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Original Article

Association between the Functional Gait Assessment and spatiotemporal gait parameters in individuals with obesity compared to normal weight controls: A proof-of-concept study

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Abstract

Objectives: Obesity is a significant global health concern that involves motor impairment, including deficits in gait and balance. A simple tool would be useful to capture gait and balance impairment in obesity. We assessed whether the Functional Gait Assessment (FGA) captures impairment in individuals with obese BMI ($\geq$30 kg/m^2) and whether impairment was related to spatiotemporal gait parameters. **Methods**: Fourteen individuals with obese BMI and twenty individuals of normal weight underwent the FGA. Spatiotemporal gait parameters were collected while participants walked on a pressure sensitive walkway under five conditions: pre-baseline (flat ground walking), crossing small, medium, and high obstacles, and final-baseline (flat ground walking). **Results**: Individuals with obesity had lower scores on the FGA ($p \leq 0.001$) and showed less efficient spatiotemporal gait parameters than healthy controls, particularly when crossing over obstacles (all $ps \leq 0.05$). For participants with obesity, lower FGA scores were associated with decreased gait velocity, but only during obstacle crossing ($p \leq 0.05$). **Conclusions**: The FGA may be a useful tool to capture gait impairment in populations with obesity. Obstacles may help reveal meaningful gait impairments. To our knowledge, this is the first study to examine the FGA in individuals with obesity, and represents a proof-of-concept that motivates further validation studies.

Keywords: Balance, Functional Gait Assessment, Gait, Obesity, Spatiotemporal Gait Parameters

Introduction

Obesity, defined as excessive body fat and elevated body mass index (BMI)$\geq$30 kg/m^2, continues to be a profound domestic and global health crisis[1,2]. In addition to numerous and wide-ranging health risks[3], individuals with obesity show differences in movement and gait compared to individuals of healthy weight[4,5]. These deficits in movement contribute to an increased incidence of falling ranging from 12%[6] to as high as 31%[7], and an 18% increase in reported ambulatory stumbling[6].

Differences in gait and balance in adults with obesity appear to be compensatory strategies to cope with increased mass and to mitigate falling. Those with obese BMI tend to have altered spatiotemporal gait characteristics, including increased step width and double-limb support time and decreased step length and gait velocity[8]. These effects are exacerbated when participants must adjust to altered environmental constraints, such as stepping over obstacles[8,9]. Increased time in double-limb support may be a compensatory mechanism for poor postural control[8]. Obesity may also cause increased joint moments and modified joint kinematics as a result of carrying greater weight. However, results are equivocal; some report no change in joint kinematics and increased joint moments[10], while others report the reverse, where individuals with obesity modify their joint kinematics to maintain or reduce joint moments during gait, particularly about the knee[11,12]. Individuals with obesity also experience differences in postural stability and balance compared to those of healthy weight, affecting both dynamic and static control parameters[13,14]. Rapid corrective actions in response to balance perturbations may be more

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difficult for individuals with obesity, as they show lower muscular power after adjusting for body mass[15,16].

Given the challenges in gait and balance associated with obesity, assessing the severity of gait difficulties and postural stability in this population is important to gain a complete picture of fall risk. Yet, few formal methods of assessing fall risk for this population exist. Thus, it is important for both clinicians and researchers to have an inexpensive, reliable, and simple method to assess gait and balance impairment in individuals with obese BMI.

The primary purpose of this study was to determine how to capture gait and balance impairments in adults with obesity using an inexpensive method as a proof-of-concept for possible future validation. We used a dynamic balance measurement that has been validated in other populations: the Functional Gait Assessment (FGA)[17]. To our knowledge, the FGA has not been employed to assess gait impairment in cohorts of adults with obesity. A secondary purpose was to determine whether scores on the FGA were associated with changes in spatiotemporal gait characteristics during flat ground walking and while stepping over obstacles; this manipulation changes external constraints to better detect gait disturbances. We predicted that individuals with obesity would show lower gait scores on the FGA compared to controls, and that lower FGA scores in those with obesity would be correlated with deficits in spatiotemporal gait parameters within that population.

Methods

Participants

Seventeen participants with obesity ($BMI \geq 30$ kg/m^2) were recruited prior to receiving Roux-en-Y bariatric surgery from the Weight Loss Surgery Program at Boston Medical Center in Boston, Massachusetts. Three participants voluntarily discontinued participation in the gait task after one trial, leaving 14 individuals with obese BMI who participated in the study (M_{BMI}=40.95 (*SD*=5.46), M_{Age}=50.36 (*SD*=10.97), 12 females). Twenty participants with a normal BMI (BMI ≥19 kg/m^2 and ≤25 kg/m^2) were recruited from the greater Boston area (M_{BMI}=23.77 (*SD*=2.53), M_{Age}=45.55 (*SD*=8.77), 14 females). All participants were free of neurological difficulties, had normal or corrected to normal vision and could walk without assistive devices. Participants provided informed verbal and written consent prior to participating in the study. The study was approved by the Boston University institutional review board and conformed to the Declaration of Helsinki.

Gait task

The gait task used in this experiment has been described in previous work[8]. Spatial and temporal footfall data were collected on a GAITRite Walkway system (CIR Systems Inc., Sparta, NJ). The walkway was 4.88 m long x 0.61 m wide, and measured footfall pressure at 120 Hz with a spatial resolution of 1.27 cm.

After collection of anthropometric measures, participants walked at a self-selected pace along the GAITRite walkway under five conditions (5 trials per condition). First, in the initial baseline condition, participants walked over flat ground without obstacles. In the following three conditions, participants encountered small (4 cm), medium (8 cm), or large (16 cm) obstacles that were placed halfway down the walkway (2.44 m). The heights were a proxy for obstacles that participants might encounter in everyday life like a door threshold, short step, or tall step. The obstacle was a wooden dowel suspended across the walkway that was inserted into holes on two wooden towers. Obstacle conditions were counterbalanced between participants. Finally, in the final baseline condition, participants again walked over flat ground without obstacles.

Functional Gait Assessment (FGA)

The FGA has been used to evaluate gait impairment in many clinical populations[18-25]. The FGA has high interrater reliability between population groups and is a reliable and valid measure of gait impairment[17], and can be easily administered in many different settings. The FGA consists of 10 tasks that assess locomotion, balance, and coordination. These tasks are: flat ground walking (Item 1), changing gait speed (Item 2), walking with horizontal and vertical head turns (Items 3 and 4, respectively), walking with a pivot turn (Item 5), stepping over an obstacle (Item 6), heel-to-toe walking (Item 7), walking without visual input (Item 8), walking backwards (Item 9), and walking up and down stairs (Item 10). Each task was scored on a four-point ordinal Likert scale ranging from zero to three, with three denoting superior performance, and zero denoting severe impairment on the task. Prior to each item, participants were first verbally instructed how to perform each task. Demonstrations were performed by a trained experimenter if necessary. Performance on each item was directly observed by the experimenter and assessed immediately upon completion of each task.

Data processing and statistical analyses

Data from the gait task were pre-processed using GAITRite software and custom Matlab scripts (Mathworks, Inc., Natick, MA). For the gait task, the six dependent variables were gait velocity (cm/s), step length (cm), step width (cm), cadence (steps/minute), single- and double-limb support (as a percent of the gait cycle). During baseline walking conditions, these variables were computed for each leg as an average across a given trial. During obstacle conditions, these variables were computed for the leading leg step across the obstacle. Statistical analyses were performed using custom-written scripts in RStudio software. The alpha threshold was set at $p<0.05$ for all tests. The control group demonstrated a ceiling effect in the total FGA score, which violated assumptions of homogeneity of variance for parametric tests. Thus, to examine differences in FGA scores, we used nonparametric tests. First, we conducted a Mann-Whitney U-test to examine

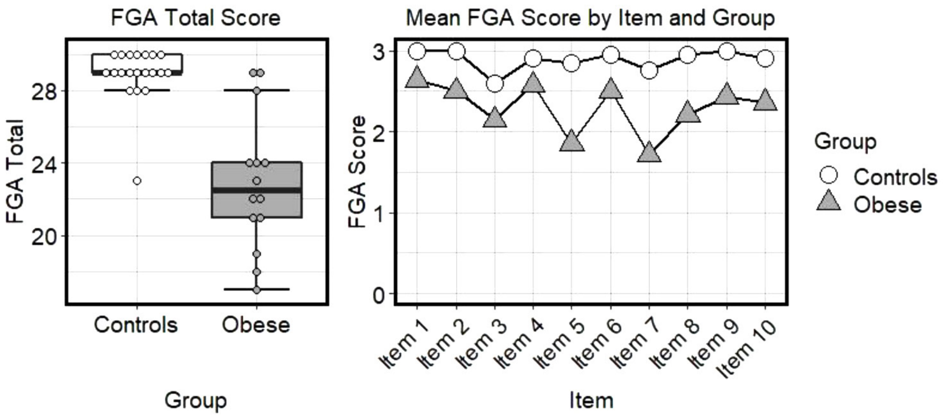

Figure 1. Left panel shows a box-and-whisker plot of the FGA total score between the two groups. Points represent individual participants. Right panel shows averaged scores for each item on the FGA by group.

Table 1. Demographic and anthropometric data for study participants.

Participant	Group	Age	Sex	Height (m)	Weight (kg)	BMI (kg/m²)	FGA Total
1	Obesity	56	Female	1.66	110.0	40.11	17
2	Obesity	45	Female	1.63	117.62	36.41	22
3	Obesity	37	Female	1.68	142.0	51.6	28
4	Obesity	49	Female	1.55	100.4	41.82	21
5	Obesity	51	Female	1.65	117.42	43.39	22
6	Obesity	35	Female	1.71	113.48	38.8	24
7	Obesity	62	Male	1.77	111.36	35.54	24
8	Obesity	61	Male	1.84	130.9	38.66	29
9	Obesity	64	Female	1.65	104.54	38.35	23
10	Obesity	54	Female	1.83	173.01	35.78	24
11	Obesity	59	Female	1.61	136.46	52.64	18
12	Obesity	62	Female	1.57	104.23	42.28	19
13	Obesity	35	Female	1.73	127.56	42.64	29
14	Obesity	38	Female	1.68	99.2	35.3	21
15	Control	40	Male	1.78	83.90	26.54	30
16	Control	38	Female	1.70	63.50	21.92	28
17	Control	40	Male	1.68	72.60	25.85	29
18	Control	57	Female	1.65	52.20	19.15	28
19	Control	46	Female	1.68	67.10	23.89	30
20	Control	43	Male	1.80	86.20	26.52	30
21	Control	38	Female	1.60	58.10	22.70	29
22	Control	38	Female	1.60	53.50	20.70	29
23	Control	40	Female	1.78	73.90	23.38	28
24	Control	66	Female	1.50	47.20	21.03	29
25	Control	38	Female	1.60	47.60	18.59	30
26	Control	48	Female	1.75	72.60	23.63	30
27	Control	60	Female	1.73	67.10	22.50	23
28	Control	48	Female	1.73	71.70	24.04	29
29	Control	43	Male	1.80	86.20	26.52	30
30	Control	56	Female	1.70	79.80	27.55	29
31	Control	55	Female	1.70	76.20	26.30	29
32	Control	39	Male	1.78	77.10	24.39	29
33	Control	35	Male	1.77	78.50	25.06	30
34	Control	43	Female	1.70	72.10	24.95	29

group differences in the FGA total score. Next, we separately assessed whether groups differed on each individual item. For each item, frequency tables were constructed between the group variable (two levels: Control vs. Obese BMI) and performance variable (four levels: 0 (severe impairment) through 3 (no impairment)). Small overall sample size and expected cell frequencies less than five disallowed chi-square analyses. As such, Fisher's Exact Tests were conducted to evaluate whether groups differed at each FGA item.

We next evaluated how the two groups differed on the gait tasks to confirm differences in spatiotemporal characteristics and replicate prior findings from our group[8,9] in this subset of participants. Preliminary results showed that effect sizes between the initial and final baseline conditions were negligible. Thus, to determine whether flat ground walking was affected by the obstacle conditions, an independent samples t-test was performed between groups at the initial baseline condition for each of the six spatiotemporal dependent variables. Then, to determine how obstacles modified gait characteristics between groups, a 2 Group (Obese BMI, Normal BMI) vs. 3 Condition (Small, Medium, and Large obstacles) mixed-design ANOVA was used to evaluate if group gait parameters differed across the three obstacle heights. Violations of sphericity were adjusted with a Huynh-Feldt correction where appropriate. Within- and between-subjects contrasts were evaluated with Tukey adjustment to further examine significant effects. Effect sizes were computed using cohen's d for t-tests, and generalized eta squared for ANOVAs (η_g^2; [26]).

Last, we evaluated whether performance on the FGA was related to performance on the gait task. Since the control group was at ceiling, this analysis was performed only in the obese BMI group. Pearson's correlations were used to test the association of the total FGA scores with each of the six spatiotemporal gait task measures during the initial baseline condition and during the high obstacle condition to capture gait parameters under normal and the maximally perturbed conditions in the tasks. This captured the relationship between these variables during both flat ground and obstacle crossing conditions.

Results

Demographic and anthropometric measures for all participants are presented in Table 1. We first examined FGA scores between the obese and control BMI participants to determine whether the FGA produced different scores between the groups. The results showed that those with an obese BMI had lower total FGA (Median=22.5, IQR=21-24) scores than controls (Median=29.00, IQR=29-30; *U*(17, 14)=257, $p \leq 0.001$). Significant differences between groups were found for all items ($p \leq 0.05$) with the exception of vertical head turns and climbing stairs; the obese BMI group always achieved a lower average score than controls for each item (Figure 1).

Before determining whether FGA scores were related to differences in spatiotemporal gait parameters, we first wished to confirm that the groups indeed showed different spatiotemporal gait characteristics over flat ground walking and while stepping over obstacles, as has been shown in prior research[8,9]. T-tests comparing groups for each spatiotemporal variable during the initial baseline condition revealed significant differences between the groups; individuals with obese BMI demonstrated significantly shorter step lengths, larger step widths, slower step velocity, shorter single-limb support percent, longer double-limb support percent, and slower cadence while walking over flat ground (all $p \leq 0.001$; Table 2). Effect sizes for these measures were large ($d \geq 0.8$).

Analyses comparing groups during obstacle crossing conditions yielded main effects of group for all gait measures; obese BMI participants had significantly shorter step lengths, larger step widths, slower step velocity, shorter single-limb support, longer double-limb support time, and slower cadence than controls (all $p \leq 0.01$; Table 3, Figure 2). Effect sizes were medium to large, suggesting robust differences between groups. Between the control and obese groups (within conditions), post-hoc contrasts showed that groups were significantly different at all obstacle heights in all six spatiotemporal dependent variables (all $p \leq 0.05$). Thus, post-hoc comparisons between groups consistently showed that obesity resulted in less efficient gait in all obstacle conditions. A significant main effect of obstacle condition was found for step width, step velocity, single-limb support, double-limb support, and cadence. Effect sizes were generally small. Between conditions (within groups), post-hoc contrasts revealed that both groups showed significantly slower step velocity and slower cadence from small to medium, medium to large, and small to large obstacles (all $p \leq 0.05$). Single limb support time percent in the control group increased significantly from small to medium, medium to large, and small to large obstacles; in the group with obesity, single limb support percent was significantly increased only when comparing the large obstacle to the small and medium obstacles (all $p \leq 0.05$). Likewise, double limb support time percent in the control group decreased significantly from small to medium, medium to large, and small to large obstacles; in the group with obesity, double limb support percent was significantly reduced only when comparing the large obstacle to the small and medium obstacles (all $p \leq 0.05$). Finally, participants with obesity showed significantly wider step width between the small and tall obstacles only ($p=0.02$); control participants showed no significant difference in step width between obstacle conditions. No post-hoc contrasts revealed differences between obstacle conditions for either group in step length. Taken together, post-hoc comparisons between conditions (within groups) showed that the gait of both the control and obese groups became less efficient when encountering progressively larger obstacles; as obstacles became larger, double-limb support increased, while single-limb support, step velocity, and cadence decreased. No Group x Condition interactions were observed. Overall, obese BMI and increasing obstacle heights both contributed to changes in spatiotemporal gait parameters.

Table 2. Results of independent samples t-tests for spatiotemporal gait variables. $^{+}p<0.10$, $^{*}p<0.05$, $^{**}p$ $p<0.01$, $^{***}p<0.001$.

Initial baseline condition independent samples t-test					
Measure and effect	***t* (df)**	***p***	***d***	***Control Mean (SD)***	***Obesity Mean (SD)***
Step Length (cm)	6.31(32)	≤0.001***	2.20 (large)	54.93(4.90)	45.28 (3.49)
Step Width (cm)	-3.77 (32)	≤0.001***	-1.32 (large)	7.76 (2.20)	11.13 (3.00)
Step Velocity (cm/s)	6.54 (32)	≤0.001***	2.28 (large)	105.36 (14.75)	75.86 (9.69)
Single Limb Support %	4.43 (32)	≤0.001***	1.54 (large)	36.18 (1.24)	33.54 (2.22)
Double Limb Support %	-5.39 (32)	≤0.001***	-1.88 (large)	12.25 (1.39)	15.27 (1.88)
Cadence (steps/min)	3.72 (32)	≤0.001***	1.30 (large)	107.23 (9.62)	94.82 (9.52)

Table 3. Results of 2 (Group) x 3 (Condition: Low Obstacle, Medium Obstacle, High Obstacle) mixed-design ANOVAs for the six spatiotemporal variables. $^{+}p<0.10$, $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$.

Obstacle condition mixed-design ANOVA results			
Measure and effect	***F* (df)**	***p***	η_g^2
Step Length			
Group	*F* (1, 32) = 11.79	< 0.01**	0.26
Condition	*F* (1.92, 61.54) = 0.28	0.75	0.0006
Group x Condition	*F* (1.92, 61.54) = 0.22	0.79	0.0005
Step Width			
Group	*F* (1, 32) = 8.54	< 0.01**	0.19
Condition	*F* (1.92, 61.43) = 3.52	< 0.05*	0.01
Group x Condition	*F* (1.92, 61.43) = 1.50	0.23	0.005
Step Velocity			
Group	*F* (1, 32) = 22.06	< 0.001***	0.40
Condition	*F* (1.93, 61.87) = 52.16	< 0.001***	0.07
Group x Condition	*F* (1.93, 61.87) = 0.13	0.87	0.0002
Single Limb Support %			
Group	*F* (1, 32) = 14.31	< 0.001***	0.27
Condition	*F* (1.89, 60.60) = 32.62	< 0.001***	0.15
Group x Condition	*F* (1.89, 60.60) = 0.99	0.37	0.006
Double Limb Support %			
Group	*F* (1, 32) = 29.42	< 0.001***	0.39
Condition	*F* (1.95, 62.40) = 0.60	< 0.001***	0.22
Group x Condition	*F* (1.95, 62.40) = 1.07	0.35	0.007
Cadence			
Group	*F* (1, 32) = 18.14	< 0.001***	0.35
Condition	*F* (1.84, 58.97) = 41.72	< 0.001***	0.05
Group x Condition	*F* (1.84, 58.97) = 0.79	0.45	0.001

Finally, we assessed the relationship between the FGA and spatiotemporal gait parameters (Figure 3). We found that in the initial baseline condition, no significant correlations were present between FGA and the gait task (all $p>0.05$). However, in the high obstacle condition, a higher FGA score was significantly correlated with faster stepping velocity ($r(12)=0.58$, $p\leq0.05$).

Discussion

The primary aim of this study was to investigate whether impairments in gait in individuals with obesity could be successfully detected by the Functional Gait Assessment[17]. We found that the FGA successfully captured differences in gait between individuals with obesity and control participants.

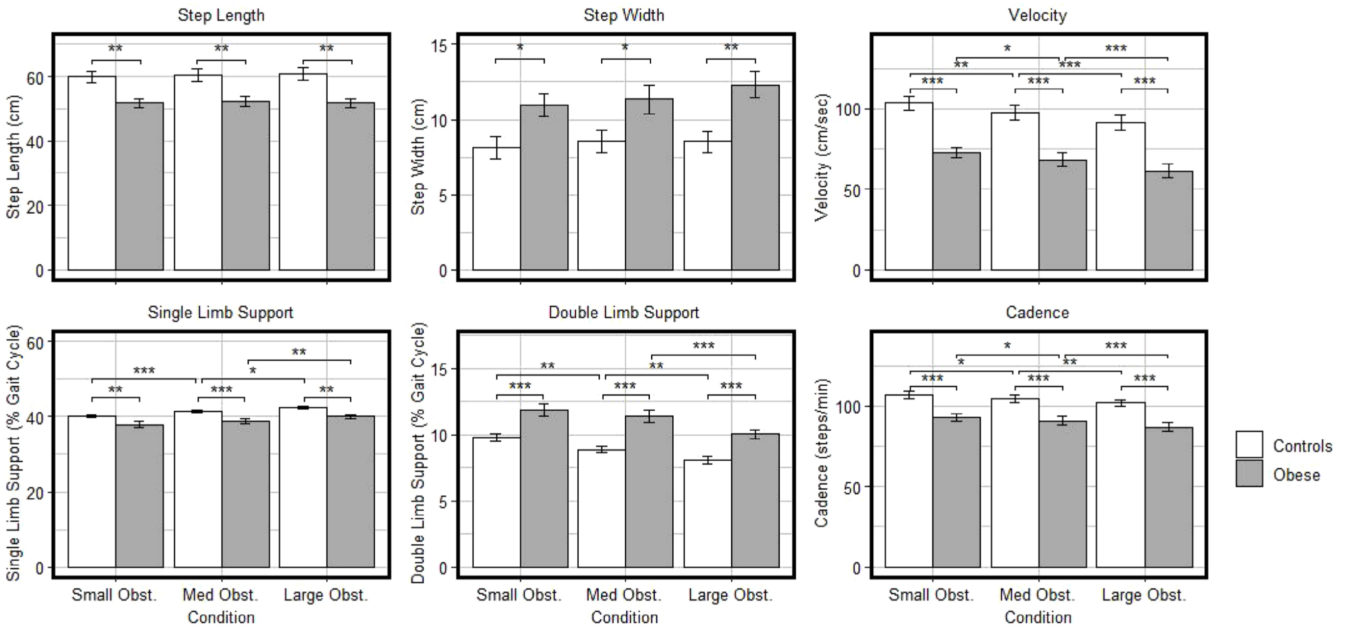

Figure 2. Results of the obstacle crossing conditions for each group across the six spatiotemporal variables of the gait task. Error bars denote standard error of the mean (SEM). Asterisks and horizontal lines represent *select* significant post-hoc comparisons; for figure clarity, comparisons from the small to large obstacles are omitted and the reader is referred to the text of the results section. $^{+}p<0.10$, $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$.

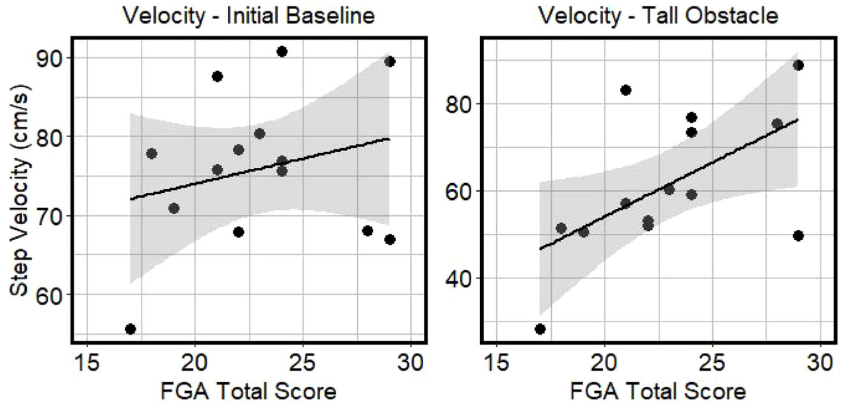

Figure 3. Correlations between gait velocity and FGA total score for the initial baseline (left panel) and tall obstacle (right panel). Gait velocity was significantly associated with FGA score in the tall obstacle condition. A general linear model was used to fit the trend lines. Clouds represent 95% CI.

These differences were evident in both the overall score and in eight of the ten individual items. Additionally, this study aimed to determine whether differences in spatiotemporal gait parameters were associated with performance on the FGA. For individuals with obesity, no association between these two tools was detected during flat ground walking. However, when participants were asked to step over an obstacle, greater impairment in FGA was associated with a decreased step velocity. In other words, we found that individuals with obesity not only crossed obstacles more slowly than controls, but also that in individuals with obese BMI, greater slowing of gait when encountering the obstacle was indicative of broader gait impairment as captured by the FGA.

The results of this study constitute a proof-of-concept for the use of the FGA in obese populations, providing a practical and inexpensive means of investigating gait impairment. To date, most investigations of gait and balance in individuals with obesity have utilized expensive or cumbersome equipment to measure kinetics and kinematics. Importantly, these measures can sometimes suffer from validity and reliability issues due to difficulty in locating bony landmarks and consistent placement of reflective markers due to excess subcutaneous tissue[27,28]. While such tools certainly provide invaluable measures of gait, they are often difficult to scale to large samples or use in a clinical setting. Thus, the FGA could fill an important need to easily assess gait in these settings, or supplement other quantitative gait and balance assessments. This study motivates further research to better identify construct and criterion validity of the FGA with larger sample sizes of individuals with obesity, and determine test-retest and interrater reliability measures, as has been done for other populations[22-25].

Interestingly, in addition to showing greater impairment than controls of healthy weight, our participants with obese BMI showed gait and balance problems that were similar in magnitude to several other disorders. Our participants with obesity had a roughly equivalent FGA score (Mean: 22.5) compared to older adults (Mean: 23.3 (60-90 years old)[24] and 20.8 (80-89 years old)[29]) and patients with Parkinson's disease who had not experienced a fall (Median: 24[25] and Mean: 22.5 off medication[18]). In comparison to stroke patients, our participants with obesity showed FGA scores that were roughly equivalent to patients in one study (Median: 22[23]), though substantially better than patients in another (Mean: 13.86 or 15.21, depending on the rater[22]). Taken together, this suggests that as assessed by the FGA, obesity may be on par with other serious conditions known to have deleterious effects on gait and balance.

Research has indicated that obesity is associated with increased risk of falling. Indeed, one study reported that obese individuals report greater prevalence of fall-related events, with a 12-31% increase in reported fall incidence, and an 18% increase in reported ambulatory stumbling[6,7]. Injury rates due to falls are unclear, with one study reporting that obese individuals may be as much as 48% more likely to experience an injury[30] but another reporting no difference in injury rates between an obese sample and normal-weight controls[7]. Critically, the FGA has been used to measure fall risk in older adults. Wrisley and colleagues (2010) determined that an FGA score of 22 was effective as a fall risk threshold for adults between 60 and 90 years of age. In our study, seven of the fourteen participants with obesity fell at or below this cutoff, supporting increased fall risk in this population. Future work should identify an FGA fall risk cutoff specific to individuals with obesity to better understand and evaluate fall risk in this population.

In this study, we found that individuals with obesity had different spatiotemporal gait parameters than controls during both level ground walking and when crossing obstacles. These differences included increased step width and double-limb support and reduced step length, gait velocity, single-limb support, and cadence. Together, these findings indicated an overall slowing of gait on all conditions, particularly when crossing over obstacles, and are generally consistent with prior work[8,31]. In our results, it was interesting to note reduced single-limb support and extended double-limb support in the group with obesity. These gait changes likely represent adaptive behaviors in the face of unstable postural control, where individuals with obesity increase their base of support for a greater amount of time relative to a single gait cycle. However, reduced single-limb support may increase the likelihood of tripping by crossing the obstacle more quickly and with less clearance, and should be investigated more closely in future research.

Critically, we also found that FGA impairment was associated with slowing of gait when participants with obesity were asked to step over an obstacle, but not during flat ground walking. These findings suggest that slowed gait in individuals with obesity is indeed indicative of gait impairment. Additionally, the presence of these associations during obstacle crossing but not flat ground walking suggests that the presence of environmental constraints on walking may be an informative means of exposing gait impairment in individuals with obesity and other populations. As such, researchers and clinicians alike could consider asking participants or patients to contend with obstacles during gait or balance tasks to gain a clearer or more differentiated picture of a given impairment.

This study is not without limitations. First, the sample size of this study was small, limiting statistical power. Second, given the clinical setting of the assessment and the use of direct observation, experimenters were not blinded to the group assignment of participants. As such, experimenter bias may have influenced FGA scores. Participants were also rated live and only by a single rater, precluding computations of test-retest and inter-rater reliability. Finally, it would have been informative to investigate how FGA scores were striated across different weight classes (i.e., normal weight, overweight, obese I, II, & III). However, given the small number of participants who completed both the FGA and gait task and the mechanisms of recruitment, we did not have a sufficient number of individuals in each of these classes, presenting an opportunity for future investigations.

Conclusion

The Functional Gait Assessment captures impairment of gait in individuals with obesity as compared to normal-weight control participants. Additionally, poorer FGA scores in the obese group were associated with slowing of gait when encountering obstacles, but not during flat over-ground walking. The FGA represents a simple and affordable means of assessing impairment in gait and balance in populations with obesity and can be easily utilized in clinical and research settings. Further, the presence of obstacles during gait tasks may be helpful in revealing meaningful gait impairments in obesity and other populations. To our knowledge, this is the first study to examine the FGA in a sample of individuals with obesity.

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