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Associations of Neighborhood Environmental Attributes with Walking in Japan: Moderating Effects of Area-Level Socioeconomic Status

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Abstract Several studies have examined how the associations of built environment attributes with walking behaviors may be moderated by socioeconomic status (SES). Such understanding is important to address socioeconomic inequalities in health through urban design initiatives. However, to date, there is no study examining the moderation effects of SES in the relationships of environmental attributes and walking in non-Western countries. The current study aims to examine associations of environmental attributes with walking behaviors among Japanese adults, and to test whether these associations were moderated by area-level SES. Data on walking were collected from Japanese adults using a nationwide Internet survey ($N = 4605$). Built environment measures including population density, street density, distance to the nearest public open space, and distance to the nearest commercial destination were calculated using geographic information systems software. An index of neighborhood deprivation was used as an area-level indicator of SES. Logistic regression models adjusted for clustering and sociodemographic variables were used. It was found that more residents in high SES areas walked for commuting, for errands, and for exercise compared with those who lived in low SES areas. When the whole sample was examined, all environmental attributes were associated with walking behaviors (except for street density not being associated with walking for exercise). Associations of environmental attributes with walking behaviors were moderated by area-level SES only in walking for exercise.

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Walking for exercise was associated with higher population density, higher street density (marginally significant), and shorter distance to the nearest commercial destination only in high SES areas. Our findings showed that the associations of these environmental attributes and walking behaviors were largely consistent across different SES levels. Therefore, urban design interventions focusing on low SES areas may help to reduce socioeconomic disparities in walking.

Keywords Urban design · Built environment · Physical activity · Socioeconomic disparities · Geographic information systems

Introduction

Reducing health inequalities has become one of the key goals of public health in many countries [1]. For example, the "Healthy Japan 21," the official plan to promote health of people in Japan, listed reducing socioeconomic disparities in health as one of its main objectives [2]. Several studies in the context of Western countries reported that adult residents of areas with low socioeconomic status (SES) engaged in less physical activity for recreation, compared with those who lived in high SES areas [3, 4]. Physical inactivity is indeed regarded as a key risk behavior that needs to be addressed to reduce health inequalities [5, 6]. Therefore, it is important to understand how physical activity can be enhanced in low SES areas to close the socioeconomic gap in health. Walking is particularly relevant, as it is globally the most common type of physical activity [7, 8] with numerous known health benefits [9].

Ecological models of walking have highlighted the importance of the built environment as a barrier or facilitator of walking [10]. A review study found that availability of local destinations, such as local shops, parks, services, and transit stops, is consistently associated with adults' walking [11]. However, destinations and facilities related to walking (e.g., parks, recreational facilities, bus stops, schools) are not evenly distributed in areas of different SES levels. For instance, several studies conducted in Western countries report that low SES neighborhoods tend to have poor access to such facilities [12–14]. A study across six states in the USA found low SES areas to have fewer recreational facilities such as walking trails and dog parks [14]. Another study in the UK reported that those who lived in low SES areas had poorer access to recreational destinations including gyms and sports facilities [13]. Although there are also studies showing no clear socioeconomic patterns in access to local destinations [15, 16], research has also reported that low SES areas tend to have poorer quality recreational destinations [17] and less favorable routes to destinations [18]. Thus, urban design interventions have the potential to address the walking disparities between low and high SES areas.

However, it is not totally clear whether environmental attributes are equally associated with walking in different SES areas. This is a relevant question because improving a particular attribute that is associated with greater walking only in high SES areas may widen the gap between low and high SES areas. Several studies have examined how environmental attributes are associated with walking in low and high SES areas in Western countries [18–20]. A recent study conducted in Australia found that walking infrastructure was associated with recreational walking only in high SES areas, suggesting that improving this aspect may not have any impact on residents of low SES areas [18]. Another study in Belgium found that those participants who lived in more walkable neighborhoods walked more for transport regardless of their socioeconomic strata [19]. However, previous studies examining the socioeconomic moderation of the relationships between environmental attributes and walking have been conducted in the USA, Australia, and Belgium. It is timely to examine this topic in non-Western countries, especially in Asia, where socioeconomic inequalities in health are becoming a serious public health issue [21]. Asian cities also have different environmental characteristics in comparison with Western cities. For example, Japanese cities tend to have higher population density with better access to public transport than Western cities [22, 23]. It is also unknown whether there are socioeconomic disparities in access to destinations in Japan. Therefore, the previously obtained evidence on the role of environmental factors in socioeconomic disparities in walking may not be applicable to Asian cities.

This study examined associations of environmental attributes with walking behaviors among Japanese adults and tested, for the first time in Japan, whether these associations were moderated by area-level SES.

Methods

Data Source and Study Setting

A nationwide cross-sectional online survey was conducted from September 25 to October 8, 2015. Samples of

Japanese adults aged 20–64 years were recruited from the registered panel members of the survey company (Network Panel by Nippon Research Center). The company held 5.5 million registered members (as of July 2015), who were recruited through advertisements on the Internet and other media. Once registered, members are eligible to participate in various online surveys. For this survey, invitation emails were sent to the panel of 201,219 members. The survey panel included a wide range of members with regard to the demographic and socioeconomic status and geographic locations. They were invited in a sequential manner so that the demographic and location profile of the sample is comparable to that of the Japanese population: the quota sampling design was used to ensure a representative distribution in age, gender, geographical region, and population size of municipality (an administrative unit of city, ward, town, and village in Japan, with an average size of approximately 200 km^2). The survey was closed in 2 weeks, once the requested number of responses was collected. In total, 5002 members completed the survey. Participants received a small financial compensation upon completion of the survey (¥39 = US$0.30). Respondents who provided detailed residential address information were included in this study (n = 4726). Ethics approval was obtained from the Research Ethics Committee of Chukyo University (2015-004).

Measures

Outcomes Respondents were asked to report their frequency of walking (days/week) and average walking duration each day (min/day) in the past week for three specific purposes: for commuting, for errands, and for exercise. The validity of walking questions was reported elsewhere [24]. Since the distribution of walking duration was highly skewed, three dichotomized walking outcomes were calculated for each participant: any walking or not for each purpose.

Exposures Four neighborhood environmental attributes including population density, street density, distance to the nearest public open space (POS), and distance to the nearest commercial destination were calculated using geographic information systems (GIS). Two density measures were obtained at the levels of neighborhood. Population density was measured at the smallest administrative unit ("*chocho-aza*," an average population of about 500 people), which is roughly comparable to a US census block group. Street density data were available at the tertiary mesh level as the total length of streets divided by the area of the tertiary mesh in which respondents located. Tertiary mesh is about a 1 km × 1 km grid defined by latitude and longitude. POS in this study included any park or green space with the minimum area of 50 m^2. Commercial destinations included grocery stores, supermarkets, clothing stores, household and general shops, hair salons, drug stores, restaurants, sporting goods stores, amusement facilities (e.g., video game arcade, movie theatres), professional offices (e.g., medical clinics, real-estate offices), banks, and accommodations. They did not include non-commercial destinations such as train stations, schools, and parks. Since we did not have data on street network or access points, distance to the nearest POS was measured using the straight-line distance from the respondents' home to the centroid of each POS. The 2010 population census of Japan was used for population density. Data on street density and POS were obtained from the 2010 National Land Numerical Information. For commercial destinations, polygon retail area data for 2011 released by Zenrin Co. Ltd. were used [25].

Potential Moderator A census-based index of neighborhood deprivation was used as an area-level indicator of SES [26]. This index is a weighted sum of several factors such as proportion of rented houses, proportion of single-mother households, proportion of agricultural workers, proportion of old single households, and the unemployment rate. The reference unit is *chocho-aza* as in the case of population density. The detailed methods of constructing this index have been described elsewhere [26]. In this study sample, the median neighborhood deprivation score was 5.46 (mean = 5.54, standard deviation = 1.11). All respondents were categorized into low and high SES areas using the median split of the neighborhood deprivation index.

Covariates The following sociodemographic characteristics were reported by participants: age, gender, work status (full-time; part-time; no job), educational attainment (tertiary or higher; below tertiary), marital status (single; couple), and household income (< ¥5,000,000; ≥ ¥5,000,000; missing).

Statistical Analysis

Differences in sample characteristics between participants in low and high SES areas were examined with

Pearson's chi-squared test (categorical measures) and independent *t* test (continuous measures). Separate logistic regression models were used to examine associations of each environmental attribute with each of the three walking behaviors. All models were adjusted for clustering at the level of municipalities (n = 1032) and for sociodemographic variables. It was not necessary to consider clustering at the level of *chocho-aza* or tertiary mesh because most of those units contained only one participant. The interaction between the area-level SES and each environmental attribute was also included. When the interaction term was significant, stratified analyses were conducted. The significance level of 0.10 was used for the interaction effects, because interaction terms are likely to be underpowered [27]. Analyses were conducted using Stata 14.0 (StataCorp, College Station, Texas).

Results

After excluding those for whom the neighborhood deprivation index was not available (n = 121), data from 4605 were analyzed. Table 1 shows the characteristics of study participants. About 47, 81, and 44% of the sample reported walking for commuting, for errands, and for exercise, respectively. These proportions differed significantly between low and high SES areas (all $p \leq 0.01$). In low SES areas, 43, 79, and 42% of participants reported walking for commuting, for errands, and for exercise, respectively; these proportions were higher in high SES areas: 53, 83, and 46%, respectively. Table 2 shows the mean scores for environmental attributes across area-level SES strata. Population density, street density, and distance to the nearest commercial destination were significantly different according to the area-level SES ($p \leq 0.01$). In contrast with low SES areas, high SES areas had higher population density, higher street density, and shorter distance to the nearest commercial destination. There was no significant difference in distance to the nearest POS between area-level SES strata.

Table 3 shows the results of regression analyses (main effects). In the adjusted models, higher population density was associated with a significantly higher odds of any walking for commuting, for errands, and for

Table 1 Characteristics of study participants: total and stratified by area-level SES

Variable	Total sample, % (N = 4605)	Low SES, % (n = 2303)	High SES, % (n = 2302)	p^a
Age (years)				
20–34	28.4	28.4	28.5	ns
35–49	37.9	37.4	38.4	
50–64	33.7	34.3	33.1	
Gender				
Women	49.8	48.7	50.8	ns
Work status				
Full-time	53.8	53.3	54.3	< 0.05
Part-time	18.2	19.7	16.6	
No job	28.0	27.0	29.0	
Education				
Tertiary or higher	74.0	70.7	77.2	< 0.01
Marital status				
Couple	58.2	56.0	60.5	< 0.01
Household income (per annum)				
< ¥5,000,000	40.8	46.1	35.6	< 0.01
< ¥5,000,000	44.2	38.6	49.9	
Missing	14.9	15.3	14.6	
Any walking for commuting	47.7	42.9	52.5	< 0.01
Any walking for errands	81.1	79.0	83.3	< 0.01
Any walking for exercise	43.9	41.6	46.2	< 0.01

ns not significant

[a] Based on chi-squared test

Table 2 Characteristics of neighborhood environmental attributes, overall, and according to area-level SES ($N = 4605$)

Variable	Range	Mean (SD)			p^c
		Total sample	Low SES	High SES	
Population density (persons/km^2)[a]	7–68,109	8767 (7511)	7606 (6866)	9928 (7939)	< 0.01
Street density (m/km^2)[b]	199–45,138	18,047 (9410)	16,896 (9653)	19,199 (9017)	< 0.01
Distance to the nearest POS (m)	4–42,998	608 (4005)	710 (1802)	507 (5368)	ns
Distance to the nearest commercial destination (m)	0–17,001	694 (1553)	756 (1351)	632 (1730)	< 0.01

[a] Measured at each *chocho-aza* where each participant resided

[b] Measured at each tertiary mesh where each participant resided

[c] Based on independent *t* test

exercise. Higher street density was associated with a significantly higher odds of any walking for commuting and for errands. No significant association was found between street density and walking for exercise. Those participants who had a longer distance to the nearest POS or the nearest commercial destination were less likely to walk for commuting, for errands, and for exercise.

Interactions of SES and environments with walking for exercise were significant for population density ($p = 0.06$), street density ($p = 0.07$), and distance to the nearest commercial destination ($p = 0.06$), but not for distance to the nearest POS. Interactions between area-level SES and any environmental attributes were not significant in walking for commuting and for errands. Table 4 shows the results of stratified analyses by area-level SES for the environmental attributes in which the interaction was significant. These environmental attributes were significantly associated with walking for exercise: Higher population density, higher street density, and closer distance to the nearest commercial destination were associated with a higher odds of walking for exercise only in high SES areas (marginal association for street density).

Discussion

This Japanese nationwide study examined associations between objectively measured environmental attributes and purpose-specific walking behaviors, and how these relationships differed across area-level SES strata. Consistent with previous studies [18, 28, 29], we found that participants who lived in low SES areas reported less

Table 3 Associations of environmental attributes with walking behaviors: main effects ($N = 4605$)

	Unadjusted OR (95%CI)			Adjusted[a] OR (95% CI)		
	Any walking for commuting	Any walking for errands	Any walking for exercise	Any walking for commuting	Any walking for errands	Any walking for exercise
Population density	1.21 (1.18, 1.23)**	1.13 (1.10, 1.16)**	1.03 (1.01, 1.05)*	1.23 (1.20, 1.27)**	1.12 (1.09, 1.15)**	1.03 (1.01, 1.05)*
Street density	1.18 (1.16, 1.21)**	1.10 (1.07, 1.13)**	1.02 (1.00, 1.04)	1.20 (1.17, 1.24)**	1.09 (1.06, 1.12)**	1.01 (0.99, 1.03)
Distance to the nearest POS	0.91 (0.89, 0.93)**	0.94 (0.91, 0.96)**	0.96 (0.94, 0.98)**	0.90 (0.88, 0.93)**	0.95 (0.92, 0.97)**	0.97 (0.95, 0.99)*
Distance to the nearest commercial destination	0.88 (0.87, 0.90)**	0.91 (0.88, 0.93)**	0.97 (0.95, 0.99)*	0.89 (0.87, 0.91)**	0.92 (0.89, 0.94)**	0.97 (0.95, 0.99)*

*$p \leq 0.05$; **$p \leq 0.001$

[a] All models adjusted for clustering at the municipality level, and for age, gender, work status, educational attainment, marital status, and household income. The ORs correspond to each decile increment in population density, street density, distance to the nearest POS, and distance to the nearest commercial destination

Table 4 Associations of objective neighborhood environmental attributes with walking behaviors: stratified by area-level SES ($N = 4605$)

Variable	OR (95% CI)	
	Area-level SES	Any walking for exercise
Population density	Low	1.00 (0.97, 1.03)
	High	1.04 (1.01, 1.07)*
Street density	Low	0.99 (0.96, 1.02)
	High	1.03 (1.00, 1.06)**
Distance to the nearest commercial destination	Low	0.99 (0.96, 1.02)
	High	0.95 (0.93, 0.98)*

All models adjusted for clustering at the municipality level, and for age, gender, work status, educational attainment, marital status, and household income. The ORs correspond to each decile increment in population density, street density, distance to the nearest POS, and distance to the nearest commercial destination. Results of stratified analyses were shown only when the interaction was significant ($p < 0.10$)

*$p \leq 0.05$; **$p \leq 0.10$

walking for all three purposes (for commuting, for errands, and for exercise) compared with those who lived in high SES areas. In particular, the proportion of walkers for commuting was markedly different: 43% in low SES areas versus 53% in high SES areas. Since commuting is a long-term, daily behavior, and an alternative travel mode is likely to be car use, the difference in this behavior observed can be a source of socioeconomic inequalities in health. The differences in the proportion of walkers for errands and for exercise were 4% points in both cases. Although these types of walking may not be as regular as walking for commuting, they are likely to be an important source of physical activity for people who are not working (more than a quarter of the sample). Walking for exercise, which can typically involve a longer duration than walking for errands [30], may be encouraged in low SES areas to reduce the socioeconomic gap in health.

Our study found that low SES areas were disadvantaged in environmental attributes related to walking. Low SES areas were lower in population and street density, and had poorer access to commercial destinations. Considering that most environmental attributes were significantly associated with walking equally for low and high SES areas, improving these attributes in lower SES areas may enhance walking, and thus assist to reduce the gap between low and high SES areas. It is important to consider the effect size of these environmental attributes on the walking measures. According to Table 3, population density had the highest effect size for walking for commuting. Given that population density of low SES areas was 23% lower than that in high SES areas (Table 2), this can be a barrier for residents in low SES areas to engage in walking. Although increasing population density in existing neighborhoods is not straightforward, opportunities for developing vacant land ("greyfield" development) or redeveloping underutilized land can be a possible strategy to increase population density. Such infill development in low SES areas may have a potential of facilitating walking among residents.

Another important consideration is to target relatively modifiable environmental factors. In comparison to population/street density and the distance to commercial areas, the distance to parks may be relatively easier to improve because building parks can be done by a local authority (without involving private sectors). Although it was found that low SES areas were not particularly disadvantaged in access to parks, reducing the distance to parks (by creating a new park in areas without parks nearby) may help residents of low SES areas to walk more for various purposes.

The study did not find significant moderation by SES in walking for commuting and for errands. All four environmental attributes were associated with these walking behaviors regardless of SES levels. These findings are in line with previous studies conducted in Western countries [18–20]. However, the study did find socioeconomic moderation for the associations of walking for exercise with population density, street density, and distance to the nearest commercial destination: associations were significant (or marginally significant) only in high SES areas. The findings suggest that improving these environmental measures may not influence walking for exercise in low SES areas. Our findings are inconsistent with a recent study that found the associations of the built environment with active travel to be weaker for residents of low SES areas [31]. The authors of this study, which did not examine leisure-time walking, commented that other factors such as social norms and crime/disorder in local areas may have attenuated the influence of built environmental attributes on active behaviors in low SES areas [31]. The same explanation may apply to the effect of modification found for walking for exercise in this study. Since walking during leisure time is a discretional activity, it may be more subject to such social factors [32]. Further studies are necessary to identify social and environmental factors that may be modified to facilitate recreational walking in low SES areas. Our finding on the population density is in contrast with the previous study conducted in Australia that found higher residential density to be associated with recreational walking only in disadvantages areas [18]. The exact reasons for these findings are unknown. Population density in Japanese cities is typically much higher compared with Australian cities [23]. In Sugiyama et al. [18], low and high SES areas did not differ significantly in residential density, whereas in the current study, high SES areas had on average 30% higher density than low SES areas. Such differences may have played a role in producing opposite findings. Further research is needed to confirm how population density is related to walking for recreation in different SES areas.

There are some limitations in this study. Our self-reported walking measures may be subject to recall error and bias, even though it is relatively easy to recall whether one walked or not, compared to walking frequency or duration. The study did not consider self-selection (participants who preferred to walk may have chosen to live in activity-friendly neighborhoods), which may attenuate the associations observed. Previous studies have shown the relevance of environmental attributes to walking after accounting for participants' attitudes and preferences [33, 34]. However, the way people choose their residential location may differ between people of low and high SES. Thus, self-selection may have differential effects for socioeconomic strata, which can be examined in future studies. There was also a temporal mismatch between data collection from participants (2015) and extraction of the neighborhood deprivation index (2010). However, changes in the neighborhood deprivation index are likely to be slow; thus, this time difference is likely to have a limited impact on the findings. In addition, the area-level units, within which population and street density were calculated, may not exactly correspond with participants' walking areas. Since this is a national study where participants were scattered across Japan, creating an individual buffer for each participant was deemed arduous. Nonetheless, this can produce a mismatch between environmental exposures and walking behavior. Since we did not have street network data across the entire Japan, straight-line distance was used to calculate the availability of POS and commercial destination measures. Our distance measures were shorter than the actual (network) distance to destinations, particularly in areas with low street density. Thus, the error in the distance measures could be larger in lower SES areas, where street density was lower. Further investigation using network distance is warranted. Future studies can also use other measures of POS and commercial destinations such as the total area of POS, the number of destinations within a certain distance from participants' location, and distance to an area where commercial destinations are clustered. Furthermore, while participants were selected nationwide using the quota sampling design, they were not nationally representative due to the nature of data collection (Internet survey); therefore, the results may not be generalizable to the Japanese population.

Conclusions

This Japanese nationwide study found that more residents in high SES areas walked for commuting, for errands, and for exercise compared with those who lived in low SES areas. Low SES areas were disadvantaged in environmental attributes that were found to be associated with walking behaviors. Since the associations of these environmental attributes and walking behaviors were largely consistent across different SES levels, urban design interventions focusing on low SES areas may help to reduce socioeconomic disparities in walking.

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