What built environmental factors mitigate decline in older adults' step count? Three-year longitudinal study with a large sample in Yokohama, Japan

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Abstract

Background: Neighborhood walkability achieved through land-use and transport planning is an important determinant of physical activity, especially for older adults who spend more time in their neighborhoods than do other ages. This three-year study aimed to examine the longitudinal association between the change in the step count of older adults and the built environment (BE) around their homes in Yokohama, Japan.

Methods: We analyzed pedometer data in March 2016 and March 2019 that was acquired from 21 557 older adults aged 65–79 years at baseline, who lived in 758 neighborhoods in Yokohama city who participated in the Yokohama Walking Point Program (YWPP). Neighborhoods were classified into quartiles for each of the six built environmental variables (population density, intersection density, the proportion of commercial land use, normalized difference vegetation index (NDVI), the average distance to the nearest railway station, and average distance to the nearest bus stop), which were selected based on previous studies. Using multilevel regression analysis, we examined the connection between the BE variables, baseline step count, and the change in step count during the three years.

Results: Higher population density, lower intersection density, and the second shortest quartile of the average distance to the nearest railway station were associated with a higher baseline step count. A lower intersection density and shorter average distance to the nearest railway station were associated with a smaller decline. The lowest quartile of population density was reversely associated. Additionally, female and older groups recorded a lower baseline step count and a larger decline. A higher baseline step count was associated with a larger decline, as well.

Conclusions: The neighborhood BEs (i.e., population density, intersection density, and average distance to the nearest railway station) of older adults were not only associated with their step count at a certain time point, but also widened the disparity of the step count over the three years. Urban planners and designers should place emphasis on interdisciplinary collaboration with health promotion professionals in order to create compact cities centered around railway stations that are protected from traffic, so older adults feel safe.

Background

The promotion of regular physical activity (PA) decreases the risk of non-communicable diseases and increases life expectancy [1]. Older adults, in particular, can benefit from regular PA to maintain their physical, social, and mental health, as well as decrease the risk of dementia. [2, 3].

To promote PA for a population, a walkable built environment (BE) achieved through land-use and transport planning is essential [4, 5]. The attributes of a walkable BE, known as the “5Ds” (i.e., Density, Diversity, Design, Destination accessibility, and Distance to transit), are well known. [6, 7]. Such attributes would be more influential for older adults whose geographic reach of activity space is smaller and who spend more time in their neighborhoods than other ages [8, 9].

Previous studies have examined associations between older adults' walking and/or PA and the 5D attributes: density (e.g., population density and household density) [10, 11], diversity (e.g., land use mix and green land use) [10, 12–14], design (e.g., intersection density and street connectivity) [6, 10, 11, 13, 14], destination accessibility (e.g., accessibility to amenities, commercial facilities, and services) [10, 13–16], and distance to transit [17]. However, these were cross-sectional studies, while longitudinal studies are needed to avoid the self-selection bias and establish causal relationships between the BE and PA [18, 19]. In other words, the accumulation of longitudinal studies is required to confirm the observed associations between the BE and PA found in cross-sectional studies [13].

A few studies examined the relationship between the longitudinal change of walking and/or PA of older adults and the BE factors, i.e., access to PA facilities [20], proximity to parks and trails [21], closeness to functional spaces (e.g., supermarkets and PA facilities) [22], proximity to services and amenities [23], living in greener neighborhoods [24], and combined walkability score [25]. However, these studies considered only some of the 5D attributes and used self-reported data of PA.

Thus, this study aims to examine the association between the change in the step count of older adults over three years and the BE around their homes in Yokohama, Japan. For comparison, the association between their baseline step counts and their BE is examined, as well. The uniqueness of this study lies in that the step count from a large sample, and the BE variables based on all of the 5Ds were objectively measured and analyzed longitudinally.

Methods

Target Area

The target area of this study was the 758 neighborhoods (postal code area) that constitute Yokohama city, the second most populous city in Japan with a population of approximately 3.75 million people, of which 27.1% are 65 years or older as of January 2020. Located 30–40 km from Tokyo, the city's railway network has been developed with many lines running toward central Tokyo and has 157 railway stations (Fig. 1). Like other big cities in Japan, railway stations in Yokohama host a comprehensive set of services and products [26], serving as a destination for residents. The local bus network has been expanded around the railway stations, enabling approximately 90% of the citizens access to the railway stations within 15 minutes.

Measurements

Step count data

Step count data was obtained from older participants (aged 65–79 years) of the Yokohama Walking Point Program (YWPP), which the city launched in November 2014 to encourage citizens to improve their health and healthy life expectancy. It provided free pedometers (Omron HJ-326F, Japan) for volunteers

aged 18 years and above who live and/or work in Yokohama. Participants were awarded points based on their step count by scanning their pedometers via special readers installed at approximately 1000 stores and other facilities in the city. The accumulation of a certain number of points made participants eligible to win prizes. The scanned data were sent to a data server through the Internet, allowing participants to monitor their step count and rank among all the participants using a computer or smartphone [27].

We used the data from March 2016 (baseline) and March 2019 (endline). The climate in Yokohama in March is mild. The average minimum and maximum temperatures on March 2016 were 7.0 °C and 14.5 °C, respectively, while those on March 2019 were 7.3 °C and 15.1 °C, respectively [28]. The average step count of participants aged 65 or older in March 2016 was the seventh highest of the preceding 12 months, starting in April 2015 [29].

The sample of this study was selected from 303 629 YWPP participants (as of the end of March 2019). We excluded participants aged less than 65 or more than 79 (60.0%), and participants whose record for participation in March 2016 or March 2019 was less than 16 days (74.8% and 75.0%, respectively). We further excluded participants whose addresses were outside of Yokohama city (4.2%), decreasing the number of participants to 22 357. Finally, 101 participants whose postal codes had changed during the three-year period, and 699 participants whose step count in March 2016 and/or March 2019 was in either the upper or lower 1% of the remaining participants were excluded as outliers. A resulting total of 21 557 participants was selected as the sample of this study (Fig. 2).

Built environment variables and control variables

Six BE variables selected based on the 5Ds were computed using ArcMap 10.6 (Esri, Redlands, CA) and used in the following analyses. Neighborhoods were classified into quartiles for each BE variable.

First, population density (per ha) was used as an index of density (Fig. 1), calculated based on the population census conducted in 2015. Second, intersection density (per ha) was used as an index of design following previous studies [6, 10, 11]. The source of information was the Advanced Digital Road Map Database 2013 (Sumitomo Electric Industries, Ltd., Osaka, Japan). Third, the proportion of commercial land use (%) was used as an index of diversity and destination, calculated based on the result of the Basic Surveys Concerning City Planning in 2013 provided by Yokohama city. Fourth, the normalized difference vegetation index (NDVI), as of 2016, was used as an index of diversity and destination, as well. The NDVI quantifies vegetation by measuring the difference between near-infrared light (which vegetation strongly reflects) and red light (which vegetation absorbs). It ranges from - 1 to + 1. When it is positive, the land cover is likely to be green vegetation, including parks and promenades, which can be destinations for residents. On the other hand, when negative, the land cover is likely to be street surfaces and buildings. The NDVI was selected as a BE variable because green land use was associated with older adults' PA in both cross-sectional [30] and longitudinal studies [24]. Fifth, the average distance to the nearest railway station (km) was used as an index of distance to transit and destination. It was calculated using data from the National Land Numerical Information download

service [31], as of 2018. Lastly, the average distance to the nearest bus stop (km) was used as an index of distance to transit, which was calculated using data from the same service, as of 2010. Considering the shared role between railways and buses in Yokohama, as mentioned above, the average distance to the nearest railway station and bus stop should be separate variables, although most previous studies did not separate the two [14, 32]. As the precise address of each participant was unknown, the distance to the nearest railway station and bus stop from each participant's address was computed by measuring the distance from the 50-meter grid points within each neighborhood, calculating the average for each neighborhood.

Although many studies used a composite measure of walkability [17, 25, 33–36], this study uses BE variables without compounding them because composite measures are less useful for urban planners and designers as they cannot know the effect of each BE variable. The control variables in both analyses were participants' sex, age group (65–69, 70–74, and 75–79 years old; as of March 2016).

Statistical analysis

As our data had a multilevel structure with individuals at level one nested within 758 neighborhoods, at level two, we performed multilevel regression analyses with random intercepts. The outcome variables were step count at the baseline in the first analysis, and the change in step count during the three-year period for the second analysis. The explanatory variables were the six BE variables and control variables of sex and age group in the first analysis, and baseline step count was added in the second analysis. The significance level was set at $p < 0.05$. All statistical analyses were conducted using IBM SPSS Statistics 26 (IBM Corp., Armonk, NY, USA).

Results

Descriptive statistic

The descriptive statistics of the sample are presented in Table 1. Males constituted 48% of the sample. The age groups 65–69 years, 70–74 years, and 75–79 years constituted 43%, 35%, and 22% of the sample, respectively. The average step count at the baseline was 7699.0 ± 3252.1 , and the endline was 6845.3 ± 3252.1 , representing that the step count of the sample decreased by an average of 850 steps during the three-year trial.

Table 1
Descriptive statistics of the sample ($N=21557$)

		n	%
Sex	Male	10 303	48%
	Female	11 254	52%
Age (in years)	65–69	9359	43%
	70–74	7507	35%
	79–79	4691	22%

Descriptive statistics of the BE variables of 758 neighborhoods are presented in Table 2. The median of population density and intersection density per ha were 115.60 and 2.03, respectively. The proportion of commercial land use was generally low, and the median was 3.3%. The NDVI was positive in all neighborhoods. The median of the average distance to the nearest railway station and the nearest bus stop was 647 m and 175 m, respectively, representing the convenience of public transportation in Yokohama.

Table 2
Descriptive statistics of BE variables of 758 neighborhoods

	Min	Max	Mean	SD	1st quartile	Median	3rd quartile
Population density (per ha)	0	723.30	116.66	79.11	68.28	115.60	148.38
Intersection density (per ha)	0	7.72	2.09	1.18	1.33	2.03	2.76
Proportion of commercial land use (%)	0.0	51.2	6.0	7.6	1.5	3.3	6.8
NDVI	0.01	0.34	0.08	0.05	0.05	0.08	0.10
Average distance to the nearest railway station (km)	0.07	3.99	0.817	0.618	0.362	0.647	1.056
bus stop (km)	0.06	1.72	0.197	0.103	0.141	0.175	0.225

Multilevel regression analyses

The results of the multilevel regression analyses are presented in Table 3.

Table 3
Associations between BE variables and step count (baseline and change) using multilevel regression (*N* = 21,557)

	Baseline step counts			Change in step counts		
	B	95% CI	P	B	95% CI	P
BE variables						
Population density (ref: Q4)						
Q1 (Lowest)	-213.7	(-396, -31.3)	0.022	-115.9	(-225.9, -5.9)	0.039
Q2	-118.9	(-262.1, 24.4)	0.104	-10.8	(-97.6, 76)	0.807
Q3	-113.3	(-250.4, 23.7)	0.105	-4.3	(-87.4, 78.8)	0.919
Intersection density (ref: Q4)						
Q1 (Lowest)	208.0	(52.5, 363.4)	0.009	87.9	(-5.4, 181.3)	0.065
Q2	50.7	(-75.6, 177)	0.430	129.7	(53.3, 206.2)	0.001
Q3	-37.0	(-157.4, 83.4)	0.545	31.9	(-41, 104.8)	0.391
Average distance to the nearest railway station (ref: Q4)						
Q1 (Shortest)	120.5	(-49.2, 290.2)	0.163	130.7	(27.9, 233.5)	0.013
Q2	200.0	(73.1, 326.9)	0.002	117.5	(40.7, 194.3)	0.003
Q3	110.0	(-3.8, 223.8)	0.058	117.1	(48.6, 185.6)	0.001
Control variables						
Sex (ref: Female)						
Male	1821.7	(1738.4, 1905)	0.000	358.6	(304.3, 412.8)	0.000
Age (ref: 75–79)						
65–69	815.4	(705.8, 925)	0.000	314.9	(246.1, 383.8)	0.000
70–74	460.7	(347, 574.4)	0.000	154.0	(82.7, 225.2)	0.000
Baseline step counts	-	-	-	-0.3	(-0.3, -0.3)	0.000

In the first analysis with the outcome variable of step count at the baseline, a higher population density and lower intersection density were associated with a higher baseline step count. The association between the average distance to the nearest railway station and baseline step count was nonlinear; however, the second shortest quartile (Q2) was associated with a significantly higher baseline step count. Other BE variables: the proportion of commercial land use, the NDVI, and the average distance to the nearest bus stop, were not significant.

In the second analysis with the outcome variable of change in step count during the three years, the lowest quartile (Q1) of population density was associated with a larger decline. In addition, lower intersection density and shorter average distance to the nearest railway station were associated with a smaller decline in step count. The other three BE variables were not significant.

Regarding control variables over the course of the study, being female was associated with a lower baseline step count and larger decline, as was being in the older age group. Additionally, a higher baseline step count was associated with a larger decline.

[Table 3 should appear here]

Discussion

This study examined the association between the change in step count of older adults and the BE around their homes in Yokohama, Japan, over a three-year period. The main finding was that of the 5Ds, four of the Ds (Density, Diversity, Destination accessibility, and Distance to transit) mitigated the decline in older adults' step count corresponding with previous cross-sectional studies relating to walking and/or the PA of older adults. In addition, the association of the BE with baseline step count was examined.

Comparisons of the results of the two models showed that the significant variables selected were mostly the same, and the direction of the coefficients was consistent in both models. In other words, the BEs of older adults were not only associated with their step count at a certain time point but also widened the disparity of their step count over the three years.

Regarding each variable, a lower population density was associated with a lower baseline step count, and older adults living in the lowest quartile neighborhoods of population density had significantly decreased step count during the three years. This result is consistent with a previous study that found higher baseline levels of population density were associated with greater increases in walking for transportation, although the sample was not limited to older adults [37]. Population density ensures public transport and local shops and services are more viable [38] and serves as a proxy variable showing the convenience of walking for local residents. Older adults in sparsely-populated and inconvenient areas might decrease their trip frequency or change their transportation mode from walking. It was estimated that the population of Yokohama reached its peak in 2019 and would begin declining as cities in Japan [39]. On a micro-scale level, areas that are inconvenient to reach in the city would experience a greater decrease in population, resulting in the withdrawal of facilities and even greater inconvenience to residents. Considering low residential mobility in Japan, especially that of older adults [40], health promotion interventions for PA would be necessary for such areas.

Inversely, lower intersection density was associated with higher baseline step count and a smaller decline in step count over the course of the study. High intersection density indicates there are many route opportunities for traversing a road network and is thought to promote walking [6], as previous cross-sectional studies have shown, there is a positive association between older adults' self-reported walking and intersection density [10, 11]. In previous longitudinal studies, not limited to older adults, higher street

connectivity proved to be associated with a greater increase in walking for transportation [37, 41]. Although our results contradicted these studies, another study conducted in Japan also stated that the number of intersections was negatively associated with walking time [42]. It may be that intersection density cannot be an index of walkability in a city with high intersection density like Yokohama. The intersection density in Yokohama is approximately twice the figure compared to 100 cities all over the world, excluding Japanese cities, and as high as the highest city (Lisbon, Portugal) in developed countries [43]. Considering a previous study that showed that the number of street intersections contributed to walking activity only when residents perceived that the traffic conditions were safe [11]; the older adults in neighborhoods with a high intersection density in this study might feel unsafe as intersection density acted as an index of traffic accident risk.

Regarding the average distance to the nearest railway station, older adults living in the second closest quartile neighborhood recorded a significantly higher baseline step count, which suggests that they could not walk much when living too close to stations. A walkable design where older adults feel safe and are more willing to walk around is desirable around railway stations. More importantly, it was found that older adults living closer to railway stations experienced a smaller decline in step count. Taking this into consideration with a previous study of older Japanese showing a lower risk of functional limitations among those using public transport after driving cessation [44], closeness to railway stations would enable older adults to maintain their active living, their step count, and their health even after they give up driving. Yokohama city aims to accumulate residential functions around railway stations, even in suburban areas, as well as commercial and business functions [45]. Such a compact city policy, which is thought to positively influence the overall health of city populations [46], would be more beneficial in an aging society like Yokohama city provided that consideration is given to outskirt areas, as noted above.

The other BE variables, the proportion of commercial land use, the NDVI, and the average distance to the nearest bus stop, were not significantly associated with step counts in either regression analyses. It might be because of their strong correlation with the other BE variables. Regarding personal attributes, females and the older group recorded a lower baseline step count and a larger decline over the course of the study. Additionally, a higher baseline step count was associated with a larger decline, which was consistent with a previous study [20].

While making an important contribution to existing research on BE factors that mitigate the decline in the step count of older adults, this study has limitations. For instance, previous studies showed social environmental factors, such as neighborhood cohesion [47], income deprivation [48], participation with friends [49], social support [34], and neighbor relationships [50], were associated with walking and/or PA. Unfortunately, this study was not able to assess the impact of social environments of older adults as it is difficult to collect data on social environmental factors from a large sample. Therefore, future studies should consider them when examining the longitudinal association between changes in older adults' PA. In addition, study participants may not be representative of the general population of Yokohama city in that they were motivated to have pedometers, suggesting a greater intention to walk than others. We

thought that study participants would be less affected by the BE because of their higher motivation and that the effect of the BE would be underestimated in this study.

Conclusion

The importance of this study lies in the large sample size for which step count was measured longitudinally. The neighborhood BEs of older adults were not only associated with their step count during a certain time period, but also widened the disparity of the step count during the three-year study. It is essential that urban planners and designers place emphasis on interdisciplinary collaboration with health professionals to create compact cities centered around railway stations that are protected from traffic to ensure the safety of older adults.

Abbreviations

PA: Physical Activity; BE: Built Environment; CI: Confidence intervals; YWPP: Yokohama Walking Point Program; NDVI: Normalized Difference Vegetation Index

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Ethical Committee of School of Engineering, the University of Tokyo (approved July 2015). All participants provided written informed consent.

Consent for publication

Not applicable.

Availability of data and materials

The data that support the findings of this study are able to be obtained from Yokohama city, but restrictions apply to the availability of these data. They were used under an agreement for the current study, and so are not publicly available.

Competing interests

The authors declare that they have no competing interests.

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Author Contributions

KH designed this study, acquired and analyzed data, and drafted the manuscript. MH and HU assisted with acquisition and interpretation of data, and critically reviewed the manuscript. All authors approved the final version of the manuscript.

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Figures

Figure 1

Target area (Yokohama city)

Figure 2

Sample selection flow diagram