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Patterns of Walkability, Transit, and Recreation Environment for Physical Activity

Marc A. Adams, PhD, MPH[1], **Michael Todd, PhD**[2], **Jonathan Kurka, MS**[1], **Terry L. Conway, PhD**[3], **Kelli L. Cain, MA**[3], **Lawrence D. Frank, PhD**[4], and **James F. Sallis, PhD**[3]

[1]Exercise Science and Health Promotion, School of Nutrition and Health Promotion, Arizona State University, Phoenix, Arizona

[2]College of Nursing and Health Innovation, Arizona State University, Phoenix, Arizona

[3]Department of Family and Preventive Medicine, School of Medicine, University of California, San Diego, San Diego, California

[4]Schools of Population and Public Health and Community and Regional Planning, University of British Columbia, Vancouver, British Columbia, Canada

Abstract

Introduction—Diverse combinations of built environment (BE) features for physical activity (PA) are understudied. This study explored whether patterns of GIS-derived BE features explained objective and self-reported PA, sedentary behavior, and BMI.

Methods—Neighborhood Quality of Life Study participants (N=2,199, aged 20–65 years, 48.2% female, 26% ethnic minority) were sampled in 2001–2005 from Seattle/King County, WA and Baltimore, MD/Washington, DC regions. Their addresses were geocoded to compute net residential density, land use mix, retail floor area ratio, intersection density, public transit, and public park and private recreation facility densities using a 1-km network buffer. Latent profile analyses (LPAs) were estimated from these variables. Multilevel regression models compared profiles on accelerometer-measured moderate to vigorous PA (MVPA) and self-reported PA, adjusting for covariates and clustering. Analyses were conducted in 2013–2014.

Results—Seattle region LPAs yielded four profiles, including low walkable/transit/recreation (L-L-L), mean walkability/transit/recreation (M-M-M), moderately high walkability/transit/recreation (MH-MH-MH), and high walkability/transit/recreation (H-H-H). All measures were higher in the H-H-H than the L-L-L profile (difference of 17.1 minutes/day for MVPA, 146.5 minutes/week for walking for transportation, 58.2 minutes/week for leisure-time PA, and 2.2 BMI points; all *p*<0.05). Baltimore region LPAs yielded four profiles, including L-L-L, M-M-M, high land use

Address correspondence to: Marc A. Adams, PhD, MPH, Assistant Professor, Exercise Science and Health Promotion, School of Nutrition and Health Promotion, Arizona State University, 500 N. Third Street (Mail Code 3020), Phoenix AZ 85004. marc.adams@asu.edu.

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mix, transit, and recreation (HLU-HT-HRA), and high intersection density, high retail floor area ratio (HID-HRFAR). HLU-HT-HRA and L-L-L differed by 12.3 MVPA minutes/day; HID-HRFAR and L-L-L differed by 157.4 minutes/week for walking for transportation (all $p<0.05$).

Conclusions—Patterns of environmental features explain greater differences in adults' PA than the four-component walkability index.

Introduction

Most Americans do not meet physical activity (PA) guidelines.[1] People live in neighborhoods that are mosaics of modifiable[2,3] built environment (BE) features (e.g., walkability, access to public transportation, public park, private recreation facilities).[4–7] Such features have been individually and consistently linked to PA among adults[8–13] and have shown behavior-specific associations with different domains of PA (e.g., recreation, transportation).[8,13–17] Mixed evidence exists for relations of BEs with sedentary behaviors and obesity.[18–22]

Emerging evidence suggests greater diversity of BE features[23, 24] and unique combinations of features[25] may explain differences in PA and obesity better than individual features. Combinations of diverse neighborhood features have not been studied as often as single features in relation to PA domains.[26] Capturing complex patterns of diverse features that include walkability, transportation, and recreation features is a challenge.

Modern geodemographic methods[23] for characterizing patterns of BE features in neighborhoods include factor analysis,[27–29] modeling statistical interactions,[30] or classifying individuals into subgroups based on multidimensional patterns with techniques such as latent profile analysis (LPA).[25, 31] LPA is a probability-based approach for grouping individuals based on patterns of responses across variables. LPA can help identify patterns of features that show functionally different relationships with PA and other health outcomes.

Few studies have explored patterns of BE features. Two studies of adults found that patterns of perceived BE features supportive of PA had the highest moderate to vigorous PA (MVPA) and walking for transportation and recreation levels compared with unsupportive patterns.[25, 32] Studies suggest that certain combinations of self-reported BE features were more strongly related to meeting PA guidelines in adults than any single factor.[33, 34] Three studies examined objectively measured BE features for adolescents' PA,[31, 35, 36] but none examined objectively measured features for adults' PA.

The current study examined whether unique patterns of BE features could be derived from a combination of seven GIS-measured indicators using LPA among adult residents in two metropolitan regions. Based on previous research,[25, 32] we hypothesized that multiple profiles would emerge with at least one in each region reflecting an overall PA-supportive pattern. Our second aim was to examine how profiles related to accelerometer-measured PA and sedentary time, as well as self-reported PA, sedentary time, and BMI, after adjusting for covariates. We hypothesized that participants in neighborhoods characterized by an overall activity-supportive profile, compared with the other profiles, would have the highest PA and lowest sedentary time and BMI.

Methods

Study Sample

This analysis used data collected between 2001 and 2005 from the Neighborhood Quality of Life Study (NQLS),[37] an observational study of BEs and health-related outcomes (e.g., PA, BMI) conducted in 32 neighborhoods from metropolitan Seattle/King County, WA and Baltimore, MD/Washington DC regions (hereafter referred to as "Seattle" and "Baltimore," respectively). The design of NQLS has been described previously.[4,37] First, Census block groups in each region were screened based on the BE construct of walkability—defined by GIS-derived measures of net residential density, land use mix, street connectivity, and retail floor area ratio (RFAR). Block groups were classified according to deciles of walkability scores and Census-derived median household income, which were used to form a 2 (high versus low walkability) × 2 (high income versus low income) matrix, with eight neighborhoods per cell in each region.[4] Second, participants (N=2,199, aged 20–65 years, 48.2% female, 26% racial/ethnic minority) were systematically sampled and recruited across all four cells simultaneously over 12 months in each region to prevent seasonal bias. IRBs from participating institutions approved the study. Participants provided written informed consent.

Neighborhood Environment Measures

Because proximal environments around participants' homes may be more important than the overall block group environment,[18] ESRI's ArcGIS, version 10.0 was used to geocode participants' residences and measure seven features within 1-km street–network buffers uniquely for each residence.

Neighborhood walkability[4] represents an indicator of local accessibility and destinations near home, composed of:

1. net residential density—ratio of residential dwelling units to land area devoted to residential land use;
2. street connectivity—number of intersections with three or more legs divided by total land area—higher intersection density corresponds to more direct paths between destinations;
3. land use mix—diversity and evenness of accessible destinations based on five land use types (residential, retail/commercial, entertainment, food-related, and civic/ institutional—including medical and government); values ranged from 0 (single land use) to 1 (even distribution across all five types); and
4. RFAR—ratio of retail building floor areas divided by retail parcel land areas—low RFAR is a marker for areas with retail development likely accompanied by substantial parking space, whereas high RFAR is a marker for buildings with smaller set backs from the street, indicating pedestrian-oriented design.

Individual walkability components were included as four separate indicators in LPAs.

Access to public transportation has differed strongly between neighborhoods and is predictive of PA,[32, 38, 39] suggesting its importance for characterizing neighborhoods. Transit and bus stop locations were obtained from transit providers and regional planning agencies. Transit density (combined bus and rail) was defined as the number of stops/ stations in a buffer divided by its land area.

A comprehensive enumeration of parks, fitness centers, community recreation centers, swimming pools, and yoga and ballroom dance studios was conducted using information from park departments, parcel databases, and online and print business listings. Parks were defined as freely accessible, improved and unimproved green spaces based on these sources. Private recreation facilities included places where PA could occur and required payment (e.g., golf courses, fitness facilities, dance studios). Separate park density and private recreation density variables were calculated as the number of locations divided by the buffer's land area.

Physical Activity, Sedentary, BMI, and Demographic Measures

Participants wore ActiGraph accelerometers (Pensacola, FL; model 7164 or 71256) on their right hip using an elastic belt during waking hours for 7 days to measure MVPA. Participants were asked to re-wear the accelerometer if <5 valid days or <66 valid hours across 7 days were obtained. Accelerometer data were scored using MeterPlus, version 4.0 (www.meterplussoftware.com) and a "valid day" was defined as ≥8 valid hours of wear, with non-wear defined as ≥30 consecutive minutes of zero activity counts. On valid days, within valid wearing time, each minute ≤100 counts was summed to compute total sedentary minutes. The duration of MVPA minutes was based on the 1-minute epochs and the Freedson 3-MET cut point for adults (≥1,952 counts).[40] Average minutes of sedentary time and MVPA per valid wearing day, plus a dichotomous indicator of attaining >30 minutes/day of MVPA (approximating the 150 minutes/week guideline) were used in analyses. ActiGraph accelerometers have produced reliable and valid estimates of sedentary time[41] and MVPA[42] in adults.

Participants completed the International Physical Activity Questionnaire (IPAQ) long form assessing walking for transportation, leisure-time PA, and sitting time over the last 7 days (IPAQ; www.ipaq.ki.se). Sitting time (minutes/week) was estimated from asking about time usually spent sitting on a weekday and on a weekend day, and was operationalized as the weighted sum of five times the usual sitting minutes/day on weekdays plus two times the usual minutes/day on weekend days. Leisure-time PA (minutes/week) was operationalized as the sum of frequency (days/week) × duration (minutes/day) of walking, moderate-intensity PA, and vigorous-intensity PA. A similar measure was computed for usual minutes/week (i.e., days/week × minutes/day) of walking for transportation. IPAQ reliability (ρ=0.80) and validity (ρ=0.30) was similar to other self-reported PA measures when compared to accelerometers.[43] Self-reported weight and height were used to calculate BMI (kg/m^2).

Participants answered questionnaire items assessing sex, age (years), race/ethnicity (non-Hispanic white versus non-white or Hispanic), annual household income (11 levels from <10,000 to >100,000), educational attainment (seven levels from seventh grade to completed graduate degree), number of motor vehicles and eligible drivers in household (continuous), marital or cohabitation status (married or living together versus other), number of people in household (continuous), and years at current address (continuous).

Statistical Analysis

We used LPA to derive mutually exclusive profiles of observations (i.e., patterns) that maximized between-class variance and minimized within-class variance across seven continuous indicators of neighborhood features. Adjustments were made for block group–level clustering via TYPE=COMPLEX specification under Mplus, version 7.11. LPA models were estimated separately in each region (Seattle, *n*=1,287; Baltimore, *n*=912) using: net residential density, land use mix, intersection density, RFAR, transit density, park density, and private recreation density. Derived solutions ranged from one to five profiles or until model convergence was not obtained. Selection of profile solutions was based on substantive interpretability, indices of model fit, and within-profile sample sizes. Relative model fit and quality was judged using sample size-adjusted Bayesian information criterion (BIC) values. Upon selection of an appropriate and interpretable LPA solution for each region, respondents were assigned to the profile for which their analytically derived probability of membership was highest.

Next, using generalized linear mixed models in SAS, version 9.3, we examined relations of profile membership to:

1. meeting MVPA recommendations (PROC GLIMMIX);
2. log-transformed accelerometer-measured MVPA and sedentary minutes/day (2–4 PROC MIXED);
3. log-transformed self-reported PA minutes/week (i.e., walking for transportation, leisure-time) and sitting time minutes per week; and
4. BMI.

As in the LPA step, analyses were conducted separately by region, and individual respondents were treated as nested within block groups. Block group–level intercepts were modeled as random effects. All analyses adjusted for the aforementioned demographic variables and accelerometer wear time when appropriate. Figures present model-adjusted means, and for analyses of log-transformed measures, figures show anti-logged means and SE bars. The Appendix describes sedentary and BMI results. Analyses were conducted between 2013 and 2014.

Results

Table 1 presents descriptive statistics separately for Seattle and Baltimore region participants on demographic and personal characteristics, PA and sedentary times, and neighborhood environment factors.

Model fit values indicated that a five-profile solution (BIC=30,800.7) was better than a four-profile solution (BIC=31,424.3) in Seattle; for Baltimore, five-profile (BIC=25,942.8) and four-profile (BIC=26,491.0) solutions were better than a three-profile solution

(BIC=27,853.6). Based on interpretability and the presence of very small proportions and potentially unreliable estimates of the region's sample in five-profile solutions, four-profile solutions for both Seattle and Baltimore were more plausible. Figures 1A and 1B present final profiles and their variable patterns, with variable means standardized to *z*-scores in each region.

For Seattle, the most common profile, characterized by a combination of low values for residential density, land use mix, and intersection density, with relatively low values on public transit access and limited access to parks and private recreational facilities ("L-L-L"), comprised 36.0% (*n*=463) of participants. The next most common profile, characterized by mean (near 0) *z*-score values for walkability, transit access, and recreation access ("M-M-M") comprised 35.8% (*n*=461) of participants. The third most common profile, characterized by moderately positive *z*-score values (near 1.0) for walkability (except for residential density), transit access, and recreation access ("MH-MH-MH"), comprised 21.8% (*n*=280) of participants. The least common profile, characterized by high values (*z*-scores above or near 2.0) for residential density, land use mix, RFAR, intersection density, transit access, and access to fitness facilities and parks ("H-H-H"), comprised 6.4% (*n*=83) of participants.

Similar to Seattle, the most common profile for Baltimore had low walkability, low transit access, and low recreation access ("L-L-L") and comprised 53.6% (*n*=489) of participants. The next most common profile, characterized by near mean levels of walkability, transit, and recreation access ("M-M-M") for the region, included 36.6% (*n*=334) of participants. The third profile, characterized most prominently by high land use mix, high transit access, and high recreation access ("HLU-HT-HRA"), included 6.9% (*n*=63) of participants. The smallest profile included 2.9% (*n*=26) of participants and also had high residential density, but was distinguished from other profiles by very high intersection density and RFAR ("HID-HRFAR") values.

Figure 2 presents model-adjusted means for accelerometer-measured MVPA across latent profiles for Seattle and Baltimore regions, along with pairwise comparisons of means. For Seattle, tests of overall between-profile differences were significant for meeting PA recommendations and MVPA minutes per week. H-H-H participants had an average of 49.2 MVPA minutes/day, and 77% attained at least 30 MVPA minutes/day on average compared with 32.1 MVPA minutes/day and 43% in L-L-L participants, a significant difference. M-M-M and MH-MH-MH participants did not differ significantly from each other, but did differ significantly from L-L-L participants. For Baltimore, HLU-HT-HRA participants differed significantly on MVPA minutes from L-L-L and M-M-M participants. However, HLU-HT-HRA and HID-HRFAR participants did not differ significantly from each other, nor did L-L-L and M-M-M. HLU-HT-HRA participants had 40.7 MVPA minutes/day and 56% attained ≥30 MVPA minutes/day on average compared with 28.4 MVPA minutes/day and 35% in L-L-L participants.

Figure 3 shows that minutes/week of walking for transportation differed across profiles in both regions ($p<0.05$). Seattle L-L-L participants reported significantly fewer minutes of walking for transportation (13.7 minutes/week) than M-M-M (28.0 minutes/week) and MH-

MH-MH (60.8 minutes/week) participants, which were all significantly lower than H-H-H participants (160.2 minutes/week). The same relative ordering was seen across Baltimore profiles, with L-L-L participants (18.2 minutes/week) reporting significantly fewer minutes of walking for transportation than HLU-HT-HRA (107.1 minutes/week) and HID-HRFAR (175.6 minutes/week) participants. No significant differences were observed between L-L-L and M-M-M participants or between HLU-HT-HRA and HID-HRFAR participants in Baltimore. Leisure-time PA minutes/week differed significantly in Seattle but not Baltimore. In Seattle, H-H-H (117.3 minutes/week) and MH-MH-MH (88.5 minutes/week) participants differed significantly from L-L-L (59.1 minutes/week) and M-M-M (54.8 minutes/week) participants. Figure 4 presents adjusted BMI values across profiles in each region after adjusting for covariates.

Discussion

Meaningful activity-supportive profiles emerged from seven GIS-measured environmental variables and were positively and strongly related to accelerometer-derived MVPA, walking for transportation, leisure-time PA, and BMI (albeit less consistently). Relations between profiles and sedentary time were not supported.

In contrast to the main NQLS outcome analysis,[37] the current analysis examined patterns and a more-diverse set of objective features within regions. In the main NQLS analysis, participants from block groups ranked as high versus low on GIS-measured walkability differed significantly by a maximum of 5.8 minutes/day for accelerometer-measured MVPA, 31.5 minutes/week for walking for transportation, 4.3 minutes/week for leisure-time PA, and non-significantly by 0.4 points for BMI.[37] In the current analysis, Seattle region profiles differed by as much as 17.1 minutes/day for accelerometer-measured MVPA, 147.0 minutes/week for walking for transportation, 57.6 minutes/week for leisure-time PA, and 2.2 points for BMI. Baltimore profiles differed by as much as 12.3 accelerometer-measured MVPA minutes/day and 157.2 minutes/week for walking for transportation. Relative to the main NQLS analyses, the latent profiles explained at least a twofold difference in MVPA minutes/day, approximately fivefold difference in both walking for transportation minutes/week and BMI, and 13-fold difference in leisure activity minutes/week.

Differences between current and main NQLS results could be explained by

1. operationalizing neighborhood as a 1-km network buffer (versus block group), as block groups can include features made inaccessible by barriers like freeways or rivers and can exclude accessible features just across block group boundaries;

2. inclusion of transit, parks, and recreation facilities, allowing for more-complex BE patterns to emerge and contributing to a more-comprehensive picture of neighborhoods;

3. specific feature patterns resulting from the LPA methodology; or

4. some combination of these methodologic components.

In sum, region-specific latent profiles explained greater differences in PA than the four-component block group walkability index.[37]

There were regional similarities and differences in emergent profiles. In both regions, we identified activity-unsupportive profiles (i.e., L-L-L) and a type of activity-supportive profile (i.e., H-H-H or HLU-HT-HRA). In both regions, the largest proportion of participants resided in PA-unsupportive neighborhoods, whereas the fewest resided in activity-supportive neighborhoods. This is not surprising, as U.S. cities are known to have a high prevalence of sprawl and limited recreation and transit access compared with other countries.[24, 44, 45] Profiles suggest that improving pedestrian access to destinations, transit, public parks, and recreation facilities may result in progressively higher MVPA and walking for transportation in both regions compared with neighborhoods with fewer walkable, transit, and recreation features (e.g., L-L-L). For leisure-time PA and BMI, the significant differences in Seattle and lack of differences in Baltimore across profiles are difficult to explain, but may be a function of specific feature combinations in “activity-supportive” profiles, relatively lower street connectivity in HLU-HT-HRA, or unmeasured aspects such as lack of amenities, traffic, or safety concerns modulating use of recreation environments or lack of nutrition environments for BMI. Results for sedentary behavior support previous mixed findings.[18–22]

LPA studies of self-reported feature combinations among U.S. adults,[25] older adults,[32] and international samples[34] parallel the current analysis by including perceived indicators of walkability, public transit, and recreation features, but differ by including aspects difficult to measure objectively such as aesthetics, crime and traffic safety, and pedestrian/cycling facilities. Latent profile/class analyses based on self-reported measures also have identified activity-unsupportive and -supportive profiles across a diverse set of measures. Consistent with present results, perceived activity-unsupportive profiles had the greatest proportion of people and lowest PA levels compared with higher levels of supportive features. LPA using self-reported and objective BE measures agree that more-comprehensive characterizations of environments strengthen associations with both objective and self-reported PA. BMI results are inconsistent, perhaps because of lack of nutrition environment measures.

Limitations

Similar results for objective and self-reported PA measures limit concerns of common source bias. Analyses controlled for design effects and several confounding variables, suggesting robust results. Because cross-sectional designs do not allow for evaluation of cause–effect relations, future studies should examine the utility of latent profiles for predicting changes to PA and incidence of health outcomes. Residential self-selection was not accounted for, and we could not confirm that participants engaged in PA inside of neighborhoods. Previous studies suggest self-selection may attenuate, but not extinguish, the effect of the BE on PA. Amenities available in parks, transit service levels, and other microscale and qualitative features (e.g., sidewalks or safety from traffic and crime) could have produced a different number or pattern of profiles; unfortunately, objective measures of these aspects were unavailable.

Conclusions

Current results add to growing evidence that more-comprehensive characterizations of BE strengthen associations with PA. Walkability, recreation, and transit features of neighborhood environments should be measured and considered in planning and policy decisions.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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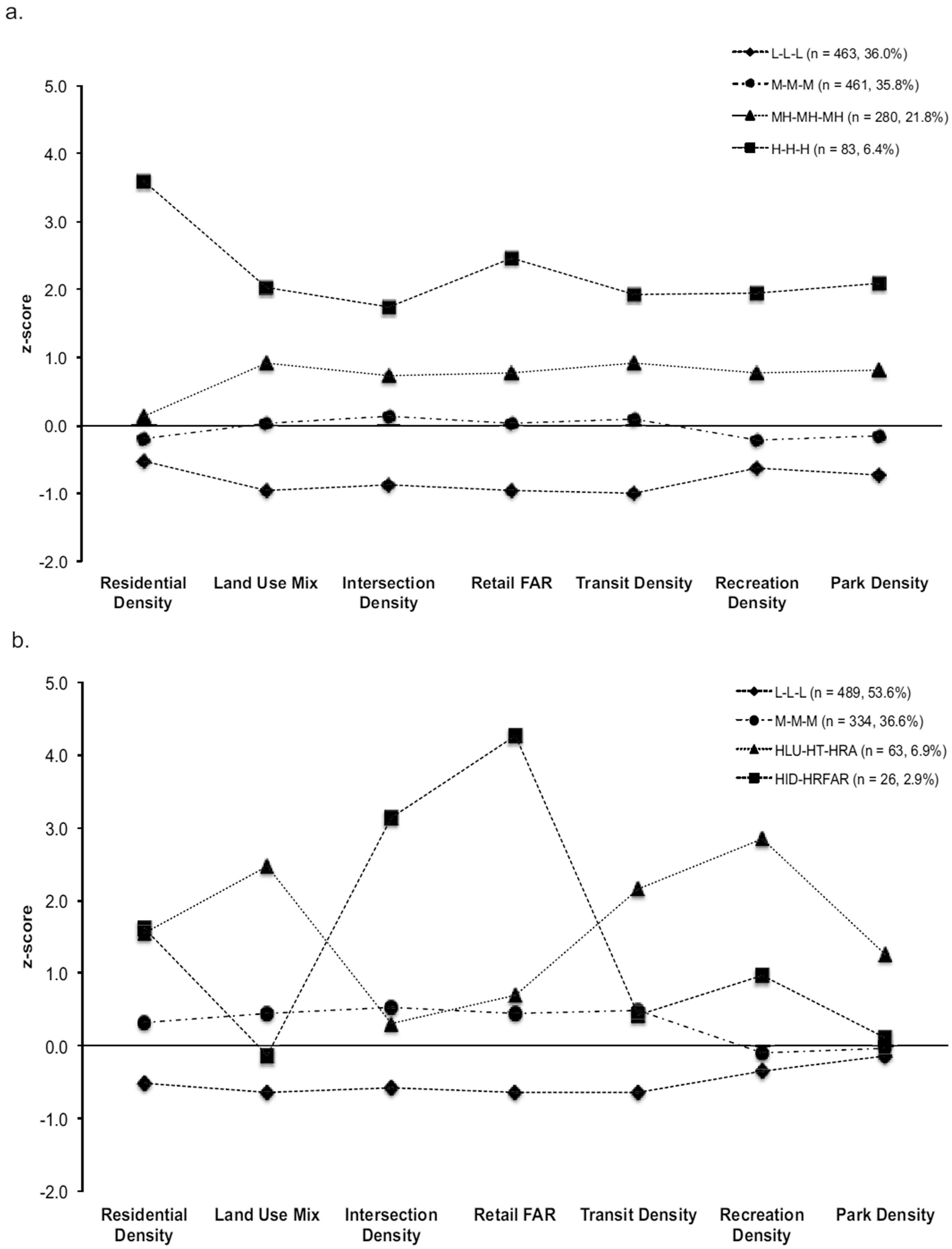

Figure 1.

A. Four latent profile derived neighborhood patterns for the Seattle-King County, WA region.

B. Four latent profile derived neighborhood patterns for the Baltimore, MD/Washington DC region.

A z-score equal to ± 1 reflects an indicator value ± 1 standard deviations from the average value of that indicator in the region. L-L-L = low walkability, low transit access, and low recreation access. M-M-M = medium levels of walkability, transit access, and recreation access. MH-MH-MH = moderately high levels of walkability, transit access, and recreation access. H-H-H= high levels of walkability, transit access, and recreation access. HLU-HT-HRA = high land use mix, high transit access, and high recreation access. HID-HRFAR = very high intersection density and retail floor area ratio.

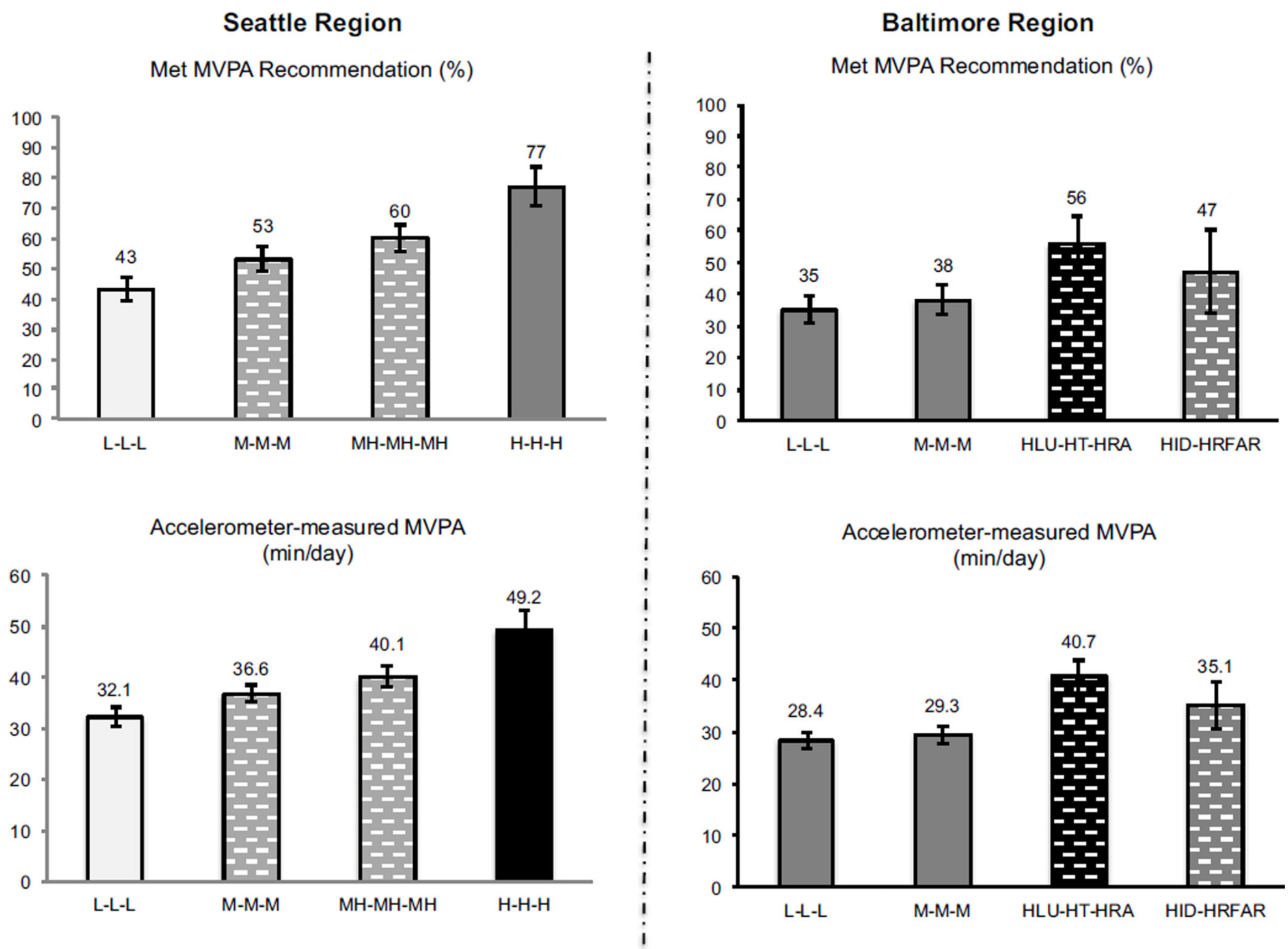

Figure 2.

Adjusted means for accelerometer-MVPA by latent profile in Seattle, WA and Baltimore, MD/Washington, DC regions.

[1]Accelerometer derived MVPA recommendations and minutes/per day adjusted for accelerometer wear time and sex, age, race/ethnicity, annual household income, educational attainment, number of motor vehicles and eligible drivers in household, marital or cohabitation status, number of people in household, and years at current address. [2]Within each panel, *non-significant* comparisons are reflected across profiles by bars with matching colors or matching patterns. Values reflect anti-logged model-adjusted means and standard error bars.

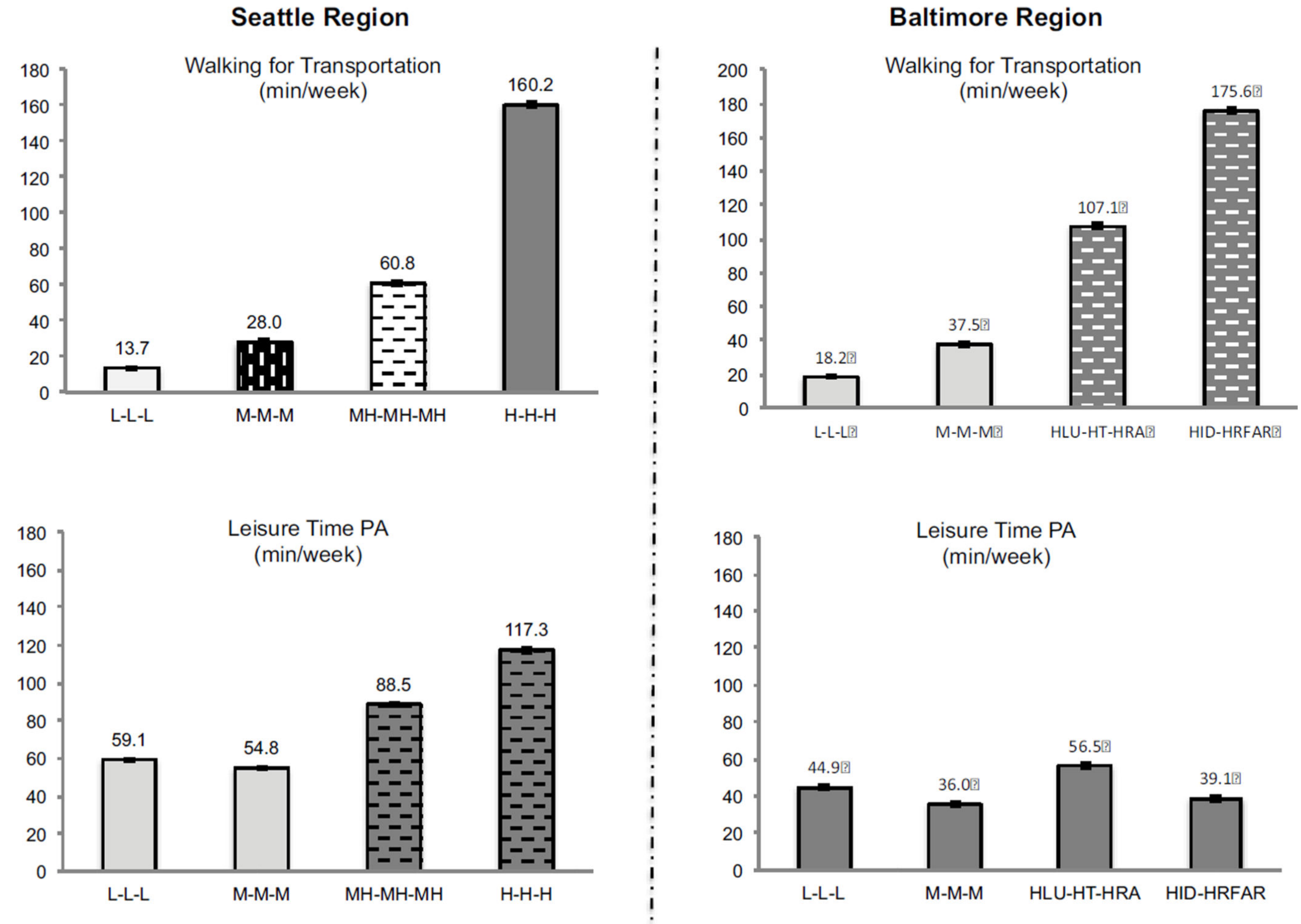

Figure 3.

Latent profiles and self-reported physical activity in Seattle, WA and Baltimore, MD/ Washington, DC regions.

[1]Walking for transportation and leisure time PA adjusted for sex, age, race/ethnicity, annual household income, educational attainment, number of motor vehicles and eligible drivers in household, marital or cohabitation status, number of people in household, and years at current address.

[2]Within each panel, *non-significant* comparisons are reflected across profiles by bars with matching colors or matching patterns. Values reflect anti-logged model-adjusted means and standard error bars.

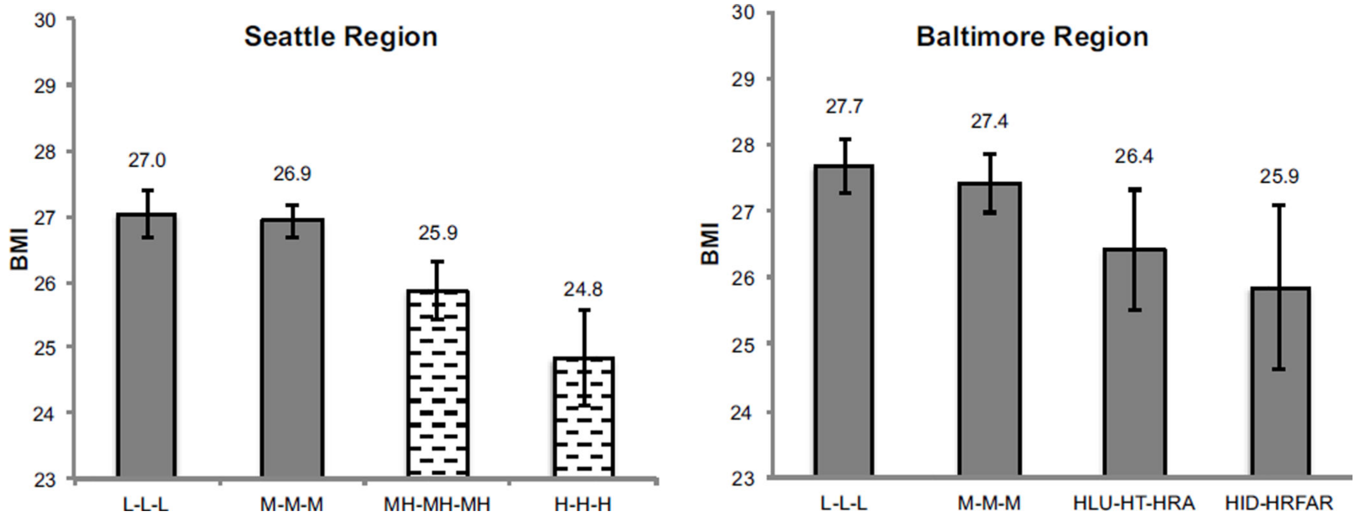

Figure 4.

Adjusted means for BMI by latent profile in Seattle, WA and Baltimore, MD/Washington, DC regions.

[1] BMI adjusted for sex, age, race/ethnicity, annual household income, educational attainment, number of motor vehicles and eligible drivers in household, marital or cohabitation status, number of people in household, and years at current address. [2]Within each panel, *non-significant* comparisons are reflected across profiles by bars with matching colors or matching patterns. Values reflect model-adjusted means and standard error bars.

Table 1

Sample Descriptive Statistics and Participant Characteristics by Study Region

	Seattle region		Baltimore region	
Participant demographics and other characteristics	*M* or %	*SD*	*M* or %	*SD*
Age (years)	44.0	11.0	46.6	10.7
% Female	45.2	-	52.3	-
% Hispanic non-white	18.0	-	62.6	-
Highest education level (%)				
Less than high school diploma/GED	1.6	-	2.5	-
Completed high school	7.0	-	7.4	-
Some college or vocational training	28.8	-	22.9	-
Completed college or university	37.7	-	30.5	-
Completed graduate degree	25.3	-	36.7	-
Percent married/cohabiting (%)	63.2	-	60.5	-
Annual household income (in $1000)	60–69[a]	30–39, 90–99[b]	70–79[a]	40-
Vehicles per adult in household	1.1	0.6	1.0	49,100.05
Number of people in household	2.6	1.4	2.7	1.4
Length of time at current residence (years)	9.3	9.2	10.3	8.9
BMI	26.6	5.5	27.2	5.9
Accelerometer Measures				
Sedentary time (min/day)	494.4	106.4	506.8	105.2
MVPA (min/day)	35.9	24.9	28.7	21.8
IPAQ				
Sitting time (min/week)	2555.0	1230.5	2553.7	1253.4
Walking for transportation (min/week)	174.0	359.4	171.4	302.8
Leisure time PA (min/week)	255.4	363.1	220.4	324.0
GIS-Measured Features	*M*	*SD*	*M*	*SD*
Residential density	3085.4	3687.0	2500.5	2326.2
Land use mix	0.2	0.1	0.2	0.1
Intersection density	71.0	22.6	54.8	27.9
Retail floor area ratio	0.4	0.3	0.4	0.4
Transit density	16.0	9.8	16.9	13.5
Recreation density	1.6	2.0	1.3	2.2
Park density	2.6	1.7	1.7	1.5

[a]Median value

[b]50th and 75th percentile values

IPAQ, International Physical Activity Questionnaire