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## Walking mediates associations between neighborhood activity supportiveness and BMI in the Women's Health Initiative San Diego cohort

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### Abstract

**Objectives**—To investigate whether walking mediates neighborhood built environment associations with weight status in middle- and older-aged women.

**Methods**—Participants (N=5085; mean age=64±7.7; 75.4% White non-Hispanic) were from the Women's Health Initiative San Diego cohort baseline visits. Body mass index (BMI) and waist circumference were measured objectively. Walking was assessed via survey. The geographic

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information system (GIS)-based home neighborhood activity supportiveness index included residential density, street connectivity, land use mix, and number of parks.

**Results**—BMI was 0.22 units higher and the odds ratio for being obese (vs. normal or overweight) was 8% higher for every standard deviation decrease in neighborhood activity supportiveness. Walking partially mediated these associations (22–23% attenuation). Findings were less robust for waist circumference.

**Conclusions**—Findings suggest women who lived in activity-supportive neighborhoods had a lower BMI than their counterparts, in part because they walked more. Improving neighborhood activity supportiveness has population-level implications for improving weight status and health.

### Keywords

aging; obesity; physical activity; waist circumference; walkability

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Obesity reduction and prevention are national [1, 2] and global [3] priorities. The neighborhood built environment has been associated with obesity across age groups [5–10]. The most consistent associations have been found for residential density, mixed land use, and walkability indices in adults, with some evidence of associations with street connectivity and access to parks and recreation facilities. Specifically, those in neighborhoods with greater residential density, mixed land use, and walkability had better weight profiles than their counterparts [5–10]. Findings have been similar for older adults [11], though there is less evidence in this population.

Physical activity is a potential mechanism through which neighborhood built environments may influence obesity. A large body of literature has found associations between objective neighborhood walkability and physical activity [12–15]. Some studies have found physical activity to be a mediator of the neighborhood environment - body mass index (BMI) association [16–19]. In particular, walking for transportation has been observed as a stronger mediator of the neighborhood environment – BMI association than overall physical activity [19]. However, more evidence is needed to understand the role of built environment factors and walking on weight status in middle- and older-aged women. This less-studied population is particularly important to investigate because of the beneficial role of walking and healthy weight in maintaining physical functioning with aging [20], and the lower observed physical activity levels in women as compared to men [21]. It is also important to better understand the role of neighborhood built environment factors and walking on weight status in Hispanics/Latinos, particularly because neighborhood environment and weight status associations are less clear in this less studied and underserved population which has a higher prevalence of obesity and cardiometabolic diseases than the general population [22, 23].

The present study was conducted in a large cohort of middle- and older-aged women from the Women’s Health Initiative (WHI), San Diego site. Study aims were to investigate (1) objective neighborhood built environment associations with BMI and waist circumference and (2) whether these associations were mediated by overall walking. Primary analyses

included the full sample and follow up analyses were conducted in Hispanic/Latino participants.

## Methods

### Participants and Procedures

Data were from baseline visits from the San Diego, California cohort of the Women's Health Initiative (WHI; N = 5085). The WHI is a multi-center prospective cohort study of postmenopausal women aged 50–79 years in the US that was primarily designed to investigate determinants of major chronic diseases such as cardiovascular disease, cancer and osteoporotic fractures. Details of the study have been previously published [24]. Briefly, between 1993 and 1998, participants were recruited at 40 centers nationwide and enrolled in one or more of the three clinical trials or the observational study. Women were eligible if they were postmenopausal, unlikely to move or die within three years, did not possess characteristics that would interfere with study adherence (alcoholism, drug dependency, mental illness, dementia), and were not currently participating in any other clinical trial [24]. This study was approved by the sponsoring institution's Human Subjects Protection Committee, and written informed consent was obtained from all participants. Of the 5626 participants from the San Diego area, 5401 (96.0%) had verifiable addresses available for assessing neighborhood built environment characteristics [25] and full information was available for 5085 of these participants.

### Measures

**Anthropometry**—Measures of weight, height and waist circumference were collected by trained staff according to standardized protocols. Weight was measured to the nearest 0.1 kg using a balance beam scale with participants wearing indoor clothing without shoes. Height was measured using a wall-mounted stadiometer to the nearest 0.1 cm. Waist circumference was taken from the natural waist or the narrowest part of the torso using a standardized measuring tape and recorded to the nearest 0.1 cm. Body mass index (BMI,  $\text{kg}/\text{m}^2$ ) was computed using weight (kg) divided by height squared ( $\text{m}^2$ ). Both continuous and dichotomous outcomes were investigated. BMI cut-offs from the World Health Organization were used to dichotomize BMI as obese ( $\geq 30 \text{ kg}/\text{m}^2$ ) vs. normal weight or overweight ( $<30 \text{ kg}/\text{m}^2$ ) [26]. Waist circumference was dichotomized as  $\geq 88 \text{ cm}$  (substantially increased risk) vs.  $<88 \text{ cm}$  (normal or increased risk) [27].

**Overall walking**—Women completed the WHI physical activity questionnaire [28] which asked about walking outside of the home for more than 10 minutes without stopping in terms of frequency, duration, and intensity (i.e., casual strolling, average or normal, fairly fast, very fast, or don't know). MET values for walking were assigned as: very fast walking = 5, fairly fast walking = 4, average normal walking = 3, and casual walking = 2. Total walking was calculated as MET hours/week for all walking intensities. Test-retest intraclass correlation coefficients were 0.71–0.75 and were comparable across age and race/ethnic groups [28].

**Neighborhood built environment characteristics**—Data from the SANDAG Data Warehouse [29], which included information from the 2000 US Census, were integrated into Geographic Information Systems (GIS) to derive built environment features within a 0.5-mile street-network buffer (i.e., neighborhood area) around each participant's geocoded home address. This buffer type and size has support for validity in previous studies [30]. The GIS procedures were presented in more detail in Kerr et al. 2014 [25]. Net residential density (housing units per residential acre), intersection density (intersections per acre), number of parks, and land use mix were calculated within each participant buffer. The land use mix variable represents the evenness of the distribution of acreage of residential, retail/commercial, office, and institutional land use, with lower values representing more single (i.e. residential) land use, and higher values representing a more even distribution of the four land use types [31]. These variables were standardized for the San Diego region as z-scores, and an overall “neighborhood activity supportiveness” index was created by taking the sum of the four z-scored variables [31]. Based on previous literature [5–15, 31], higher scores were hypothesized to be associated with more walking and a more favorable weight status. An index was used rather than individual environmental components because it is the overall pattern of neighborhood attributes that is often associated with physical activity and health outcomes (e.g., [31–33]). Neighborhood median household income from Census block groups was apportioned based on area to each participant's buffer and used as a covariate.

**Participant characteristics (covariates)**—A questionnaire was used to obtain self-reported demographic information which included age, race/ethnicity, education (dichotomized as college degree vs. no college degree) and marital status (dichotomized as single vs. married/cohabitating). Treatment intervention group membership was included as an additional covariate to designate participation in any of the 3 trials in WHI [24].

### Statistical Analyses

Relations of the neighborhood activity supportiveness index to the participants' anthropometric measures were assessed using linear (BMI, waist circumference) and logistic (BMI obese vs. normal and overweight; waist circumference  $\geq 88$  cm vs.  $<88$  cm) regression models. Models were investigated in the full sample and the subsample of Hispanic/Latino participants.

Overall walking was tested as a potential mediator of the association between weight status and the activity supportiveness index. The methods used were outlined in MacKinnon [34]. In brief, mediation coefficients, which were used in conjunction with confidence intervals to assess significance of the mediated effects, were calculated as  $a * b$  (the equivalent of  $c - c'$ ), with  $a$  representing the relation of activity supportiveness to walking,  $b$  representing the relation of walking to the outcome,  $c$  and  $c'$  representing the relation of activity supportiveness to the outcome, unadjusted and adjusted for walking. Percent attenuation from  $c$  to  $c'$  was calculated by dividing  $c'$  by  $c$ . Confidence intervals (95%) around the

mediation coefficients were calculated as  $1.96 * SE$ , with  $SE = \sigma_{\hat{a}\hat{b}} = \sqrt{\sigma_{\hat{a}}^2 \hat{b}^2 + \sigma_{\hat{b}}^2 \hat{a}^2}$ . Mediation was tested even in the absence of a significant association between activity supportiveness and weight status, as recommended by Cerin and MacKinnon [35].

All models were adjusted for participant age, race/ethnicity, education, marital status, intervention group membership and neighborhood income. All independent variables were mean centered. Standardized regression coefficients ( $\beta$ s and Odds Ratios [ORs]) are reported in addition to unstandardized coefficients to support the interpretation of strength of associations across models. A significance level of 0.05 was used. Analyses were conducted in 2015 using SPSS v22.

## Results

Sample characteristics are presented in Table 1. Participants were on average 64 years of age ( $SD = 7.7$ ), 75.4% were White non-Hispanic, and 35.9% were college graduates. The mean BMI was  $27.5 \text{ kg/m}^2$  ( $SD = 5.5$ ), with 27.1% of participants being obese. Participants reported a mean of 5.5 MET-hours/week of overall walking ( $SD = 6.3$ ), which is equivalent to approximately 1.8 hours/week of normal-paced walking on average. Table 2 presents data on the activity supportiveness index and its components. The neighborhood activity supportiveness index was positively associated with walking ( $B = 0.17$ ; 95% CI = 0.09, 0.24;  $\beta = .06$ ; data not shown).

### Neighborhood activity supportiveness, walking, and weight status in full sample

The neighborhood activity supportiveness index was associated with lower BMI and lower odds of being obese (see Table 3). For every one unit increase in the neighborhood activity supportiveness index, BMI was lower by 0.09 units on average and the odds of being obese were 4% lower ( $p = .009$  and  $.008$ ). Walking was negatively associated with BMI and being obese and partially mediated the relation of neighborhood activity supportiveness to BMI (see Figure 1) and being obese (percent attenuation = 22% and 23%). The neighborhood activity supportiveness index had a negative and marginally significant association with waist circumference ( $B = -0.20$ ;  $p = .057$ ) but was not associated with waist circumference  $\geq 88 \text{ cm}$  ( $OR = 0.98$ ;  $p = .124$ ). Walking partially mediated the relation of neighborhood activity supportiveness to these two outcomes (percent attenuation = 30% and 45%).

### Neighborhood activity supportiveness, walking, and weight status in Latino/Hispanic subsample

In Latinos/Hispanics, the neighborhood activity supportiveness index was associated with lower BMI ( $B = -0.23$ ;  $p = .031$ ) and marginally associated with a lower odds of being obese ( $OR = 0.91$ ;  $p = .053$ ; see Table 4). The neighborhood activity supportiveness was not associated with waist circumference or having a waist circumference  $\geq 88 \text{ cm}$ . The neighborhood activity supportiveness index was positively but not significantly associated with walking in Hispanic/Latinos ( $B = 0.23$ ; 95% CI =  $-0.02, 0.47$ ;  $\beta = .07$ ; data not shown). When adjusted for walking, the direct associations between the neighborhood activity supportiveness index and outcome variables were attenuated by 10% for 3 of the 4 outcomes (BMI: 11%, waist circumference: 23%, and having a waist circumference  $\geq 88 \text{ cm}$ : 22%). However, none of the 4 p-values were  $<0.05$  ( $ps = .069-.112$ ).

## Discussion

In this large observational cohort study of women in San Diego, CA, we found that greater neighborhood activity supportiveness was associated with more favorable weight status, and these associations were explained in part by overall walking. This indicates that women living in activity-supportive neighborhoods may have had a lower BMI and risk for obesity than their counterparts, in part because they walked more. These findings provide support for the hypothesis of a mediational pathway from neighborhood attributes, through physical activity, to obesity; a critical health problem in the US [36] and globally [37]. Based on these findings, improving neighborhood activity supportiveness could have population-level implications on improving health.

Although the magnitude of association between neighborhood activity supportiveness and BMI was small, built environment improvements are likely to have meaningful impacts on the prevention and reduction of obesity given that neighborhood built environment improvements can reach large numbers of people. Participants living in neighborhoods with low activity supportiveness (two SDs below the mean) had a BMI that was 0.86 units higher and a 32% higher odds for obesity than those in high activity-supportive neighborhoods (two SDs above the mean). Associations between neighborhood activity supportiveness and waist circumference were in the expected direction though not significant in the full sample or Hispanic/Latino subsample, suggesting other factors may be more important to abdominal weight, for example nutrition environments and psychological stress. It is also likely that BMI had less measurement error than waist circumference, resulting in the wider confidence intervals and lack of significance for waist circumference.

Overall walking explained a small to moderate percentage (22–23%) of the relation of neighborhood activity supportiveness to BMI and obesity status. These findings were similar to previous studies documenting physical activity [16–19], and particularly walking [19], as a mediator of the neighborhood – BMI association, although the magnitude of mediation is difficult to compare because of the differing metrics reported. It is important to note that neighborhood built environments have been a stronger and more consistent correlate of transportation walking than leisure walking and overall physical activity [14], and a stronger mediator of the environment – weight status association [19]. In the present study, all types of walking were grouped together, but it is possible that the observed findings would have been stronger if transportation-specific walking had been assessed. The accumulation of evidence suggests that transportation walking is a primary mechanism linking neighborhood environments to weight status. Thus, public health strategies to improve neighborhood environments to better support walking are warranted. Mixed-use development and redevelopment are examples of efforts to make neighborhood environments more health supportive.

Findings on the relations of neighborhood activity supportiveness to BMI and being obese were stronger in magnitude in Hispanic/Latinos than White non-Hispanics, though still small. This suggests that creating activity-supportive neighborhoods could support Hispanic/Latino health, a population subgroup who experience high rates of metabolic diseases [22, 23]. Walking was not a significant mediator of the neighborhood activity supportiveness -



anthropometric associations in the Hispanic/Latino subsample, though 3 of the 4 mediation tests indicated a percent attenuation 10%, suggesting potential mediation. Other environmental factors such as social deprivation, pedestrian safety, and food environments (some of which may work through mechanisms other than physical activity, such as diet/nutrition and stress) are particularly important to study in underserved populations [38, 39], as well as potential moderators (e.g., neighborhood safety) that may explain some of the residual variance in the neighborhood environment - BMI association in Hispanic/Latinos.

### Strengths and limitations

Study strengths included a large sample of women, a previously less studied population, and the derivation of an objective measure of neighborhood built environment patterns from GIS. The investigation of mediation using the widely accepted MacKinnon [34] methods, which are considered more rigorous than traditional methods [34, 40], was also a strength. However, causal sequences cannot be inferred from these cross-sectional data. This study was conducted in only one major metropolitan area, so findings may not generalize to other areas. However, previous research indicates that San Diego, CA has less variability in activity supportive built environment characteristics than other (typically older) areas of the US [41] and world [42]. So it is possible that similar analyses would reveal stronger associations between neighborhood activity supportiveness and anthropometrics in a more geographically diverse sample. The data were collected in the 1990s and may not generalize to the date of publication. The built environment variables were derived after the individual participant information was collected, so changes in environments during that time period could have led to measurement error, although the environmental variables assessed in this study are generally stable over several years because they are difficult to change. Self-reporting of walking could have led to measurement error which could have biased our coefficients in either direction, so future studies should employ objective measurement when possible, as is being done currently in WHI. This study did not adjust for neighborhood self-selection, which could have explained some of the association between activity supportiveness and walking/weight status, although previous evidence suggests only a small role of self-selection [43].

### Conclusions

The findings of the current study provide support for a significant role of neighborhood attributes in relation to physical activity (walking) and obesity. Based on the study results, improving neighborhood activity supportiveness may have population-level implications for improving weight status and health through increased walking. Walking is an especially promising target because it can be incorporated into existing daily travel patterns when destinations are within walking distance and neighborhood environments are supportive of walking. To affect health-related improvements in neighborhood environments, evidence-based policies and practices need to be incorporated into transportation and urban planning decision making, and built environment improvements should be monitored and evaluated to gauge their health impacts.

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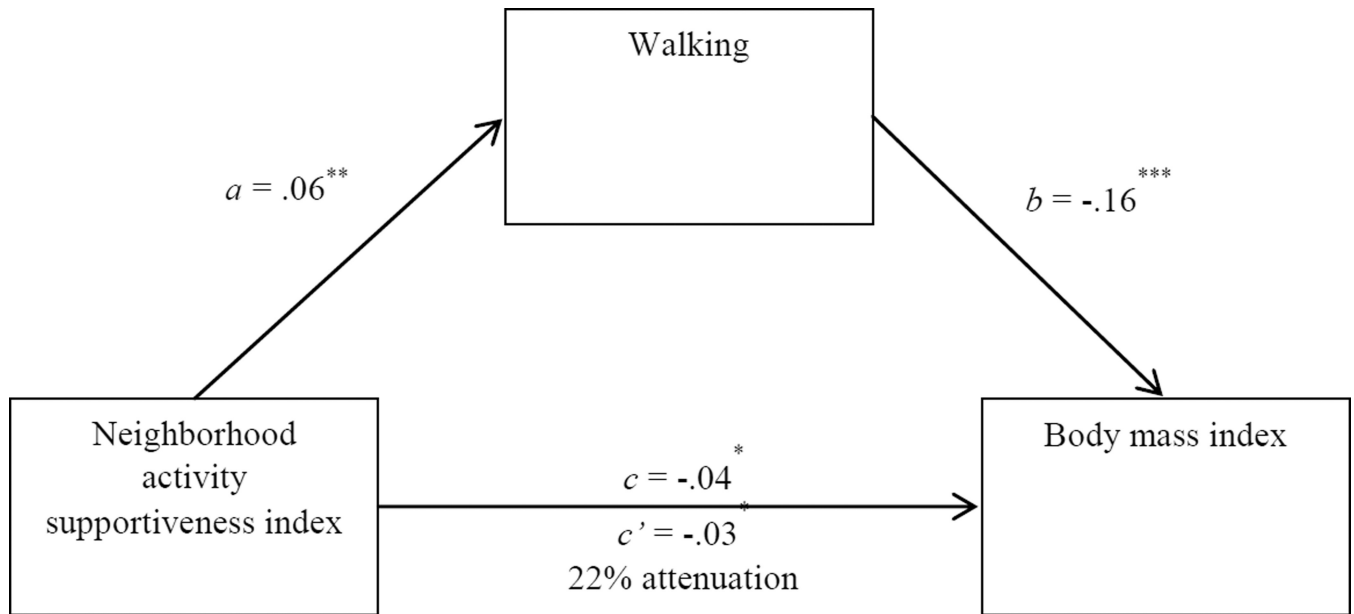
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### Highlights

- Healthy neighborhoods include density, mixed land use, connectivity and parks.
- Neighborhood environments can support healthy body weight in older-aged women.
- Walking partially mediates the neighborhood environment – body weight association.
- Findings are similar between White non-Hispanics and Hispanics.



**Figure 1.** Standardized regression coefficients ( $\beta$ s) for the association between the neighborhood activity supportiveness index and body mass index as mediated by walking. The coefficient representing the association between the neighborhood activity supportiveness index and body mass index, adjusted for walking, is noted as  $c'$ . \* $p < 0.05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$

**Table 1**

## Sample characteristics

Total sample size	5085
Number (%) White non-Hispanic	3834 (75.4%)
Number (%) Hispanic/Latino	797 (15.7%)
Number (%) Black	193 (3.8%)
Number (%) Asian	127 (2.5%)
Mean (SD) age in years	64.0 (7.7)
% college degree	35.9
% married or living with partner	58.5
Mean (SD) BMI	27.5 (5.5)
% obese	27.1%
Mean (SD) waist circumference	85.4 (16.5)
% waist circumference $\geq$ 88 cm	36.5%
Mean (SD) neighborhood income in dollars	55,348 (21,539)
Mean (SD) residential density (housing units per residential acre)	9.4 (41.1)
Mean (SD) street connectivity (intersections per acre)	0.3 (0.1)
Mean (SD) land use mix (0–1)	0.4 (0.1)
Mean (SD) number of parks	0.5 (1.1)
Mean (SD) neighborhood activity supportiveness index	0.0 (2.4)
Mean (SD) neighborhood activity supportiveness index, Hispanics only	0.7 (2.0)
Mean (SD) walking (MET-hours/week)	5.5 (6.3)
Mean (SD) walking, Hispanics only (MET-hours/week)	5.0 (6.1)

**Table 2**

## Activity supportiveness index

Total sample (N = 5085)	
Mean (SD) neighborhood activity supportiveness index	0.0 (2.4)
Activity supportiveness index components	
Mean (SD) residential density (housing units per residential acre)	9.4 (41.1)
Mean (SD) street connectivity (intersections per acre)	0.3 (0.1)
Mean (SD) land use mix (0–1)	0.4 (0.1)
Mean (SD) number of parks	0.5 (1.1)
Hispanics/Latinos (N = 797)	
Mean (SD) neighborhood activity supportiveness index	0.7 (2.0)
Activity supportiveness index components	
Mean (SD) residential density (housing units per residential acre)	11.0 (12.2)
Mean (SD) street connectivity (intersections per acre)	0.3 (0.1)
Mean (SD) land use mix (0–1)	0.4 (0.1)
Mean (SD) number of parks	0.5 (1.1)

Note: A 1 standard deviation increase in any index component would result in a 1 unit increase in the activity supportiveness index



Direct and indirect relations of neighborhood activity supportiveness to BMI and waist circumference in adult women (N = 5085)<sup>a</sup>

Table 3

	BMI			Obese vs. overweight and normal weight		
	B (95% CI)	$\beta$	p value	B (SE or 95% CI)	OR (95% CI)	p value
Intercept	27.51	-	-	-1.07	0.34	-
Initial models						
Activity supportiveness index <sup>b</sup>	-0.09 (-0.16, -0.02)	-0.04	.009	-0.04 (0.02)	0.96 (0.93, 0.99)	.008
Mediation models (adjusted for walking)						
Walking MET-hours/week	-0.17 (-0.19, -0.14)	-0.19	<.001	-0.08 (0.01)	0.93 (0.91, 0.94)	<.001
Activity supportiveness index	-0.07 (-0.13, 0)	-0.03	.044	-0.03 (0.02)	0.97 (0.94, 1.00)	.045
Mediation coefficient	-0.03 (-0.04, -0.01)	-	.002	-0.01 (-0.02, -0.01)	-	<.001
Percent attenuation	22%	-	-	23%	-	-
	Waist circumference (cm)			Waist circumference, $\geq 88$ vs $< 88$ (cm)		
	B (95% CI)	$\beta$	p value	B (SE or 95% CI)	OR (95% CI)	p value
Intercept	85.33	-	-	-0.60	0.55	-
Initial models						
Activity supportiveness index <sup>b</sup>	-0.20 (-0.40, 0.01)	-0.03	.057	-0.02 (0.01)	0.98 (0.95, 1.01)	.124
Mediation models (adjusted for walking)						
Walking MET-hours/week	-0.42 (-0.49, -0.35)	-0.16	<.001	-0.07 (0.01)	0.94 (0.93, 0.95)	<.001
Activity supportiveness index	-0.14 (-0.35, 0.06)	-0.02	.163	-0.01 (0.01)	0.99 (0.96, 1.02)	.391
Mediation coefficient	-0.07 (-0.11, -0.02)	-	<.001	-0.01 (-0.02, -0.01)	-	<.001
Percent attenuation	30%	-	-	45%	-	-

<sup>a</sup>All models were adjusted for participant age, race/ethnicity, education, marital status, neighborhood income, and intervention group membership, all of which were mean centered

<sup>b</sup>The activity supportiveness index was calculated as the sum of z scores for residential density, street connectivity, land use mix, and number of parks

Direct and indirect relations of neighborhood activity supportiveness to BMI and waist circumference in Hispanic/Latino subsample (N = 797)<sup>a</sup>

Table 4

	BMI			Obese vs. overweight and normal weight		
	B (95% CI)	β	p value	B (SE or 95% CI)	OR (95% CI)	p value
Intercept	28.11	-	-	-0.71	0.49	-
Initial models						
Activity supportiveness index <sup>b</sup>	-0.23 (-0.43, -0.02)	-0.09	.031	-0.09 (0.05)	0.91 (0.84, 1.00)	.053
Mediation models (adjusted for walking)						
Walking MET-hours/week	-0.14 (-0.20, -0.08)	-0.16	<.001	-0.06 (0.02)	0.94 (0.92, 0.97)	<.001
Activity supportiveness index	-0.20 (-0.41, 0)	-0.08	.052	-0.08 (0.05)	0.92 (0.84, 1.01)	.082
Mediation coefficient	-0.03 (-0.07, 0)	-	.076	-0.01 (-0.03, 0)	-	.069
Percent attenuation	11%	-	-	8%	-	-
	Waist circumference (cm)			Waist circumference, 88 vs < 88 (cm)		
	B (95% CI)	β	p value	B (SE or 95% CI)	OR (95% CI)	p value
Intercept	87.46	-	-	-0.31	0.74	-
Initial models						
Activity supportiveness index <sup>b</sup>	-0.25 (-0.76, 0.25)	-0.04	.326	-0.03 (0.04)	0.97 (0.89, 1.05)	.450
Mediation models (adjusted for walking)						
Walking MET-hours/week	-0.34 (-0.48, -0.19)	-0.16	<.001	-0.05 (0.01)	0.95 (0.92, 0.97)	<.001
Activity supportiveness index	-0.19 (-0.69, 0.31)	-0.03	.446	-0.03 (0.04)	0.98 (0.90, 1.06)	.555
Mediation coefficient	-0.08 (-0.17, 0.02)	-	.112	-0.01 (-0.03, 0)	-	.069
Percent attenuation	23%	-	-	22%	-	-

<sup>a</sup>All models were adjusted for participant age, race/ethnicity, education, marital status, neighborhood income, and intervention group membership, all of which were mean centered

<sup>b</sup>The activity supportiveness index was calculated as the sum of z scores for residential density, street connectivity, land use mix, and number of parks