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Built environment and lower-extremity physical performance: Prospective findings from the Study of Osteoporotic Fractures in Women

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Abstract

Objectives: We examined the association between walkability of the built environment and changes in physical performance among women aged 65 or older ($n = 1,671, 253$ neighborhoods). **Methods:** Street connectivity and street density, markers for neighborhood walkability, were assessed through linkage to secondary data sources. Physical performance was measured with timed-walk and chair-stand tests assessed during follow-up visits about every two years for 12–14 years. Multilevel models predicted change in physical performance, controlling for age, number of incident comorbidities, self-rated health, and death during follow-up. **Results:** Overall, physical performance declined during follow-up ($p < 0.001$). Neighborhood walkability had no effect on change in physical performance among women who reported not walking at baseline. However, among women who walked, greater neighborhood walkability was associated with a slower decline in dynamic leg strength, indicated by score on chair stand. **Discussion:** Neighborhood walkability may protect against decline in physical performance.

The role of neighborhood in determining health outcomes among older adults has been examined in a growing number of studies over the past decade (Yen, Michael, & Perdue, 2009). A recent review of this literature from 1997–2007 reported consistent evidence in support of an association between built environment and amount of walking, but highlighted limitations – cross-sectional studies and the failure to specify theory or use direct measures of neighborhood features – and identified the need for additional research to determine if neighborhood design is associated with (downstream) health outcomes, such as disability, via physical activity behavior (Yen, et al., 2009).

In 2005, Clarke and George proposed a model of the ‘disablement pathway’ in which the built environment exacerbates or narrows the gap between an individual’s physical performance and the physical demands of a given activity (Philippa Clarke & George, 2005). The term ‘built environment’ is an umbrella term that encompasses three integral

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Declaration of Conflicting Interests

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urban planning concepts: urban design, land use, and transportation systems (Handy, Boarnet, Ewing, & Killingsworth, 2002). Recent articles have begun to evaluate the role of built environment characteristics in the disablement process (Beard et al., 2009; Bowling & Stafford, 2007; Brown et al., 2008; P. Clarke, Aishire, Bader, Morenhoff, & House, 2008; P. Clarke, Aishire, & Lantz, 2009; Freedman, Grafova, Schoeni, & Rogowski, 2008). However, all of these studies except two (Brown, et al., 2008; P. Clarke, et al., 2009) were cross-sectional. In addition, all of these studies except one (Brown, et al., 2008) used self-reported measures of physical function. Performance-based measures have been shown to add important information in the assessment of older adults (Myers, Holliday, Harvey, & Hutchinson, 1993), to identify functional problems that the individual or family may not have reported (Curb et al., 2006), and are strong predictors of outcomes such as disability, frailty, and mortality (Ferrucci et al., 2004). No previous studies included walking behavior, the proposed mechanism linking built environment and physical performance, in their analysis. Finally, most of these studies lacked an explicit theoretical framework to guide determination of which neighborhood factors may impact mobility.

Travel behavior theory proposes that the demand for travel is related to the demand for activities. It has been assumed that people will choose to minimize time and cost of travel if given a choice (Cunningham & Michael, 2004). Travel behavior theory predicts a link between transportation infrastructure and pedestrian behavior (Cervero & Kockelman, 1997). Transportation systems include the street network within a region and influence how easy it is to travel through a neighborhood and get to places a person wants to go. A street network that is “highly connected” has many possible routes between destinations making trips more direct. Further, small blocks shorten the distance people have to travel to a desired destination. Empirical research is equivocal but generally confirms that areas characterized by a highly connected street network encourage walking, meaning that a greater number of trips to desired destinations are accomplished by foot rather than by motorized transportation (Berrigan, Pickle, & Dill, 2010; Hess, Moudon, Snyder, & Stanilov, 1999). Better street connectivity (i.e., streets leading to other streets, rather than ending in cul-de-sacs that are more common in newer developments) is associated with more walking among the general population (Saelens, Sallis, & Frank, 2003) and in older adults (F. Li, Fisher, Brownson, & Bosworth, 2005; Saelens & Papadopoulos, 2008). Other studies reported no association (Nagel, Carlson, Bosworth, & Michael, 2008; Satariano et al., 2010). Street density is the strongest predictor of non-motorized travel; smaller block size is a proxy for higher density and greater walkability (Cervero & Kockelman, 1997; Hess, et al., 1999). Shorter blocks mean more intersections and, therefore, shorter travel distances and a greater number of routes between locations (Cervero & Kockelman, 1997). Neighborhoods with small blocks and continuous sidewalks had three times the amount of walking compared to neighborhoods with large blocks and incomplete sidewalks (Hess, et al., 1999).

To address the limitations of these earlier studies, we used longitudinal data from a cohort study of older women to assess the association between the walkability of the built environment, specifically street connectivity and street density, and changes in walking and lower extremity physical performance.

Materials and Methods

Study Population

The Study of Osteoporotic Fractures (SOF) is a prospective cohort study of community-dwelling older women. It was established in 1986, when 9,704 white, non-Hispanic women aged 65 and older were recruited from four metropolitan areas. Participants returned to study clinics for follow-up visits about every two years over 16 years. Data were collected on an

array of factors relating to health, exercise, and functional status, at each follow-up visit. Recruitment methods and additional details are previously published (Walsh, Pressman, Cauley, & Browner, 2001). The protocol for the present analysis was approved by the Institutional Review Boards at Kaiser Permanente Northwest and Drexel University.

The analysis presented here includes SOF participants from the Portland, Oregon metropolitan area. Membership lists for the Kaiser Permanente Northwest (KPNW) health plan were used to recruit women in the region. KPNW includes Medicare and Medicaid recipients, and was representative of the general population at time of recruitment (Greenlick, Freeborn, & Pope, 1988). The Portland metropolitan region encompasses three counties (Clackamas, Multnomah, Washington) and 24 cities, and includes areas ranging from the inner city to rural. We selected to work with the Portland cohort because of notably higher levels of walking in the Portland cohort at baseline compared to the other SOF regions; (Walsh, et al., 2001) also, regional and local planning policies were specifically designed to limit sprawl and enhance non-motorized transit in the metropolitan area (Chapman & Lund, 2004). As a result, the Portland metro area provides a laboratory for evaluating the influence of land-use planning policy on health-related outcomes. These findings will provide essential information for other mid-sized cities that may consider adopting policy changes in an effort to improve health and well-being. Additionally, while the policies in Portland metro are designed to limit sprawl, the built environment in the region remains highly varied (Yan & Knaap, 2004). Having sufficient variability in the built environment enhances our ability to detect a difference associated with the built environment, if one exists. Participant addresses at each visit were geocoded. Out of 13,600 participant-visit records, the geocoding process matched 12,956 (95.3%) of the records.

The second visit, occurring in 1988–1990, was selected as the baseline visit for these analyses because the visit was closest in time to the dates of the data on the built environment (1990 Census data, 1988 neighborhood data). Follow-up for the present analysis continued through visit 8 (2002–2004) with a total of 6 visits; retention through this period averaged more than 90% of the Portland baseline cohort. Of the 2,421 women recruited at baseline, we excluded those who did not attend a full clinic visit at visit 2 ($n = 526$), had no follow-up visit after baseline (e.g., only 1 visit, $n = 185$), could not be geocoded (no address data) ($n = 22$), or had no information on physical performance at baseline ($n = 17$), leaving 1,671 women residing in 253 census tracts at baseline. Of the 1,671 women included, 1,473 (88%) of the women contributed at least 3 years of follow-up, 1,020 (61%) contributed at least 8 years of follow-up, and 525 (31%) contributed 14 years of follow-up.

Ascertainment of outcomes

Walking—Respondents who reported walking outside the home were asked how many city blocks they walked weekly for “exercise” and “as part of your normal routine, such as when you go shopping.” Responses were summed to provide the total number of blocks walked per week at each visit. Because these data were skewed to the right, participants were assigned a score ranging from 1 to 10 based on their decile of walking, using baseline distribution to determine decile.

Lower extremity physical performance—Timed-walk and chair-stand tests provided information on gait and dynamic leg strength, respectively, and are strongly associated with incident disability (Guralnik et al., 1994; Verbrugge & Jette, 1994). For each measure, the better of two trials were included in the study data. The timed-walk test measured the number of seconds (to the nearest one-tenth second) from start to when the first foot completely crossed the end line of a 6-meter course. Participants used ambulatory aids as

needed. Walk pace was calculated as meters per second (more meters per second indicate better functional ability). The chair-stand test measured the time in seconds needed to stand up and sit down from a chair five times without use of the arms; shorter times indicate better functional ability.

Individual-level covariates

Data on age, educational attainment, and self-reported history of years of manual labor were obtained at the first visit. History of chronic conditions and self-reported health were assessed at baseline and updated at all subsequent visits.

Census-tract-level covariates

We created a neighborhood socioeconomic status score for each census tract by summing z-scores for six U.S. Census variables: median household income percentage of households with interest, dividend, or rental income; median value of housing units; percentage of persons 25 or over having completed high school; percentage of persons 25 or over having completed college; and percentage of persons in executive, managerial, or professional specialty occupations (Diez Roux et al., 2001).

Built environment

Walkability of the built environment was assessed through linkage to secondary data sources provided primarily through RAND's Center for Population Health and Health Disparities. These measures, calculated at the census tract level (Krieger, Chen, Waterman, Rehkopf, & Subramanian, 2003), were obtained from the 1990 and 2000 Topologically Integrated Geographic Encoding and Referencing system (TIGER). Street connectivity and street density were used as markers for walkability of the built environment.

Street connectivity—We included two measures of connectivity, with higher values indicating more connectivity: alpha (the ratio of the actual number of complete loops to the maximum number of possible loops given the number of intersections, range 0–1), and gamma (the ratio of actual street segments to maximum possible given the number of intersections, range 0–1) (Berrigan, et al., 2010). Alpha values can be used to evaluate the number of alternative routes to travel from one location to another within a neighborhood. Areas with streets in a grid pattern will have high gamma values, while areas with many cul-de-sacs will have low values. The correlation between alpha and gamma is 0.99 ($P < 0.001$).

Street density—We included two measures of density, with lower values indicating greater density: block size, the average area of street blocks (feet²), and block length, the average length of the long side of a city block (feet). As a result of a left skewed distribution, these variables were categorized into quartiles and modeled as a continuous variable with the median value of the quartile entered as the value. The correlation between block length and block area is 0.94 ($P < 0.001$).

Statistical analysis

We estimated the associations of the built environment variables with walking and physical performance, using a two-level multilevel linear model in HLM 6 (Raudenbush, 2004). The level 1 (within-person) model represents the values in walking or physical performance over time for each member of the population experienced during the 14-year study period. In the level 2 (between-person) model, the level 1 parameters are modeled as a function of built environment characteristics and other individual characteristics. Although neighborhood could potentially be examined as a third level of analysis, we chose not to do so because the clustering of women within neighborhoods in our subsample is quite sparse at baseline

(median = 7, range 1–37) and particularly over the follow-up visits (median 2, range 1–9 respondents per tract by visit 8).

Primary analyses were stratified by whether or not study members reported at baseline that they routinely walked. This stratification was based on the hypothesis that if built environment prevents decline in physical performance by encouraging physical activity, we would expect to see it associated with change in physical performance only among women who already walked outside the home.

The baseline analysis evaluated the association between built environment variables and walking and physical performance adjusting for all baseline covariates. To explain between-person variation in the rate of change over time, we began by estimating an unconditional growth model, then examined how trajectories of physical performance varied by built environment characteristics. Age, mean comorbidities, and mean self-rated health across the 14-year study period were included as covariates. Since mortality accounts for a substantial loss of subjects in this study (26% by visit 8), we also included a dummy indicator for death over the course of the study to address the possibility that those who survived throughout the study are systematically different (with respect to their risk of decline in physical performance) from those who did not. Other baseline characteristics that were associated with between-person variation in change in physical performance over time with significant bivariate relationships were considered for inclusion in the multivariate model. However, none were significant in the multivariate model with a p -value < 0.05 and thus no additional covariates were retained. As a sensitivity analysis, we evaluated whether built environment characteristics were associated with whether or not women walked at baseline and during follow-up controlling for covariates with a two-level logit model in HLM 6 (Raudenbush, 2004). In another sensitivity analysis, we repeated the primary analysis using the subset of women who did not move during the follow-up period. A two-tailed alpha of .05 was used to assess statistical significance. We report effects as regression coefficients with associated 95% confidence intervals.

Results

Table 1 provides characteristics of the 1,671 women in the study population by reported walking at baseline; approximately 60% of the women reported walking for exercise or as part of her daily routine. Women included in the baseline analysis were younger, less likely to report history of manual labor, had more years of education, higher neighborhood SES, fewer comorbidities, and reported higher self-reported health than the 750 women who were excluded (see study population description).

Table 2 shows the association between the built environment and walking and lower extremity physical performance at baseline, and between built environment and changes in function during follow-up, stratified by reported walking. Qualitatively, the results for the two measures of street connectivity were the same and the measures were highly correlated, so only one (alpha) is displayed; similarly only one of the measures of street density (block length) is displayed.

All of the measures of built environment were significantly associated with the number of blocks walked at baseline, among women who walked. For example, a one-unit increase in alpha was associated with 8 additional blocks walked at baseline, and each additional foot of block length (less density) was associated with approximately 1 fewer blocks walked. Built environment measures were not significantly associated with baseline physical performance. As expected, older age, more years employed in a labor-intensive job, lower neighborhood

SES, more comorbid conditions, and poorer self-reported health were associated with worse physical performance at baseline.

In longitudinal analyses in the study population, walk speed declined and time to complete chair stands increased significantly during follow-up ($p < 0.001$), indicating reduced physical performance. Neighborhood walkability had no association with change in physical performance among women who reported not walking at baseline in adjusted models. However, among women who walked, greater street connectivity was associated with a slower decline in dynamic leg strength indicated by score on chair stand ($B = -0.434$, $p = 0.027$), and less street density was associated with a greater decline in dynamic leg strength ($B = 0.039$, $p = 0.023$). Built environment was not associated with changes in blocks walked or changes in the walk speed measure. In an analysis using the combined cohort, built environment parameters were not associated with whether or not the women walked at baseline and over time, with or without covariates included in the model.

Sixty-five percent of the women had the same address throughout follow-up (or until death). Thirty-five percent ($n = 350$) moved at least once and 7% moved more than once. We evaluated whether these women moved to neighborhoods that were similar to their baseline neighborhoods in terms of built environment, between their baseline address and last known address during follow up. Of the 350 who moved during follow-up, 198 (57%) were in the same or higher quartile of walkability by the time of their last known address in the study period, 24% ($n = 83$) declined by one quartile, and 20% ($n = 69$) by two or more quartiles. In sub-analyses re-running the primary models excluding women who moved during follow-up, effect sizes for the association between the built environment and walking and physical performance were similar to the primary analyses although no longer statistically significant (data not shown).

Discussion

Our results provide support for the role of built environment in the maintenance of dynamic leg strength among older women. In this study, residence in a more walkable environment was contemporaneously associated with more blocks walked, but not with trajectory of change in walking during follow-up. The association between greater street connectivity and lower extremity physical performance trajectory was limited to women who walked at baseline. This supports our hypothesis that if built environment works to prevent decline in physical performance by enabling physical activity, its association with change in physical performance would be found only those who already walk regularly. By providing an environment that increases current walking activity, future reductions in physical function may be prevented.

Our results are similar to the previous longitudinal study of the relationship between neighborhood built environment and changes in older adults' mobility over time (P. Clarke, et al., 2009), which evaluated the role of the built environment on trajectories of self-reported mobility disability. Adults aged 45 and older from the Americans' Changing Lives Study were followed for 15 years. Among those aged 75 and older, residence in neighborhoods with more motorized travel was associated with a 50% greater odds of self-reported outdoor mobility disability.

We observed a statistically significant association between built environment and change in one measure of mobility – chair stand – but not another, walk speed. Although the performance measures are highly reliable (Curb, et al., 2006), they were not designed to cover all possible domains of physical performance but to measure global functional deficits

which appear to be clinically important. Walk speed may not be the optimal operationalization of the functional domain influenced by the built environment.

Unlike findings from prior research (Beard, et al., 2009; Bowling & Stafford, 2007; P. Clarke, et al., 2008), built environment characteristics were not cross-sectionally associated with physical performance in our results. The difference may be related to the measured outcome; previous studies reported a cross-sectional association with self-reported disability, while we assessed physical performance, pre-clinical markers of disability (L.P. Fried, Bandeen-Roche, Chaves, & Johnson, 2000; L.P. Fried, Herdman, Kuhn, Rubin, & Turano, 1991). Further, built environment may play a role in progression, rather than initiation, of disability by moderating the progression from lower extremity limitations to disability (Philippa Clarke & George, 2005; L.P. Fried, et al., 1991). Additionally, this relationship may differ by gender. For example, Freedman and colleagues found an association between higher neighborhood connectivity and decreased risk of limitations in Instrumental Activities of Daily Living only among men (Freedman, et al., 2008).

In contrast to our null finding related to baseline disability, our finding of a significant cross-sectional association between built environment and walking in older adults is consistent with prior research (Berke, Koepsell, Moudon, Hoskins, & Larson, 2007; Fisher, Li, Michael, & Cleveland, 2004; Lee, Ewing, & Sesso, 2009; Nagel, et al., 2008). Nagel and colleagues found that amount of automobile traffic and presence of nearby commercial establishments were associated with increased levels of activity among older adults who walk. Similar to the results in the current study, Nagel and colleagues also reported no association between built environment and the likelihood of walking or not walking (Nagel, et al., 2008).

A limited number of longitudinal analyses showed mixed results. Similar to the result reported here, Lee and colleagues found that sprawl was associated with walking in cross-sectional but not longitudinal analyses (Lee, et al., 2009). In contrast, Li and colleagues reported that greater facility accessibility and fewer self-reported safety problems were associated with less decline in walking over a 12-month follow-up (F. Li, Fisher, & Brownson, 2005).

Our study has several limitations. While we used street connectivity and street density to measure walkability of the built environment, other related aspects, such as access to retail and services, were not assessed. Second, walkability was assessed at the level of census tract. Administrative boundaries may not reflect relevant neighborhood boundaries for residents and are subject to the modifiable areal unit problem (MAUP) or the concern that the same study area can be different if aggregated in different ways (Flowerdew, Manley, & Sabel, 2008). Third, we were unable to account for certain characteristics of women – such as type of residence and use of transportation – that may influence the extent and degree to which they interact with their residential neighborhood environment. Fourth, walking activity was self-reported and did not specify the location of the walking activity. Self-reports have been shown to overestimate the amount of activity when compared to objective data (Troiano et al., 2008). Misclassification of walking is likely non-differential, and the error would bias our results towards the null. Fifth, study sample is limited to older women living in a single metropolitan region, the study results may not be applicable to older men and may not be broadly generalizable to women of this age in other urban areas.

However, this study has several important strengths, including its prospective design. Cross-sectional studies cannot evaluate the temporal relationship between built environment and physical performance, as we were able to do. Further, we assessed functional status using

performance-based measures rather than self-report, and we were able to account for neighborhood and individual level socioeconomic status.

In summary, our results are supportive of a protective role of built environment on the progression of limitations in physical performance in older women. Additional prospective studies that include other aspects of the walkability of the built environment, such as access to retail and services, are essential for establishing whether policy approaches to improving the built environment holds promise for preventing disability.

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Table 1

Summary of selected baseline characteristics of 1,671 SOF participants who lived in the Portland, Oregon metropolitan area at baseline, Mean (SD) or Percent

Characteristic	Walk at Baseline		P-value
	Yes N = 1,008	No N = 663	
Age (years)	71 (5)	72 (5)	< .0001
Education (years)	13 (3)	12 (3)	0.0012
Neighborhood SES	0.3 (4)	-0.2 (4)	0.0103
History of manual labor (%)			0.0371
None	35	41	
10 years	29	25	
> 10 years	36	33	
Comorbidities (%)			0.0044
0	32	27	
1	50	50	
2 or more	18	23	
Self-reported health (%)			0.0177
Excellent	35	31	
Good	53	54	
Fair	11	14	
Poor/very poor	1	1	
Blocks walked ^a	19 (13)	NA	
Walk pace (meter/seconds) ^b	0.9 (0.2)	0.8 (0.2)	< .0001
Chair stand time (seconds) ^c	11 (4)	12 (5)	0.0197

Note: P-value testing the difference in baseline characteristic by walking at baseline; SOF = Study of Osteoporotic Fractures in Women; SD = standard deviation; SES = socioeconomic status;

^aOverall range, 1 to 96

^bRange in walkers, 0.2, 1.7; range in non-walkers, 0.3, 1.4

^cRange in walkers, 4, 56; range in non-walkers, 5, 53

Table 2

Parameter estimates and 95% CI from random effects models of lower extremity physical performance and blocks walked: SOF Portland, Oregon metropolitan area

Among women who walked at baseline (n = 1,008)			Chair Stand (s)			Walk Speed (m/s)		
	β	95% CI	β	95% CI	β	β	95% CI	
Baseline:								
Street connectivity (alpha)	9.63	2.18, 17.08	-1.08	-3.60, 1.43	0.001		-0.10, 0.11	
Street density (block length)	-0.79	-1.47, -0.12	-0.05	-0.27, 1.16	0.01		-0.004, 0.016	
Age	-0.36	-0.52, -0.21	0.19	0.13, 0.25	-0.01		-0.013, -0.009	
Education	0.04	-0.23, 0.31	-0.10	-0.19, 0.00	0.006		0.002, 0.010	
Neighborhood SES	0.09	-0.05, 0.22	-0.08	-0.15, -0.01	0.004		0.002, 0.006	
10 yrs manual labor vs none	0.16	-1.22, 1.54	-0.22	-1.33, -0.21	0.02		0.01, 0.05	
> 10 yrs manual labor vs none	1.23	-0.10, 2.56	-0.77	-0.81, 0.38	0.03		0.001, 0.05	
Comorbidities	-0.83	-1.63, -0.03	0.58	0.26, 0.90	-0.01		-0.03, -0.001	
Self-reported health	-1.43	-2.34, -0.51	0.61	0.25, 0.97	-0.04		-0.05, -0.02	
Trajectory†:								
Time (alone)	-0.68	-0.75, -0.62	0.59	0.54, 0.63	-0.01		-0.014, -0.01	
Street connectivity × time	-0.02	-0.69, 0.66	-0.43	-0.82, -0.05	0.01		-0.01, 0.02	
Block Length × time	0.001	-0.058, 0.06	0.04	0.01, 0.07	-0.001		-0.003, 0.001	
Among women who did not walk at baseline (N = 663)			Chair Stand (s)			Timed Walk (m/s)		
	β	95% CI	β	95% CI	β	β	95% CI	
Baseline:								
Street connectivity (alpha)	NA		-1.05	-4.14, 2.04	-0.01		-0.14, 0.11	
Street density (block length)	NA		0.08	-0.20, 0.36	0.001		-0.01, 0.01	
Age	NA		0.19	0.12, 0.27	-0.01		-0.01, -0.006	
Education	NA		-0.08	-0.21, 0.06	0.01		0.006, 0.014	
Neighborhood SES	NA		0.04	-0.05, 0.13	0.001		-0.003, 0.005	
10 yrs manual labor vs none	NA		0.11	-0.69, 0.90	0.03		0.005, 0.06	
> 10 yrs manual labor vs none	NA		0.02	-0.01, 0.04	0.02		-0.007, 0.043	
Comorbidities	NA		0.57	0.04, 0.99	-0.03		-0.003, 0.001	
Self-reported health	NA		1.29	0.81, 1.77	-0.05		-0.009, 0.001	

Among women who did not walk at baseline (N = 663)				Chair Stand (s)		Timed Walk (m/s)	
Blocks Walked		β		β		β	
95% CI		95% CI		95% CI		95% CI	
<i>Trajectory^a:</i>							
Time (alone)		NA		0.52		-0.01	
Street connectivity $\times$ time		NA		0.30		0.001	
Block Length $\times$ time		NA		-0.02		0.001	
Notes: bolded text indicates p-value < 0.05; SOF = Study of Osteoporotic Fractures in Women; CI = confidence interval; SES = socioeconomic status; NA = not applicable.							

^aControlling for age, average number of incident comorbidities, average self rated health, and death during follow-up

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