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Original Article

The effects of weight and activity on select kinematic gait variables in adult females

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Abstract:
Problem Statement: Multiple studies have examined the effects of weight on gait, and some studies have examined the effects of activity on gait. However the combination of the two has yet to be explored. Approach: In this preliminary study of the combination of weight and activity a survey was used to assess activity. A survey was used to assess activity for two reasons: ease of administration and accessibility to the practitioner. Purpose: The purpose of this study was to examine how weight and activity affect gait. Participants were 22 adult females (10 normal weight, 12 overweight). Participants had BMI determined and underwent gait analysis. Step width, preferred walking speed, stride length, angular displacement at the knee and ankle, and peak knee flexion and extension velocity were examined. A multivariate approach was utilized to determine if significant differences existed between the groups. Univariate tests were examined if multivariate significance was found. Results: Overweight participants had decreased preferred walking speed (1.31 ± 0.16 m/s vs. 1.53 ± 0.18 m/s; $p < .03$) and stride length (1.23 ± 0.11 m vs. 1.38 ± 0.11 m; $p < .03$). There were no significant effects for activity or the interaction of weight and activity. Conclusions: Additional research is needed to further explore weight status grouping methods and the interaction of weight status and activity.
Key words: obesity, walking, biomechanics, kinematics.

Introduction

Walking is a fundamental form of ambulation that is altered in many populations. Many studies have shown alterations in the gait of overweight and obese individuals (de Souza et al., 2005; DeVita & Hortobágyi, 2003; Lai, Leung, Li, & Zhang, 2008; Malatesta et al., 2009; Spyropoulos, Pisciotta, Pavlou, Cairns, & Simon, 1991; Vismara et al., 2007). Exercise interventions have also been shown to affect gait (Lopopolo, Greco, Sullivan, Craik, & Mangione, 2006), but the effects of activity in an overweight population have not yet been investigated. As activity can play a major role in weight management (Donnelly et al., 2009), the effects on activity in overweight individuals is a topic in need of investigation. Therefore, the purpose of this study was to examine the effects of current activity levels on gait in overweight females.

Kinematic Gait Alterations in the Overweight and Obese

Several alterations in gait have been found in overweight and obese subjects. A slower walking velocity has been a common finding (de Souza et al., 2005; DeVita & Hortobágyi, 2003; Lai et al., 2008; Malatesta et al., 2009; Vismara et al., 2007), though a few studies have found no difference in preferred walking speed (Browning, Baker, Herron, & Kram, 2006; Browning & Kram, 2005). Other differences include reduced cadence (de Souza et al., 2005; Spyropoulos et al., 1991), increased step width (Browning & Kram, 2007; de Souza et al., 2005; Spyropoulos et al., 1991), and decreased step or stride length (de Souza et al., 2005; Lai et al., 2008; Malatesta et al., 2009; Vismara et al., 2007). Changes to the gait cycle are also evident. Stance phase is increased (Browning & Kram, 2007; DeVita & Hortobágyi, 2003; Lai et al., 2008), and swing phase is shortened (Becker et al., 2006; Browning & Kram, 2007; DeVita & Hortobágyi, 2003). DeVita and Hortobagyi (DeVita & Hortobágyi, 2003) also found overweight individuals had longer stance phases and shorter swing phases when walking at preferred walking speed compared to walking at a faster standard speed. This indicates the overweight individual can adopt normal gait characteristics but for some reason often walks with alterations to gait. There are also changes in joint displacement. Hip extension and plantar flexion are increased (DeVita & Hortobágyi, 2003), while knee flexion is reduced (DeVita & Hortobágyi, 2003; Gushue, Houck, & Lerner,

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2005). These changes result in a more upright posture. An increase in foot angle (toeing out) has also been found (de Souza et al., 2005; Messier et al., 1994). This body of evidence supports that gait is altered in the overweight individual.

Activity and Gait

Most of the literature examining gait and exercise focuses on exercise interventions. In a meta-analysis, Lopopolo and associates (Lopopolo et al., 2006) found increased gait speed in community-dwelling older adults after exercise interventions incorporating strength training, aerobic exercise with other types of exercise, high intensity, and high frequency exercise. Schlicht, Camaione, and Owen (Schlicht, Camaione, & Owen, 2001) and Topp, Mikesky, Dayhoff, and Holt (Topp, Mikesky, Dayhoff, & Holt, 1996) found gait speed increased following a strengthening program. However, Buchner et al. (Buchner et al., 1997) did not find any effects on gait after strength training or endurance programs. There have also been mixed results for stretching programs. A single study found increased step length, velocity, and swing time coupled with decreased stand and double support time (Cristopoliski, Barela, Leite, Fowler, & Rodacki, 2009), while other studies have found no changes (Godges, MacRae, & Engelke, 1993; Kerrigan, Xenopoulos-Oddsson, Sullivan, Lelas, & Riley, 2003). Combinations of aerobic and strength training interventions have been the most successful in effecting gait and associated parameters. Both gait velocity (Judge, Underwood, & Gennosa, 1993; Lord et al., 1996; Protas & Tissier, 2009; Puggaard, 2003; Sauvage et al., 1992) and maximum gait velocity (Protas & Tissier, 2009) have been increased. Stride length and cadence were also increased (Lord et al., 1996; Sauvage et al., 1992), while stride time was decreased (Lord et al., 1996). Improvements in gait instability (Hausdorff, Edelberg, Cudkowicz, Singh, & Wei, 1997; Hausdorff et al., 2001), obstacle course completion (Cao, Maeda, Shima, Kurata, & Nishizono, 2007), treadmill test results (Crowther et al., 2008), falling risk (Buchner et al., 1997), and gait variability (Hausdorff et al., 2001) have also been found.

Though there is a fair body of work relating to changes in gait resulting from exercise interventions, there is limited information about the effects of weight reduction on gait. The few studies to examine the effects of weight loss on gait have found reductions in plantar pressure (Kostelnikova & Hlavacek, 2008) and load at the knee (Messier, Gutekunst, Davis, & DeVita, 2005). An increase in walking speed has also been found (Villareal, Banks, Sinacore, Siener, & Klein, 2006), though this study also incorporated an exercise intervention. There is also little information on how current activity levels relate to gait. A single study found that active males walked faster than sedentary males (Niang & McFadyen, 2005). Another study found obese women who increased their steps per day by 2000 or more with pedometer usage walked faster and with longer steps; after one year, these women also demonstrated gait patterns similar to normal-weight adults (Toole, Thorn, Panton, Kingsley, & Haymes, 2007).

The current project

Although both obesity and exercise have been shown to alter gait, the interaction of obesity and exercise has not been studied. Therefore, the purpose of this study was to determine the effects of weight status and current activity status on select kinematic variables during walking in females aged 25 to 45 years. As a preliminary investigation, sample size was limited, and a simple paper and pencil measure of activity was used. This method was chosen for ease of administration as extensive activity measurement (analysis of pedometer, accelerometer, or activity log data) would be an obstacle to quickly assessing individuals. If a paper and pencil method is sensitive enough to identify differences, this could be a valuable tool for those working with overweight individuals. As gait is different in males and females, the study was restricted to females. The specific variables examined were walking velocity (preferred walking speed), stride length, step width, angular velocity at the knee (peak knee flexion velocity and peak knee extension velocity), and angular displacement at the knee and ankle. Understanding the impact of obesity on the gait of this population and whether this impact is affected by currently participating in physical activity will shed light on the impact of obesity on biomechanics and whether the impact of obesity is mitigated by physical activity. Determining if activity has an impact on the biomechanics of obese individuals will allow activity programs to be modified to best serve the individual.

This is especially important to understand because of the popularity of walking for physical activity among adults. If obesity alters gait to make walking more taxing and physical activity can reduce these effects, it may be possible to make walking for exercise more comfortable for the obese population. Because of the positive health benefits associated with even low levels of physical activity, walking should be encouraged for all individuals.

Method

Participants

Participants were 24 adult females between the ages of 25 and 45 recruited from the surrounding community via flyers and electronic news media. To be eligible, participants had to be pre-menopausal and free from major lower body injuries or impairments, diabetes mellitus, and neuropathy. This project was approved by the institutional review board. All participants provided informed consent. Two participants were excluded from data analysis because of a previous injury (n = 1) and problems with data collection during gait analysis (n = 1).

Definitions for weight and activity status

Weight status. Weight status was based on standard BMI guidelines (Donnelly et al., 2009). If the participant had a BMI greater than or equal to 25, she was placed in the overweight group. If the participant had a BMI less than 25, she was placed in the normal-weight group.

Activity status. The participants completed the *General Practice Physical Activity Questionnaire* (GPPAQ; Department of Health, United Kingdom) to determine activity status. The GPPAQ asks questions about employment, activity at work, physical activity, and walking pace. However, only the physical activity and employment questions are used to assigned activity status. A rating of inactive is assigned for individuals who engage in no exercise or cycling and have sedentary jobs. Individuals with sedentary jobs who exercise or cycle less than 1 hour per week and individuals who have a standing job and do not engage in physical exercise or cycling are rated moderately inactive. Those with a sedentary job with 1 – 2.9 hours of exercise or cycling, a standing job with some but less than 1 hour of physical exercise or cycling, or a physical job with no exercise or cycling are classified as moderately active. Those with sedentary jobs who engage in more than 3 hours of exercise or cycling, have standing jobs and engage in 1 – 2.9 hours of exercise or cycling, have a physical job with less than 1 hour of exercise or cycling, or have a heavy manual job are classified as active. Individuals engaging in 3 or more hours of exercised or cycling weekly are rated as active. Participants scoring "inactive" or "moderately inactive" were categorized as inactive. Participants scoring "moderately active" or "active" were categorized as active.

Protocol

Height, weight, and BMI. Height in meters and weight in kilograms were measured using a balance beam scale equipped with a stadiometer (Detecto Scale Co., Webb City, MO). The participants wore light clothing (t-shirt and shorts or similar attire) and removed the shoes to have height and weight measured. Height was measured to the nearest half centimeter. Weight was measured to the nearest tenth of a kilogram. Body mass index (BMI) was calculated from the participant's height and weight using the standard equation: BMI = (weight in kilograms)/(height in meters)^2 (Heyward, 2006).

Gait analysis. Participants were dressed in tight fitting clothing and removed socks and shoes for gait analysis. Gait analysis was performed using Peak Motus 9.2 motion analysis software (Vicon Inc., Centennial, CO). Two cameras recording at 60 Hz were used for data capture: a Canon ZR250MC (Canon Inc., Itasca, IL) and a Bosch Dinion^{XF} (Bosch, Fairport, NY). This allowed for data collection in the sagittal and frontal planes. Reflective markers were placed on anatomical landmarks on the right side and back of the body. Six anatomical landmarks were used for reflective markers in the sagittal view: the anterior superior iliac spine, the external border of the greater trochanter, the lateral epicondyle of the femur, the lateral malleolus, the base of the fifth toe, and the back of the heel. Markers were placed on the sacrum and back of both heels for the frontal view. All researchers were involved in pilot testing to provide consistency in placing reflective markers. The participants walked at preferred walking speed over a level pathway. Participants were instructed to walk normally and were allowed to walk the pathway until indicating they were comfortable.

Three trials showing three strides with the right leg were captured. The trial with the clearest recording was analyzed. Approximately 5 frames before initial right heel strike and 5 frames after the 4th right heel strike (3 strides) were analyzed. The middle stride was used for analysis. A minimum of two steps were required before and after the analyzed stride to avoid the effects of starting and stopping on gait pattern. For consistency, all data were analyzed by the lead author. Automatic digitization was used when possible. When automatic digitization was not possible, the data were manually digitized. Each frame of the trial was digitized. The default filter settings were used.

The data were used to calculate walking velocity, stride length, and step width. Walking velocity was calculated as the average velocity of the marker placed on the greater trochanter over the period from heel-strike to heel-strike of the right foot similar to the method described by Richardson and associates (2004). Stride length was calculated as the horizontal displacement of the right heel marker from heel strike to heel strike of the right foot in accord with the definition set forth by Whittle (2007) . Step width was calculated as the horizontal displacement between the marker of the right heel at approximately midstance of the right leg and the marker of the left heel at approximately midstance of the left leg in accord with the definition set forth by Whittle (Whittle, 2007).

Statistics

A series of two by two factorial multivariate analyses of variance were conducted using SAS 9.2 (SAS Inc., Cary, NC). The analysis involved two between subject factors: weight status (normal-weight and overweight) and activity status (inactive and active). Variables were divided into 3 groups for analysis. Group 1 consisted of step width (STW), preferred walking speed (PWS), and stride length (STR). Group 2 consisted of angular displacement at the knee (KDIS) and ankle (ADIS). Group 3 consisted of peak knee flexion velocity (KFV) and peak knee extension velocity (KEV). Multivariate significance was set at $p < .10$ because of the small sample sizes. Significance for the univariate follow-up tests was set using a Bonferroni correction resulting in values of $p < .03$, $p < .05$, and $p < .05$ respectively. The univariate follow-up tests were only examined if multivariate significance was found. Effect size was calculated at the multivariate (D^2) and univariate (*d*) levels. Retrospective power was also calculated.

Results

Participant Characteristics

According to BMI categorization, 10 participants were normal-weight (NW), and 12 participants were overweight (OW). Eleven participants were categorized as inactive (IACT) and 11 participants were categorized active (ACT). When grouped by weight and activity status, there were 5 participants in the normal-weight and inactive (NWIA) and normal-weight and active (NWA) groups and 6 participants in the overweight and inactive (OWIA) and overweight and active (OWA) groups. Descriptive information regarding participant characteristics may be found in Tables 1 through 3. There were significant differences in height between the OW and NW groups, $F(1, 20) = 4.79$, $p < .05$. However, the correlation between height and preferred walking speed was not significant, $r = .29$, $p = .19$. Therefore, preferred walking speed was not normalized to account for differences in height.

Comparisons Based on Weight Status According to BMI and Activity Status

Descriptive information for the dependent variables when grouped based on weight status according to BMI and activity status may be found in Table 1. There was not a significant interaction effect for Weight Status x Activity Status for any of the variable groups – Group 1 $F(3, 16) = 1.17$, $p = .35$, Wilk's $\Lambda = 0.82$; Group 2: $F(2, 17) = 1.98$, $p = .17$, Wilk's $\Lambda = 0.81$; Group 3: $F(2, 17) = 2.09$, $p = .15$. Power for the interaction effect on all multivariate comparisons was less than 0.70 according to the power estimations in Stevens (Stevens, 2002).

Table 1
Descriptive Characteristics: Grouped by BMI and Activity Status

	Normal-weight (BMI < 25)		Overweight (BMI ≥ 25)	
Variables	Inactive *n* = 5	Active *n* = 5	Inactive *n* = 5	Active *n* = 6
Age (years)	38.20 ± 5.63	37.40 ± 7.80	34.67 ± 6.28	29.83 ± 5.49
Height (m)	1.66 ± 0.04	1.67 ± 0.06	1.61 ± 0.05	1.63 ± 0.02
Weight (kg)	64.14 ± 4.46	56.18 ± 5.72	77.78 ± 12.21	87.42 ± 7.54
BMI	23.32 ± 1.42	20.10 ± 1.10	30.01 ± 5.76	32.82 ± 2.88
Body fat (%)	38.50 ± 6.06	25.28 ± 3.75	44.22 ± 5.38	46.33 ± 4.28
STW (m)	0.08 ± 0.02	0.08 ± 0.04	0.12 ± 0.05	0.11 ± 0.03
PWS (m/s)	1.61 ± 0.15	1.46 ± 0.19	1.27 ± 0.12	1.35 ± 0.19
STR (m)	1.41 ± 0.05	1.35 ± 0.14	1.21 ± 0.09	1.24 ± 0.14
KDIS (°)	58.45 ± 4.12	48.28 ± 17.22	58.74 ± 6.28	59.75 ± 3.08
ADIS (°)	33.12 ± 1.46	29.03 ± 9.93	27.89 ± 2.61	29.95 ± 4.71
KFV (°/s)	310.28 ± 29.29	316.59 ± 29.26	287.01 ± 19.87	300.15 ± 19.04
KEV (°/s)	-379.52 ± 33.67	-355.91 ± 20.71	-357.82 ± 37.49	-391.05 ± 52.82

Note. All values in *M* ± *SD*. Activity level determined using the General Practice Physical Activity Questionnaire. STW = step width. PWS = preferred walking speed. STR = stride length. KDIS = angular displacement at the knee. ADIS = angular displacement at the ankle. KFV = peak knee flexion velocity. KEV = peak knee extension velocity.

Table 2
Descriptive Characteristics: Grouping by BMI

Variables	Normal-weight (BMI < 25) *n* = 10	Overweight (BMI ≥ 25) *n* = 12
Age (years)	37.80 ± 6.43	32.25 ± 6.17
Height (m)	1.66 ± 0.05	1.62 ± 0.04
Weight (kg)	60.46 ± 6.40	82.90 ± 10.90
BMI	21.71 ± 2.08	31.42 ± 7.03
Body fat (%)	31.89 ± 8.43	45.28 ± 4.76

Step width (m)	0.08 ± 0.03	0.11 ± 0.04†
Preferred walking speed (m/s)	1.53 ± 0.18	1.31 ± 0.16$^{\dagger **}$
Stride length (m)	1.38 ± 0.11	1.23 ± 0.11$^{\dagger **}$
Knee angular displacement (°)	53.37 ± 12.97	59.24 ± 12.62
Ankle angular displacement (°)	31.08 ± 7.03	28.77 ± 3.84
Peak knee flexion velocity (°/s)	313.43 ± 27.80	293.58 ± 19.33
Peak knee extension velocity (°/s)	-367.71 ± 29.14	-374.43 ± 46.99

Note. All values in *M* ± *SD*. † Multivariate significance at $p < .10$. * Univariate significance at $p < .05$. ** Univariate significance at $p < .03$.

Table 3

Dependent Variable Descriptive Characteristics: Grouping by Activity Status

Variables	Inactive *n* = 11	Active *n* = 11
Age (years)	36.27 ± 5.98	33.27 ± 7.42
Height (m)	1.63 ± 0.05	1.65 ± 0.05
Weight (kg)	71.58 ± 11.54	73.22 ± 17.54
BMI	26.97 ± 5.44	27.04 ± 6.98
Body fat (%)	41.62 ± 6.17	36.76 ± 11.64
Step width (m)	0.10 ± 0.04	0.10 ± 0.03
Preferred walking speed (m/s)	1.42 ± 0.22	1.40 ± 0.19
Stride length (m)	1.30 ± 0.13	1.29 ± 0.14
Knee angular displacement (°)	58.61 ± 5.15	54.53 ± 12.62
Ankle angular displacement (°)	30.1 ± 3.55	29.53 ± 7.13
Peak knee flexion velocity (°/s)	297.59 ± 25.86	307.62 ± 24.44
Peak knee extension velocity (°/s)	-367.68 ± 35.84	-375.08 ± 43.93

Note. All values in *M* ± *SD*.

Comparisons Based on Weight Status According to BMI

Descriptive information for the dependent variables when grouped based on weight status according to BMI may be found in Table 2. There was a significant main effect for weight status according to BMI on the first group of variables (STW, PWS, and STR), Wilk's $\Lambda = 0.61$, $F(3, 16) = 3.47$, $p = .04$. Follow-up univariate *F* tests were significant for PWS, $F(1,20) = 10.03$, and STR, $F(1, 20) = 10.15$ (both $p < .03$) but not for STW, $F(1, 20) = 3.15$, $p = .09$. Normal-weight participants had a higher PWS (NW: 1.53 ± 0.18 m/s; OW: 1.31 ± 0.16 m/s) and STR (NW: 1.38 ± 0.11 m; OW: 1.23 ± 0.11 m). There was not a significant main effect for weight status for the second (Wilk's $\Lambda = .86$, $F(2, 17) = 1.43$, $p = .27$) or third (Wilk's $\Lambda = 0.81$, $F(2, 17) = 2.09$, $p = .15$) variable groups. Multivariate effect size was large for the first group of variables ($D^2 = 2.12$), medium for the second group ($D^2 = 0.81$), and small for the third group ($D^2 = 0.55$). Power for the multivariate comparisons could be no greater than 0.72 (Stevens, 2002). Univariate effect size was large for PWS ($d = 1.34$), STR ($d = 1.33$), and KFV ($d = 0.82$).

Comparisons Based on Activity Status

Descriptive information for the dependent variables when grouped based on activity status may be found in Table 3. There was not a main effect for activity status on the multivariate level for any of the variable groups – Group 1: Wilk's $\Lambda = 0.98$, $F(3, 16) = 0.10$, $p = .96$; Group 2: Wilk's $\Lambda = 0.92$, $F(2, 17) = 0.74$, $p = .49$; Group 3: Wilk's $\Lambda = 0.95$, $F(2, 17) = 0.42$, $p = .66$. Multivariate effect size was small for all variable groups (Group 1: $D^2 = 0.06$; Group 2: $D^2 = 0.16$; Group 3: $D^2 = 0.28$). Power for the multivariate comparisons could be no greater than 0.32 (Stevens, 2002).

Discussion

The purpose of this study was to examine the effects of weight and activity status on select kinematics of gait in females aged 25 to 45 years. According to this study, the combination of being overweight and active or inactive did not affect gait. However, being overweight did affect gait. Both preferred walking speed and stride length were significantly reduced in the overweight group.

The lack of an effect on gait associated with activity stands in contrast to several studies finding changes in gait associated with an exercise intervention (Cristopoliski et al., 2009; Judge et al., 1993; Lopopolo et al., 2006; Lord et al., 1996; Protas & Tissier, 2009; Puggaard, 2003; Sauvage et al., 1992; Schlicht et al., 2001) or activity levels (Niang & McFadyen, 2005; Toole et al., 2007). However, several other studies had similar results (Buchner et al., 1997; Godges et al., 1993; Kerrigan et al., 2003) with no gait changes being associated with activity. Additional research on the effects of activity and the interaction of weight status and activity on gait is needed. The instrument used in this study only accounted for activity status over the previous week, which means only acute activity status was determined. Activity status could have been effected by a short term event (such as an illness), leading to the classification of the participant on a short-term basis that would be different than classification of activity based on the past six months or previous year. The instrument also did not consider walking as a form of exercise. Walking is a very popular form of exercise, and failing to classify walking as activity may also have led to discrepancies in actual activity level and activity status. Capturing physical activity is difficult, and it may be that the best way of assessing the effects of activity on gait is in an intervention setting where the level of activity can be controlled.

The overweight group did walk significantly slower with significantly shorter strides and slightly larger step widths than the normal-weight group. This was consistent with much of the literature and adds to the body of work indicating a decreased walking speed in the overweight and obese (de Souza et al., 2005; DeVita & Hortobágyi, 2003; Lai et al., 2008; Malatesta et al., 2009; Vismara et al., 2007). The results for stride length were also consistent with the literature in that overweight participants had decreased stride length (de Souza et al., 2005; Lai et al., 2008; Malatesta et al., 2009; Vismara et al., 2007). Although not significant, overweight participants had slightly greater step width, which is in line with other studies showing greater step width for overweight individuals (Browning & Kram, 2007; DeVita & Hortobágyi, 2003; Lai et al., 2008).

The results of this study have several practical implications for the researcher and practitioner. The presence of large effect sizes for multiple comparisons based on weight and activity status raises the possibility that substantial differences may exist, but this study did not have sufficient power to detect the differences because of the small number of participants. Understanding there are differences in gait when dealing with the overweight population is important. Exercise prescriptions utilizing walking need to address distance as well as time to accurately prescribe a volume of aerobic exercise to elicit gains. Individuals also tend to walk at a speed that minimizes metabolic cost (Browning et al., 2006; Browning & Kram, 2005). Encouraging an overweight individual to walk at a slightly higher pace will help increase caloric expenditure and achieve greater improvements in aerobic capacity. However, it should be remembered that this pace is likely not comfortable, may have biomechanical consequences, and will likely need to be used intermittently. Each of these changes (slower speed, shorter strides, and wider steps) also serves to increase stability during walking. Changing these characteristics could make the individual less stable, so monitoring the individual's balance while walking is also important. There were several significant findings in this study even with a small sample size. From the results associated with weight status according to BMI, it was concluded that being overweight was associated with decreased walking speed and stride length. There were not significant results associated with activity status or the combination of weight status according to BMI and activity status. Effect sizes were large for several comparisons, which may indicate low power lead to a lack of significant results. It was concluded that additional investigation into the effects of activity and the interaction of activity and weight is needed with a specific emphasis on obtaining an activity measure with a higher level of reliability and validity.

Conclusions

Obesity will continue to be an issue for exercise scientists for the foreseeable future. Designing appropriate strategies for weight management will be key. This study contributes to the growing biomechanical investigation of obesity that must be integrated with the physiological implications to ensure exercise is conducted safely and efficiently. Based on the results of this study, future investigations should involve more sensitive measures of activity. It may also be beneficial to include information about body fat distribution in the analysis. More research is needed regarding the biomechanics of the overweight and obese populations. It is important to continue to analyze exactly how excess weight and adipose tissue affect movement and how that weight and adipose tissue interact with activity.

References

Becker, M., Nelson, A., Rothman, J., Ng, A., Barker, V., Brady, S., & Koser, A. (2006). Reductions in body mass deliver positive gait changes. *Biomechanics, 13*(10), 59-69.

Browning, R. C., Baker, E. A., Herron, J. A., & Kram, R. (2006). Effects of obesity and sex on the energetic cost and preferred speed of walking. *Journal of Applied Physiology, 100*(2), 390-398.

Browning, R. C., & Kram, R. (2005). Energetic cost and preferred speed of walking in obese vs. Normal weight women. *Obesity Research, 13*(5), 891-899.

Browning, R. C., & Kram, R. (2007). Effects of obesity on the biomechanics of walking at different speeds. *Medicine & Science in Sports & Exercise, 39*(9), 1632-1641.

Buchner, D. M., Cress, M. E., de Lateur, B. J., Esselman, P. C., Margherita, A. J., Price, R., & Wagner, E. H. (1997). The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 52*(4), M218-224.

Cao, Z. B., Maeda, A., Shima, N., Kurata, H., & Nishizono, H. (2007). The effect of a 12-week combined exercise intervention program on physical performance and gait kinematics in community-dwelling elderly women. *Journal of Physiological Anthropology, 26*(3), 325-332.

Cristopoliski, F., Barela, J. A., Leite, N., Fowler, N. E., & Rodacki, A. L. (2009). Stretching exercise program improves gait in the elderly. *Gerontology, 55*(6), 614-620.

Crowther, R. G., Spinks, W. L., Leicht, A. S., Sangla, K., Quigley, F., & Golledge, J. (2008). Effects of a long-term exercise program on lower limb mobility, physiological responses, walking performance, and physical activity levels in patients with peripheral arterial disease. *Journal of Vascular Surgery, 47*(2), 303-309.

de Souza, S. A., Faintuch, J., Valezi, A. C., Sant' Anna, A. F., Gama-Rodrigues, J. J., de Batista Fonseca, I. C., . . . Senhorini, R. C. (2005). Gait cinematic analysis in morbidly obese patients. *Obesity Surgery, 15*(9), 1238-1242.

DeVita, P., & Hortobágyi, T. (2003). Obesity is not associated with increased knee joint torque and power during level walking. *Journal of Biomechanics, 36*(9), 1355-1362.

Donnelly, J. E., Blair, S. N., Jakicic, J. M., Manore, M. M., Rankin, J. W., & Smith, B. K. (2009). American college of sports medicine position stand. Appropriate physical activity intervention strategies for weight loss and prevention of weight regain for adults. *Medicine & Science in Sports & Exercise, 41*(2), 459-471.

Godges, J. J., MacRae, P. G., & Engelke, K. A. (1993). Effects of exercise on hip range of motion, trunk muscle performance, and gait economy. *Physical Therapy, 73*(7), 468-477.

Gushue, D. L., Houck, J., & Lerner, A. L. (2005). Effects of childhood obesity on three-dimensional knee joint biomechanics during walking. *Journal of Pediatric Orthopedics, 25*(6), 763-768.

Hausdorff, J. M., Edelberg, H. K., Cudkowicz, M. E., Singh, M. A., & Wei, J. Y. (1997). The relationship between gait changes and falls. *Journal of the American Geriatrics Society, 45*(11), 1406.

Hausdorff, J. M., Nelson, M. E., Kaliton, D., Layne, J. E., Bernstein, M. J., Nuernberger, A., & Singh, M. A. (2001). Etiology and modification of gait instability in older adults: A randomized controlled trial of exercise. *Journal of Applied Physiology, 90*(6), 2117-2129.

Heyward, V. H. (2006). Assessing body composition *Advanced fitness assessment and exercise prescription* (5th ed.). Champaign, IL: Human Kinetics.

Judge, J. O., Underwood, M., & Gennosa, T. (1993). Exercise to improve gait velocity in older persons. *Archives of Physical Medicine and Rehabilitation, 74*(4), 400-406.

Kerrigan, D. C., Xenopoulos-Oddsson, A., Sullivan, M. J., Lelas, J. J., & Riley, P.O.(2003). Effect of a hip flexor-stretching program on gait in the elderly. *Archives of Physical Medicine and Rehabilitation, 84*(1), 1-6.

Kostelnikova, L., & Hlavacek, P. (2008). Changes of plantar pressure distribution of obese children after a weight reduction program. *Clinical Biomechanics, 23*(5), 139-140.

Lai, P. P., Leung, A. K., Li, A. N., & Zhang, M. (2008). Three-dimensional gait analysis of obese adults. *Clinical Biomechanics, 23 Suppl 1*, S2-6.

Lopopolo, R. B., Greco, M., Sullivan, D., Craik, R. L., & Mangione, K. K. (2006). Effect of therapeutic exercise on gait speed in community-dwelling elderly people: A meta-analysis. *Physical Therapy, 86*(4),520-540.

Lord, S. R., Lloyd, D. G., Nirui, M., Raymond, J., Williams, P., & Stewart, R. A. (1996). The effect of exercise on gait patterns in older women: A randomized controlled trial. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 51*(2), M64-70.

Malatesta, D., Vismara, L., Menegoni, F., Galli, M., Romei, M., & Capodaglio, P. (2009). Mechanical external work and recovery at preferred walking speed in obese subjects. *Medicine & Science in Sports & Exercise, 41*(2), 426-434.

Messier, S. P., Davies, A. B., Moore, D. T., Davis, S. E., Pack, R. J., & Kazmar, S. C. (1994). Severe obesity: Effects on foot mechanics during walking. *Foot & Ankle International, 15*(1), 29-34.

Messier, S. P., Gutekunst, D. J., Davis, C., & DeVita, P. (2005). Weight loss reduces knee-joint loads in overweight and obese older adults with knee osteoarthritis. *Arthritis and Rheumatism, 52*(7),2026-2032.

Niang, A. E., & McFadyen, B. J. (2005). Effects of physical activity level on unobstructed and obstructed walking in young male adults. *Gait & Posture, 22*(1), 75-81.

Protas, E. J., & Tissier, S. (2009). Strength and speed training for elders with mobility disability. *Journal of Aging and Physical Activity, 17*(3), 257-271.

Puggaard, L. (2003). Effects of training on functional performance in 65, 75 and 85 year-old women: Experiences deriving from community based studies in odense, denmark. *Scandinavian Journal of Medicine & Science in Sports, 13*(1), 70-76.

Richardson, J. K., Thies, S. B., DeMott, T. K., & Ashton-Miller, J. A. (2004). A comparison of gait characteristics between older women with and without peripheral neuropathy in standard and challenging environments. *Journal of the American Geriatrics Society, 52*(9), 1532-1537.

Sauvage, L. R., Jr., Myklebust, B. M., Crow-Pan, J., Novak, S., Millington, P., Hoffman, M. D., . . . Rudman, D. (1992). A clinical trial of strengthening and aerobic exercise to improve gait and balance in elderly male nursing home residents. *American Journal of Physical Medicine & Rehabilitation, 71*(6), 333-342.

Schlicht, J., Camaione, D. N., & Owen, S. V. (2001). Effect of intense strength training on standing balance, walking speed, and sit-to-stand performance in older adults. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 56*(5), M281-286.

Spyropoulos, P., Pisciotta, J. C., Pavlou, K. N., Cairns, M. A., & Simon, S. R. (1991). Biomechanical gait analysis in obese men. *Archives of Physical Medicine and Rehabilitation, 72*(13), 1065-1070.

Stevens, J. P. (2002). *Applied multivariate statistics for the social sciences* (4th ed.). Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Toole, T., Thorn, J. E., Panton, L. B., Kingsley, D., & Haymes, E. M. (2007). Effects of a 12-month pedometer walking program on gait, body mass index, and lower extremity function in obese women. *Perceptual and Motor Skills, 104*(1), 212-220.

Topp, R., Mikesky, A., Dayhoff, N. E., & Holt, W. (1996). Effect of resistance training on strength, postural control, and gait velocity among older adults. *Clinical Nursing Research, 5*(4), 407-427.

Villareal, D. T., Banks, M., Sinacore, D. R., Siener, C., & Klein, S. (2006). Effect of weight loss and exercise on frailty in obese older adults. *Archives of Internal Medicine, 166*(8), 860-866.

Vismara, L., Romei, M., Galli, M., Montesano, A., Baccalaro, G., Crivellini, M., & Grugni, G. (2007). Clinical implications of gait analysis in the rehabilitation of adult patients with "prader-willi" syndrome: A cross-sectional comparative study ("prader-willi" syndrome vs matched obese patients and healthy subjects). *Journal of Neuroengineering and Rehabilitation, 4*, 14.

Whittle, M. W. (2007). *Gait analysis: An introduction* (4 ed.). Philadelphia, PA: Elsevier.