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Investigation of the association between the neighborhood environment (NE) and daily physical activity (PA) is new and limited. The purpose of the study was to clarify the association between NE and PA in a community in Japan.

Two types of regions with different residential density, land use mix-diversity, and street connectivity were selected. Residents were selected using a stratified random sampling method. Each resident's NE was objectively and subjectively measured using the Geographic Information System (GIS) and a questionnaire. PA was measured using a pedometer (accelerometer type) and a questionnaire.

For female residents, walking time for leisure was significantly longer with a high GIS score for the land use types, and total walking steps and walking time for leisure were higher among those who perceived land use mix-access. For male residents, total walking steps were significantly higher for those who perceived accessibility to working places and hardware stores, and the walking time for leisure was longer for those who perceived accessibility to working places and fast-food restaurants.

The study results reveal that mixed land use that is in proximity to several non-residential facilities could promote daily walking steps and walking time. However, there is a sex difference in the association between NE and PA. Studies are needed in various communities with environmental variability in Japan.

Key words : geographical information system (GIS), health promotion, neighborhood environment, physical activity, sex difference

I Introduction

Despite the well-documented benefits of a

physically active life-style (U. S. Department of Health and Human Services, 1996), a large percentage of the population in developed countries,

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including Japan, does not engage in sufficient levels of daily physical activity (PA) (CDC, 2007 ; Office for Lifestyle Related Disease Control, General Affairs Division, Health Service Bureau, Ministry of Health, Labour and Welfare, Japan, 2009). Effective public health approaches for promoting PA must address modifiable factors that support behavioral change (Schmid et al., 1995).

Among many models of human behavior modification, ecological models consider the importance of connections between people and their environments. The term "environment" in ecological models simply means the space outside the person (Sallis and Owen, 2002). The ecological model has specified explicitly the role of the physical environment which include features of the nature environment, such as geography and weather, as well as features of the built environment, such as urban designs (Moose, 1980).

The physical environment posits that PA resources in neighborhood, such as parks, trails, sidewalks, and exercise facilities, serve as cues for PA and might make it easier for residents to be physically active (Owen et al., 2000 ; Sallis et al., 1997). The transportation field studies showed that urban designs combining moderate density with mixed residential and commercial land use were consistently associated with more walking and cycling for transportation (Cervero and Gorman, 1995 ; Frank and Pivo, 1995).

Objectively measured physical neighborhood environment (NE), such as high residential density, high land use mix-diversity, high street connectivity (Lee et al., 2006 ; Saelens et al., 2003a, 2003b), and accessibility to facilities (Lee and Moudon, 2006) were studied and showed positive association with residents' daily PA. However, study of the association between the physical NE and PA is relatively new and the evidence is limited in Japan.

Previously, we compared residents' PA between

two objectively different communities on the basis of differences in residential density, mixed land use, and street connectivity for the first time in Japan (Lee et al., 2006). One community was a ward of metropolitan Tokyo and the other was a medium-sized city which has around 100,000 population. The study results showed that there were significant differences between the two communities in daily total walking time.

The NE factors associated with residents' PA differed depending on the communities (Lee et al., 2006). The association between NE and PA could be different depending on the physical NE of the study regions. Therefore determining the association between NE and PA in various regions in Japan is required.

Most previous studies of the association between NE and PA have focused on either objectively measured NE or residents' perception of the NE. Investigation of which one is associated with residents' PA is essential. The identification of specific NE for specific types of PA is particularly important because different types of PA are often performed in a distinct setting (Owen et al., 2000). For example, vigorous fitness training is often done in health clubs, and walking is most often done in one's neighborhood.

The other study which compared objectively different types of regions (Kondo et al., 2009) in a small-sized community revealed that there were sex differences in the association between NE and PA. Sex difference of the association is another concern of our study because only a few studies focused on this difference.

The objectives of this study were to assess in a medium-sized community of the northern part of Japan 1) the association between objective and/or subjective NE and residents' daily PA, 2) the sex difference of the NE association with PA, and 3) the NE factors which are associated with PA in

detail.

Thus, we measured NE using both objective measurement and residents' perception. PA measurement methods also included both objective and subjective tools. Because an accelerometer, which has been recommended for objectively measuring total PA (Ward et al., 2005), cannot measure separate PA based on the purpose of the activity, PA was also measured using an accelerometer type pedometer and a questionnaire in this study.

II Methods

1. Study community

The study community was Tsuruoka City in Yamagata Prefecture. According to the 2005 Census of Japan, the city has a medium-sized population of 142,384 in a 1,311-km² area (Cabinet Office, Government of Japan, 2004).

In previous studies, daily PA was found to be high among residents living in neighborhoods with high residential density, high land use mix-diversity, and high street connectivity (Saelens et al., 2003a, 2003b). In these studies, two different types of regions in a community were compared (Frank et al., 2005). This selection method was adapted in the International Physical Activity and Environment Study (IPEN, 2004).

According to this selection method (IPEN, 2004), two types of regions were selected to make a large inter-variation of residents' NE. One was a region with high residential density, land use mix-diversity, and street connectivity (Dense region); and the other was a region with low residential density, land use mix-diversity, and street connectivity (Sparse region). The Dense region had residential and nonresidential land uses (grocery stores, restaurants, small retail stores) along the main corridor; whereas, the Sparse region was mostly residential.

2. Study participants

The study participants were selected using a stratified random sampling method among the residents (age range: 30–69 years) from each region by sex and 5-years age strata on the basis of data from the Basic Resident Register in September 2006. A total of 385 residents (192 from the Dense region and 193 from the Sparse region) were selected.

A cover letter, a written consent form, and a self-administered questionnaire were sent to the selected residents by mail in November 2006. Introduction of the study, encouragement for participation, and a request to monitor daily PA using an accelerometer were included in the cover letter.

The questionnaire contained items about perceived NE, daily PA according to the purpose of the activity, and demographic variables. The demographic variables included age, sex, height, body weight, car ownership, and habitual exercise.

When the signed consent form and the questionnaire were returned, a pedometer (accelerometer type) was sent to the residents in which their height, weight, and age had been input. The participants were asked to wear the pedometer (accelerometer type) for one week and send it back by mail.

This study was approved by the Ethical Committee of the Graduate School of Medicine, The University of Tokyo, Japan.

3. Neighborhood environment

Objective measurements of neighborhood environmental characteristics

For the objective measure of resident's NE in this study, Geographic Information System (GIS) was used. Each participant's neighborhood was defined as the area with a 500 m radius of their house. It was assumed to be a 10-min walking distance (Harano, 2007).

Because there was no GIS database of land use

type for the study city, fieldwork was carried out in the study regions. Land use types were determined by two researchers in each region and classified according to the 28 types defined by the Tokyo City Planning Basic Survey (Bureau of Urban Developments Tokyo Metropolitan Government, 2001).

Using Arc GIS 9 (ESRI-Japan Co., Tokyo, Japan), the following NE indices were calculated for each participant : (1) number of households, as a quantification measure of residential density (Statistical Bureau, 2001) ; (2) number of land use types, as a quantified measure of land use mix-diversity (Zenrin, 2006) ; (3) length of streets (meters), as street connectivity (Japan Map Center, 2006) ; (4) number of intersections, as street connectivity (Japan Map Center, 2006) ; (5) length of sidewalks (meters), as walking places (Zenrin, 2006), and (6) width of streets (meters), as safety (Zenrin, 2006).

4. Subjective measurements of neighborhood environmental characteristics

For the perception of the participants' NE, the Japanese self-administered questionnaire of the Abbreviated version of the Neighborhood Environment Walkability Scale (ANEWS) (Cerin et al., 2006) was used.

ANEWS assesses the following NE characteristics : (1) residential density ; (2) "land use mix-diversity" as an indication of proximity to nonresidential land uses, such as restaurants and retail stores ; (3) "land use mix-access", as an easy access to nonresidential land uses, such as restaurants and retail stores ; (4) "street connectivity", as an easy access to streets ; (5) "walking places", such as sidewalks and pedestrian trails ; (6) aesthetics, such as attractive nature sights (landscaping, views), or attractive building or homes, and (7) "safety" of traffic and crime.

Each question included 6, 25, 7, 3, 4, 4, and 9 items, respectively. A participant's neighborhood was defined as an approximate 10-min walking distance from their house. On the basis of the answers to these questions, seven NE scores were calculated according to the method by Cerin et al. (2006). The higher the scores, the more positive the perception of their NE was.

The questionnaire also included accessibility to particular facilities within a 10-min walking distance. Facilities included hardware stores, fast-food restaurants, restaurants, post offices, bank/credit unions, participant's work places, bus stop/stations, parks, and gymnasium/fitness facilities. Participants were classified according to whether particular facilities were within a 10-min walking distance in their neighborhood.

The reliability and internal consistency of the Japanese translation of the ANEWS was moderate to high, and a detailed description of the reliability and internal consistency of the Japanese translation of the ANEWS was reported elsewhere (Inoue et al., 2009 ; Kondo et al., 2009).

5. Physical activity

Total number of walking steps (steps/day) was measured using an accelerometer type pedometer for 1 week (Lifecorder, Suzuken Co., Aichi, Japan) (Crouter et al., 2003 ; Schneider et al., 2003). Data were excluded for the days when the pedometer was worn for less than 8 hours, and periods of ≥ 30 continuous minutes when the count was equal to zero were defined as periods when participants did not wear the accelerometer type pedometer (Schmidt et al., 2006). The minimum number of datasets needed for analysis was 3 days (Masse et al., 2003).

The questionnaire included the International Physical Activity Questionnaire (IPAQ) to measure PA according to its purpose (Craig et al., 2003 ;

Lee, 2000). IPAQ was developed to provide common instruments for health-related PA. The validity and reliability of the Japanese version of IPAQ were tested and reported elsewhere (Murase et al., 2002). Daily time (minutes/day) of walking for leisure was used in this study.

6. Statistical analysis

Differences in NE characteristics between the two selected regions were tested using the Student's *t* test. The characteristics of participants between the two regions were compared using the Student's *t* test or χ^2 test.

Testing the association between objective NE and PA, a comparison of daily walking steps and walking time for leisure between the Dense and Sparse regions was conducted using an analysis of covariance (ANCOVA) adjusting for age and sex.

As the next analysis, all participants were classified as being in the high scoring group (score was equal to and above the median) or low scoring group (score was below the median) based on the GIS measures or the perception scores of the ANEWS. The ANCOVA adjusting for age was used to compare, according to sex, walking steps and walking time for leisure between the high scoring group and low scoring group.

The participants were further classified into the two groups according to perceived accessibility to particular facilities within a 10-min walking distance. An ANCOVA adjustment for age was used to compare walking steps and walking time for leisure between those with and without accessibility.

Statistical analysis was conducted using the SAS statistical package, Windows version (release 9.1; SAS Institute, Cary, N. C.). A *p* value < 0.05 was considered statistically significant.

III Results

1. Participants to the study

Sixty-one residents (32%) from the Dense region and 46 (24%) from the Sparse region answered the questionnaire; of these, 49 (26%) from the former region and 37 (19%) from the latter region wore an accelerometer type pedometer for one week. Although those who answered the questionnaire were significantly older than those who did not, female to male ratio did not differ (data not shown). Those who wore an accelerometer type pedometer were not significantly different than those who did not in regards to age, percentage of habitual exercisers, and the walking time for leisure.

Table 1 shows the comparison of participants' characteristics between the two types of regions. There were no significant differences in the mean age, height, body weight, BMI, percentage of female participants, percentage of car ownership, and percentage of habitual exercisers between the two regions.

2. Selected regions and PA

First, NE characteristics, measured using both objective and subjective methods, were compared between the selected two types of regions (Table 1).

All the objective NE indices measured using the GIS, number of households, number of land use types, length of streets, number of intersections, length of sidewalks, and width of streets were significantly different between the two types of regions.

However, among the NE perception scores using the ANEWS, only the land use mix-diversity and walking places were significantly different between the two types of regions.

Daily PA of the participants in the two regions

Table 1 Comparison of participants' characteristics, neighborhood environments, and daily physical activities between the types of region

	Dense region (n=61)	Sparse region (n=46)	
Neighborhood characteristics using the GIS			
Number of households (n)	1443.5±85.9	1012.8±133.2	*
Number of land use types (n)	23.2±0.8	22.7±0.8	*
Length of streets (m)	12292±308	8885.8±495.6	*
Number of intersections (n)	67.2±3.7	32.7±3.7	*
Length of sidewalks (m)	3053.2±309	1061.3±586.1	*
Width of streets (m)	10.3±0.8	11.3±1.2	*
Neighborhood perception scores using the ANEWS			
Residential density	235.9±82.6	226.7±32.0	
Land use mix-diversity	3.3±0.6	2.5±0.4	*
Land use mix-access	3.1±0.5	3.0±0.4	
Street connectivity	2.8±0.9	2.9±0.7	
Walking places	2.0±0.6	1.6±0.6	*
Aesthetics	2.3±0.6	2.1±0.6	
Safety	2.1±0.3	2.0±0.2	
Participants' characteristics			
Age (year)	54.8±8.9	56.1±9.5	
Height (cm)	161.4±8.1	160.6±7.8	
Weight (kg)	59.1±10.2	57.8±9.8	
BMI (kg/m ²)	22.6±3.0	22.4±3.0	
Female (%)	52.5	47.8	
Ownership of cars (%)	98.4	95.7	
Habitual exercisers (%)	55.7	52.2	
Physical activities using the IPAQ			
Walking for leisure (min/day)	6.4±2.2	3.0±2.6	
Physical activities using an accelerometer	(n=49)	(n=37)	
Total walking steps (steps/day)	7460±398	8003±458	

Data are given as the mean±SD or percentage. Student's t test or χ^2 test ; * : $P<0.05$.

PA times and walking steps are given as adjusted mean±SE for age and sex.

(n) : number, (m) : meter.

Dense region : a region with high residential density, land use mix-diversity, and street connectivity.

Sparse region : a region with low residential density, land use mix-diversity, and street connectivity.

Habitual exercisers : subjects who reported exercising regularly.

IPAQ : International Physical Activity Questionnaire.

was compared (Table 1). There were no significant differences in the total walking steps per day and the walking time for leisure per day between the two regions.

3. Association between objective NE and PA

As the next analysis, all participants were classified into the high scoring group or the low scoring group according to their objective NE measured using the GIS. Table 2 shows the comparison of the number of total walking steps and walking

Table 2 Comparison of daily physical activities between the high and the low scoring groups according to objective neighborhood environment measurements using the GIS by sex

	Males				Females			
	High scoring group		Low scoring group		High scoring group		Low scoring group	
	n		n		n		n	
<i>Total walking steps using an accelerometer (Steps/day)</i>								
Number of households (n)	21	7175±492	18	7690±532	23	7074±640	24	8746±626
Number of land use types (n)	20	7050±425	19	8229±640	22	8510±542	25	6685±791
Length of streets (m)	20	7216±507	19	7619±520	23	7723±678	24	8108±636
Number of intersections (n)	27	7155±506	12	7684±519	32	7804±664	15	8046±650
Length of sidewalks (m)	20	7143±507	19	7697±520	22	7567±634	25	8338±677
Width of streets (m)	20	7060±501	19	7784±514	25	7827±681	22	8016±639
<i>Walking time for leisure using the IPAQ (min/day)</i>								
Number of households (n)	25	7.7±2.7	26	1.4±2.7	26	2.1±1.6	25	5.8±1.6
Number of land use types (n)	26	3.5±2.3	25	6.9±3.6	25	5.5±1.4	26	0.5±2.0 *
Length of streets (m)	26	7.7±2.7	25	1.1±2.7	26	3.7±1.7	25	4.2±1.6
Number of intersections (n)	36	4.8±2.8	15	4.2±2.8	35	3.6±1.6	16	4.3±1.7
Length of sidewalks (m)	25	6.0±2.8	26	3.1±2.8	27	4.4±1.6	24	3.4±1.7
Width of streets (m)	26	7.5±2.7	25	1.4±2.7	25	3.9±1.7	26	4.0±1.6

Data are adjusted mean±SE. ANCOVA adjusting for age ; * : $P<0.05$.

(n) : number, (m) : meter.

GIS : Geographical Information System.

IPAQ : International Physical Activity Questionnaire.

High scoring group : participants with environment measurements using the GIS equal to and above the median.

Low scoring group : participants with environment measurements using the GIS below the median.

time for leisure between the high and low scoring groups by sex after adjustment for age.

For both sexes, there were no significant differences in total walking steps between the two groups for the number of households, number of land use types, length of streets, number of intersections, length of sidewalks, and width of streets. Only for females, however, the walking time for leisure was significantly 5 min/day longer in the high scoring group than in the low scoring group for the number of land use types.

4. Association between perception of NE and PA

Participants were classified into the high scoring group or the low scoring group according to each

NE perception score using the ANEWS. Table 3 shows the comparison of the total walking steps and walking time for leisure between the two groups, according to sex, after adjustment for age.

For male participants, there were no significant differences between the groups. However, for female participants, the total walking steps and the walking time for leisure were significantly higher in the high scoring group than in the low scoring group for the land use mix-access score. The mean difference of the total walking steps was 2,133 steps/day and the walking time for leisure was 5.5 min/day between the groups, respectively.

Table 3 Comparison of daily physical activities between the high and the low scoring groups according to neighborhood environment perception scores using the ANEWS by sex

	Males				Females			
	High scoring group		Low scoring group		High scoring group		Low scoring group	
	n		n		n		n	
<i>Total walking steps using an accelerometer (Steps/day)</i>								
Residential density	24	7948±448	15	6556±570	29	8153±590	18	7565±750
Land use mix-diversity	23	7335±474	16	7524±569	24	8502±641	23	7328±654
Land use mix-access	15	6769±570	24	7815±451	17	9289±771	30	7156±569 *
Street connectivity	22	7374±489	17	7463±558	28	7641±601	19	8350±731
Walking places	23	7187±471	16	7737±565	26	8021±625	21	7812±695
Aesthetics	20	6792±488	19	8065±500	29	7927±592	18	7930±751
Safety	21	7032±487	18	7857±526	24	7842±656	23	8017±670
<i>Walking time for leisure using the IPAQ (min/day)</i>								
Residential density	31	5.0±2.5	20	3.7±3.2	30	4.5±1.5	21	3.1±1.8
Land use mix-diversity	26	5.1±2.8	25	3.9±2.8	27	3.3±1.6	24	4.6±1.7
Land use mix-access	19	7.3±3.2	32	2.8±2.5	20	7.3±1.9	31	1.8±1.5 *
Street connectivity	30	4.0±2.6	21	5.2±3.1	28	3.0±1.6	23	5.0±1.7
Walking places	30	3.7±2.6	21	5.7±3.1	29	3.4±1.5	22	4.6±1.8
Aesthetics	28	7.4±2.6	23	1.0±2.9	30	2.8±1.5	21	5.6±1.8
Safety	29	6.7±2.6	22	1.6±2.9	26	3.1±1.6	25	4.8±1.7

Data are adjusted mean±SE. ANCOVA adjusting for age ; * : $P<0.05$.

ANEWS : Abbreviated version of the Neighborhood Environment Walkability Scale.

IPAQ : International Physical Activity Questionnaire.

High scoring group : participants with environment scores of the ANEWS equal to and above the median.

Low scoring group : participants with environment scores of the ANEWS below the median.

5. Accessibility to particular facilities and PA

Participants were further classified according to whether particular facilities were within a 10-min walking distance in their neighborhood. The total walking steps and walking time for leisure were compared by sex after adjustment for age (Table 4).

For males, the total walking steps and the walking time for leisure were significantly higher for those who perceived accessibility to workplaces than for those who perceived inaccessibility (Mean differences between the groups : 3,427 steps/day and 8.1 min/day, respectively). Further, the total walking steps were 2,232 steps/day significantly higher for those with accessibility to hardware stores, and the walking time for leisure was 11.6

min/day significantly longer for those with accessibility to fast-food restaurants than for those without accessibility.

For females, the total walking steps and walking time for leisure were significantly higher for those with accessibility to bus stops/stations (1,803 steps/day and 5.0 min/day, respectively) or gymnasium/fitness facilities (2,136 steps/day and 7.3 min/day, respectively) than for those without accessibility. Further, the total walking steps was 2,228 steps/day significantly higher for those with accessibility to hardware stores, and the walking time for leisure was 3.8 min/day significantly longer for those with accessibility to restaurants than for those without accessibility.

Table 4 Comparison of daily physical activities between accessibility to particular facilities within 10 minutes of walking distance in neighborhood by sex

	Males				Females			
	Accessible group		Inaccessible group		Accessible group		Inaccessible group	
	n		n		n		n	
<i>Total walking steps using an accelerometer (Steps/day)</i>								
Hardware stores	35	9416±1080	4	7184±365	*	40	9824±1164	7 7596±487 *
Fast food restaurant	32	7443±859	7	7406±401		45	6541±2265	2 7989±473
Restaurants	19	7404±511	20	7422±524		25	8406±679	22 7507±636
Post offices	15	7435±464	24	7377±588		13	8377±531	34 6753±859
Banks/credit unions	22	7209±552	17	7570±484		27	7910±713	20 7941±613
Places of work	35	10488±1000	4	7061±337	*	42	10203±1389	5 7657±476
Bus or train stops	9	7688±403	30	6494±737		17	8580±558	30 6777±742 *
Parks	4	7428±384	35	7279±1142		9	8129±516	38 7080±1079
Gyms or fitness facilities	28	7388±685	11	7422±429		37	9609±980	10 7473±505 *
<i>Walking time for leisure using the IPAQ (min/day)</i>								
Hardware stores	45	3.5±5.8	6	4.6±2.1		42	7.1±2.7	9 3.2±1.3
Fast food restaurant	45	14.7±5.5	6	3.1±2.0	*	49	0.4±5.9	2 4.1±1.2
Restaurants	25	2.4±2.7	26	6.7±2.8		28	6.0±1.7	23 2.2±1.6 *
Post offices	21	2.0±2.5	30	8.1±3.0		13	4.8±1.3	38 1.4±2.3
Banks/credit unions	32	2.6±3.2	19	5.6±2.5		29	3.8±1.8	22 4.0±1.6
Places of work	46	11.8±6.2	5	3.7±2.0	*	46	1.3±3.8	5 4.2±1.2
Bus or train stops	11	4.2±2.2	40	5.4±4.3		17	5.6±1.4	34 0.6±1.9 *
Parks	7	5.3±2.1	44	0.8±5.4		9	4.1±1.3	42 3.1±2.8
Gyms or fitness facilities	39	3.2±4.0	12	4.9±2.2		41	9.8±2.5	10 2.5±1.2 *

Data are adjusted mean±SE. ANCOVA adjusting for age ; * : $P<0.05$.

IPAQ : International Physical Activity Questionnaire.

Inaccessible group : participants without particular facilities within 10 minutes of walking distance in their neighborhood.

Accessible group : participants with particular facilities within 10 minutes of walking distance in their neighborhood.

IV Discussion

The current study purpose was to clarify the association between NE and daily PA in a medium-sized community of the northern part of Japan. The NE was assessed using both objective measures and the residents' perception. PA was also assessed using an objective measure and a questionnaire.

The study results revealed that mixed land use in NE, that is in proximity to several non-residential facilities from home, both measured using GIS and residents' perception could promote daily walking steps and walking time for female residents. The association between objective or subjective NE and objective or subjective PA were not differ-

ent in overall. The number of study participants was relatively small ; thus, the study lacked sufficient power to detect meaningful differences. Because of the limited number of participants, this study might not detect significant association between the other indices of NE and daily PA. However, our study results showed significant and large differences in walking behavior with high mixed land use.

The first objective of this study was to assess association between objective and/or subjective NE and PA. We selected different types of two regions in a community based on the residential density, land use mix-diversity, and street connectivity, and compared randomly selected residents' PA (Table 1) within the regions. The objectively

measured characteristics of NE using the GIS between the regions were significantly different in the indices of residential density, land use mix-diversity, and street connectivity. However, residents' daily PA did not show significant differences between the regions. Because the perception scores of NE only differed in the land use mix-diversity and walking places between the regions, the results were interpreted to mean that regional NE differences were not sufficiently large enough to detect differences of residents' daily PA in the current study.

As the next step, all participants were classified as being in the high scoring group or low scoring group based on the GIS measures or the perception scores of the ANEWS, and compared to residents' PA depending on each NE factor separately (Table 2, 3). The number of land use types as an index of the land use mix-diversity was positively and significantly associated with female residents' walking time for leisure (Table 2). Of the perception indices, the land use mix-access was positively associated with female residents' total walking steps and walking time for leisure (Table 3). Because each index of NE is either positively or negatively associated with residents' PA, overall index of the NE such as Dense or Sparse region did not show significant association with residents' PA.

The other indices of NE measured in this study objectively and subjectively, residential density, street connectivity, walking places, aesthetics and safety, did not show any significant association with residents' PA. For the residential density, because residents living in a dense area with many multi-family dwellings could easily walk to visit a neighbor, residential density might influence residents' transport (Saelens et al., 2003b). However, in Japan, residents in single-family dwellings have significantly more friends in their neighborhood

than residents in multi-family dwellings (Kaku, 2007). In the current study, the Sparse region was mostly a residential area with predominantly single-family homes, and this might explain why the residential density has no association with PA.

Street connectivity was reported positively associated with residents' PA in the USA (Atkinson et al., 2005). In America, cul-de-sacs are built according to city planning and cul-de-sacs interfere with the connectivity. This is not the case in Japan (Ieda and Oka, 2002), and there are relatively few cul-de-sacs in Japan. Therefore, the results of earlier studies could not be directly applied to Japan.

The walking places and safety were not associated with residents' PA in the current study. The walking places were measured using the sidewalk surrounding the neighborhood. Safety was measured by residents' perception of quantity of traffic, speed of traffic, street lights at night, and crime rate. Because the current study was conducted in a medium-sized community, these kinds of indices might not sufficiently vary among residential neighborhoods.

A previous study conducted in Japan showed that residents' daily walking time for leisure was longer for those who perceived neighborhood aesthetics (Kondo et al., 2009). Humpel et al. (2004) also found that the walking time was positively associated with residents' perceptions of neighborhood aesthetics. However, the current study did not find an association between neighborhood aesthetics and residents' PA. The reason for the inconsistency between the current study result and the earlier studies may be that aesthetics, such as attractive or interesting nature scenes or buildings, was not sufficiently different in the current study participants' neighborhoods. Study to compare the different neighborhood aesthetics will be needed.

The second research objective of this study was

to assess the sex difference of the NE association with PA. The study results revealed that land use mix-diversity, measured both objectively and subjectively, were associated with female residents' daily PA. The current study did not have a sufficient number of participants to detect an association between NE and PA. Nevertheless, both objectively and subjectively measured land use mix-diversity were associated with female residents' daily PA, but not with male residents'.

The current study results support previous findings that daily PA was high among Japanese female residents living in a neighborhood with land use mix-diversity (Kondo et al., 2009; Lee et al., 2006). In general, women may be more likely to limit their daily behavior to their neighborhood more than men. Earlier studies also reported the sex differences in the association between NE and PA; accessibility to facilities for females (Humpel et al., 2004), accessibility to sidewalks for both males and females (Giles-Corti and Donovan, 2002), and aesthetics for males (Kondo et al., 2009) were positively associated with PA. Further study concerning the detailed contents of sex differences will be needed.

The third objective of this study was to assess the NE factors which are associated with residents' daily PA in detail. We investigated the association between residents' perceived accessibility to particular facilities within a 10-min walking distance and PA by sex. Residents' PA was compared between those with accessibility to particular facilities and those without (Table 4). Male residents who perceived closer proximity to their working places showed significantly longer walking steps and walking time. The observed mean differences in walking steps and walking time between the groups were 3,427 steps/day and 8.1 min/day, respectively. Further, perceived accessibility to hardware stores and fast-food restaurants were

positively associated with the total walking steps and walking time for leisure, respectively. These kinds of facilities which correlated with male's daily PA may be favored by the male residents. Also, the perceived accessibility to or from working places could promote male residents' daily PA.

For female residents who perceived accessibility to bus stops/stations or gymnasium/fitness facilities within a 10-min walking distance, the total walking steps and the walking time for leisure were significantly longer than those who perceived inaccessibility to these facilities. Further, the walking time for leisure was significantly longer in female residents with restaurants in their neighborhood. These results are in accordance with the previous findings that perception of accessibility was positively associated with walking time among females (Humpel et al., 2004). Exercise facilities or restaurants are the places for social contact especially for female residents. Women are likely to walk when they perceive closer proximity to these facilities and to public transportation resources.

There are several limitations in this study. The response rate for this study was relatively low. One possible reason of this low response rate was that participants had to not only answer the questionnaires but also wear an accelerometer type pedometer during 7 consecutive days. This kind of study in other countries reported similar response rates with the current study (Saelens et al., 2003a). There was a significant difference in the mean age between participants who answered the questionnaire and participants who did not. Therefore, the results of the study could be generalized for residents who are relatively old. However, differences in participants' age and PA measured using the IPAQ were not observed between participants who wore an accelerometer type pedometer and participants who did not.

This study is cross-sectional, thus it cannot confirm the causal linkage between NE and residents' PA. However, our study is one of the first studies to report both on multi-level factors assessed from the residents' perception and on objective environments in the NE related to daily walking behavior in a medium-sized community in Japan. Furthermore, daily PA was assessed using an accelerometer type pedometer and a self-administered questionnaire.

Finally, we found relatively large PA differences with a limited number of study participants. The observed significant differences in the total walking steps per day were around more than 2,000 steps. The 2,000 steps are two times larger than the national objective of increasing the daily number of walking steps within a 10-year period in Japan in the Health Japan 21 (Ministry of Health, Labour and Welfare, 2000). The extra 2,000 steps for an individual weighing 60 kg can be calculated as a further energy expenditure of at least 60 kcal per day. Accumulation of this energy expenditure during a year can be estimated as an approximate decrease of 3 kg of body fat. Daily total walking steps included walking steps in leisure time. The significant mean difference of walking time for leisure in our study was around 5 min/day. Because walking steps/day depend largely on the transportation, 5 min of walking time in leisure thus can be largely contributed to differences of daily PA.

We propose a hypothesis for further studies in other communities of Japan. Furthermore, our study established the assessment methods for the NE and daily PA of residents in Japanese communities and proposes assessment methods for future studies. The NE with smaller blocks and accessible non-residential facilities are also supported in the urban planning literature as a desirable design feature for walking (Transportation Research Board, 2005). Political efforts, to increase mixed

land use development in residential NE, to facilitate residents' walking behaviors for commute and/or transport purposes or pleasure, have already been launched and are underway in the USA (Tester, 2009).

V Conclusions

The study results reveal that mixed land use, that is in proximity to several non-residential facilities from home, could promote daily walking steps and walking time. The association between perceived accessibility to particular facilities and daily PA was different for male and female residents. Further studies are needed in various communities with environmental variability in Japan.

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