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Aging in Neighborhoods Differing in Walkability and Income: Associations with Physical Activity and Obesity in Older Adults

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Abstract

While there is a growing literature on the relations between neighborhood design and health factors such as physical activity and obesity, less focus has been placed on older adults, who may be particularly vulnerable to environmental influences. This study evaluates the relations among objectively measured neighborhood design, mobility impairment, and physical activity and body weight in two U.S. regional samples of community dwelling older adults living in neighborhoods differing in walkability and income levels. An observational design involving two time points six months apart was employed between 2005–2008. U.S. Census block groups in Seattle-King County, Washington and Baltimore. Maryland-Washington DC regions were selected via geographic information systems to maximize variability in walkability and income. Participants were 719 adults ages 66 years and older who were able to complete surveys in English and walk at least 10 feet continuously. Measurements included reported walking or bicycling for errands (i.e., transport activity) and other outdoor aerobic activities measured via the CHAMPS questionnaire: accelerometry-based moderate-to-vigorous physical activity; reported body mass index; and reported lower-extremity mobility impairment measured via the Late-Life Function and Disability Instrument. Across regions, time, and neighborhood income, older adults living in more walkable neighborhoods had more transport activity and moderate-to- vigorous physical activity and lower body mass index relative to those living in less walkable neighborhoods. The most mobility-

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impaired adults living in more walkable neighborhoods reported transport activity levels that were similar to less mobility-impaired adults living in less walkable neighborhoods. The results add to the small literature aimed at understanding how neighborhood design may influence physical activity and related aspects of health linked with day-to-day function and independence as people age.

Keywords

USA; physical activity; older adults; built environment; walkability; obesity; physical function; accelerometry; neighbourhoods

Introduction

Older adults represent the most rapidly growing population segment in many industrialized nations, and are among the least physically active (de Groot et al., 2004). In U.S. and Swedish population studies employing objective activity measurement, fewer than 5% of adults over age 65 met physical activity recommendations (Hagstromer et al., 2010; Troiano et al., 2008). Decreases in physical activity and increases in body weight that often accompany aging are linked with deterioration of a range of physiological systems that can lead to impairments in day-to-day function. These systems are often critical to maintaining mobility, independent living, and overall quality of life (Alley & Chang, 2007; Hirvensalo et al., 2000; A. C. King & Guralnik, 2010).

Functional impairments, as well as inactivity levels, can be exacerbated by the environmental contexts in which older adults live (Clarke & George, 2005; Yen, Michael, & Perdue, 2009). For example, Clarke and George (2005) reported that older adults with reduced physical function were less able to perform daily utilitarian activities when they lived in residential neighborhoods with few destinations nearby (Clarke & George, 2005). Neighborhood opportunities to engage safely in active transport (i.e., walking or bicycling for errands) may help even mobility impaired older adults avoid further disability and dependence (Hirvensalo et al., 2000; Langlois et al., 1997).

Numerous studies of younger adults using objective measures of neighborhood walkability (i.e., higher residential density, land-use mix, street connectivity, etc., assessed using geographic information systems [GIS]) have documented consistent associations between living in neighborhoods designed to support active transport and reduced risks of inactivity, overweight, and obesity (Heath et al., 2006; Saelens & Handy, 2008; Sallis et al., 2009). Fewer such studies exist among older adults (Frank et al., 2010; W. C. King et al., 2003; Yen et al., 2009), and those that have included objective measures of the built environment have shown inconsistent results (Frank et al., 2010; W. C. King et al., 2005; Yen et al., 2009). Studies of older adults have rarely included objective measures of physical activity (i.e., accelerometry), and, to our knowledge, only two studies have reported obesity outcomes in older adults (Berke et al., 2007; Frank et al., 2010).

The purpose of the study was to evaluate the relations among objectively measured neighborhood design, mobility impairment, and physical activity and body weight in two U.S. regional samples of community dwelling older adults living in neighborhoods differing in walkability and income levels. Outcomes of interest were walking/cycling for transport, given its potential relation with aging in place (Langlois et al., 1997), objectively measured moderate to vigorous physical activity which has been linked consistently to health outcomes associated with aging, and reported body mass index. The potential moderating effect of mobility impairment on these relations was explored.

METHODS

Study Design

The Senior Neighborhood Quality of Life Study was an observational study designed to compare physical activity and other health and well being outcomes among older residents of neighborhoods stratified on objectively derived ‘walkability’ characteristics and median household income. Based on the study design and methods used in the Neighborhood Quality of Life Study targeting younger adults (Sallis et al., 2009), data were collected from 2005 to 2008 in the Seattle-King County, Washington and Baltimore-Washington DC regions of the U.S. These two metropolitan areas were chosen based on availability of parcel level land use information and variability in neighborhood walkability (Frank et al., 2009; Sallis et al., 2009). The study was approved by Institutional Review Boards at participating academic institutions, and participants gave written informed consent.

Neighborhood Selection

The study area in the Seattle region consisted of the western urbanized portion of King County, WA. In the Baltimore, Maryland region, the study area consisted of the Counties of Baltimore, Howard, Montgomery and Prince George’s. Participants were recruited from 216 U.S. 2000 Census block groups (i.e., a subsection of a Census tract that consists of about 1500 people) differing in median household income and built environment features (Seattle-King County=116 block groups; Baltimore-Washington DC=100 block groups). Block groups within each region were prioritized based on the numbers of potentially available participants in the study age range (the more seniors in a block group, the higher the block group prioritization). There was a median of 2 participants per block group (range=1–22 participants). Block groups were categorized as “lower” income if they were at or below the region-specific median (\$50,907 for the Baltimore-Washington DC four-county study region; \$56,676 for Seattle-King County). “Higher” income block groups were above the region-specific median. Region-specific median splits allow walkability-outcomes relations to be evaluated within the relative variations in walkability to which participants are actually exposed. It also allowed enough candidate block groups per neighborhood type in each region to provide a sufficient pool of participants. Basing walkability median split on the combined distributions would likely have created imbalances in the participant pool in some neighborhood types in each region.

For each block group, a validated GIS-based walkability index was derived as a composite of four variables chosen on the basis of city planning theory and empirical studies (Cervero & Kochelman, 1997; Saelens et al., 2003), described in detail elsewhere (Frank et al., 2009). Walkability means the neighborhood has a diversity of uses and a connected street network that supports walking to destinations (Frank et al., 2003; Saelens et al., 2003). The walkability index was based on four components using data obtained from the US Census, publicly-available road network files, and county tax assessor files on parcel size, building square footage, and category of use: (a) net residential density (ratio of residential units to the land area devoted to residential use); (b) retail floor area ratio (retail building square footage divided by retail land square footage); (c) land-use mix (diversity of land use types per block group; normalized scores ranged from 0 to 1, with 0 being single use and 1 indicating an even distribution of floor area across 5 uses--residential, retail, entertainment, office, institutional); and (d) intersection density (connectivity of street network measured as the ratio of number of intersections with 3 or more legs to land area of the block group in acres). This walkability index and variants have been used and validated in multiple studies in several countries (Frank et al., 2005; Kligerman et al., 2007; Leslie et al., 2007; Sallis et al., 2009). Higher and lower walkability were characterized using region-specific median splits (described earlier). The walkability and income characteristics of each block group

were crossed to create four quadrants: higher walkable/higher income, higher walkable/lower income, lower walkable/higher income, and lower walkable/lower income (Frank et al., 2009; Sallis et al., 2009). Block groups in each quadrant met both income and walkability criteria for that quadrant (i.e., a stratified design). For example, block groups included in the lower income-lower walkability quadrant were below the region-specific median splits for each of these two variables. Study participants were sampled from these designated block groups (i.e., block groups that met the above criteria were identified first, with participants drawn subsequently from these block groups). A descriptive summary of the four quadrants is shown in Table 1.

Participant Recruitment and Assessment Procedures

Participants in the Seattle-King County region were recruited and assessed in 2005–2007. Participants in the Baltimore-Washington DC region were recruited and assessed in 2006–2008. Participants in each region were recruited throughout the first 12 months, and a second assessment was conducted six months later to control for seasonal variation in physical activity.

Contact information for people residing within the selected block groups was purchased from a marketing company (CAS marketing--www.cas-online.com) with the specific ability to provide block group and age based household enumeration using a variety of public and private sources. Letters introducing the project were mailed to all eligible households within the selected block groups, followed by telephone contacts. If the initially targeted adult refused or was ineligible, another adult in the household was invited. Eligibility was defined as being 66 years of age or older (the original Neighborhood Quality of Life Study sample included adults up to 65 years old from the same regions) (Sallis et al., 2009), able to complete surveys in English, and absence of a medical condition that interfered with the ability to walk more than 10 feet at a time. Consent forms were mailed, signed and returned. A telephone contact was used to review the study purpose and exclude individuals who had sufficient cognitive impairment that they could not adequately explain the study tasks required of them.

Participants were mailed an accelerometer with instructions for wearing and mailing it back (Sallis et al., 2009). At the end of the 7-day accelerometer period, participants completed the survey by mail, online, or via telephone interview. Six months later, participants were sent another accelerometer and completed a second survey. Upon receipt of accelerometer and survey data at each time point, participants received \$25 for their participation.

Measures

Outcome Variables

Reported physical activity: Participants completed the CHAMPS physical activity questionnaire, which has been extensively validated with older populations (Stewart et al., 2001), at each measurement point to capture usual weekly amounts and intensities of various types of activity engaged in over the previous 4 weeks. Participants reported the number of times/week they usually engaged in each activity, and chose one of 6 categories reflecting the time range that they usually engaged in each activity, from less than 1 hour/week to 9 or more hours/week. The midpoint of each category's range was used to provide an estimate of activity time for each item (e.g., 1 to 2.5 hours=105 minutes per week) (Stewart et al., 2001). *Transport activity*--of major interest in light of research in younger adults showing this outcome to be particularly related to neighborhood design--was assessed by summing two CHAMPS items inquiring about walking or bicycling for errands. *Other outdoor aerobic activities* typically occurring in neighborhoods consisted of the sum of six CHAMPS items assessing walking (i.e., walking fast, walking for leisure, walking uphill, dog walking),

bicycling, and jogging or running for leisure. Scores represented total minutes per week spent engaging in the composite items (calculated using the midpoint of the usual length of time category checked for each item) (Stewart et al., 2001).

Accelerometer measured physical activity: Ambulatory assessment of moderate-to-vigorous physical activity recommended for optimal health benefits (Physical Activity Guidelines Advisory Committee, 2008)--was accomplished using the extensively validated Actigraph accelerometer (Actigraph, LLC; Fort Walton Beach, FL, model 7164 or 71256 accelerometers) (Troiano et al., 2008). Participants were instructed to wear the accelerometer during waking hours for 7 days at each of the two measurement points. The accelerometer was placed over the right hip using a provided elasticized belt. Data were collected in 1-minute epochs. Participants were asked to re-wear the accelerometer if an assessment contained either less than 5 valid days or less than 66 valid hours across 7 days, or the accelerometer had malfunctioned during data collection. Across the two data collection periods, 167 participants (out of 1448 total data collection points; 11.5%) were asked to re-wear the accelerometer at a time point, and 143 (86%) of those asked did so. For compliance scoring, a valid accelerometer hour was defined as less than 30 consecutive 'zero' intensity counts, and a valid day consisted of at least 10 valid hours/day. Data were cleaned and scored using MeterPlus version 4.0 software from Santech, Inc. (www.meterplussoftware.com). Scoring of moderate to vigorous physical activity was based on a commonly used cut-point (1952 counts/minute) (Freedson et al., 1998), and derived as average minutes of moderate to vigorous physical activity per valid wearing day (Hekler et al., In press,). To provide comparability with current physical activity recommendations based on minutes per week (Physical Activity Guidelines Advisory Committee, 2008), this variable was multiplied by 7 to obtain an estimate of average weekly minutes of moderate to vigorous physical activity. In addition to analyzing this outcome as a continuous variable, the proportion of persons in each neighborhood income-walkability quadrant meeting the nationally recommended 150 minutes or more per week of moderate to vigorous physical activity for U.S. adults and older adults was analyzed (Physical Activity Guidelines Advisory Committee, 2008).

Body mass index (BMI): Self-reported weight and height were used to calculate BMI (kg/m^2). Overweight was defined as BMI ≥ 25 and obesity as BMI ≥ 30 (National Heart Lung and Blood Institute, 1998).

Covariates—In addition to geographic region (Seattle-King County, Baltimore-Washington DC), demographic variables assessed by survey were gender, age (continuous), education (7 levels from less than 7th grade to completed graduate degree), race/ethnicity (7 categories), number of motor vehicles/adults in household, marital status (4 categories—never married, married or living with partner, divorced/separated, widowed), number of people living in household, and years at current address.

Potential Moderator: Self-rated Mobility Impairment—Mobility impairment was assessed at both time points using the validated 11-item advanced lower extremity subscale of the Late-Life Function and Disability Instrument (LLFDI) (Sayers et al., 2004), which assesses a broad range of functional capabilities requiring lower body function on a 1 to 5 scale (e.g., walking several blocks, going up and down 3 flights of stairs, getting up from the floor). Validation studies support the use of the LLFDI scales as a substitute when onsite functional testing is infeasible (Sayers et al., 2004).

Statistical Analyses

Reflective of a multilevel ecological framework for exploring person-environment interactions (Sallis & Owen, 2002), repeated measures mixed effects simultaneous regression models (using SAS PROC MIXED) were fitted for all continuous outcome variables and included the regional and demographic covariates described above. GLIMMIX was used for dichotomous outcomes. Three level models were fitted to account for repeated measures nested within subjects and subjects nested within block groups. The main effects of neighborhood walkability and income and their interaction as represented by the four walkability/income quadrants of the study design was the main focus of the analyses.

To examine lower extremity mobility impairment as a potential moderator of the neighborhood walkability-physical activity relation, a second set of regression analyses was conducted identical to the first set but with the addition of the lower extremity mobility impairment score as a main effect and as part of an interaction term with walkability. Variables entered into the interaction term were first centered at the mean of the distribution to aid interpretability.

RESULTS

Participant Characteristics and Representativeness

A total of 3,359 eligible adults living in the selected block groups were contacted by telephone and invited to participate. Study enrollment rate (i.e., returned Survey 1/eligible contacts) was 21.4% overall (n=719, with 363 from Seattle and 356 from Baltimore regions), and did not differ significantly by region or by quadrant (quadrant range of 17.7% to 25.1%). The 6 month retention rate was 91% overall (n=647, with 319 from Seattle region and 328 from Baltimore region) (quadrant range of 90.5% to 92.4%), after eliminating those who were no longer eligible because they moved out of the region (n=9). Reasons for loss to follow up included no response to repeated Survey 2 mailing or telephone contacts (n=16), dropping out after completion of the first survey (n=8), or refusing to participate in Survey 2 after being contacted (n=21). Ninety percent of participants completed the surveys via mail, 9% online, and 1% via telephone.

Sample demographics by neighborhood income/walkability quadrant are reported in Table 2. The sample was well balanced by sex, generally well educated, most were married or living with a partner (56.8% overall, with fewer than 2% of that category living with a partner without being married), and 28% were nonwhite. Residents had lived in their neighborhoods an average of 24.7 years (SD=15.5) (Seattle region mean=24.6, SD=16.5; Baltimore region mean=24.8, SD=14.4). Senior Neighborhood Quality of Life Study participants were comparable with 2000 Census block group data in basic demographic variables (i.e., age, education) (Table 3). The Baltimore sample was also similar to the 2000 Census regional population with respect to percent Caucasian (Table 3). The sample from the Seattle region had a somewhat greater percentage of Caucasian participants relative to the 2000 Census regional population, likely due, at least in part, to the greater percentage of adults in that region representing racial and ethnic minority groups (primarily Asian and Hispanic) who spoke a language other than English.

Reflecting the study's stratified design and recruitment protocol, Table 4 shows the differences among participants living in neighborhoods in the higher vs. lower walkability and higher vs. lower income quadrants, including means, standard errors, and with all results adjusted for all covariates. Of note, no significant time effects (i.e., no differences between the two measured time points) or neighborhood walkability by income interactions were found (p values>.10), with the exception of percent of participants who were overweight/obese (described below). Because there were no significant interactions (with the one

exception noted above), we describe the significant main effects for each factor, averaging across the other main effect (e.g., the higher vs. lower walkability means reported below represent the average of their respective means in the higher plus lower income strata shown in Table 4).

Neighborhood Walkability Effects

Active Transport—The walkability main effect was significant ($p<0.0001$), indicating higher average number of minutes/week of self-reported walking for transportation (errands) in higher walkable neighborhood quadrants (38.1 [SE=10.5] minutes/week) compared to lower walkable quadrants (6.7 [SE=10.7] minutes/week).

Other Outdoor Aerobic Activities—The walkability main effect was not significant ($p=.28$) for other outdoor aerobic activities.

Accelerometer-derived Moderate and Vigorous Physical Activity—The walkability main effect was marginally significant ($p=0.056$), with older adults living in higher walkable neighborhoods averaging 69.4 (SE=17.3) minutes/week of accelerometer-derived moderate to vigorous physical activity compared to 52.2 (SE=17.7) minutes/week in lower walkable neighborhoods.

When the likelihood of meeting the national recommendation of 150 or more minutes/week in moderate to vigorous physical activity was evaluated, there was a trend for the walkability main effect ($p<0.08$). Those quadrants with higher walkability and/or income levels (p for income main effect=0.01) were linked with a greater likelihood of meeting the recommendation (higher walkable-higher income quadrant=17.8%, lower walkable-higher income=11.2%, higher walkable-lower income=8.6%; lower walkable-lower income=3.9%).

Body mass index (BMI)—The walkability main effect was significant ($p=0.02$), with older adults living in higher walkable neighborhoods having lower BMI (mean=26.2, SE=0.73) compared to those in lower walkable neighborhoods (mean=27.1, SE=0.75).

Percent Overweight/Obese (BMI > 25.0)—There was a significant walkability X neighborhood income interaction for percent overweight/obese ($p=0.015$). The combination of higher walkability and higher income yielded the lowest proportion of overweight/obese individuals (48%), whereas having only one or neither of these neighborhood features was associated with higher proportions of overweight/obesity, representing more than half of these groups (range=58–62%). The latter three quadrants did not differ significantly from one another (p values 0.33).

Impact of Mobility Impairment on Neighborhood Walkability Associations—The mobility impairment main effect was significant in all models (p values <0.0001), with individuals with greater mobility impairment reporting less physical activity and higher BMI. The walkability main effect remained significant in the models predicting transport activity and BMI. In the analysis predicting transport activity, the mobility impairment X walkability interaction also achieved significance ($p=0.001$). To evaluate this interaction further, mobility impairment scores were divided into tertiles. A summary of the results is shown in Figure 1. While mean minutes/week of transport activity was generally greater in higher relative to lower walkable neighborhoods for all mobility impairment tertiles, the difference between the two walkability levels was particularly pronounced for older adults who were least mobility impaired (net mean difference between higher and lower walkability residents of 48.9 minutes/week, SE=7.0) relative to those in the middle mobility impairment tertile (net mean difference of 26.2 minutes/week, SE=6.3) and the highest

mobility impairment tertile (net mean difference of 24.5 minutes/week, SE=5.0) (p values for least mobility impaired tertile difference relative to differences in other two tertiles 0.016). Of note, the mean minutes/week of transport activity for those who were most mobility impaired living in higher walkable neighborhoods (35 minutes/week, SE=4.0) was not statistically different from the mean minutes/week of transport activity for persons in the two less impaired tertiles living in lower walkable neighborhoods (middle tertile=28 minutes/week, SE=4.0; lowest tertile=26 minutes/week, SE=4.0; p 0.11).

Neighborhood Income Effects

In addition to the results described above, there were significant neighborhood income main effects for the following dependent variables: *Other outdoor activities* (p=0.02: higher income neighborhoods=125.5 [SE=28.8] minutes/week, lower income=92.9 [SE=28.1] minutes/week); *accelerometer-derived moderate and vigorous physical activity* (p=0.05: higher income neighborhoods=69.8 [SE=17.8] minutes/week, lower income=51.8 [SE=17.3] minutes/week); and *body mass index* (p=0.026: higher income neighborhoods mean=26.2 [SE=0.75], lower income neighborhoods mean=27.0 [SE=0.73]).

DISCUSSION

Objectively measured neighborhood walkability was related to older adults' self-reported and accelerometer-derived physical activity as well as BMI. Of particular note, residents of higher walkable neighborhoods reported 22–40 more minutes/week of active transport than those in lower walkable neighborhoods, irrespective of neighborhood income. This replicates a pattern commonly found in younger adults (Saelens & Handy, 2008), but which has been less well studied among older populations (Frank et al., 2010). In contrast, there was a lack of association between neighborhood walkability and more recreational forms of outdoor aerobic activity (e.g., leisure walking, leisure cycling, jogging). This result is expected given that the walkability index used was designed to predict utilitarian or “destination based” forms of activity. The results are consistent with previous findings concerning the specificity of urban design associations in relation to different physical activity types and purposes (Giles-Corti et al., 2005; Lee & Moudon, 2006).

The difference in transport activity between the two walkability categories was more than 30 minutes per week, indicating residents of higher walkable areas reported 400% more transport activity than the low walkability group. Engaging in reasonable amounts of weekly walking or similar forms of physical activity has been associated with lower rates of CHD and type 2 diabetes in several large epidemiological studies of older adults (Hu et al., 1999; Manson et al., 2002). Of note, it is becoming increasingly apparent that to meet current recommendations (Physical Activity Guidelines Advisory Committee, 2008), many older adults will likely need to engage in a combination of active leisure and active transport (Hekler et al. in press). Living in neighborhood environments that are conducive to transport activity can lead to routine forms of daily activity that do not require the types of planning and scheduling often required for recreational activity. The approximately 30 minutes per week difference in transport activities translates to 20% of the weekly physical activity recommendation.

On a related note, the difference in accelerometer-derived moderate and vigorous physical activity was about 17 minutes/week, indicating residents of higher walkable neighborhoods were about 33% more active in moderate and vigorous physical activity than those living in lower walkable neighborhoods. When converted into net energy expenditure, this difference translates into an approximately 1.5 pound difference across a year between the two types of neighborhoods. Given that overweight/obesity rates are high (approximately 71%) (Ogden et al., 2006) among U.S. adults in this age group, the health benefits of living in more walkable

neighborhoods could accumulate over time. The modest difference in minutes per week is magnified by the expectations that the effects apply on average to everyone in the neighborhoods as long as they live there, suggesting a potentially important public health impact.

It is notable that moderate and vigorous physical activity measured via accelerometry was low overall, averaging less than 20 minutes/week even among older adults in higher walkable neighborhoods. These low levels are commensurate with recent U.S. population data (Troiano et al., 2008). It is also not surprising that the differences between the CHAMPS and moderate and vigorous physical activity measures were large, given differing measurement modalities, differences in the types of physical activity variables each was targeting, and the fact that the CHAMPS variables of interest were not limited to the moderate and vigorous physical activity range specifically. As noted in the literature, both self-reported and objective physical activity measures add useful information and appear to capture distinct aspects of physical activity related to health outcomes (Atienza et al., 2011).

The BMI difference between higher and lower walkable neighborhoods of about one BMI unit amounts to an approximately 6 pound (2.7 kilogram) difference, similar to an investigation of adults ages 20–65 years using the same study design in the same regions (Sallis et al., 2009). Given the present results were consistent across lower and higher income neighborhoods, improvements in neighborhood walkability could potentially be expected to benefit older adults across the income spectrum. The only significant walkability by neighborhood income interaction was found for proportion of overweight/obese individuals, with persons living in higher walkable/higher income neighborhoods faring better generally than those in the other three quadrants. This result suggests that, for seniors, there may be protective effects of living in higher walkable/higher income neighborhoods when it comes to overweight/obesity status that go beyond what is gained from living in either neighborhood type alone. The differences among quadrants could be related to the different mix of and access to destinations, particularly more healthful food outlets, in higher walkable, higher income neighborhoods relative to other neighborhoods. This issue deserves further exploration, particularly given that results from a review of the neighborhood income-obesity relationship were mixed (Black & Macinko, 2008). In that review, availability of healthful versus unhealthful food was inconsistently related to BMI, whereas neighborhood features that discouraged physical activity were consistently associated with higher BMI.

In addition to overweight/obesity status, neighborhood income was also significantly associated with accelerometer-derived moderate to vigorous physical activity, mean BMI levels, and other outdoor activities. In contrast, neighborhood income was not associated with active transport, suggesting that aspects of the built environment linked specifically with walkability (e.g., street connectivity, diversity of destinations/land use) are a particularly important factor for that mode of activity in older populations across neighborhood income levels.

Of particular interest was the moderating effect of mobility impairment on the walkability-transport activity relationship. Respondents who were least mobility impaired appeared to particularly benefit from walkable neighborhoods. As important, however, was the finding that the most mobility impaired group living in higher walkable neighborhoods reported transport activity levels that were similar to less impaired groups living in lower walkable neighborhoods. Older adults in lower walkable neighborhoods did little transport activity, regardless of level of impairment. There was a much greater range of transport activity in higher walkable areas, suggesting walkable designs allow residents at all levels of mobility impairment to optimize transport activity. One interpretation of this result is that higher

walkable neighborhoods may enable mobility impaired older adults to undertake brief errands by walking, thereby facilitating levels of continued independence that are critical to older adults' wellbeing and quality of life (Hirvensalo et al., 2000). Exploration of these relationships across longer time periods is recommended given that, to the best of our knowledge, no other study has explored associations among transport activity, physical functioning, and neighborhood walkability.

Limitations

Study limitations included the short observational period (6 months) and self-report of active transport, mobility impairments, and BMI, which may result in some misreporting. The study did not directly address potential impacts of attitudinal predispositions and self-selection factors associated with neighborhood design relationships and physical activity (Frank et al., 2003; Transportation Research Board and Institute of Medicine of the National Academies, 2005). In addition, while the overall aim of the block group selection process was to obtain block group populations that were reasonably similar across the two study regions, the Baltimore region showed a somewhat lower mean income level in the lower walkability block groups relative to Seattle region (see Table 1). This is an artifact of the differences between the two regions and their socio-demographic and geographic makeup, and how such inherent regional differences impacted the results for the lower-income quadrants remains unclear. The principle focus of the study was on walkability, with the analyses adjusted for income at the quadrant level as well as for other factors associated with income (e.g., number of vehicles/household).

Epidemiological investigations using both objectively measured physical activity and objectively measured built environments are rare in older populations. Our search of the literature did not uncover another study of older adults with these methodological strengths. The overall 21.4% study enrollment rate may appear low relative to response rates reported for single surveys (Dillman, 2007; Wilcox et al., 1999). However, the methods employed in the current study, which involved close to 10 hours of data collection across two time periods and included wearing an accelerometer for two weeks, yielded a response rate similar to that obtained in a similarly designed study of the same regions targeting younger adults (26%) (Sallis et al., 2009). The addition of an accelerometer has been shown to decrease response rates. For example, while in the SMARTRAQ study of Atlanta, Georgia, USA the response rate to the one-time brief survey was 30.4% of eligible households, this response rate dropped to 20.3% when participants were also asked to wear an accelerometer or GPS device (Frank et al., 2005). Similarly, response rates from the U.S. National Health and Nutrition Examination Survey are instructive. While response rates for this comprehensive national survey are approximately 54–66% in the older age group, when accelerometry data collection was added to the same survey battery in 2003, the overall response rate dropped by 26% (Troiano et al., 2008).

Encouragingly, basic comparisons with U.S. Census information from the designated block groups indicated that study enrollees were generally similar to older adults in the targeted areas in age distribution, education, and, for the Baltimore region, proportion of Whites. However, we lacked information on those potential household-eligible individuals with working phone numbers who we were unable to reach by phone (28% of those in the original GIS-defined contact pool), or who, when reached, refused participation.

It is difficult to estimate what types of bias could be present in the latter subgroups relative to those older adults who participated in the study. For example, it is possible that those seniors who never answered the phone despite repeated call attempts could have been engaged more regularly in activities occurring outside of the home. This might suggest a higher than average level of health or function. Alternatively, it is possible that those not

answering the phone may have had more physical or cognitive deficits than the norm, making them less inclined to pick up the phone even when at home. Similarly, those who refused participation upon being contacted could have done so due to busy schedules linked with a more active lifestyle, or because of a greater number of health impairments. Such conjectures would be useful to explore in future studies. Finally, while use of a well-respected marketing company to identify age and geographically appropriate households is an efficient and regularly used strategy in the U.S., possible biases related to the population segments represented in such databases remain unclear (Dillman, 2007).

Lack of information on transit service characteristics shown to be related with walking and overall physical activity (Zimring et al., 2005) limits the study as well. Though not investigated here, aspects of the indoor built environment, such as the presence or absence of stairs, may also be important predictors of physical activity among older populations that deserve further consideration (Zimring et al., 2005).

Finally, studies have indicated how loss of driving can lead to loss of independence and increased anxiety and nursing home placement (Carr & Ott, 2010). While number of motor vehicles/adults in household was controlled for in the current analyses, information related to driving abilities and habits was not. Additional research can help to clarify how walkability impacts older adults' vehicle use in relation to physical activity and body weight.

Conclusions

This study expands the built environment and aging literature by studying older adults from two U.S. regions using a study design that maximized variation in walkability and income and featured objective measures of the built environment and physical activity. Though older adults had very low levels of physical activity, regardless of measure, living in more walkable neighborhoods was associated with more active transport and moderate to vigorous physical activity and lower body weight irrespective of neighborhood income and mobility disability levels. In light of the aging of the population in the U.S. and elsewhere, the study results support calls by public health organizations for the promotion of those environmental features that can support healthy aging (World Health Organization, 2004).

Research Highlights

- Across two U.S. regions, objective neighborhood walkability predicted older adults' physical activity irrespective of income.
- Neighborhood walkability-physical activity relations were similar using self-report and objective physical activity measures.
- Across income levels, older adults living in walkable neighborhoods weighed less than those in less walkable neighborhoods.
- Across mobility impairment level, older adults engaged in more walking or cycling for errands in more walkable neighborhoods.

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Figure 1.
Significant Interaction between Mobility Impairment Tertile and Neighborhood Walkability
for Mean Transport Activity (minutes per week)

Table 1

Study Design: Census Block Group Level^a, Walkability, and Median Household Income by Quadrant

Income	Region	Variable	Lower Walkability		Higher Walkability		Lower Walk	Higher Walk
			Mean	SD	Mean	SD	block group number	block group number
Lower	Seattle-King County	Walkability Index ^b	-0.50	0.27	1.60	0.93	30	24
		Income ^c	\$44,687	\$7,772	\$35,019	\$13,314		
	Baltimore-Washington DC	Walkability Index ^b	-0.57	0.11	0.40	0.58	30	46
		Income ^c	\$39,960	\$6,420	\$36,703	\$8,710		
Higher	Seattle-King County	Walkability Index ^b	-0.64	0.26	0.64	0.48	42	24
		Income ^c	\$81,111	\$18,683	\$69,423	\$10,639		
	Baltimore-Washington DC	Walkability Index ^b	-0.71	0.13	0.86	1.43	13	19
		Income ^c	\$71,955	\$13,692	\$69,027	\$14,273		

^aUsing the set of block groups in each region that contained survey participants

^bWalkability Index -- regionally normalized value of the weighted sum of ZNRD_acre+2*Zint_density_sqkm+Zifa+Zmix_fl_5

^cIncome -- 2000 Census block group median household income

Table 2
Descriptive Statistics for Demographic Variables Stratified by Neighborhood Income and Walkability Quadrants

Variables:	Low Walkability/ Low Income		Low Walkability/ High Income		High Walkability/ Low Income		High Walkability/ High Income		Total	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
People in household (number)	156	1.8 (0.7)	186	1.9 (0.8)	197	1.7 (0.8)	172	1.8 (0.7)	711	1.8 (0.8)
Age (years)	156	74.3 (5.9)	189	73.2 (5.8)	201	75.3 (6.6)	172	74.6 (6.5)	718	74.4 (6.3)
BMI (kg/m ²)	156	26.9 (5.3)	189	26.7 (4.3)	200	27.1 (4.9)	172	25.0 (4.2)	717	26.4 (4.7)
Current health conditions (number) ^a	155	1.3 (1.1)	188	1.2 (1.0)	200	1.4 (1.0)	172	1.2 (1.0)	715	1.2 (1.0)
	N	%	N	%	N	%	N	%	N	%
Age: 66 – 74 yrs	87	55.8	120	63.5	98	48.8	93	54.1	398	55.4
75 – 84	58	37.2	60	31.7	82	40.8	64	37.2	264	36.8
85 & over	11	7.0	9	4.8	21	10.4	15	8.7	56	7.8
Women	83	53.2	89	47.1	122	60.7	87	50.6	381	53.1
Current smoker	12	7.7	10	5.3	16	8.0	5	2.9	43	6.0
Completed high school	32	20.5	17	9.0	44	21.9	21	12.3	114	15.9
Completed college	65	41.7	105	55.8	67	33.3	114	66.2	351	49.0
Non-Hispanic White	117	75.5	144	76.2	109	54.2	143	83.6	513	71.6

^aCurrent health conditions: Rheumatoid arthritis, osteoarthritis, lupus or systemic lupus erythematosus; Parkinson's disease or other neurological disorder; high blood pressure; diabetes; heart attack, heart condition or angina; cancer.

Table 3

Basic demographic variables for the study sample and U.S. 2000 Census block group data, by study region

Variables	Seattle/King County		Baltimore 4-County Region	
	Study Sample	Census ^a	Study Sample	Census
Age range (yrs):	%	%	%	%
65–69 ^b	21.7	25.4	28.8	28.6
70–74	20.8	23.5	29.7	25.6
75–79	24.1	22.1	21.5	21.4
80–84	15.4	15.5	14.1	13.7
85 and over	18.0	13.5	5.9	10.7
Education:	%	%	%	%
Completed high school only	13.2	19.2	18.5	23.2
Completed college	49.8	47.7	44.5	41.1
Caucasian (%)	87.7	75.7	53.3	52.1

^a Census block groups that match those used in study sample^b In the study sample, lowest age was 66 years

Table 4
Results showing Adjusted Means by Study Quadrant and Statistical Tests for Neighborhood Income and Walkability

Continuous Outcomes	Adjusted Means (Standard Error) ^a				F statistics		
	Low Walk/ Low Income	Low Walk/ High Income	High Walk/ Low Income	High Walk/ High Income	Income X Walk Interaction	Income Main Effect	Walk Main Effect
Transport activities ^b (minutes/week; CHAMPS)	10.0 (11.3)	3.5 (11.5)	32.4 (10.9)	43.8 (11.5)	2.76	0.19	32.82 **
Other Outdoor activities ^c (minutes/week; CHAMPS)	89.7 (30.2)	113.9 (30.6)	96.0 (29.1)	137.2 (30.4)	0.39	5.48 *	1.16
MVPA ^d (minutes/week; accelerometry)	48.5 (18.7)	55.9 (19.0)	55.1 (18.0)	83.6 (18.9)	1.41	3.85	3.66
BMI (reported)	27.2 (0.79)	26.9 (0.81)	26.9 (0.76)	25.5 (0.80)	2.14	4.97 *	5.40 *
Dichotomous Outcomes	Adjusted Odds Ratios (95% Confidence Interval) (Percent Prevalence)						
	Low Walk/ Low Income	Low Walk/ High Income	High Walk/ Low Income	High Walk/ High Income	Income X Walk Interaction	Income Main Effect	Walk Main Effect
% meeting MVPA ^d recommendations (accelerometry) (7.8% prevalence)	0.37 (0.18, 0.77) (1.3%)	0.57 (0.29, 1.13) (8.5%)	0.43 (0.18, 1.21) (6.0%)	1.00 (ref) (15.0%)	0.09	6.53 *	3.19
% overweight or obese (< 25.0 BMI) (56.9% prevalence)	1.56 (0.82, 2.97) (56.1%)	2.16 (1.13, 4.11) (61.9%)	2.14 (1.11, 4.14) (61.5%)	1.00 (ref) (48.0%)	5.96 *	0.97	1.08

Note: There were no interactions with site;

^a All Models were adjusted for gender, age, education, ethnicity, number of motor vehicles/adult in household, site, marital status, number of people in household, and length of time at current address. All models were adjusted for neighborhood clustering and time. Degrees of freedom for F statistic were 1,111 for CHAMPS variables, 1,1078 for accelerometry, and 1,1101 for BMI and overweight or obese variables.

^b Transport activities: Walking for errands, biking for errands.

^c Other outdoor activities items: Ride bicycle, walk fast, walk for leisure, walk uphill, walk your dog, jog/run.

^d MVPA=Moderate and vigorous physical activity.

* p<0.05;

** p<0.001