Biomechanical evaluation of the relationship between postural control and body mass index

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1. Introduction

Postural balance is fundamental in allowing us to perform tasks and maintain our daily life. Balance can be defined as the ability to return the center of mass (CoM) within the base of support (BoS) in order to maintain body equilibrium against perturbation (Alexandrov et al., 2005). In the recent years, obesity has rapidly become a global problem and the number of obese individuals is gradually increasing every year throughout the world. If there is a relationship between the weight of individuals and their ability to balance, this could have severe implications, as poor balance is considered to be one of the major risk factors for the occurrence of falls that could lead to severe injury or death.

Individuals’ postural control involves a complex system that allows them to maintain balance during quiet standing. The information that is required in order to sustain balance is secured from the physiological system which includes vestibular, proprioception and visual systems (Karimi et al., 2008). Additionally, there are six conditions that affect an individual’s ability to maintain balance and postural control. These are biomechanical task constraint, movement strategies, orientation in space, controls of dynamics, sensory strategies and cognitive processing (Salsabili et al., 2011). Shumway-Cook and Woollacott (2007) described that there is a small amount of spontaneous postural sway in quiet standing. Aside from that, researchers have found that response of the multiple body segments may affect the postural control (Hodges et al., 2002). During the balance against perturbation in quiet standing, ankle, hip and stepping strategies were used as the movement patterns that recover stability by regulating the CoM in the sagittal plane. When there is a small perturbation, the line of gravity falls slightly in front of the knee, and ankle strategy is applied by activating the gastrocnemius which produces plantar flexion torque against the forward motion of the body. Hamstring and paraspinal muscle that may affect the proximal body segment were activated to maintain hip and knee while the iliopsoas prevents hypertensions of the hips. The activation of the thoracic erector muscle helps the trunk to move in the backward direction (Horak and Nashner, 1986; Nashner, 1976; Shumway-Cook and Woollacott, 2007). If the perturbation to equilibrium in forward direction is large, abdominals and quadriceps will be activated and as a result the body...
shifts in the backward direction. This is known as the hip strategy where it restores the larger displacement of CoM in response to larger and faster perturbation (Horak and Nashner, 1986; Salsabili et al., 2011). For the stepping strategy, changes of BoS may help in equilibrium recovery since the ankle and hip strategies are insufficient to regulate the displacement of CoM against the perturbations (Brown et al., 1999). According to Abe et al. (2010), the acceleration of CoM in medial–lateral direction is a more plausible determinant that was induced by the musculo-skeletal system. Nevertheless, Granacher and Gollhofer (2011) suggested that no significant interaction occurs between the variables postural control and muscle strength, but, significant interaction has been observed between variables isometric and dynamic muscle strength.

Body mass index (BMI) is a commonly-used index of relative weight (Keys et al., 1972). BMI is defined as body weight divided by the square of body height. The World Health Organization categorizes BMI into four classifications: underweight (< 18.50 kg/m²), normal weight (18.50–24.99 kg/m²), overweight (25.00–29.99 kg/m²) and obese (> 30 kg/m²). Obesity is generally acknowledged as an excess of body mass and body adipose tissue distribution that could increase the health risk and decrease occupational and recreational comfort as a result of injuries such as sprains, strains and dislocations (Matter et al., 2007). Poor postural performance and reduced motor activity were shown to be most prevalent among obese children than in non-obese children (Matter et al., 2007). Fjeldstad et al. (2008) also documented that obese elderly groups experience a high prevalence of fall, poor health and a lower quality of life and claimed that adipose tissue distribution could be considered as a major contributory factor to balance impairment. Increased obesity had been proven to have an impact on postural control in terms of postural sway, energy cost, attentional cost, motor reaction time and muscular torque (Katch et al., 1988; Salsabili et al., 2011).

The clinical tools that is commonly used for the assessment of balance performance are the force plate, Lord sway-meter and star excursion balance test (Blaszczyk et al., 2009; Colné et al., 2008). However, in the recent years, the Biodex Balance System SD provides distinct advantage in data measurement such that various types of tests are available and convenient for the data error checking. It is easy to administer, available for multi-range of people and simple to interpret (Aydóg et al., 2006; Salsabili et al., 2011). The aim of this study was to assess the postural activity among healthy young adults according to their BMI classification (underweight/normal weight/overweight(obese) and gender during two types of quiet standing conditions (bipedic stance and unipedic stance) in order to elucidate whether BMI does act as an indicator of individuals’ ability to sustain postural ability. It was hypothesized that a difference in postural activity may be impacted by an individual’s BMI whether they were male or female.

2. Methods

Forty healthy male subjects (age = 22.1 ± 2.0 y; height = 1.71 ± 0.07 m; mass = 73.4 ± 20.5 kg) and forty female subjects (age = 21.4 ± 1.8 y; height = 1.58 ± 0.05 m; mass = 61.6 ± 15.5 kg) consented to participate in the study. The subject inclusion criteria consisted of subjects’ age (between 19 and 26 yr old) and good health. None of the subjects had undergone previous balance training programs using BBS prior to the study and none of them had suffered from any previous foot/ankle injury, vestibular impairment, or balance disorders. The research was implemented in a cross-over study design, where all subjects randomly underwent the same procedures. Approval from the Institutional Review Board for the test procedure was obtained.

Subjects were categorized into four groups based on their BMI: underweight, normal weight, overweight and obese. In this study, the Biodex Balance System SD (BBS; Biodex Medical System Inc., Shirley, NY, USA) is utilized to measure the displacement of the center of foot pressure (CoP) and it is composed of a circular platform that allows up to 20° of platform tilt in a 360° range of motion at a sampling rate of 20 Hz. The measures of postural stability score for BBS are Overall Stability Index (OSI), Medial–Lateral Stability Index (MLSI) and Anterior–Posterior Stability Index (APSI). These indices are standard deviations that assess the path of sway around the zero point from the center of the platform and are measured in degrees. The stability indexes scores show the foot displacement (‘y’ for motion in sagittal and frontal planes. Within this study, the displacements from horizontal along medial–lateral (ML) axes as x-direction, and from vertical along anterior–posterior (AP) axes as y-direction were evaluated as MLSI and APSI respectively. The equations for OSI, MLSI and APSI scores are as follows:

\[
\text{OSI} = \frac{\sqrt{\sum (0 - Y)^2 + \sum (0 - X)^2}}{\text{samples}}, \quad \text{MLSI} = \frac{\sum (0 - Y)^2}{\text{samples}}, \quad \text{APSI} = \frac{\sum (0 - X)^2}{\text{samples}}
\]

The BBS recorded the foot displacement in the x-direction and y-direction. Then, the system will generate the OSI, APSI and MLSI using the equations above. The OSI score was established by combining the degree of tilt for AP and ML axes, as this had been suggested as the best balance indicator to measure overall platform balance (Arnold and Schmitz, 1998a). Calibrations of the platform actuator and tilt sensor were selected in the BBS before commencing the test. Arnold and Schmitz (1998b) found the intrater reliability of the BBS were 0.82 (OSI), 0.43 (MLSI) and 0.80 (APSI). Cachupe et al. (2001) showed that the examination of measure across 5 test evaluations indicated that the BBS reliable measures 0.92 (OSI), 0.90 (MLSI) and 0.86 (APSI).

Subjects stood on the BBS without footwear for all balance tests. The bipedic stance test (BLS) and unipedic stance test (ULS) were accomplished by using BBS to measure the postural balance score under the static level. Test order was randomized during both sets of tests. During the BLS test, subjects were asked to stand still on the platform of the BBS with their arms crossed over their chest. They were required to stand comfortably and maintain their visual level by focusing straight ahead on the monitor. The platform was unlocked and subjects were allowed to adjust their foot placement until a comfortable standing position was achieved while they simultaneously maintained a moving pointer at the center point on the monitor. Following this, the platform was locked and foot placement of the subject remained constant throughout the static balance test. Only one practice trial was performed for the instrument acquaintance with BBS to ensure that the collected data is reliable across the spectrum of stability level. All differences that affected the data collection are not related to learning and the learning effect could be minimized (Pincivero et al., 1995). Subjects were encouraged to maintain the moving pointer at the center point throughout the test. The BLS was assessed at the static level for 30 s. Five test evaluations were performed with a rest period of 10 s between each test and the data was averaged. The test protocol for ULS was similar to that utilized during BLS, excluding the standing posture. In ULS, subjects were instructed to stand with the dominant leg, which is defined as the preferential use in voluntary motor acts of ipsilateral members of the lower limb (Lanshammar and Ribom, 2011). The knee of the contra-lateral limb was held in a slightly flexed position to 90°. However, the non-supported limb was not allowed to come into contact with the supporting limb throughout the test. The use of the holding rail was only permitted as a means of avoiding falling. The test was to be aborted and repeated in the event that the subject lost balance and fell down.

All the data was presented as mean values and standard deviation (mean ± SD). Dependent-sample t-tests were used to compare the postural stability index score between BLS and ULS. Levene’s test was used to analyze the equality of variances. For the basis of statistical analysis among groups, normality of the data was investigated using the Kolmogorov–Smirnov test. A two-way analysis of variance (ANOVA) was then performed to determine the main effect of BMI and gender on bipedic and unipedic conditions. Post-hoc analysis was performed using the HSD Tukey test to determine where the significant differences occurred. The alpha level was set at p < 0.05 for all analysis. The analysis of normality test showed that all data was normally distributed. The data was normalized with respect to body weight and relative stability used in the data analysis in order to avoid the potential misinterpretation of data and to reduce the absolute stability differences (Winter and Maughan, 1991). All statistical analysis was performed using the statistical software SPSS 19.0 (Version 19, IBM Corp., Armonk, NY).

3. Results

The demographic characteristics of subjects for this study are summarized in Table 1. There were significant differences in body weight and BMI. The dependent sample t-test revealed that there was a significant difference in postural performance between BLS and ULS. The changes in OSI, APSI and MLSI stability scores across the different category classifications of BMI between male and female groups are presented in Table 2. The changes of OSI score between BLS and ULS in male and female while using BBS are summarized in Fig. 1.
Results of the two-way ANOVA exhibited significant main effect of BMI on the OSI score (F_{1,72} = 7.2; p < 0.001), APSI score (F_{1,72} = 8.0; p < 0.001) and MSLI score (F_{1,72} = 4.8; p = 0.004). There was significant main effect of gender for BLS as shown on the OSI score (F_{1,72} = 10.8; p = 0.002), APSI score (F_{1,72} = 6.2; p = 0.015) and MSLI score (F_{1,72} = 4.8; p = 0.004). The obese group demonstrated significant lower mean stability score than the underweight group and normal weight group.

In ULS analysis of variance, significant main effect of BMI was found on OSI score (F_{1,72} = 16.7; p < 0.001), APSI score (F_{1,72} = 12.0; p < 0.001) and MSLI score (F_{1,72} = 10.9; p < 0.001). Significant main effect of gender was found on OSI score (F_{1,72} = 12.5; p = 0.001), APSI score (F_{1,72} = 9.6; p = 0.003) and MSLI score (F_{1,72} = 4.1; p = 0.047). In the obese group, the mean stability scores were significantly lower than those of the other three BMI groups. Generally, for both the BLS and ULS conditions, there are no interactions found between BMI group and gender for all variables measured. The mean stability scores for female in the obese group were lower than those of the remaining groups. Post-hoc pair-wise comparisons showed that the OSI, APSI and MSLI scores of the obese group were significantly lower than those of the remaining BMI groups (Table 2).

The mean of OSI score in BLS decreased by 5.5%, 18.3% and 15.3% with respect to the increase in BMI, while the stability score in ULS decreased by 9.60%, 14.2% and 22.3% with respect to the increase in BMI value. There were significant, but low, correlations between the stability score and BMI for bipedal stance (r = -0.511, p < 0.001) and unipedal stance (r = -0.650, p < 0.001). Individuals in the underweight group are more likely to demonstrate a higher stability score in both conditions. No subject grasped the holding rail to regain balance during the balance tests.

### 4. Discussion

The main aim of this study was to investigate the impact of both the BMI and gender of young adults on postural balance activity. The primary findings revealed that those individuals in the underweight group demonstrated a better balance performance, and that postural activity was negatively affected by increased BMI in both BLS and ULS. The findings also revealed that there is a trend in female young

### Table 1

<table>
<thead>
<tr>
<th>Sex ratio</th>
<th>Underweight</th>
<th>Normal weight</th>
<th>Overweight</th>
<th>Obese</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male/female</td>
<td>10/10</td>
<td>10/10</td>
<td>10/10</td>
<td>10/10</td>
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<tr>
<td>Age (yr)</td>
<td>21.5 ± 1.5</td>
<td>21.3 ± 1.3</td>
<td>22.4 ± 2.6</td>
<td>21.9 ± 1.8</td>
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<tr>
<td>Height (cm)</td>
<td>1.65 ± 0.09</td>
<td>1.64 ± 0.08</td>
<td>1.64 ± 0.09</td>
<td>1.64 ± 0.10</td>
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<tr>
<td>Weight (kg)</td>
<td>48.2 ± 4.8</td>
<td>57.0 ± 7.7</td>
<td>73.7 ± 9.5</td>
<td>91.2 ± 13.5</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>17.4 ± 0.9</td>
<td>21.1 ± 1.7</td>
<td>27.4 ± 1.6</td>
<td>33.8 ± 2.4</td>
</tr>
</tbody>
</table>

* Values for age, height, weight are mean ± standard deviation.

### Table 2

<table>
<thead>
<tr>
<th>Sex</th>
<th>OSI</th>
<th>Mean ± SD</th>
<th>95% CI</th>
<th>APSI</th>
<th>Mean ± SD</th>
<th>95% CI</th>
<th>MSLI</th>
<th>Mean ± SD</th>
<th>95% CI</th>
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</thead>
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<tr>
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<td>0.008 ± 0.002</td>
<td>0.006–0.009</td>
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<td></td>
<td>Normal weight</td>
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<td>Overweight</td>
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<td>Obese</td>
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1. p < 0.05: significant difference in comparison to bilateral stance and unilateral stance.
2. p < 0.05: significant difference in gender group among the same postural condition.
3. p < 0.05: significant difference when compared with BMI group (underweight) among the same postural condition by using Post-hoc pair-wise comparisons.
4. p < 0.05: significant difference when compared with BMI group (normal weight) among the same postural condition by using Post-hoc pair-wise comparisons.
5. p < 0.05: significant difference when compared with BMI group (obese) among the same postural condition by using Post-hoc pair-wise comparisons.
adults to generate greater postural sway in AP and ML directions when compared to the male young adults.

In line with previous studies, it is important to investigate the biomechanical factors that may influence postural activity. Chiari et al. (2002) reported that height, weight, BoS, maximum foot width and feet opening angle should be taken into account when considering biomechanical factors. Age is not a factor that is associated with the postural control for different BMI categories (Cruz-Gómez et al., 2011). The static control balance results for obese group during the experiment are more revealing with regard to their ability to maintain postural control. A related study revealed that the obese group could not generate sufficient muscle force to control the displacement of CoM (Corbê et al., 2008).

The obese group had a greater postural sway for BLS and ULS. Weight distribution may relate to the increase of postural sway. The results of this study are in agreement with those of previous related studies. Hue et al. (2007) argued that obesity is generally associated with greater balance instability, as increases in the contact area and pressure reduce the sensory information executed from the planter mechanoreceptor in middle-aged adults. Corbeil et al. (2001) claimed that excessive body weight among obese group will increase falling risk than in non-obese group. It is evidenced that weight loss in obese male will directly improve their postural control (Teasdale et al., 2007). Furthermore, Himes (2000) suggested that sedentary lifestyle might lead to the muscle mass reduction, increasing weight gain and disease prevalence rate.

In the present study, there is a greater difference in ML than AP stability during BLS and ULS, since the postural instability is usually associated with an increase in lateral body sway (Blaszczyk et al., 2007). Generally, balance control in ML direction occurs at the hip and trunk of the body while the pelvis generates ML motion in the lateral direction (Shumway-Cook and Woollacott, 2007). When descending response of the body segment takes place, head movement will occur first, followed by trunk and hip movements. The data revealed that there was significant increase in ML sway for the obese group in ULS compared to the remaining BMI groups. This is in agreement with McGraw et al. (2000) who also found difference in ML stability between obese and non-obese boys. Furthermore, McClanaghan et al. (1996) found a significant difference for postural balance in ML stability between young adults and elderly group. Menegoni et al. (2009) argued that a decrease in AP stability among elderly individuals in the static position could lead to an increase in motor activity. They also indicated that only AP stability is correlated with body weight. Additionally, weight gain in the BMI group induced a similar effect on AP and ML stabilities in both gender groups.

Although all the studies above used a static force platform as the assessment tool kit it is evident that BBS measurements are more reliable compared with the data obtained from a static force platform (Himman, 2000).

The current investigation revealed that there is a trend in female subjects displaying a greater postural sway compared to their male counterparts; however these differences were significant only in some underweight and normal-weight groups. The greater postural sway that occurred with the female subjects indicated an increase in CoP displacements towards the limit of BoS. However, this finding is in contrast with earlier studies, which found that males had a greater postural sway than females (Mickle et al., 2010). We suggested that the discrepancy in the findings could be related to the adipose tissue mass distribution of gender, as the android type normally occurs in males and gynoid type in females. The adipose tissue distribution for android type (apple-like body shape) is concentrated in the thorax–abdominal region, while for the gynoid type (pear-like body shape) adipose tissue is usually found around the hip and thigh areas (Clark, 2004). Both males and females can have an android body type (Menegoni et al., 2009). Goodman-Gruen and Barret-Connor (1996) described that obese females tend to accumulate a greater amount of adipose tissue in lower extremity. Besides, the arch angle of the foot in females presents a greater ligament laxity. Higher body weight and a flexible longitudinal arch would lead to a greater postural sway (Aurichio et al., 2011). People should take consideration of whatever was revealed between male and female groups in this study.

ULS is a clinical tool that is utilized to measure postural steadiness in static position (Josson et al., 2004), since it is a posture which requires greater motor control than BLS and it requires a posture balance recovery movement at both the ankle and hip joints in order to create musculature restoration forces. In a research that assessed the postural control of 453 women aged between 20 and 80, it was found that women in their 70s have difficulty in maintaining postural control for BLS and ULS on either leg (Choy et al., 2003). In this study, most of the subjects preferred their right lower limb (86%) as the dominant leg. Greve et al. (2007) observed that no difference in balance performance was found in the dominant leg and non-dominant leg during ULS.

Although there are studies in existence that have investigated postural balance, the impact of BMI on stability was the main concern of this study. Learning may affect the result which influences the proprioception and vestibular equilibrium. In this study, one practice trial was performed before the test started.
Although, it might deviate the focus from BMI and gender effect, however, with one practice trial, the subject will be able to learn and adapt for the test first. Five test evaluations were performed in this study. So, the data collected is standardized and accurate without the influence factor of the learning. In addition to this, the sample size of the group involved in current study was small ($N=80$), and all participants were from one geographical location; both of these facts may undermine the findings. This study provided normative postural stability data for the balance ability of healthy adolescents (between 19 and 26 yr old) in a static balance test. Coaches should consider the impact of gender and BMI in practical fields such as athlete selection for sporting activities that require quiet standing. Further studies should consider muscle activity and other dynamic components during the balance test.

5. Conclusions

In conclusion, this study revealed a relationship between static balance ability in young adults and their BMI and gender. The data indicated that balance performance was diminished as the BMI value of the subjects increased and subjects who were categorized in the obese group were more likely to exhibit greater postural sway. This indicates that changes in the relationship of BMI may alter an individual’s ability to balance, although other biomechanical factors may also affect the performance. In terms of static balance, there is a trend in females displaying a greater postural sway compared to males in certain BMI classifications.

Conflict of interest statement

None of the authors had any conflict of interest during this study.

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