took part in a weight loss programme that consisted of diet and physical activity (Sartorio et al., 2001). However, in the absence of a control group it is difficult to establish if the improvement observed was due to weight loss or because of physical activity.

It has been suggested that body weight may not be the only cause for postural instability in overweight and obese individuals and impairment in sensory-motor control might also play a role (Colne, Frelut, Peres, & Thoumie, 2008). A study that investigated the effect of sensory information on balance maintenance reported that overweight children have lower plantar cutaneous sensation compared with normal weight individuals, but no difference in the postural sway between groups was observed (D'Hondt et al., 2011).

It is also known that exercise has a profound impact on balance improvement and reducing the risk of fall (Arnold, Sran, & Harrison, 2008; Granacher, Muehlbauer, Zahner, Gollhofer, & Kressig, 2011). However, to the best of our knowledge, sensory integration and response to balance perturbation has not been studied in physically active overweight individuals.

The use of computerized dynamic posturography has recently been used to access ground reaction forces from which the centre of pressure and centre of gravity sway angles can be calculated (Chaudhry, Bukiet, Ji, & Findley, 2011). EquiTest (version 4.04, NeuroCom International, Clackamas, OR) measures the sway under different conditions and can potentially distinguish between different causes of postural dysfunction such as vestibular, proprioceptive, and visual. Such equipment also measures participants' ability to respond to unexpected external perturbation. To the best of our knowledge this method has never been used to compare overweight and normal weight participants. Furthermore, whether individuals who are physically active can compensate for some of the negative effects that excessive body weight has on balance is still unknown. Therefore, the aim of this study is to compare sensory integration and response to balance perturbation in overweight and normal weight physically active participants.

Methods

Study design and participants

This is a case control study in which participants were allocated to normal weight and overweight groups. Young adults aged 17-23 years old were recruited from a Sports Science program from a University in Hong Kong. Participant's body mass index (BMI) derived from body weight and height measurement were used as an indicator for group classification. Since here is a population difference on BMI, percentage of body fat and body fat distribution for

Asian populations the World Health Organization (WHO Expert Consultation, 2004) recommended the following BMI categories: <18.5 kg/m^2 (underweight) ; 18.5-23 kg/m^2 (increasing but acceptable risk); 23-27.5 kg/m^2 (increased risk) ; and >27.5 kg/m^2 (high risk). In this study,23 kg/m^2 was used as the cutoff point for the Asian population overweight classification.

Ethical approval was obtained from the Human Research Ethics Committee (HREC) at the Hong Kong Institute of Education (study protocol number 2012-2013-0166). This study was conducted according to the principles expressed in the Declaration of Helsinki. All participants received an information sheet and signed an informed consent form prior to their participation.

Participants completed a Physical Activity Readiness Questionnaire (PAR-Q) for screening of cardiac or other health-related problems. Participants who answered “yes” to any of the PAR-Q questions or presented any type of lower limb injury were considered ineligible to participate in this study.

Participants were also asked to specify their participation in exercise by answering the following question: “Do you take part in moderate intensity exercise at least three times per week for a minimum of 30 minutes?”. In this context, it was explained to participants that moderate activity was any sports and exercise related activity that noticeably accelerates the heart rate. The cut-off time of 30 min of physical activity and 3 times per week was based on the recommendation provided in the Participation Patterns of Hong Kong People in Physical Activities, 2009 (Community Sports Committee of the Sports Commission, 2009). Participants had to select one of the following options: (A) Yes, I take part in moderate exercise for six months or more; (B) Yes, I take part in moderate exercise but for less than six months; C. No, but I plan to participate exercise in next 30 days; (D) No, but I plan to participate exercise in the next six months; and (E) No, I have no intention to participate exercise. Participants who answered “A” or “B” were considered physically active, whereas those who answered other options were considered physically inactive and ineligible for the study. Participants were also asked if they are current members of a sports team to indicate their exposure to physical activity.

Procedure

Participants had their body weight and height measured (FTS-A, DPS-Promatic® Srl, Italy). A static and dynamic balance test was performed using computerized dynamic posturography equipment (SMART Equitest, NeuroCom, Clackamas, RR, USA). Participants wore a safety harness during the test and safety straps were attached to the safety bar with the correct tension as a safety precaution. The SMART Equitest utilizes a dynamic force plate with rotation and translation capabilities to quantify the vertical forces exerted through the participant’s feet (Chaudhry et al., 2011). This platform can measure force in an antero-posterior direction and has been previously validated (Monsell, Furman, Herdman, Konrad, & Shepard, 1997). Two test protocols were applied: Sensory organization test and the Motor control test.

A. Sensory organization test

The Sensory Organization Test (SOT) assesses the contribution of different sensory inputs in posture maintenance (Neurocom International Inc, 2002).

The protocol adopted the following six conditions: (1) eyes open and platform fixed; (2) eyes closed and platform fixed; (3) eyes open, sway-referenced vision, and platform fixed; (4) eyes open and sway-referenced platform; (5) eyes closed and sway-referenced platform; and (6) eyes open, sway-referenced vision, and sway-referenced platform. The test contained three trials per each condition and each trial lasted 20 seconds. The test provided information on the equilibrium score, which measures the amount of sway in the anterior-posterior direction. The mean score was calculated for each condition. The sensory ratio was calculated on basis of the mean equilibrium scores on specific pairs of sensory test conditions as explained in Table 1.

<Insert Table 1>

After the SOT test, participants took a one-minute rest and started the motor control test.

B. *Motor control test*

The Motor Control Test (MCT) assessed the ability of participant's automatic motor responses to unexpected external perturbation (Neurocom International Inc, 2002). The platform moved in two directions (i.e., backward and forward) at three translations (i.e., small, medium, and large). The parameters used for analysis included: (1) amplitude scaling (degrees/ seconds), which quantifies the response strength by measuring the angular momentum from both legs imparted by an active force response to stop the induced sway and move back to equilibrium (this measurement is based on the rate at which the position of the vertical force changes just after the onset of an active force response); (2) weight symmetry quantifies the relative distribution of weight on each leg; a symmetry score of 100 indicates a perfect symmetry between both limbs, whereas values over or below 100 represent more body weight carried over the left or right legs, respectively; and (3) latency (milliseconds), is defined as the time between translation (stimulus) onset and onset of a participant's active response to the induced sway. The latency score is the mean of the individual score for the two legs displayed for the medium and large translations.

Data analysis

All data collected were analyzed using the Statistical Package for Social Sciences version 18.0. The mean and standard deviations were calculated between different groups (i.e., normal weight and overweight) using 23 kg/m^2 as the cutoff point, in accordance with the WHO classification for Asian populations (WHO Expert Consultation, 2004). A comparison of sensory integration (SOT) and postural control (MCT) between the normal and overweight groups was performed using one-way analysis of variance (ANOVA.) The statistical significance was set at $p \leq 0.05$. To measure the magnitude of a treatment effect, the effect size was reported when statistical differences were observed. Effect sizes were calculated using the Cohen's standard method (d) to assess the practical significance of the results (Cohen, 1988). The effect size was calculated using the difference between two group means and divided by the polled standard deviation (i.e., square root of the mean of the squared standard deviations). Effect sizes of 0.2 to 0.5 were considered small, 0.51 to 0.8 were considered moderate, and over 0.8 were considered large.

Results

A total of 62 young adults participated in this study; 45 participants (72.6%) were classified as normal weight, whereas 17 participants (27.4%) were classified as overweight using the cutoff point for Asian populations (≥ 23 kg/ m^2). The participants' characteristics are depicted in Table 2.

<Insert Table 2>

Normal weight participants scored significantly higher (medium effect size) than the overweight participants on the somatosensory score (Table 3). No other statistical differences were observed for the other parameters (i.e., visual ratio, vestibular ratio, and preference).

<Insert Table 3>

The MCT results are shown in Table 4. Overweight participants scored significantly higher in the response strength (i.e., amplitude scaling) for the left leg in the two directions (i.e., backward and forward) and three translations (i.e., small, medium, and large). They also scored significantly higher for the right leg for the backward direction and large translation and right leg forward for the three translations (i.e., small, medium, and large). No significant differences were observed between groups in weight symmetry and time between the stimulus and active response (i.e., latency score).

<Insert Table 4>

Discussion

This study is the first to investigate sensory integration and response to balance perturbation using computerized dynamic posturography in physically active overweight individuals.

Physically active overweight participants presented a slightly lower score in the somatosensory ratio compared with normal weight participants. Nevertheless, overweight participants showed higher amplitude scaling for the left and right legs in most sequences of platform translations and directions, indicating higher angular momentum in this group compared with the normal weight group. No differences in weight symmetry and latency score were observed between the two groups.

The results of this study show a marginally lower somatosensory score in overweight participants compared with normal weight (normal weight: 0.99 ± 0.01 vs. overweight: 0.98 ± 0.02, $p = 0.04$). Although the mean difference was relatively small, this represents a moderate effect size of 0.63. Cutaneous and load receptor inputs are critical to maintaining dynamic balance (van Deursen & Simoneau, 1999). Therefore, a higher body weight can impair mechanoreceptors in muscles that could explain the slightly lower somatosensory score observed in this study. In a recent study (D'Hondt et al., 2011), overweight children presented lower plantar cutaneous sensation than normal weight children. The authors suggested that excessive body weight might decrease the quality of sensory information provided by mechanoreceptors on the foot, which can contribute to postural instability;

however, no differences in the postural sway were observed between the two groups. In comparison, another study (Menegoni et al., 2011) did not observe differences in the Romberg quotient (i.e., ratio between body sway values recorded in visual and non-visual conditions) between overweight and normal weight participants during quiet stance, which indicates no sensory impairment. However, their study found that obese individuals presented higher centre of pressure displacement than the normal weight group. This result contrasts with our findings, in which similar onset responses to unexpected postural perturbation (latency) were observed in physically active overweight participants using computerized dynamic posturography (Table 4).

The similar onset responses to unexpected postural perturbation might be associated with the significantly higher response strength (i.e., amplitude scaling) of the overweight group compared to the normal weight group for most platform sequences. Amplitude scaling measures the angular momentum (i.e., normalized to body height and weight) necessary to counteract the sway for both legs and three translation sizes. It is known that obese adults have higher absolute muscle strength and power of the lower limb than normal weight adults (Xu, Mirka, & Hsiang, 2008). However, muscle strength from obese individuals is lower when results are normalized to body weight (Capodaglio et al., 2010). This might be related to an unfavorable utilization of the muscle force-velocity relationship to generate power (Lafortuna, Maffiuletti, Agosti, & Sartorio, 2005). It has been shown that obese participants are less capable of recovering balance when perturbations involve an initial angular velocity compared with normal weight individuals (Matrangola & Madigan, 2011).

Exercise can also improve muscle strength and balance (Granacher et al., 2011). A recent study found that movement speed during a motor control behavior task is slower in inactive obese individuals compared with active ones (Mignardot, Olivier, Promayon, & Nougier, 2013). The fact that overweight participants were physically active in our study might have enhanced their muscle function and strength, and consequently their response strength, enabling them to maintain a similar latency response to unexpected external perturbation.

Previous research has indicated that weight loss might be more important than strength training to improve balance (Matrangola & Madigan, 2009). However, our study found that the ratio between strength and balance was higher in the overweight group, and balance control was similar between the groups. These results indicate that muscle strength could have overcome the dangers associated with being overweight and having impaired balance.

The results from amplitude scaling appeared to be consistently better for the left leg (six out of the six conditions) than the right leg (four out of the six conditions) in the overweight group compared with the normal weight group. The reason for this result is unclear because both groups present good symmetry between both legs (i.e., symmetry score values close to 100) and similar weight symmetry between groups (Table 4). As far as we know, only one study has looked to symmetry in obese individuals and found that obese children display higher asymmetry in gait, particularly when walking was beyond the normal walking pace (Hills & Parker, 1992).

Although previous studies have explored the association between overweight, obesity, and balance, our study is the first to investigate sensory integration and response to balance perturbation among physically active overweight individuals. However, the present study has some limitations, including a higher proportion of males in the overweight group (88%) compared with the normal weight group (55%). Previous study has indicated that gender does not affect anterior posterior instability, but is associated with increased mediolateral instability in males (Menegoni et al., 2009). This scenario can be related to different fat distribution in genders because the fat mass among males is usually concentrated in the thorax-abdominal region, which could account for increased medial lateral instability. The computerized dynamic posturography EquiTest only measures force in the antero-posterior direction, therefore this might have not affected the results. It is also important to note that participants from the overweight group were not severely overweight as only 1 out of the 17 participants had a BMI above 27.5 kg/m^2 (i.e., high risk for cardiovascular disease), whereas the other 16 participants had BMI between 23 and 27.5 kg/m^2 (i.e., low risk for cardiovascular disease) (WHO Expert Consultation, 2004).

This study attempted to improve the understanding of sensory integration and dynamic postural control in physically active overweight individuals. The results suggest that overweight individuals present a slightly lower somatosensory response to dynamic balance than overweight individuals. However, a similar response to unexpected postural perturbation and higher angular momentum was observed on overweight individuals. This might indicate the importance of physical activity in improving balance in overweight individuals.

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TABLE 1. Sensory analysis based on average equilibrium score from each condition

Sensory ratio	**Computation**	**Functional relevance**
Somatosensory ratio :	ES of Condition 2/ ES of Condition 1	Ability to use input from the somatosensory system to maintain balance
Visual ratio :	ES of Condition 4/ ES of Condition 1	Ability to use input from the visual system to maintain balance
Vestibular ratio :	ES of Condition 5/ ES of Condition 1	Ability to use input from the vestibular system to maintain balance
Preference	ES of Condition 3/ ES of Condition 6	Degree to which patient relies on visual information to maintain balance

Abbreviation: ES: Average of three trial equilibrium score

TABLE 2. Participants' characteristics according to BMI group: mean ± SD (n=62)

Variables	**Normal weight Group (n=45)**	**Overweight Group (n=17)**
Age	19.4 ± 1.44	19.10 ± 1.41
Gender	25 males and 20 females	15 males and 2 females
Body Height (cm)	169.3 ± 8.43	174.8 ± 8.28
Body Weight (kg)	58.6 ± 7.05	73.9 ± 8.65
Body Mass Index (kg/m^2)	20.4 ± 1.19	24.1 ± 1.49
Sports team member	28 ± 62.2%	9 ± 52.9%

TABLE 3. Comparison of balance control under different sensory conditions in normal weight and overweight participants: mean ± SD.

	Normal weight	Overweight	*P* Value	Effect Size
Somatosensory ratio	0.99 ± 0.01	0.98 ± 0.02	.04	0.63
Visual ratio	0.93 ± 0.04	0.91 ± 0.04	.44	0.50
Vestibular ratio	0.74 ± 0.12	0.76 ± 0.11	.42	-0.17
Preference	1.00 ± 0.08	0.99 ± 0.05	.85	0.15

TABLE 4. Comparison of amplitude scaling (degrees/second), weight symmetry and latency (milliseconds) of the motion control test for normal weight and overweight participants: mean ± SD.

Amplitude Scaling (degrees/second)						
			Normal Weight Group	Overweight Group	*P* Value	Effect Size
Left Leg	Backward	Small	2.56 ± 1.37	3.53 ± 1.74	.02	0.62
		Medium	4.80 ± 1.94	6.47 ± 2.55	<0.01	0.74
		Large	7.02 ± 2.51	9.71 ± 3.30	<0.01	0.92
	Forward	Small	2.09 ± 1.30	3.24 ± 1.35	<0.01	0.92
		Medium	4.30 ± 1.82	5.76 ± 1.86	<0.01	0.79
		Large	5.95 ± 2.20	7.82 ± 2.10	<0.01	0.87
Right Leg	Backward	Small	2.80 ± 1.25	3.06 ± 1.20	.47	0.21
		Medium	4.82 ± 2.18	5.71 ± 2.11	.16	0.41
		Large	6.95 ± 2.32	8.76 ± 2.57	.01	0.74
	Forward	Small	2.27 ± 1.13	3.18 ± 1.51	.01	0.68
		Medium	4.45 ± 1.81	5.53 ± 1.81	.04	0.60
		Large	6.16 ± 2.24	7.65 ± 2.69	.03	0.60
Weight Symmetry						
	Backward	Small	100.56 ± 3.6	99.35 ± 2.74	.22	0.38
		Medium	100.13 ± 3.32	100.06 ± 3.09	.94	0.02
		Large	100.30 ± 3.45	99.29 ± 3.18	.31	0.30
	Forward	Small	100.41 ± 3.20	100.88 ± 3.16	.61	0.15
		Medium	100.20 ± 3.70	99.94 ± 3.15	.80	0.08
		Large	100.32 ± 3.22	100.76 ± 3.72	.64	0.13
Latency (milliseconds)						
			130.97 ± 9.13	131.08 ± 7.91	.97	0.01