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Exploring the association between measures of obesity and measures of trip-induced fall risk among older adults

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Abstract

Objective: Explore the association between measures of obesity and measures of trip-induced fall risk among community-dwelling older adults.

Design: Case-control

Setting: Gait laboratory

Participants: Voluntary sample of 55 community-dwelling older adults (≥65 years of age) with body mass index (BMI) of 18.84–44.68 kg/m^2.

Interventions: Not applicable

Main Outcomes Measures: Measures of obesity included six anthropometry-based measures (BMI; thigh, hip and waist circumferences; ratio of waist-to-hip circumference; and index of central obesity) and four DEXA-based measures (percent trunk, leg and total fat; and fat mass index). Measures of risk of tripping during overground walking included median and interquartile range of toe clearance, and area under the swing phase toe trajectory. Measures of trip recovery after a laboratory-induced trip included trunk angle and angular velocity at ground contact of the first recovery step, anteroposterior distance from stepping foot to center of mass at the same instant, and step time of the first recovery step.

Results: Risk of tripping was associated with waist-to-hip ratio and thigh circumference. After grouping participants by waist-to-hip ratio, those with high ratios (≥0.9 cm for males and ≥0.85 cm for females) exhibited significantly greater variability in toe clearance. Trip recovery was associated with hip circumference, thigh circumference, fat mass index, and total fat. After grouping participants by fat mass index, those with high indices (>9 kg/m^2 for males and >13 kg/m^2 for females) exhibited less favorable trunk kinematics following a laboratory-induced trip (Cohen's *d*=0.84).

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Conclusion: Waist-to-hip ratio and fat mass index may more closely relate to trip-induced fall risk than BMI among community-dwelling older adults.

Keywords

aging; falls; gait; obese; BMI; body composition; central obesity

INTRODUCTION

The 2017–2018 National Health and Nutrition Examination Survey reported that >42% of American men and women 60 years of age or older were obese (as per body mass index), with rates significantly increasing from 1999 to 2018 (1). One of the many negative health-related consequences of obesity in older adults is an increased fall risk. A 2020 systematic review reported that obesity in adults ≥60 years of age increases fall risk by 16% relative to non-obese peers (2). Moreover, a history of falling in obese older adults is associated with lower health-related quality of life (3). There is a need to better understand the underlying causes for the increased fall risk among obese older adults to facilitate the identification of high-risk fallers and to inform the development of targeted interventions.

Falls are precipitated by a loss of balance and ultimately occur if the recovery response thereafter is insufficient to restore balance. Indeed, both frequent loss of balance (4, 5) and impaired recovery response (6) increase fall risk. Given that one-in-three falls by older adults are caused by tripping (7), the obesity-related increase in fall risk could result from more frequent tripping and/or an impaired trip recovery response. Regarding the former, older adults with a body mass index (BMI) associated with obesity (BMI ≥30 kg/m^2) exhibit a lower minimum toe clearance (toe_{min}) (8) suggestive of an increased risk of tripping (9). Regarding the latter, both younger (10) and older adults (11) with a BMI associated with obesity exhibit less favorable trunk kinematics during trip recovery.

Characterizing obesity based on BMI is problematic because BMI poorly indicates excessive fat (12, 13). This compelled the World Health Organization to recommend combining BMI with other measures, particularly those indicative of excessive abdominal fat, when assessing obesity-related health conditions. For example, a man with low BMI (one not associated with obesity) and high abdominal fat has nearly twice the mortality risk as a man with similarly low BMI but without high abdominal fat (14). Similar findings exist regarding fall risk. In a cohort of over 3000 adults age ≥50 years, fall risk was 37% higher with high versus low abdominal fat, but not with high versus low BMI (15).

The purpose of this study was to explore the association between measures of obesity and measures of trip-induced fall risk among community-dwelling older adults. Measures of obesity included both anthropometry-based and DEXA-based measures. Trip-induced fall risk was characterized using measures of risk of tripping during overground walking and measures of trip recovery after a laboratory-induced trip. No formal hypotheses were posed given the exploratory nature of this study. Nonetheless, this study is intended to guide the development of hypotheses related to identifying which measures of body habitus best associate with fall risk, which would have clinical relevance in the identification of high risk fallers, and informing the development of targeted preventions.

METHODS

Participants

Participants included 28 older adults (≥65 years of age) with low BMI (18.5–24.9 kg/m^2) and 27 with high BMI (≥30.0 kg/m^2; Table 1). Inclusion criteria were self-reported ability to walk one mile at any pace with minimum rest; no use of an assistive device for walking; no artificial joint replacement; no self-reported history of neurological conditions that interfere with gait (e.g., Parkinson's disease) nor of diabetic neuropathy. Participants completed the Fracture Risk Assessment tool and those with low/medium risk were asked to provide a dual-energy x-ray absorptiometry (DEXA) bone scan taken within ten/five years to confirm the absence of osteoporosis (t-score≤−2.5 for the femoral neck); those with no prior bone scan or at high risk were required to have a bone scan completed for this study. Participants also completed a physical exam to exclude individuals with compromised range of motion in the lower limbs or trunk, or any other pathophysiology that could compromise safety. Prior to the physical exam participants provided written informed consent to participate in this IRB-approved study.

Protocol

We first obtained 10 measures of obesity, including six anthropometry-based measures and four DEXA-based measures. We took two measurements of waist circumference (at the midpoint of the last rib and the iliac crest), hip circumference (at the level of the greater trochanters) and thigh circumference (left leg just below the gluteal fold) using a flexible tape measure and averaged the two. We then calculated BMI, ratio of waist circumference to hip circumference (waist-to-hip ratio), and the index of central obesity (waist circumference/ height) (16). This index is thought to be less sensitive to effects of race and sex (17), making it a robust measure for health outcomes (18). The four DEXA-based measures included: percent trunk fat; percent leg fat; percent total fat; and fat mass index defined as fat mass/ height^2 (19). For various reasons, n=8 of the 55 recruited participants did not complete DEXA body composition scans (but had bone scans to verify inclusion/exclusion). These individuals' anthropometry-based measures and trip-induced fall risk measures were still entered into analysis.

After obtaining measures of obesity, participants donned a safety harness attached to an overhead track via a dynamic rope. The length of the rope was adjusted such that, in the event of full-body support, participants' knees were ~10 cm from the ground. Passive reflective markers were placed on the joints of the arms and legs according to the full-body Plug-in Gait model or an obesity-specific marker set (20) and sampled at 100 Hz using an 8-camera motion capture system[a]. Participants then walked along an 8 m walkway approximately 10–20 times at a self-selected comfortable pace while motion capture cameras tracked marker motions. The cameras recorded the middle 5–6 cm of the walk. Participants were told to focus their gaze on screens at each end of the walkway that displayed images, which occasionally included large, superimposed numbers to be named aloud. During their last pass along the walkway, a hidden 5.1-cm-tall obstacle was manually triggered to rise from the walkway just after toe off to obstruct the swinging limb and induce a trip (see Supplemental Material). If the foot did not impact the obstacle and the participant was unaware of the trip, then a second attempt was made to induce a trip.

Data processing

A mean of 87±38 steps were recorded from each participant prior to the trip trial. For each of these recorded steps, we plotted a curve of the vertical position of the marker on the dorsum of the second metatarsal head ("toe" marker) as a function of the horizontal position (Figure 1), and calculated the area below 40 mm and above this curve - termed toe trajectory area (toe_{area}) (21). This measures has been argued to best capture the probability of contacting an obstacle while walking (21). For the 91.1±11.0% of recorded steps with a local minimum in the vertical position of the toe marker near mid-swing, we calculated this local minimum relative to that during the prior mid-stance (toe_{min}; Figure 1). Measures of risk of tripping used for analysis included mean toe_{area}, median toe_{min} (due to non-normal distribution), and toe_{min} interquartile range (IQR).

From the induced trip we calculated the following trip recovery measures as previously reported (22): angle and angular velocity of the trunk (distal end defined by midpoint of line connecting a marker on the xyphoid process and T10 vertebrae; proximal end defined by midpoint of line connecting a marker on the sternoclavicular notch and the C7 vertebrae) in the sagittal plane, relative to vertical, at the instant of ground contact of the first step over the obstacle (trunk angle and trunk velocity, respectively), with more positive values indicating greater flexion; anteroposterior distance between the toe marker of the foot that first stepped over the obstacle and the whole body center of mass at the same instant (CoM distance), and the timing of this instant relative to contact with the obstacle (step time). Forty-seven of 55 participants were successfully tripped, all of whom completed their first recovery step prior to substantial (if any) support by the harness. This was verified visually from recorded video due to a technical issue with a harness load cell that precluded force measurements and was not discovered until after testing was complete.

Data analysis

All data were checked for normality using Shapiro-Wilke tests. Demographics were compared between low and high BMI groups with independent samples *t*-tests, Mann-Whitney *U* tests, or Chi-squared tests. We used a two-step process to explore the association between measures of obesity and either measures of risk of tripping as a whole or measures of trip recovery as a whole (collectively referred to as measures of trip-induced fall risk). First, we ran a principal component analysis (PCA) using risk of tripping measures and another using trip recovery measures. Second, for each principal component (PC) with an eigenvalue >1.0, we calculated PC scores and correlated them with all measures of obesity using Spearman's or Pearson's correlations. To quantify the effect of measures of obesity on individual measures of trip-induced fall risk, we first grouped participants according to the measures of obesity that most strongly correlated with each PC score and also had established cutoffs to categorize individuals as having high or low levels of fat (Table 2). We then used independent *t*-tests or Mann-Whitney *U* tests for between-group comparisons (high vs low) of those measures of trip-induced fall risk that strongly loaded on the associated PC (loading factor>0.6). For all statistical tests, significance was set at $p \leq 0.05$ and effect size of group differences was quantified using Cohen's *d*.

RESULTS

PCA revealed that a single PC (trip risk PC1) explained ~83% of the variance among the measures of risk of tripping, with nearly equal loadings (|0.86–0.93|) for all measures. Two PCs explained 80% of the variance among measures of trip recovery. The first PC (trip recovery PC1), which accounted for 51% of the variance, loaded on trunk angle, trunk velocity and CoM distance (loadings of |0.75–0.85|), while the second PC (trip recovery PC2) loaded on step time (loading=0.95).

Associations between PC scores and measures of obesity

Thigh circumference ($r=0.31$, $p=0.025$) and waist-to-hip ratio ($r=0.29$, $p=0.041$) were associated with PC scores derived from trip risk PC1, while BMI was not ($\rho=0.15$, $p=0.278$; Table 3). Hip circumference ($\rho=0.40$, $p=0.007$), thigh circumference ($r=0.43$, $p=0.003$), fat mass index ($\rho=0.34$, $p=0.032$), and total fat ($r=0.33$, $p=0.039$) were associated with PC scores derived from trip recovery PC1, while BMI was not ($\rho=0.27$, $p=0.066$; Table 3). Finally, there were no significant associations between any measures of obesity and PC scores from trip recovery PC2.

Differences in trip-induced fall risk between older adults grouped by obesity measures

Waist-to-hip ratio was the measure of obesity from Table 2 that exhibited the strongest association with trip risk PC1 (Table 3). When grouping participants based upon waist-to-hip ratios, those with high waist-to-hip ratios exhibited a higher toe_{min} IQR ($p=0.028$; $d=0.64$; Table 4) than those with a low ratio. Median toe_{min} ($p=0.186$; $d=0.40$) and mean toe_{area} ($p=0.097$; $d=0.50$) did not differ between these groups. Fat mass index was the measure of obesity from Table 2 that exhibited the strongest association with trip recovery PC1 (Table 3). When grouping participants based upon fat mass index, those with a high fat mass index exhibited a less favorable trunk velocity ($p=0.015$; $d=0.84$; Table 4 and Figure 2) than those with low indices. Finally, after grouping participants based on high or low BMI (the measure in Table 2 which most strongly associated with trip-recovery PC2 component scores), step time did not differ between groups.

DISCUSSION

The purpose of this study was to explore the association between measures of obesity and measures of trip-induced fall risk among community-dwelling older adults. Our first finding relates to the identification of measures of obesity that most strongly associated with trip-induced fall risk. Measures of risk of tripping as a whole were most strongly associated with waist-to-hip ratio and thigh circumference, while measures of trip recovery as a whole were most strongly associated with hip circumference, thigh circumference, fat mass index and total fat. Among individual measures of obesity that have established cutoffs with respect to obesity, we observed a significant, medium-sized effect ($d=0.50$–0.79) of waist-to-hip ratios on risk of tripping, and a significant, large-sized effect ($d \geq 0.8$) of fat mass index on trip recovery. Our second finding was that the strongest associations between measures of obesity and measures of either risk of tripping or trip recovery were observed for measures other than BMI. Our findings thus contribute to the growing literature on the limitations of BMI in characterizing obesity and health risks in older adults.

Our finding that measures of obesity other than BMI more strongly associated with trip-related fall risk agrees with recent work in the area of postural control, a measure of general fall risk. For example, Meng et al. (2016) reported that percent body fat in young adults was more strongly associated with measures of postural stability than was BMI (23), confirming an earlier study on older women in which higher fat mass impaired postural control (24). A follow-up study by Meng et al. (2020) on older adults found that android to gynoid fat ratio provided better insight into postural control than did BMI (25), with the directionality of the associations confirming that gynoid but not android obesity increases community-based falls among older women (26). Together, these studies support the notion that “screening for body fat distribution as a supplement to other risk factors for falls may help to identify older adults at a greater risk of falling” (26).

Associations between measures of obesity and PC scores

Considering that 10 measures of obesity were investigated, it was surprising that both trip risk PC1 and trip recovery PC1 were most strongly associated with thigh circumference. However, toe_{min} is known to be sensitive to knee and hip motion (27, 28) and greater thigh circumference, e.g., excess soft tissue, may alter motion of the thigh during swing thereby influencing toe_{min}. Similarly, the association between trip recovery PC1 and thigh circumference may reflect increased inertia of the thigh acting to slow hip flexion and limit CoM distance during compensatory stepping. This association may also relate to strength requirements of trip recovery. Indeed, thigh circumference is a predictor of thigh muscle volume in older adults (29) and hip and knee extensor muscles are known to be important for trunk control following a trip (30). Strength requirements may also explain the association between trip recovery PC1 and greater fat mass (total fat and fat mass index); a given level of force will not produce the same dynamics for a segment with greater mass. Indeed, during normal gait older women with high BMI expend grater muscular effort than those with low BMI, likely reflecting the effect of excessive fat on segmental properties (mass/inertia) (31). Overall, additional work is needed to better understand the biomechanical mechanisms by which specific measures of obesity (Table 3) influence trip-related fall risk.

Differences in trip-induced fall risk between older adults grouped by obesity measures

Greater toe_{min} IQR among those with high waist-to-hip ratios suggests a higher risk of tripping. Indeed a more variable toe_{min} is thought to increase fall risk (32, 33), and older adults with a history of trip-related falls have more variable toe_{min} than non-fallers (34). Thus the previously reported obesity-related increase in all-cause ambulatory stumbles (i.e. losses of balance that are restored before falls occur) (3) may partly reflect an increased risk of tripping due to more variable toe_{min}. Interestingly, in the present study waist-to-hip ratio but not BMI was significantly correlated with trip risk PC1. This agrees with prior work in which toe_{min} IQR was not different between older adults with low and high BMI

(8). Although toe_{area} has been argued to better capture the probability of tripping than other measures (21), we saw no effect of measures of obesity on this measure.

While measures of reactive stepping after tripping (CoM distance or step time) did not, by themselves, differ between groups with high and low BMI or fat mass index, impairments in trunk control may be more meaningful given the extent of evidence relating trunk dynamics and falls. Following a laboratory-induced trip, healthy community-dwelling older adults who fall have larger trunk angle and trunk velocity compared to non-fallers (22), and these measures are impacted by known fall-risk factors including osteoarthritis, history of stroke and lower limb amputation (35–37). Moreover, even among healthy young adults, fall outcomes after simulated trips on a treadmill are sensitive to these measures (38). Excessive fat may increase muscular forces needed to arrest trunk angular momentum gained following a trip, a requisite of successful recovery (22, 39). The fact that excessive fat negatively influences trunk control among older adults (Table 4) could reflect the inability of the aged system to meet any such obesity-related increases in muscular demands during trip recovery. Work is needed to understand the extent to which aging and obesity possibly interact to influence trip recovery

On average, older adults with both high and low fat mass index displayed trunk extension velocities (trunk velocity <0) at foot contact of the first recovery step over the trip obstacle. However, trunk velocity among participants with a high fat mass index was less negative, suggesting an adverse effect of fat mass index (Table 4). For a given trunk velocity, increased fat mass may also increase the moment of inertia of the trunk about a mediolateral axis and in turn increase trunk angular momentum gained after obstacle contact. This would increase the difficulty of trip recovery given that this angular momentum needs to be arrested to prevent a fall. Although we did not quantify moment of inertia, others have reported a larger moment of inertia of the trunk (albeit about the longitudinal axis) among individuals with a high waist-to-hip ratio or high waist circumference compared to those with low BMI (40). Moreover, the radius of gyration for the trunk about all axes decreases with weight loss (and thus is higher with obesity) (41). Thus, while speculative, further research on the biomechanical mechanisms by which increased fat mass index influences trip recovery may provide helpful insight in the development of fall prevention interventions.

While angular momentum can be reduced by placing the recovery step more anterior to the CoM to facilitate generation of a larger external moment, CoM distance was not greater in participants with a high fat mass index. In absence of increasing CoM distance, increased momentum can be countered by greater force production in the back and/or hip extensors. However, obese individuals have reduced strength, pound-for-pound, compared to non-obese counterparts (42, 43), which may inhibit their ability to counteract increased angular momentum due to increased mass/inertia. Fortunately, it may be possible to train obese individuals to reduce trunk motion and/or to increase CoM distance through training paradigms that exposes individuals to repeated postural perturbations simulating trips. Such paradigms have been shown to improve these outcomes in many different populations (35, 44–46), and to significantly reduce prospective trip-related falls (47).

Study Limitations

Given the exploratory nature of this study, we did not correct for potential Type I error rate due to multiple comparisons. Additionally, the extent to which obesity-related impairments in risk of tripping and trip recovery measures influence real-world fall risk has not been established. For example, while toe_{min} is theoretically associated with the risk of tripping, we are aware of only one study that prospectively associated the two (48).

Conclusions

BMI does not associate with measures of risk trip-induced falls as strongly as other measures of obesity. In particular, waist-to hip ratio and fat mass index may more strongly predict an increased risk of tripping and less favorable trip recovery. Larger studies are needed to better understand the mechanisms by which specific measures of obesity affect fall risk.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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List of abbreviations

BMI	body mass index
CoM	center of mass
DEXA	dual-energy x-ray absorptiometry
IQR	interquartile range
PC	principal component
PCA	principal component analysis

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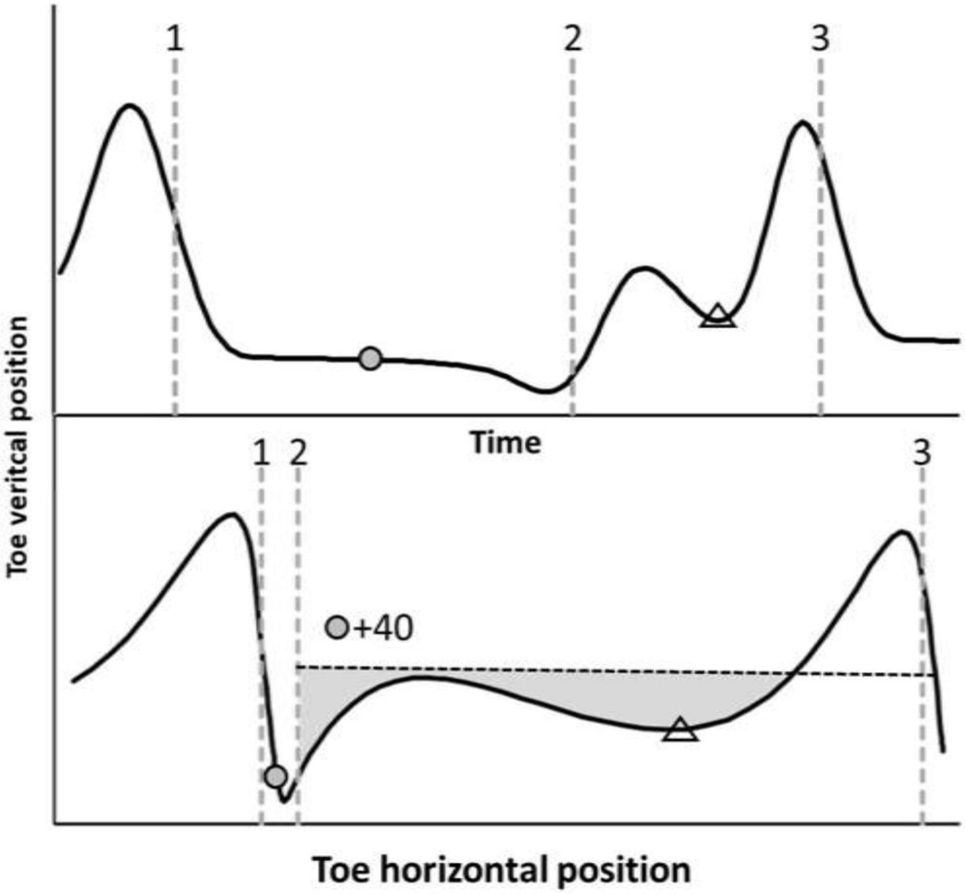

Figure 1.

Schematic representation of risk of tripping measures. The top curve shows the vertical trajectory of the toe marker as a function of time, which is commonly reported in the literature. Gait events are represented by number 1–3: 1 = heel strike; 2 = toe off; 3 = heel strike. The filled grey circle represents the mean vertical position during the midstance prior to toe off (event 2) and the open triangle represents the local minimum in the toe vertical position (toe_{min}) that was calculated as the difference in toe vertical position between the two. The bottom curve shows the vertical toe trajectory as a function of the horizontal position with the same gait events and symbols shown as in the top curve. In addition, a horizontal dotted black line is included, which is 40 mm above the mean value at the prior midstance (filled grey circle + 40). Toe_{area} is calculated as the area above the toe trajectory curve and below the black dotted line (grey fill). This area can be interpreted as a cumulative approximation of the likelihood of contacting an obstacle of 40 mm, due to insufficient toe clearance (i.e. toe vertical position < 40 mm) at any point in the swing cycle (21).

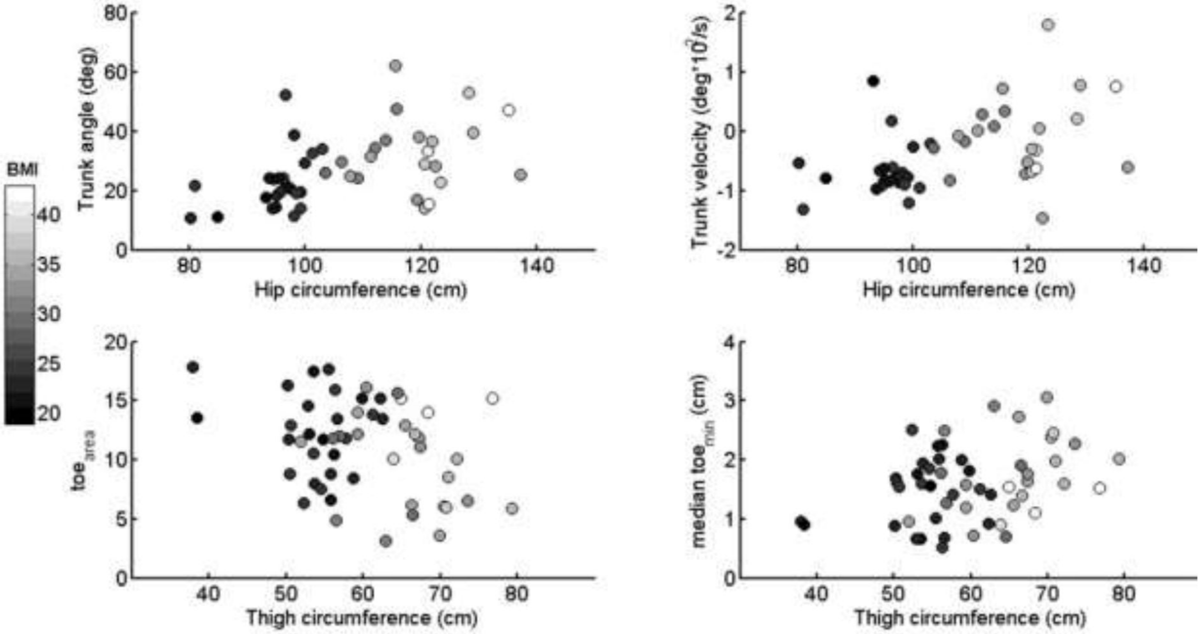

Figure 2 –.

Scatter plots for measures of trip-induced fall risk that were associated with one or more measures of obesity, with data point shaded according to BMI. For measures of trip-induced fall risk that were associated with more than one measure of obesity, a scatter plot is shown for the strongest correlation.

Table 1.

Subject characteristics presented as mean (standard deviation) for normally distributed variables(indicated by ##) or median (IQR) for non-normally distributed (indicated by #)

	low BMI (*N*=28)	**high BMI (*N*=27)**	***p*-value**
Sex (F/M)	15 /13	14 /13	0.898
Age (years)	68.5 (7.0)#	71.0 (7.0)	0.182
Mass (kg)	65.0 (10.0)##	100.4 (13.6)	< 0.001
Height (cm)	167.6 (17.4) #	170.2 (17.3)	0.953
BMI (kg/m^2)	23.1 (2.3) #	34.6 (4.1)	<0.001
Gait speed (m/s)	1.07 (0.19)##	1.00 (0.13)	0.137

Table 2.

Measures of obesity with established cutoff values that were explored in the present study.

Measure	Cutoff	Notes
BMI	Low: 18.5–24.9 kg/m^2 High: ≥ 30 kg/m^2	Cutoffs correspond to values established as normal -weight BMI and obese BMI by the World Health Organization (12)
Fat mass index	Low: ≤ 9 kg/m^2 males; ≤ 13 kg/m^2 females High: > 9 kg/m^2 males; > 13 kg/m^2 females	Cutoffs determined using established BMI cutoffs and prevalence of obese BMI in young adults to generate matching data with fat mass index (20).
Total Fat	Low: < 25.8% males; < 37.1% females High: ≥ 25.8% males; ≥ 37.1% females	In a cohort of 4735 Polish adults, cutoffs were associated with significantly higher odds of all-but-one cardiovascular risk factor associated with obesity (49)
Waist circumference	Low: < 102 cm males; < 88 cm females High: ≥ 102 cm males; ≥ 88 cm females	Cutoffs correspond to values above which risk of metabolic disease substantially increases as reported by the World Health Organization (12)
Waist-hip ratio	Low: < 0.90 males; < 0.85 females High: ≥ 0.90 males; ≥ 0.85 females	Cutoffs correspond to values above which risk of metabolic disease substantially increases, as reported by the World Health Organization (12)
Index of central obesity	Low: < 0.53 High: ≥ 0.53	The value of 0.53 corresponds to the lowest value in a cohort of 548 adults with metabolic syndrome as per the National Cholesterol Education Program Adult Treatment Panel III criteria (18)

Table 3

Spearman or Pearson correlation coefficients between measures of obesity and PC scores (*P* value)

Measure		**Trip Risk PC1**	**Trip Recovery PC1**	**Trip Recovery PC2**
Measures of obesity without established cutoffs	Trunk Fat	0.10 (.516)	0.31 (.053)	0.12 (.469)
	Leg Fat	−0.13 (.392)	0.27 (.103)	0.29 (.077)
	Hip circumference	0.12 (.419)	0.40 (.007) *	0.26 (.086)
	Thigh circumference	0.31 (.025) *	0.43 (.003) *	0.14 (.372)
Measures of obesity with established cutoffs	BMI	0.15 (.278)	0.27 (.066)	0.23 (.119)
	Fat mass index	0.06 (.708)	0.34 (.032) *	0.16 (.334)
	Total Fat	<0.01 (.967)	0.33 (.039) *	0.21 (.208)
	Waist circumference	0.27 (.053)	0.14 (.346)	0.21 (.174)
	Waist-to-hip ratio	0.29 (.041) *	−0.19 (.213)	0.05 (.735)
	Index of central obesity	0.16 (.254)	0.16 (.285)	0.16 (.299)

NOTE. P>.10 unless indicated by * and thus not significant.

*$P \le .05$.

Table 4.

Comparing trip-related measures across non-obese and obese groups defined by thresholds for the listed grouping variable

	Grouping variable	# low/ # high	Low	High	*Cohen's d (p-value)*
Risk of tripping measures					
Median toe_{min} (cm)	Waist-to-hip ratio	17/35	1.43 ± 0.58	1.68 ± 0.63	0.40 (0.186)
toe_{min} IQR (cm)	Waist-to-hip ratio	17/35	0.66 (0.28)	0.84 (0.34)	**0.64 (0.028)**
Mean toe_{area}	Waist-to-hip ratio	17/35	12.4 ± 3.2	10.5 ± 4.1	0.50 (0.097)
Trip recovery measures					
trunk angle (deg)	Fat mass index	22/17	24.0 (20.5)	29.6 (12.8)	0.58 (0.087)
trunk velocity (deg/s)	Fat mass index	22/17	−70.3 (63.4)	−16.5 (86.7)	**0.84 (0.015)**
CoM distance (cm)	Fat mass index	22/17	18.98 ± 13.42	18.12 ± 12.99	0.07 (0.842)
Step time (s)	BMI	24/23	0.515 ± 0.064	0.528 ± 0.062	0.20 (0.502)

Note: BMI= body mass index; FMI = fat mass index; WHR= waist-to-hip circumference ratio. For *trunk velocity*, negative values correspond to extension (more favorable) velocity. Bolded values correspond to p≤0.050. Although all available data was used for analysis, sample sizes differ across variables due to the fact that not all participants were successfully tripped and not all participants received a DEXA scan.