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ORIGINAL RESEARCH

Local-Area Walkability and Socioeconomic Disparities of Cardiovascular Disease Mortality in Japan

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BACKGROUND: There are spatial disparities in cardiovascular disease (CVD) mortality related to area-level socioeconomic status (SES) disadvantage, but little is known about the spatial distribution of CVD mortality according to built environment factors. We examined joint associations of neighborhood walkability attributes and SES with CVD mortality rates through linkage of Japanese national data sets.

METHODS AND RESULTS: National data were used from the 1824 municipalities (of the 1880 potentially eligible municipalities) across Japan. The outcome was mortality from CVD for a 5-year period (2008–2012) for each municipality. A national index of neighborhood deprivation was used as an indicator of municipality-level SES. A national walkability index (based on population density, road density, and access to commercial areas) was calculated. Compared with higher SES municipalities, relative rates for CVD mortality were significantly higher in medium SES municipalities (relative rate, 1.05; 95% CI, 1.02–1.07) and in lower SES municipalities (relative rate, 1.09; 95% CI, 1.07–1.12). There were walkability-related gradients in CVD mortality within the high and medium SES areas, in which lower walkability was associated with higher rates of mortality; however, walkability-related CVD mortality gradients were not apparent in lower SES municipalities.

CONCLUSIONS: CVD mortality rates varied not only by area-level SES but also by walkability. Those living in areas of lower walkability were at higher risk of CVD mortality, even if the areas have a higher SES. Our findings provide a novel element of the evidence base needed to inform better allocation of services and resources for CVD prevention.

Key Words: built environment ■ deprivation ■ heart disease ■ urban design

Cardiovascular disease (CVD) is a leading cause of death worldwide,[1] especially in the aging populations.[2] There are wide geographic variations in CVD mortality.[3–6] For example, the age-standardized rates of CVD mortality of 47 prefectures in Japan were found to range from 36 to 55 per 100 000, and disparities between prefectures have been increasing.[2] Geographic disparities in CVD mortality can be related to socioeconomic status (SES) disadvantage.[7]

The unequal distribution of health-enhancing resources and health-damaging hazards between less disadvantaged and more disadvantaged locations can contribute to such inequalities, both within and between countries.[8–10] Neighborhood-level socioeconomic disadvantage has been shown to be detrimentally associated with CVD mortality among older British men, independent of individual-level social class and CVD risk factors.[11] Similar socioeconomic gradients in CVD mortality have been identified in both men and women in the United States.[12]

Built environment attributes can be associated with risk factors for CVD, including physical inactivity,[13,14] obesity,[15] type 2 diabetes mellitus,[16] and high blood pressure.[17] For example, across 14 cities worldwide,

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CLINICAL PERSPECTIVE

What Is New?

- Cardiovascular disease mortality rates varied not only by area-level socioeconomic status but also by walkability.
- A novel finding of this study is that higher and medium socioeconomic status municipalities can also be at risk if their walkability is low.

What Are the Clinical Implications?

- Our findings can contribute to better understanding of spatial distribution of disadvantage and health, identifying where additional resources and innovative prevention initiatives are needed to reduce cardiovascular disease risk.

Nonstandard Abbreviations and Acronyms

CVD	cardiovascular disease
SES	socioeconomic status

residential density, street connectivity, and access to parks and public transit stops were found to be associated with adults' physical activity.[13] A recent systematic review of longitudinal studies also suggests that living in more walkable environments is protective against obesity, type 2 diabetes mellitus, and hypertension.[17] As the built environment attributes conducive to lower levels of physical activity and greater chronic disease risk can be unequally geographically distributed,[13,18,19] a better understanding of how built environmental attributes and area-level SES are jointly related to CVD is needed. Such evidence will inform policymakers, urban design practitioners, and clinicians of future preventive strategies for CVD by identifying high-risk areas.

Linking Japanese national databases on SES, the built environment, and CVD mortality, we examined joint associations of neighborhood walkability attributes and SES with CVD mortality rates.

METHODS

Japan national data, obtained from several sources (as described in what follows), were linked at the municipality level. The data that support the findings of this study are available from the corresponding author upon reasonable request. There were a total of 1880 municipalities (186 wards, 760 cities, 750 towns, and 184 villages) in Japan in 2010.[20] Institutional review board approval was not required for this study.

CVD Mortality

Mortality from CVD (the number of observed deaths from all types of CVD) for a 5-year period (2008–2012) for each municipality was the outcome of the study. A cardiovascular death was adjudicated when the main cause of death on the death certificate was "Heart diseases excluding hypertensive diseases" (*International Classification of Diseases, Tenth Revision (ICD-10)*, codes: I01–I02.0, I05–I09, I20–I25, I27, and I30–I52). This was reported in the Vital Statistics provided by the Health Center Districts and Municipalities.[21] Because the number of observed deaths depends on the size and age composition of each municipality, analyses were adjusted for the expected number of deaths, which was calculated using the following formula:

$$\text{(The expected number of deaths in municipality i)} = \sum_{k=1}^{n} p_{ik} \cdot r_k \times 5\,\text{years},$$

where p_{ik} is the population size of a specific 5-year age group k in municipality i, and r_k is the annual national standard mortality for age group k.

The age-specific populations for each municipality, p_{ik}, were obtained from the 2010 Population Census of Japan.[22] The national standard age-specific mortality, r_k, for the study period (2008–2012) was provided by the Ministry of Health, Labour and Welfare.[21]

Socioeconomic Status

A Japanese national index of neighborhood deprivation was used as an indicator of municipality-level SES. This index was constructed based on the Breadline Britain poverty measure,[23] and the European transnational ecological deprivation measure.[24] The detailed methods of constructing this index have been described elsewhere.[25] Briefly, this composite index included the weighted sums of several poverty-related census variables (as of 2010), including unemployment rate, proportion of sales and service workers, proportion of agricultural workers, proportion of blue-collar workers, proportion of rented houses, proportion of elderly single households, proportion of single-mother households, and proportion of elderly couple households. The weights of these variables were taken from the estimated odds ratios in a logistic regression analysis used to predict "poverty households", using microdata from Japanese social surveys measuring poverty.[25] All municipality units were stratified into tertiles according to the score of deprivation: lower, medium, and higher SES municipalities.

Built Environmental Attributes

The study used 3 neighborhood built environmental attributes (and their composite) previously developed

Table 1. Characteristics of Municipalities in Japan, Overall, and According to Municipality-Level SES

	Median (IQR)			
	Total (N=1824)	Higher SES (n=608)	Medium SES (n=608)	Lower SES (n=608)
Municipality size, km^2	107.1 (38.9 to 254.2)	56.8 (23.5 to 137.5)	123.4 (48.6 to 264.7)	175.3 (70.0 to 344.6)
Neighborhood walkability	−0.5 (−1.4 to 0.9)	0.6 (−0.5 to 2.7)	−0.6 (−1.3 to 0.5)	−1.2 (−2.0 to 0.3)
Population density (1000 people/km^2)	1.6 (0.6 to 4.4)	3.7 (1.5 to 8.1)	1.3 (0.6 to 3.5)	0.9 (0.3 to 2.0)
Access to commercial area, km	1.9 (0.9 to 3.5)	1.1 (0.5 to 2.0)	2.0 (1.0 to 3.5)	2.8 (1.6 to 4.8)
Percentages of older adults	26.4 (21.9 to 31.5)	21.9 (19.5 to 24.7)	26.8 (22.7 to 30.9)	31.7 (27.5 to 36.1)
SMR for CVD	100.6 (90.0 to 113.1)	97.6 (87.9 to 109.9)	100.0 (90.2 to 112.4)	104.7 (92.5 to 118.4)

CVD indicates cardiovascular disease; IQR, interquartile range; SES, socioeconomic status; and SMR, standardized mortality ratio.

and calculated for the entire area of Japan.[20] Briefly, population density, street density, and access to commercial areas were calculated at the municipality level using geographic information systems. These built environmental attributes were chosen based on previous studies showing their associations with physical activity.[14,26] It has been shown that high-density neighborhoods with well-connected streets tend to have more easily accessible commercial destinations, which can facilitate residents' physical activity through convenience of, and purposes for, walking.[27] Because most municipalities in Japan are not homogeneous (eg, consisting of more populated urban areas and less populated areas, such as agricultural land, forests, and mountains), simply calculating the mean environmental attributes within the municipality area can produce estimates that do not reflect the presence of less populated areas. To address this issue, we first measured the 3 environmental attributes at the neighborhood level (*chocho-aza*, the smallest administrative unit in Japan, with an average population of about 500 people), then calculated population-weighted average values (ie, summing each neighborhood's attributes multiplied by its population and dividing it by the entire population of the municipality).

The following data sources and methods were used to calculate each environmental attribute. Population density data at the *chocho-aza* level were obtained from the 2010 Population Census of Japan.[22] Street density data were available from the 2010 *National Land Numerical Information*[28] and was defined as the total length of streets within the area of the tertiary mesh. The tertiary mesh is an approximately 1×1-km grid defined by latitude and longitude. The street density of each neighborhood was obtained from the mesh that included the centroid of the neighborhood. For access to commercial areas, retail area data for 2011 released by the Zenrin Co were used.[29] For each neighborhood, straight distance from its centroid to the nearest boundary of a commercial area was used, as defined by a cluster of ≥10 retail destinations using a geographic information systems buffering technique. Retail destinations included grocery stores, supermarkets, clothing stores, household goods stores, hair salons, drug stores, restaurants, sporting goods stores, amusement facilities (eg, video game arcades, and movie theaters), professional offices (eg, medical clinics and real estate offices), banks, and accommodations. They did not include noncommercial destinations such as train stations, schools, and parks. A neighborhood walkability score was calculated by summing the *Z* scores of each of these 3 measures (the distance to commercial areas was reverse-coded with higher scores indicating shorter distances). These attributes can be considered equivalent to 3 conventional components of walkability (population density, street connectivity, and land-use diversity).[30] Walkability and each component score were categorized into tertiles.

Statistical Analysis

To characterize municipality-level variations in CVD mortality, we used standardized mortality ratios, calculated as follows:

$$\text{Standardized mortality ratio}_i = \frac{\text{(The observed number of deaths in municipality i)}}{\text{(The expected number of deaths in municipality i)}} \times 100.$$

Standardized mortality ratios indicate how each municipality's mortality is higher or lower than the national standard (set as 100). We conducted Poisson regression analyses with robust standard errors, using the number of observed deaths as the dependent variable, the expected number of deaths as the offset variable, and municipality-level SES as the independent variable (reference: higher SES municipalities). Poisson regression rather than standard ordinary least squares was chosen because this is a standard way to model count data for deaths. These more robust estimators of standard errors of coefficients were used to deal with the overdispersion (poor fitting) of Poisson regression to the data. Our analysis examined the associations of CVD mortality with the joint category of area-level SES and each walkability attribute. We produced the 3×3 categories of SES and walkability (or walkability attributes) and used them as the independent variable (reference: higher SES higher walkability). We also conducted SES-specific analyses to examine whether mortality differed significantly according to walkability levels for each SES stratum. The interactions between SES (categorical) and walkability attributes (continuous) were examined to test effect modification by SES on the associations of walkability attributes with CVD mortality (Table S1). Analyses were conducted using Stata version 15.0 (StataCorp, College Station, Texas) and the level of significance was set at $P<0.05$.

RESULTS

Of the 1880 potentially eligible municipalities, 56 were excluded because of lack of mortality data, leaving 1824 with full data. Table 1 shows the characteristics of participating municipalities, overall, and according to area-level SES. Neighborhood walkability mean was significantly higher in higher SES municipalities than in medium and lower SES municipalities. Higher SES municipalities were also more densely populated, better connected, and had better access to commercial areas than medium and lower SES municipalities. Lower SES municipalities had a significantly higher CVD mortality than higher and medium SES municipalities (ANOVA test).

Table 2 shows the median standardized mortality ratios for municipalities categorized by tertiles of SES and each environmental attribute. As shown in Table 2, the CVD mortality in lower SES, higher walkability areas was 104.5, which was very similar to that of lower SES, medium/lower walkability areas (105.5 and 104.5, respectively), and there was a reasonable number of municipalities in the former category (n=82). Figure shows the distribution of CVD mortality (SMR), SES, and walkability across Japan. The distribution of specific environmental attributes is shown in Figure S1.

Regression analyses for the whole sample found that lower and medium SES municipalities had 9% higher (95% CI, 1.07–1.12) and 5% higher (95% CI, 1.02–1.07) CVD mortality relative to higher SES municipalities. Table 3 shows the relative rates for CVD mortality for the joint categories of SES and walkability attributes. In the higher SES areas, the relative rate for lower walkability areas was 1.08 (95% CI, 1.03–1.13) relative to higher walkability area (reference). There was a similar CVD walkability gradient in the medium SES areas. The relative rate for lower, medium, and higher walkability areas were 1.08 (95% CI, 1.05–1.11), 1.07 (95% CI, 1.04–1.10), and 1.04 (95% CI, 1.00–1.07) (reference: high SES and high walkability). However, there were no significant differences in CVD mortality, according to walkability in the lower SES areas. The relative rate for lower, middle, and higher walkability

Table 2. Standardized Mortality Ratios for CVD by Joint Category of Municipality-Level SES and Built Environmental Attributes

Environmental Attributes	Median (IQR) SMR		
	Higher SES	Medium SES	Lower SES
Neighborhood walkability			
Higher (0.3 to 8.6)	94.7 (86.3–105.9)	98.5 (89.0–109.3)	104.5 (95.9–114.7)
Medium (–1.0 to 0.3)	101.7 (91.4–112.9)	99.6 (89.3–112.9)	105.5 (94.2–117.3)
Lower (–27.8 to –1.0)	101.3 (92.4–115.6)	101.7 (93.3–114.5)	104.5 (90.9–120.1)
Population density (people/km^2)			
Higher (3068 to 26 578)	94.7 (86.7–106.2)	98.3 (88.5–109.7)	104.4 (95.1–114.9)
Medium (895 to 3068)	99.6 (89.9–111.7)	99.5 (89.9–111.7)	105.4 (93.1–118.8)
Lower (5 to 895)	104.6 (92.6–117.8)	101.8 (92.0–115.7)	104.4 (91.8–119.6)
Road density, m/km^2			
Higher (9387 to 36 979)	94.5 (86.3–105.3)	98.0 (89.3–109.2)	104.1 (95.1–114.0)
Medium (5009 to 9387)	101.9 (91.6–112.6)	100.7 (90.0–113.7)	103.0 (90.7–115.8)
Lower (0 to 5009)	104.3 (93.1–118.7)	101.0 (90.8–112.8)	105.5 (92.8–121.4)
Access to commercial areas, m			
Closer (21 to 1221)	94.8 (86.8–105.9)	98.6 (88.4–110.3)	106.9 (96.2–119.9)
Medium (1221 to 2774)	100.3 (90.0–111.2)	100.0 (90.4–112.8)	105.0 (95.1–115.7)
Farther (2774 to 75 083)	103.9 (92.6–120.5)	101.2 (91.4–113.7)	103.9 (90.2–119.8)

CVD indicates cardiovascular disease; IQR, interquartile range; and SMR, standardized mortality ratio.

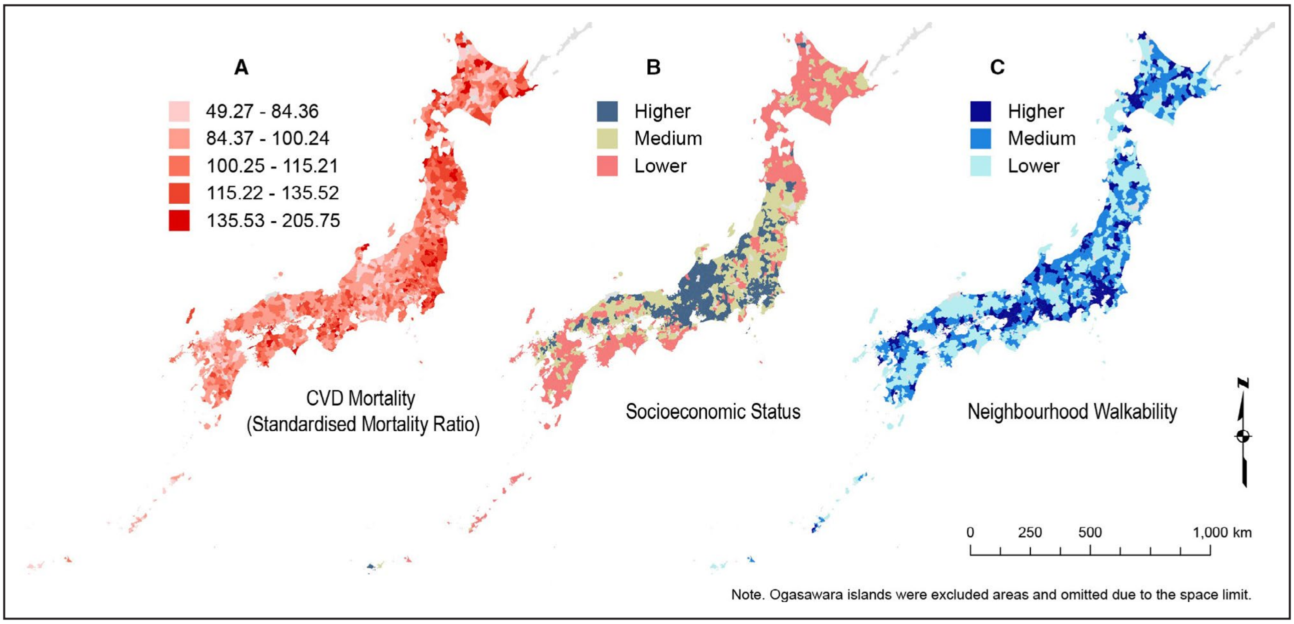

Figure. Distribution of the standardized mortality ratios for CVD, socioeconomic status, and neighborhood walkability across Japan.
CVD indicates cardiovascular disease.

areas (reference: high SES and high walkability) were 1.09 (95% CI, 1.06–1.12), 1.09 (95% CI, 1.05–1.13), and 1.11 (95% CI, 1.06–1.16). Similar patterns were observed for each specific walkability component (population density, road density, and access to commercial areas). The interaction of SES and walkability was marginally significant between lower and higher SES municipalities ($P<0.1$) but not significant between medium and higher SES municipalities (Table S1).

DISCUSSION

We found SES-related disparities in CVD mortality in Japan: Those living in lower SES areas were higher in

Table 3. Relative Rates of CVD Mortality for Joint Categories of Municipality-Level SES and Built Environmental Attributes

Environmental Attributes	Relative Rate (95% CI)		
	Higher SES	Medium SES	Lower SES
Population density			
Higher (3068 to 26 578)	1	1.04 (1.00–1.07)*	1.10 (1.06–1.15)*
Medium (895 to 3067)	1.01 (0.98–1.05)	1.06 (1.03–1.10)*	1.09 (1.06–1.13)*
Lower (5 to 895)	1.11 (1.06–1.16)*	1.09 (1.05, 1.12)*	1.10 (1.06–1.13)*
Road density			
Higher (9387 to 36 979)	1	1.04 (1.01–1.07)*	1.11 (1.07–1.16)*
Medium (5009 to 9379)	1.04 (1.00–1.07)*	1.07 (1.04–1.11)*	1.08 (1.05–1.12)*
Lower (0 to 4988)	1.08 (1.03–1.13)*	1.07 (1.04–1.10)*	1.11 (1.08–1.14)*
Access to commercial area			
Closer (9387 to 36 979)	1	1.03 (1.00–1.07)*	1.11 (1.06–1.16)*
Medium (1221 to 2772)	1.01 (0.98–1.04)	1.08 (1.04–1.11)*	1.10 (1.06–1.14)*
Farther (2774 to 75 083)	1.09 (1.04–1.14)*	1.06 (1.03–1.10)*	1.08 (1.05–1.12)*
Neighborhood walkability			
Higher (0.3 to 8.5)	1	1.04 (1.00–1.07)*	1.11 (1.06–1.16)*
Medium (–1.0 to 0.3)	1.02 (0.99–1.06)	1.07 (1.04–1.10)*	1.09 (1.05–1.13)*
Lower (–27.8 to –1.0)	1.08 (1.03–1.13)*	1.08 (1.05–1.11)*	1.09 (1.06–1.12)*

CVD indicates cardiovascular disease; and SES, socioeconomic status.
*$P<0.05$.

CVD mortality than those in higher SES areas, which is consistent with evidence from Western countries.[11,12] Our findings add to such findings and extend them to the context of Japan, where the geographic disparities in mortality are increasing.[2] We also identified another level of variability in CVD mortality within higher and medium SES municipalities, where CVD mortality was significantly greater in lower walkable municipalities. For lower SES areas, CVD mortality rates were higher, with no gradient according to walkability. The results observed for lower SES areas may be attributable to residents' perception of walkability attributes. An Australian study reported that those with lower SES tend to consider their environments not so walkable even if they live in high walkable areas.[31] A lack of concordance between objective and perceived walkable attributes may have implications for residents' predispositions to walk or not to do so. Alternatively, lower SES areas may have relevant barriers to walking, not measured in the study. These may include environmental or sociocultural factors that act to discourage residents from walking or otherwise being physically active in their neighborhoods. There is also a possibility that food environments may differ between lower SES and higher SES municipalities[32]: Residents of lower SES higher walkability areas may have better access to nutritionally deficient foods (eg, fast food) than those of high SES higher walkability areas. Further research is needed to understand why higher walkability may not the beneficial for residents' CVD mortality in lower SES municipalities.

Our findings suggest that the geographic distribution of CVD mortality may depend not only on social deprivation but also on built environmental attributes. We found that the difference in CVD mortality between lower and higher SES municipalities was 7%. The results shown in Table S1 indicate that the effect sizes for walkability attributes were modest and of similar magnitude for those of SES, within the higher SES municipalities. Although the effect sizes were smaller for medium SES municipalities and nonsignificant in lower SES municipalities, our findings suggest that the impact of walkability on CVD mortality may be comparable to that of SES in some localities. These findings will help identify areas where residents are at higher risk for developing CVD. Previous studies showed that residents of neighborhoods with lower SES are more likely to die from CVD, but our findings add that those living in areas higher in SES but lower in walkability are also at risk.

It was not possible to directly test whether the relationships observed could be attributable to differences in physical activity levels because municipality-level data on physical activity were unavailable at the national scale. Physical activity is protective against CVD,[33] and those living in higher SES areas tend to be more active during leisure time.[34,35] Although research has consistently shown associations of walkability and physical activity in Japan and several other countries,[13,20] it has been shown that the relationships between walkability and physical activity can differ between higher and lower SES areas. For instance, a recent study in Japan found that walking for exercise was associated with multiple walkability attributes in high SES areas but not in low SES areas.[36] Similarly, an Australian study showed that frequent walking during leisure time was associated with a perceived environmental attribute (walking infrastructure) only in higher SES areas.[37] Thus, it is possible that different levels of recreational physical activity between lower and higher walkability in higher SES areas may contribute to the heterogeneous distribution of CVD mortality in higher SES municipalities in this study. However, physical activity is one of many potential pathways that can link area characteristics (SES, walkability) and CVD. Further research is needed to examine behavioral and other mechanisms to better understand the geographic distributions of CVD.

Our study has limitations. Our design was cross-sectional and ecological in nature, based on the most relevant available national-level data aggregated at the level of municipalities. Thus, causal relationships between variables could not be determined. Because our study covered almost all municipalities in Japan, we were constrained to the use of a limited number of environmental attributes that were available at the national scale. Therefore, there may be other environmental attributes, such as availability of green spaces, access to public transport, motor traffic, and food environment, that may influence the relationships between SES and CVD mortality. We used municipalities as our spatial units, some of which are large and not homogeneous within their areas. Research using a smaller area unit is needed to replicate these findings. In addition, although the use of expected mortality rate has limitations, it has realistic utility in the context of our study. CVD mortality data from 2008 to 2012 were available for this study. Future studies using more recent CVD mortality data could investigate temporal relationships between SES/walkability variables and CVD mortality. Also, given the limited relevant data available at the national level, we could not control for other major potential confounders such as smoking rates or air pollution exposures. Furthermore, areas where people's daily activity takes place may not be aligned with the spatial boundaries of municipalities, which limits how accurately the actual environment to which residents were exposed could be characterized. Capturing accurate activity spaces is an ongoing challenge in the broader field of health and place.[38] Although built environmental attributes such as population density and street layout are unlikely to substantially change in a short period of time, there was a temporal difference between our environmental attributes (2010–2011) and CVD mortality (2008–2012) data.

Building on and expanding the known disparities of CVD mortality by area-level SES, we identified that urban design attributes further contribute to its geographic distribution. Confirming previous research, we found that lower SES areas have a higher risk of developing CVD. A novel finding of this study is that higher and medium SES municipalities can also be at risk if their walkability is low. Our findings may contribute to a better understanding of spatial distribution of disadvantage and health, identifying where additional resources and innovative prevention initiatives are needed to reduce CVD risk. Future research at a finer spatial scale can further improve the prediction of priority areas for CVD prevention.

ARTICLE INFORMATION

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Disclosures

None.

Supplementary Materials

Table S1
Figure S1

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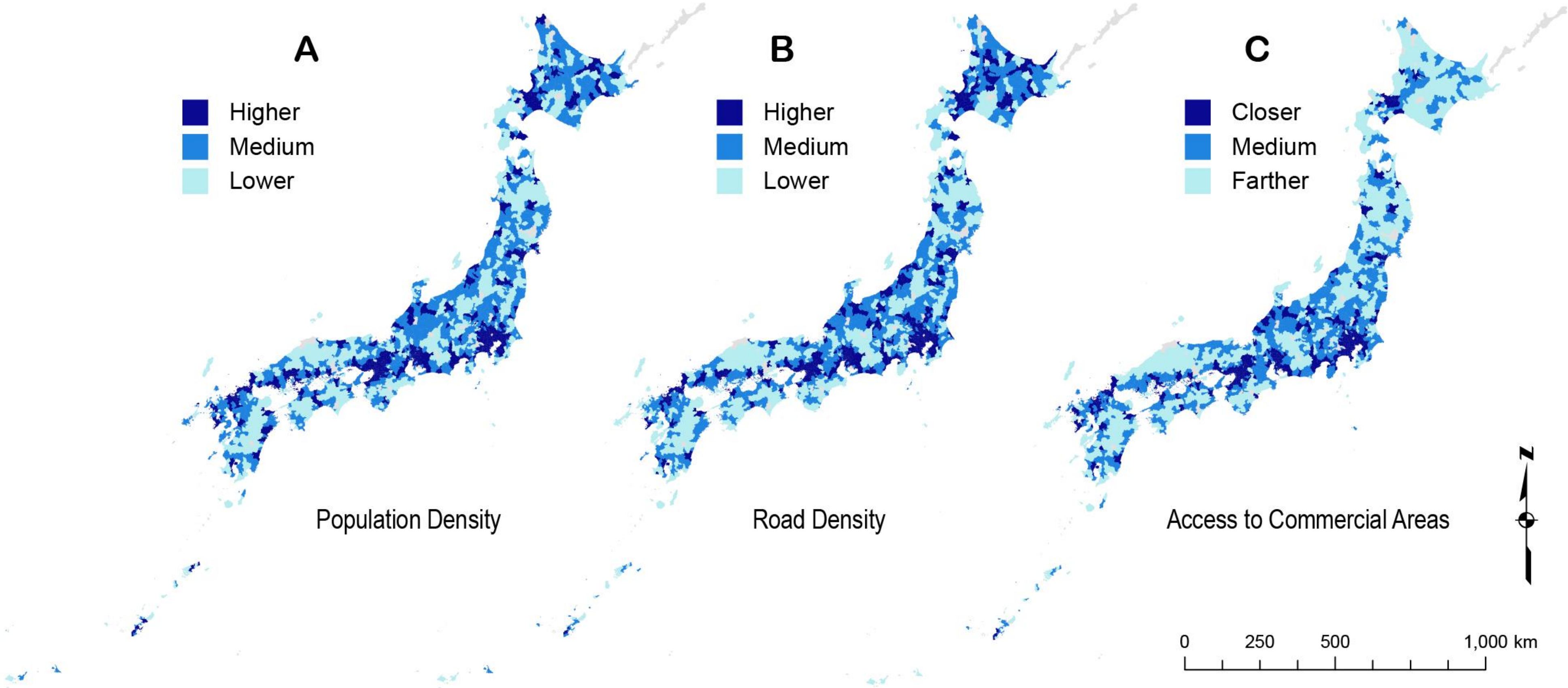
SUPPLEMENTAL MATERIAL

Table S1. Relative rates of CVD mortality for the walkability attributes stratified by SES.

Environmental attributes	Relative rate (95% CI)		
	Higher SES	Medium SES	Lower SES
Population density			
Higher	1	1	1
Medium	1.01 (0.98, 1.05)	1.03 (0.99, 1.06)	0.99 (0.94, 1.04)
Lower	1.11 (1.06, 1.16)*	1.05 (1.01, 1.08)*	0.99 (0.95, 1.04)
Road density			
Higher	1	1	1
Medium	1.04 (1.00, 1.07)*	1.03 (0.99, 1.07)	0.97 (0.92, 1.02)
Lower	1.08 (1.03, 1.13)*	1.02 (0.99, 1.06)	0.99 (0.95, 1.04)
Access to commercial area			
Closer	1	1	1
Medium	1.01 (0.98, 1.04)	1.04 (1.00, 1.08)*	0.99 (0.94, 1.04)
Farther	1.09 (1.04, 1.14)*	1.03 (0.99, 1.07)	0.98 (0.93, 1.02)
Neighborhood walkability			
Higher	1	1	1
Medium	1.02 (0.99, 1.06)	1.03 (1.00, 1.07)	0.98 (0.93, 1.03)
Lower	1.08 (1.03, 1.13)*	1.04 (1.00, 1.08)*	0.98 (0.94, 1.03)

CVD= cardiovascular disease; SES= socioeconomic status; CI= confidence interval; * $p < 0.05$

Figure S1. Distribution of the environmental attributes across Japan.



Note. Ogasawara islands were excluded areas and omitted due to the space limit.