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Original Article

Effects of obesity class on flat ground walking and obstacle negotiation

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Abstract

Objectives: Although much is known about the impact of obesity on gait, not much is understood about how classes of obesity affect movement. The purpose of this study was to examine the effects of weight classification on walking. **Methods:** Sixty-seven women with normal BMI (n=13), overweight/Class I obesity (n=18), Class II obesity (n=16), and Class III obesity (n=20) participated. Gait parameters (velocity and percent of the gait cycle spent in swing and stance phases) were collected as participants walked on flat ground and crossed three obstacle heights. **Results:** Adults with normal BMI had faster velocities (F (3,63)=12.60, p=.000017), shorter portions of the gait cycle spent in stance (F (3,62)=7.29, p=.00029), and a larger percent of the gait cycle spent in swing than those with higher BMI scores (F (3,62)=5.43, p=.002). Adults with overweight/Class I obesity had faster velocities than those with Class III obesity (p=.000082, d=1.20) as well as less variable velocities than those with Class II (p=.002, d=-.40) and Class III (p=.01, d=-1.0) obesity. No differences in velocity were found between those with Class II and Class III obesity (p=.12, d=.57). **Conclusions:** These results suggest the need to encourage adults to decrease overweight/Class I obesity but that an equally important goal is to prevent an increase in BMI leading to Class II obesity.

Keywords: Obesity, Gait, Walking, Obstacles, Weight Classification

Introduction

Obesity impacts the ability to engage in the moderate and vigorous levels of physical activity needed not only to lose weight, but to maintain weight loss[1-5]. Some of the reasons that affect the ability to participate in intense bouts of physical activity are due to limitations in gait and postural stability that have been noted in this population. Individuals with obesity demonstrate differences in walking based on biomechanical and spatiotemporal measures. When walking on flat ground, individuals with obesity tend to limit ankle, knee, and hip range of motion[6]. They also show higher ground reaction forces[7] and load at the knee[8] when walking at a preferred speed compared to those with a normal body mass index (BMI). Differences in walking are perceptible with spatiotemporal measures as well. Those with obese BMI scores decrease velocity[9-11], step length[9], swing time[9], and cadence[9] and increase double limb support time[10] and stance time[9,10] during the walking cycle: walking more slowly with shorter steps, less time balancing on one leg, and more time with both feet on the ground. These modifications could affect recovering from a loss of balance to prevent falls (e.g., impaired postural control during quiet stance)[12]; fall risks are 50% higher for adults with obesity above 65 years old[13].

Obesity also influences adults' ability to perform tasks with external constraints, particularly those that require controlling the body's center of mass. For instance, adults with obesity demonstrate decreased peak and mean vertical sacrum velocity during sit-to-stand tasks[14,15], decreased scores on balance tasks[16], and decreased velocity, swing time, step length and increased double limb support time during obstacle negotiation[3,4,17-19]. Challenges with gait and postural stability during everyday tasks increase the chance of sustaining falls and injuries in this population.

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Table 1. Means and standard deviations for body mass index, age, as well as reported physical activity/sports experience per group (yes or no).

Group	BMI (kg/m²)	n	Age (in years)	Previous physical activity/sports experience (yes or no)
Normal BMI	22.56 (1.61)	13	38.20(7.04)	9 yes/4 no
Overweight/ Class I	29.36 (3.19)	18	36.16 (12.76)	11 yes/7 no
Class II	37.78 (1.42)	16	41.17 (5.89)	6 yes/10 no
Class III	44.31 (4.24)	20	42.72 (11.43)	8 yes/12 no

Although much is known about the overall impact of obesity on gait and postural stability, not much is understood about how classes of obesity affect movement. The term obesity encompasses those with a BMI above 30 kg/m². However, according to guidelines from the Centers for Disease Control, more specific classifications exist beyond a BMI of 30 kg/m². These classifications include Class I obesity (≥30 kg/m² and <35 kg/m²), Class II obesity (≥35 kg/m² and <40 kg/m²), and Class III obesity (>40 kg/m²). The literature shows that the higher the class of obesity, the higher the association with health risks. Yet, few studies exist that examine how increasing classes of obesity affect gait and postural stability. We also understand little about variability in motor movements as they relate to increasing classes of obesity. In adulthood, high levels of variability during motor tasks are associated with individuals who are completing challenging tasks[20], those who have impaired motor patterns[21], or both[22]. Whether motor variability differs with increasing classes of obesity is not known.

The purpose of this study was to investigate how increasing obesity classes affected gait and gait variability in adults. Spatiotemporal gait parameters were compared in adults with normal BMI, overweight BMI/Class I obesity, Class II obesity, and Class III obesity. The hypothesis was that increasing classes of obesity would result in more challenges with gait and that the greatest differences would exist among those with normal BMI, Class II obesity, and Class III obesity.

Method

Participants

Sixty-seven women (*Mean* age=39.56 years, *SD*=13.47) with normal BMI (kg/m²) (*Mean* age=38.20 years, *SD*=7.04), overweight/Class I obesity (*Mean* age=36.16 years, *SD*=12.76), Class II obesity (*Mean* age=41.17 years, *SD*=5.89), and Class III obesity (*Mean* age=42.72 years, *SD*=11.43) were recruited at the Massachusetts General Hospital Weight Center (Table 1).

The sample size was estimated for changes in a primary spatio-temporal endpoint (i.e., velocity). The sample size for gait differences between those with normal and obese BMI was estimated from Gill et al.[19] in which a 5% difference between groups was observed in velocity. The clinical significance of a 5% increase in velocity (as well as changes in other gait parameters) is that the increased velocity leads to an increase in walking stability[19]. A power analysis was done using the Gill et al.[19] study with an effect size of Cohen's *d*=1.11, power of 90%, and an adjusted 2-sided alpha of 5%. With this model, 10 subjects would be needed to observe group differences in gait.

All participants had the ability to walk without the aid of an assistive device. Exclusionary criteria were: being scheduled to undergo knee surgery, having no significant cardiovascular, musculoskeletal, vestibular, or other neurologic disorders. These criteria were confirmed via participant reports and experimenters' observations. The study was approved by the Boston University Institutional Review Board and conformed to the Declaration of Helsinki. Informed written and verbal consent were obtained before testing began.

Gait measurements and obstacles

Gait parameters were obtained using a 6.10 m long × 0.89 m wide pressure-sensitive gait carpet (Protokinetics, LLC; Peekskill, NY, USA). The walkway uses an x-y coordinate system to acquire spatial and temporal gait parameters at a sampling frequency of 120 Hz with a spatial resolution of 1.27 cm and a temporal resolution accuracy of 1 sample. Dependent variables selected included velocity (speed) in cm/s, percent of the gait cycle spent in swing (percent of time with one foot moving through the air), and percent of the gait cycle spent in stance (percent of time with feet in contact with the ground). We also calculated the coefficient of variation (standard deviation/mean) for each of the variables to obtain a measure of variability.

All participants stepped over three fixed obstacle heights that represented the heights of obstacles that they would encounter in everyday life (e.g., a door threshold, a small step, or a tall step). The obstacles were created using a wooden dowel (121 cm long) and two rectangular towers (9 cm x 10 cm x 22 cm) with holes drilled at 4 cm, 8 cm, and 16 cm (low, medium, and high). Towers were placed halfway down the walking path (8 m) on either side of the gait carpet with the dowel fitted into corresponding holes in each tower.

Procedure

Before completing the obstacle task, we measured participants' height with a stadiometer and weight with

Table 2. Schematic representing the experimental protocol.

CONDITIONS	#TRIALS
Initial baseline (no obstacle)	5
Low obstacle (4 cm)	5
Medium obstacle (11 cm)	5
High obstacle (16 cm)	5
Final baseline (no obstacle)	5

a scale. During the task, participants walked at a self-selected pace for 25 trials down a 16-m walking path with the gait carpet in the center (Table 2). The 25 trials included five conditions with five trials each: initial baseline, crossing obstacles of three heights, and final baseline. Initial and final baselines involved walking on flat ground without obstacles. For obstacle conditions, low, medium, and high obstacles were placed halfway down the path. Obstacle height order was randomized using a random number generator and counterbalanced between patients. All trials were completed in one experimental session ranging from 45- to 60-minutes.

Statistical analyses

All analyses were conducted using SPSS version 24.0. To determine whether participants recalibrated to their normal walking patterns after crossing obstacles, 2 condition (initial baseline, final baseline) x 4 group (normal BMI, overweight/Class I obesity, Class II obesity, Class III obesity) repeated measures (RM) ANOVAs were conducted on the dependent variables. How participants modified their gait to adapt to the three obstacle heights was examined by running 3 condition (low, medium, high obstacles) x 4 group (normal BMI, overweight/Class I obesity, Class II obesity, Class III obesity) RM ANOVAs on the dependent variables. Significance was set at .05 for all tests. Post hoc analyses consisted of pairwise comparisons. The Bonferroni correction was used for all tests. Cohen's d is listed after each p-value as a measure of effect sizes for follow up pairwise comparisons. Interpreting effect size is based on the absolute value of Cohen's *d*. Absolute values of Cohen's *d* are interpreted as small, medium, or large: absolute values of Cohen's $d \geq 0.2$= small effects, ≥ 0.5= medium effects, and ≥ 0.8= large effects.

Results

Reliability values

Intraclass correlations for velocity and percent stance (*r*(67)=-.60, *p*=.001), velocity and percent swing (*r*(67)=.74, *p*=.001), and percent stance and percent swing (*r*(67)=-.79, *p*=.001) demonstrated reliability for the dependent gait variables. The results were also reliable for the gait variability measures for the coefficients of variation (CV) for velocity and percent stance (*r*(67)=.68, *p*=.001), velocity and percent swing (*r*(67)=.75, *p*=.001), and percent stance and percent swing (*r*(67)=-.88, *p*=.001).

Initial and final baseline walking

Comparisons of mean gait parameters at initial and final baseline showed significant results for velocity, stance time, and swing time (Table 3). For velocity, we found main effects for condition (*F* (1,63)=21.63, *p*=.000017) and group (*F* (3,63)=12.60, *p*=.000017). Velocity was faster at the final versus the initial baseline condition. Follow up analyses on group showed that those with a normal BMI had faster velocities than those with overweight/Class I (*p*=.01, *d*=.86), Class II (*p*=.000082, *d*=1.97), and Class III (*p*=.000000016, *d*=2.58) obesity. Those in the overweight/Class I obesity group had faster velocities than those in the Class III obesity group (*p*=.000082, *d*=1.20). Velocities were not significantly different between adults with Class II and Class III obesity (*p*=.12, *d*=.57) or between adults with overweight/Class I and Class II obesity (*p*=.082, *d*=.59).

Results for stance time revealed a main effect for condition (*F* (1,62)=23.60, *p*=.000008) and group (*F* (3,62)=7.29, *p*=.00029) as well as an interaction between condition and group (*F* (3,62)=9.87, *p*=.000021). Stance time decreased from the initial to the final baseline. Follow up comparisons showed that stance time was shorter for those with normal BMI compared to the overweight/Class I (*p*=.000034, *d*= -1.0) and Class III groups (*p*=.007, *d*=-.60). Follow up analyses on the condition by group interaction showed that at the final baseline condition, those with normal BMI had shorter stance times than the overweight/Class I (*p*=.000005, *d*=-2.41), Class II (*p*=.019, *d*=-.99), and Class III (*p*=.00027, *d*=-2.13) groups.

Findings for swing time showed a main effect for group (*F* (3,62)=5.43, *p*=.002); those with normal BMI had larger swing times than the overweight/Class I (*p*=.001, *d*=1.0), Class II (*p*=.025, *d*=.67), and Class III (*p*=.001, *d*=.87) groups.

Analyses on the coefficient of variation (CV) for velocity, stance, and swing revealed differences in variability. Results for the CV for velocity showed a main effect for condition (*F* (1,58)=7.49, *p*=.008), group (*F* (1,58)=4.26, *p*=.003), and an interaction between condition and group (*F* (3,58)=5.26, *p*=.003). Variability for velocity decreased from the initial to the final baseline condition. Adults in the overweight/Class I obesity group demonstrated less variability than adults with Class II (*p*=.002, *d*=-.40) and Class III (*p*=.01, *d*=-1.0) obesity. At the final baseline condition, adults in the overweight/Class I obesity group were less variable than those with Class II (*p*=.000002, *d*=-2.00) and (*p*=.000002, *d*=-1.33) Class III obesity.

The coefficient of variation for stance revealed a main effect for group (*F* (3,58)=5.26, *p*=.001); those with normal BMI had more variability in stance time than the overweight/Class I (*p*=.001, *d*=.83), Class II (*p*=.004, *d*=.67), and Class III (*p*=.000024, *d*=1.00) groups. However, a main effect for group for the CV of swing time (*F* (3,58)=3.17, *p*=.031) showed that the overweight/Class I obesity group had less

Table 3. Means and standard deviations for gait parameters at initial and final baseline.

	Group	Initial	Final
Velocity (cm/s)	Normal BMI	120.56 (17.98)	130.78 (19.15)
	Overweight/Class I	108.35 (18.86)	113.03 (19.36)
	Class II	98.69 (12.35)	103.79 (15.61)
	Class III	92.53 (12.13)	93.65 (13.79)
Stance time (%GC)	Normal BMI	62.69 (3.46)	59.53 (5.00)
	Overweight/Class I	65.60 (1.60)	65.09 (2.31)
	Class II	62.89 (2.38)	62.25 (2.74)
	Class III	63.60 (1.96)	63.70 (1.96)
Swing time (%GC)	Normal BMI	39.87 (3.02)	39.54 (3.24)
	Overweight/Class I	36.10 (3.36)	36.31 (3.44)
	Class II	37.11 (2.38)	37.75 (2.74)
	Class III	36.40 (1.96)	36.30 (1.96)
CV velocity	Normal BMI	0.07 (.05)	0.03 (.01)
	Overweight/Class I	0.05 (.03)	0.02 (.01)
	Class II	0.06 (.03)	0.06 (.02)
	Class III	0.05 (.02)	0.06 (.03)
CV stance time	Normal BMI	0.04 (.02)	0.04 (.05)
	Overweight/Class I	0.02 (.04)	0.01 (.01)
	Class II	0.02 (.01)	0.02 (.01)
	Class III	0.02 (.01)	0.02 (.01)
CV swing time	Normal BMI	0.03 (.02)	0.04 (.06)
	Overweight/Class I	0.02 (.02)	0.02 (.01)
	Class II	0.04 (.01)	0.03 (.02)
	Class III	0.03 (.01)	0.03 (.01)

**CV=coefficient of variation. *GC=gait cycle.*

variable swing times than those with normal BMI (*p*=.015, *d*=-.38) or Class II obesity (*p*=.01, *d*=-.25).

Crossing obstacles

We found significant effects for velocity, stance time, and swing time during obstacle crossing (Table 4). For velocity, we found a main effect for condition (*F* (2,118)=37.43, *p*=.00000000000026) and a main effect for group (*F* (3,59)=15.12, *p*=.00000021). Velocity was faster at the low versus medium (*p*=.001, *d*=.18) and high (*p*=.0000000000012, *d*=.48) obstacle heights. Velocity was faster for the normal BMI group compared to the overweight/Class I (*p*=.003, *d*=1.37), Class II (*p*=.000002, *d*=2.64), and Class III (*p*=.000000058, *d*=3.08) groups and for the overweight/Class I group versus the Class II (*p*=.018, *d*=1.03) and Class III (*p*=.001, *d*=1.48) obesity groups.

The results for stance revealed a main effect for group (*F* (2,118)=4.64, *p*=.049), main effect for condition (*F* (3,59)=2.78, *p*=.014), and a group by condition interaction (*F* (6,118)=2.99, *p*=.016). Stance was longer at the high versus low (*p*=.034, *d*=.40) and medium (*p*=.019, *d*=.20) obstacles. The overweight/Class I obesity group had longer portions of the gait cycle spent in stance than those with normal BMI (*p*=.012, *d*=.75) and Class II obesity (*p*=.029, *d*=1.00). Follow up comparisons on the condition by group interaction showed that on low and medium obstacles that those with overweight/Class I obesity spent more of the gait cycle in stance than those with normal BMI (low: *p*=.004, *d*=.57; medium: *p*=.007, *d*=1.20) and that on high obstacles that those with overweight/Class I obesity had a longer portion of time in stance than those with Class II (*p*=.013, *d*=1.08) and Class III (*p*=.033, *d*=1.11) obesity.

The analyses showed main effects for condition (*F* (2,118)=7.50, *p*=.001) and group (*F* (3,59)=6.03, *p*=.001) for swing. Swing was lowest at the low versus medium (*p*=.0000057, *d*=-.33) and high (*p*=.002, *d*=-.75) obstacles and those with normal BMI had longer portions of the gait cycle spent in swing than the overweight/Class I (*p*=.003, *d*=.78), the Class II (*p*=.001, *d*=1.08) and Class III (*p*=.00024, *d*=1.17) obesity groups.

The CV for velocity revealed a main effect for group (*F* (3,59)=12.94, *p*=.000001); those with normal BMI and overweight/Class I obesity demonstrate less variability than those with Class II (normal BMI: *p*=.00042, *d*=-1.50; overweight/Class I: *p*=.00015, *d*=-.80) and Class III (normal

Table 4. Means and standard deviations for gait parameters at low, medium, and high obstacles.

	Group	Low	Medium	High
Velocity (cm/s)	Normal BMI	126.66 (17.21)	125.73 (17.77)	122.85 (15.63)
	Overweight/Class I	108.27 (21.73)	106.59 (21.94)	102.30 (22.94)
	Class II	94.68 (13.05)	91.13 (14.29)	88.58 (13.18)
	Class III	87.54 (14.67)	86.05 (14.84)	82.79 (13.82)
Stance time (%GC)	Normal BMI	60.79 (6.97)	60.52 (8.04)	63.60 (5.17)
	Overweight/Class I	64.85 (2.31)	65.01 (3.71)	65.52 (4.28)
	Class II	62.30 (2.78)	62.28 (2.62)	62.27 (2.95)
	Class III	63.10 (1.52)	62.73 (1.91)	62.74 (1.69)
Swing time (%GC)	Normal BMI	41.57 (4.21)	42.97 (4.95)	43.12 (4.64)
	Overweight/Class I	37.54 (4.38)	38.48 (5.24)	39.24 (6.00)
	Class II	37.70 (2.78)	37.72 (2.62)	37.73 (2.95)
	Class III	36.90 (1.52)	37.27 (1.91)	37.26 (1.69)
CV velocity	Normal BMI	0.04 (.02)	0.03 (.01)	0.03 (.03)
	Overweight/Class I	0.03 (.02)	0.03 (.02)	0.04 (.02)
	Class II	0.06 (.03)	0.06 (.03)	0.06 (.03)
	Class III	0.07 (.02)	0.06 (.03)	0.07 (.04)
CV stance time	Normal BMI	0.06 (.12)	0.07 (.12)	0.03 (.02)
	Overweight/Class I	0.02 (.01)	0.02 (.01)	0.02 (.02)
	Class II	0.03 (.01)	0.02 (.01)	0.03 (.01)
	Class III	0.02 (.01)	0.02 (.01)	0.03 (.01)
CV swing time	Normal BMI	0.05 (.06)	0.04 (.06)	0.03 (.02)
	Overweight/Class I	0.03 (.02)	0.03 (.02)	0.03 (.02)
	Class II	0.04 (.02)	0.04 (.02)	0.05 (.01)
	Class III	0.04 (.02)	0.04 (.03)	0.05 (.02)

**CV=coefficient of variation. *GC=gait cycle.*

BMI: p=.000023, d=-2.00; overweight/Class I: p=.000006, d=-1.20) obesity.

Discussion

The purpose of this study was to examine how weight classification influenced adults' ability to adapt their gait as they crossed obstacles of varying heights. The results showed that those with normal BMI had faster velocities, shorter portions of the gait cycle spent in stance, and a larger percent of the gait cycle spent in swing than those with higher BMI scores. Adults with overweight/Class I obesity had faster velocities as well as less variable velocities than those with Class II and Class III obesity. Interestingly, no differences in velocity were found between those with Class II and Class III obesity.

As expected, we found that adults with normal BMI had faster velocities than those with overweight BMI/Class I obesity, Class II obesity, and Class III obesity. Interestingly, we also found no differences in velocity on flat ground between adults with Class II and Class III obesity. Previous studies show that obesity heightens the likelihood of developing difficulty with walking speed and distance over a 4-year period[23]. Our finding suggests that the effects of Class II obesity on gait are deleterious enough to make them indistinguishable from the effects of Class III obesity. Thus, although previous studies on differences between walking in those with normal BMI and obese BMI[6-12,19] are important for understanding the effects of obesity on gait, these results suggest that it is equally important to examine how various classes of obesity impact walking. Such investigations could lead to differences in how rehabilitation therapists treat individuals with obesity.

Variability in movement patterns is linked with impaired movement and challenges in completing difficulty tasks[24]. In this study, those with normal BMI had lower variability in velocity compared to all groups suggesting less challenges for those with normal BMI to increase speed while walking. Higher BMI scores are associated with decreased velocity[14,19]. This study is unique in demonstrating that increasing BMI is linked to less consistent velocity during walking; our overweight/Class I group had less variability in velocity than those in Classes II and III and less variable percent of the gait cycle spent in swing than those in Class II. Challenges with speed[6-8] found in those with obesity support this finding along with difficulty maintaining single limb balance[7,19], which could contribute to variable swing phases profiles. These results point to the importance of helping to improve movement consistency in those with Class II and Class III obesity. Difficulty with walking consistency predisposes adults with obesity to falls and injuries[13], which could significantly lower quality of life and independence[2].

Our results for percent of the gait cycle spent in stance show longer stance phases during obstacle crossing for the overweight/Class I obesity group compared to Classes II and III. As obstacle heights increase, those with higher BMIs may have difficulty with the motor control needed to increase the stance phase on the supporting leg during and after crossing obstacles. This finding suggests the need to improve factors related to difficulty with single limb stance in those with obesity such as leg strength[16] and practice completing functional tasks such as rising from a chair[15]. Another finding that supports the role of stance in this sample includes increased variability in percent stance for those with normal BMI. In populations with normal BMI, as walkers become more experienced through childhood[24] and in adulthood[20,25], walking is typically considered to include gait parameters that are less variable. However, little research has investigated how gait variability during task constraints differs between typical and impaired populations[21,22]. Typical movement patterns can also be associated with allowing for increases in movement variability, particularly during less challenging tasks like flat ground walking[25].

Conclusions

These results suggest that increases in classes of obesity are associated with more difficulties with spatiotemporal gait and gait variability. Most importantly, there were few differences between Class II and Class III obesity. This suggests the need to encourage adults to decrease overweight/Class I obesity and that an equally important need is to prevent an increase in BMI leading to Class II obesity.

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