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ORIGINAL ARTICLE

Association between objectively measured built environments and adult physical activity in Gyeonggi province, Korea

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Abstract

Objectives In the present study, the association between objectively measured built environments and physical activity (PA) was examined.

Methods Data were obtained from the Korean Community Health Survey (KCHS). A total of 82,419 individuals living in 546 neighborhoods of Gyeonggi province were analyzed. Built environments were measured by geographic information systems (GIS) using Korean government databases. PA was assessed using the IPAQ—short form. Multilevel logistic regression was performed.

Results Living in a community with a short distance to parks was associated with a 42% increased odds of PA; living in a community with low population density was associated with a 21% decreased odds of PA. However, most variations in PA were attributed to individual factors. Additionally, gender-specific correlates associated with PA were observed.

Conclusions Although the associations of individual factors with PA were stronger than of community factors, notably, built environments influenced most people in a community. Therefore, along with health education and service, policy makers and planners should consider more parks in less populated areas to create a supportive environment for PA.

Keywords Built environment · GIS · Physical activity · Multilevel analysis · Korea

Introduction

Industrialized countries that favor motor-vehicle mobility are being confronted with a pandemic of physical inactivity, which is a risk factor for many preventable diseases and chronic conditions, including obesity, type 2 diabetes, heart disease, stroke and some cancers (Ding et al. 2016; Hallal et al. 2012; Lee et al. 2012). One-third of adults worldwide do not meet the recommended level of physical activity (PA) to achieve substantial health benefits (Hallal et al. 2012; WHO 2010). Physical inactivity causes 6–10% of the major non-communicable diseases (NCDs) and 9% of premature mortality (Lee et al. 2012). Moreover, the economic burden of physical inactivity is substantial. Ding et al. (2016) estimated the effect of physical inactivity on five major NCDs (i.e., type 2 diabetes, breast cancer, colon cancer, heart disease and stroke) and all-cause mortality cost more than $67.5 billion worldwide in 2013 through healthcare expenditure and loss of productivity. Additionally, 13.4 million disability-adjusted life-years (DALYs) worldwide were attributed to physical inactivity (Ding et al. 2016).

Increasing PA is a key public health strategy for reducing the morbidity and mortality burden of NCDs. However, increasing PA using individual behavior change interventions had limited success despite a better understanding of how individuals can change their health behavior (Bauman et al. 2012; Conn et al. 2011; Kohl et al. 2012). Therefore, an ecological model was proposed to describe how the interrelations between individuals and their social and physical environments influence health behaviors (Bauman et al. 2012; Kohl et al. 2012; Sallis

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et al. 2012). Beyond individual-level interventions, the ecological model provides a comprehensive framework for developing multilevel interventions that include coordinated changes at the individual, social, cultural, environmental and policy levels (Bauman et al. 2012; Kohl et al. 2012). Previous studies have identified PA correlates at the individual level (i.e., gender, age, education, income, job, smoking and alcohol use, body image and being overweight and physical and mental health status) (Bauman et al. 2012; Hart et al. 2017; Mama et al. 2015). Recently, interest in the role of built environments that can influence people to be more active has grown. Most studies conducted in the USA, Australia and European countries have identified built environment features related to PA (i.e., population density, street connectivity, land-use mix [LUM] and proximity to transit and recreational facilities) (Bauman et al. 2012; Frank et al. 2004; Hajna et al. 2015; Saelens et al. 2003; Sallis et al. 2016). Population density promotes transit ridership and leads to frequent transport services within a community (Saelens et al. 2003). Therefore, residents from higher-density communities are more likely to be active (Sallis et al. 2016). Street connectivity, defined as the number of intersections with more than three legs per square kilometer within a community, promotes easy traveling within the community via a variety of routes (Frank et al. 2004; Sallis et al. 2016). LUM is a measure of the number of different types of land uses in a community. High LUM encourages residents to walk to diverse destinations (e.g., shops, churches, schools and other services) (Hajna et al. 2015; Witten et al. 2012). Moreover, communities where people live close to public transport, parks and facilities for PA tend to be more active (Adams et al. 2015; Diez Roux and Mair 2010; Sallis et al. 2016).

However, existing research examining associations between built environments and PA has several limitations. First, although objective measures of the built environment derived from geographic information systems (GIS) are increasingly used in studies of built environments and PA (Diez Roux and Mair 2010), more research using GIS-based measures is needed to avoid biases due to self-reported perceptions of neighborhood characteristics (Day 2016; Grasser et al. 2013). Second, most studies examined subcomponents of PA (i.e., transportation or recreational activities, walking or cycling) while the contribution of the built environment to total PA using a large sample has seldom been reported (Adams et al. 2015; Hajna et al. 2015; Sallis et al. 2009). Third, the lack of studies conducted in Asian countries limits generalization regarding the association between built environments and PA (Day 2016). Moreover, whether previous findings from the USA, Australia and European countries can be applied to the Asian population is unclear because urban structures differ considerably among countries. Fourth, although women are much less active than men in most countries (Hallal et al. 2012) and their health and health-related behaviors might be more influenced by residential environments than men (Stafford et al. 2005), minimal knowledge exists regarding differences in the association between neighborhood environment and PA based on gender (Ribeiro et al. 2013, 2015). To address this knowledge gap, the association between GIS-derived built environments and PA was examined using a large sample from the Korean Community Health Survey (KCHS) and gender differences in the associations were explored.

Methods

Data sources and study populations

Data were obtained from the KCHS, which was designed to provide data that could be used to plan, implement, monitor and evaluate community health promotion and disease prevention programs. The KCHS is a nationwide health interview survey conducted every year since 2008 by the Centers for Disease Control and Prevention (CDC) under the Korean Ministry of Health and Welfare (Kang et al. 2015). The KCHS used a multistage sampling design to obtain a representative sample of adults 19 years of age or older. Approximately 230,000 individuals each year with an average of 450 households from across the country were involved in this survey. Detailed information on the KCHS has been previously described (Kang et al. 2015). Our study used Gyeonggi province data obtained from the 2013 and 2014 KCHS. A total of 82,419 individuals living in 546 administrative districts were included in the current analysis. The protocols of the 2013 and 2014 KCHS were reviewed and approved by the institutional review board of the CDC (2013-06EXP-01-3C, 2014-08EXP-09-4C-A, respectively). After obtaining written informed consent for the survey, data were collected through a computer-assisted personal interview by trained interviewers using a standardized questionnaire (Kang et al. 2015).

Study area

The study area was limited to Gyeonggi province that surrounds Seoul, the capital of the Republic of Korea, in the West Central area of the Korean peninsula (Fig. 1). The area of Gyeonggi province is 10,189 km^2, accounting for approximately 10.2% of the total land area of South Korea (Gyeonggi 2017). The population of Gyeonggi province increased from 9.28 million in 2000 to 12.98 million in 2016. This province consists of 28 cities and three counties, a mix of urban, suburban and rural areas (Kim 2010). Approximately one-third of the province's 28 cities have

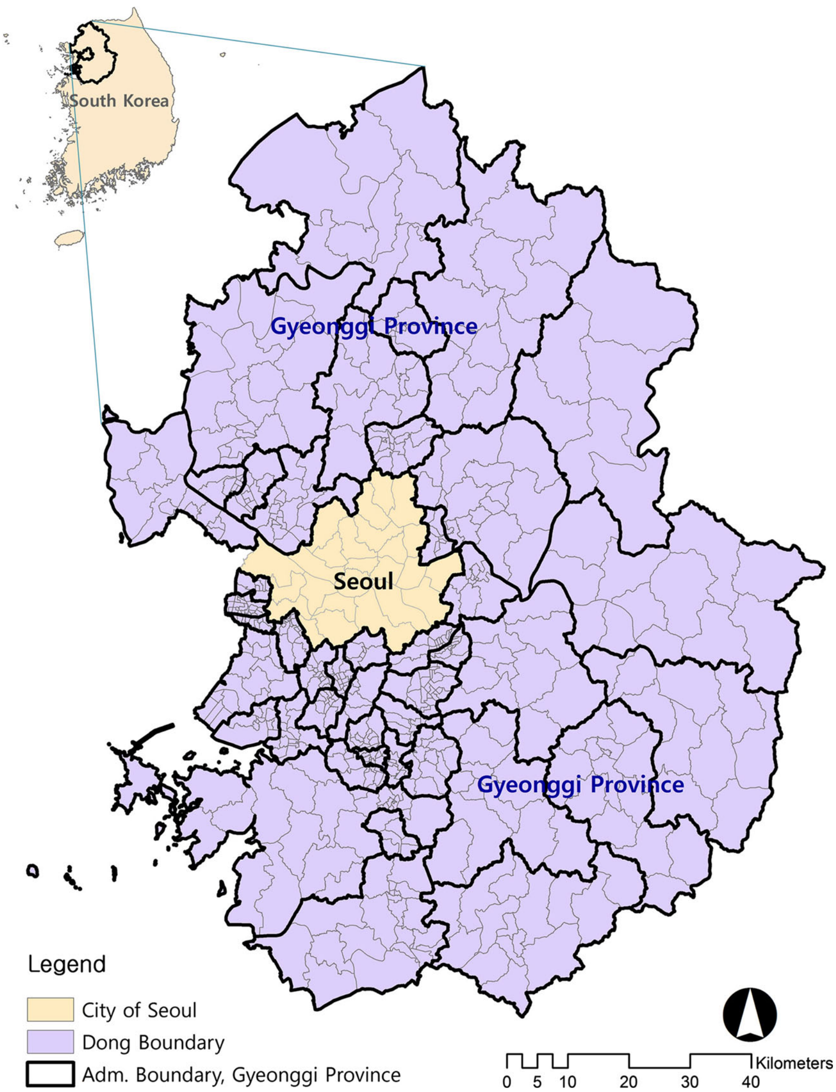

Fig. 1 Study area: Gyeonggi province, Republic of Korea

over a half million people (Gyeonggi 2017). According to the administrative division of South Korea, large cities (*si*) are subdivided into administrative districts (*gu*) with the lowest units (*dong*), including an average population of 20,115 per *dong* (Ministry of the Interior and Safety 2017). A county (*gun*) consists of one town (*eup*) and 5–10 townships (*myeon*), including an average population of 21,523 and 4128 per *eup* and *myeon*, respectively (Kim 2010; Ministry of the Interior and Safety 2017). In the current study, GIS-derived built environment data were measured in 546 *dong*, *eup* and *myeon* as the lowest units of the administrative division of Gyeonggi province, including an average population of 25,178, 39,078, and 7602 per *dong*, *eup* and *myeon*, respectively (Ministry of the Interior and Safety 2017).

Measurements

Physical activity

The International Physical Activity Questionnaire—Short Form (IPAQ-SF) (IPAQ 2005) was used to obtain self-reported PA over the previous 7 days. The IPAQ-SF assessed frequency (number of activity days in the last 7 days) and duration (minutes/day) of walking, moderate-intensity and vigorous-intensity activities. The metabolic equivalent for task (MET) min week^{-1} was calculated according to the official IPAQ scoring protocol. One MET is resting energy expenditure. Walking was assumed to correspond to 3.3 METs, moderate-intensity activity to 4 METs and vigorous-intensity PA to 8 METs. The participants were categorized into three PA levels (low, moderate or high levels of PA) based on the IPAQ scoring criteria. Thus, participants who performed vigorous-intensity activities for at least 20 min per day on 3 or more days, moderate-intensity activities and/or walking for at least 30 min per day on 5 or more days, or any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum of at least 600 MET min week^{-1} on 5 or more days were categorized into the moderate- or high-activity group. In this study, participants categorized as having moderate or high activity were classified as having met the recommendations of the WHO for PA (WHO 2010).

Built environments

GIS was used to characterize built environments (distances to public PA facilities, parks and transit, population density, street connectivity and LUM). In this study, the average distance (i.e., Euclidean distance) between the centers of 100 m × 100 m grids of urbanized land area and the nearest destination such as public PA facilities, public parks or public transit was calculated. Since urbanized land area has well-connected street networks, this average Euclidean distance is a reasonable substitute of a street-based distance measure. Urbanized land area was defined as developed land area excluding mountain areas, watershed areas and natural open spaces. In addition, LUM was calculated using the entropy index by Frank and Pivo (1994). Built environment measures were created for 546 administrative districts (*dong*, *eup* and *myeon*) of Gyeonggi province using Korean government databases (National Public PA Facility Database 2013, Korean Transport Database, Population Census 2013 and National Building Database 2013) and ArcGIS software. Table 1 presents the definitions of built environment variables, descriptive findings for the variables and the data sources for each variable. After examining the built environment variables with exploratory data analysis, the variables were categorized into four quartiles, ranging from the lowest number in Quartile 1 to the highest number in Quartile 4.

Individual factors

Information on gender, age (19–39 years of age, 40–64 years of age and $\geq$ 65 years of age), education ($\leq$ high school/$\geq$ college), household income (< 3 million won/$\geq$ 3 million won per month), job (manual, non-manual and others) and living alone (yes/no) was obtained from the survey. As health behavior and status variables, information on smoking and alcohol consumption (never, former and current), perceived body image (non-obesity/obesity), body mass index (BMI; < 25 kg/m^2/$\geq$ 25 kg/m^2), the number of diagnosed chronic diseases (e.g., hypertension, diabetes, dyslipidemia, stroke, myocardial infarction, angina and arthritis) (none, 1–2 and $\geq$ 3) and psychological health status (subjective health status [poor/good], stress perception [yes/no] and depression [yes/no]) was collected. Participants who reported moderate or high degree of stress were classified into the stress group. Depression was determined by a "yes" response to the item "During the last 12 months, were you feeling so sad or hopeless for at least 2 weeks that you stopped performing some usual activities?"

Statistical analyses

The descriptive statistics of all variables were computed. The χ^2 test was used to compare men and women based on individual factors and PA. Bivariate relationships between PA (not meeting PA recommended level vs. meeting PA recommended level) and each variable were assessed using logistic regression analysis. All univariate analyses were performed with IBM SPSS Statistics for Windows version 21.0 (IBM Corp., Armonk, NY, USA). Since the data had a two-level structure with individuals nested within communities, multilevel logistic models were used to evaluate the association between built environments and PA. A series of models was developed as follows: Model 0 included only the intercept, model 1 included the statistically significant individual factors found in the prior logistic regression analyses, model 2 included built environment features and model 3 included the statistically significant correlates of individual and community built environmental factors found in models 1 and 2 to build a parsimonious model. Median odds ratios (MORs) and intraclass correlations (ICCs) for each model were calculated to assess how much of the variance in PA could potentially be attributed to the built environment in each community (Merlo et al. 2006). MOR is the median value of the odds ratio (OR) between the area at highest risk and the area at lowest risk when randomly picking out two areas. If the MOR is equal to 1, there is no variation between communities, but it is large if considerable between-community variation exists (Merlo et al. 2006). Additionally, these analyses were conducted separately based on gender. Multilevel binominal logistic regression was performed using SAS version 9.4 (SAS Inc., Cary, NC, USA) in the GLIMMIX procedure. Statistical significance was set at $p < 0.05$.

Table 1 Objectively measured built environments (Republic of Korea 2013)

Variables	Definitions	Mean	Min	Max	Data source
Distance to public physical activity facilities (m)	Average distance between center of urbanized land area and nearest public physical activity facilities	1444.6	205.3	9783.6	National Public Physical Activity Facility Data Base 2013, Ministry of Culture, Sports, and Tourism
Distance to public parks (m)	Average distance between center of urbanized land area and nearest public parks	709.3	39.9	6183.3	National Public Physical Activity Facility Data Base 2013, Ministry of Culture, Sports, and Tourism
Distance to public transit (m)	Average distance between center of urbanized land area and nearest public transit (i.e., bus stops and subway stations)	282.2	85.1	1751.6	Korea Transport Data Base 2013, Ministry of Land, Infrastructure and Transport
Population density	The number of population divided by urbanized land area	227.6	4.2	8067.8	Population Census 2013, Statistics Korea
Street connectivity	The number of intersections with three or more legs divided by urbanized land area	0.23	0.0	2.9	Korea Transport Data Base 2013, Ministry of Land, Infrastructure and Transport
Land-use mix	Ratio of domestic, commercial and business building floor areas divided by urbanized land area; values ranged from 0 (lowest heterogeneity of land use) to 1 (highest heterogeneity of land use)	0.75	0.0	1.0	National Building Data Base 2013, Ministry of Land, Infrastructure and Transport

Results

The characteristics of the study participants are given in Table 2. More than half of the participants were female (54.3%) with a high school diploma or less (55.3%). Approximately 42% of the participants were in the middle-aged group (40–59 years of age). Approximately 64% of the participants met the PA recommendation from the WHO. Moreover, approximately 67% of the men and 62% of the women engaged in moderate- or high-intensity PA. The bivariate relationships between PA and all variables, including participant characteristics and built environment features, were analyzed (data not presented). All variables were significantly associated with PA, except living alone in men (OR 0.97, 95% CI 0.89–1.06) and smoking in women (OR 1.05, 95% CI 0.96–1.16 for never smokers; OR 1.01, 95% CI 0.87–1.17 for former smokers). These variables were excluded in the next step of analysis. Regarding built environment features, the odds of PA were significantly increased at shorter distances to public PA facilities, parks and transit. PA was positively associated with population density and street connectivity, while PA was negatively associated with LUM.

The association between objectively measured built environment features and PA is presented in Table 3. Overall, the MOR of model 0 was 1.64 and decreased to 1.60 in model 3, showing that there was an effect of neighborhood level on PA. That is, a person from a higher probability neighborhood was 64% more like to engage in PA when compared with a person from a lower probability neighborhood. Moreover, the ICC of model 0 was 0.075, showing that 7.5% of the variation in PA was attributable to between-neighborhood differences. After including the individual and environmental factors, the ICC decreased from 7.5 to 6.9%. Model 3 showed a significant association between PA and built environment features (i.e., distance to a public park and population density). The odds of PA were decreased from the first and second quartiles to the fourth quartile of distance to park, while the odds of PA increased from the first to the fourth quartile of population density. Thus, participants living in communities with a short distance to parks and high population density were more likely to engage in PA. However, distance to public PA facilities and transit, street connectivity and LUM were not associated with PA. For men, the ICC of model 0 was 8.3% and decreased to 7.6% in model 3. Similar to the results from total participants, men living in a community with a short distance to parks were more likely to be involved in PA. Moreover, living in a community with the second shortest distance to a park was associated with a 68% increased odds for PA in men compared with men living in a community with the farthest distance to a park (OR 1.68, 95% CI 1.34–2.10 for Q2 vs. Q4). However, population density was not significantly associated with PA in men, unlike the results from total participants and women. Regarding individual factors, age, education, job, smoking, drinking, perceived body image, subjective health status and stress perception were significantly associated with PA in men. For women, the ICC decreased from 8.2% in model 0 to 7.5% in model 3. Similar to the results from total participants, women living in a community with a short distance to a park and high

Table 2 Characteristics of study participants and physical activity by gender (Republic of Korea 2013–2014)

	Total (n = 82,419) n (%)	Men (n = 37,656) n (%)	Women (n = 44,763) n (%)	p value
Age (years)				
19–39	28,100 (34.1)	12,899 (34.3)	15,201 (34.0)	< 0.001
40–59	34,859 (42.3)	16,309 (43.3)	18,550 (41.4)	
≥ 60	19,460 (23.6)	8448 (22.4)	11,012 (24.6)	
Education				
≤ High school	45,524 (55.3)	18,572 (49.4)	26,952 (60.3)	< 0.001
≥ College	36,771 (44.7)	19,023 (50.6)	17,748 (39.7)	
Household income (monthly)				
< 3 million won	33,724 (42.2)	14,872 (40.6)	18,852 (43.4)	< 0.001
≥ 3 million won	46,259 (57.8)	21,720 (59.4)	24,539 (56.6)	
Job				
Non-manual labor	21,819 (26.5)	12,068 (32.1)	9751 (21.8)	< 0.001
Manual labor	28,516 (34.6)	16,668 (44.3)	11,848 (26.5)	
Other	31,988 (38.9)	8858 (23.6)	23,130 (51.7)	
Living alone				
No	76,372 (92.7)	35,186 (93.4)	41,186 (92.0)	< 0.001
Yes	6047 (7.3)	2470 (6.6)	3577 (8.0)	
Smoking				
Never smokers	51,654 (62.7)	9922 (26.4)	41,732 (93.2)	< 0.001
Former smokers	12,825 (15.6)	11,544 (30.7)	1281 (2.9)	
Current smokers	17,934 (21.8)	16,187 (43.0)	1747 (3.9)	
Drinking				
Never drinkers	11,951 (14.5)	2464 (6.5)	9487 (21.2)	< 0.001
Former drinkers	9887 (12.0)	3540 (9.4)	6347 (14.2)	
Current drinkers	60,573 (73.5)	31,650 (84.1)	28,923 (64.6)	
Perceived body image				
Non-obesity	49,834 (60.5)	24,047 (63.9)	25,787 (57.6)	< 0.001
Obesity	32,577 (39.5)	13,606 (36.1)	18,971 (42.4)	
Body mass index				
Non-overweight (< 25 kg/m^2)	60,247 (74.7)	25,386 (67.9)	34,861 (80.5)	< 0.001
Overweight (≥ 25 kg/m^2)	20,429 (25.3)	11,977 (32.1)	8452 (19.5)	
Subjective health status				
Poor	12,663 (15.4)	4574 (12.1)	8089 (18.1)	< 0.001
Good	69,751 (84.6)	33,079 (87.9)	36,672 (81.9)	
Stress perception				
No	58,548 (71.1)	26,465 (70.3)	32,083 (71.7)	< 0.001
Yes	23,851 (28.9)	11,181 (29.7)	12,670 (28.3)	
Depression				
No	76,754 (93.1)	35,958 (95.5)	40,796 (91.1)	< 0.001
Yes	5657 (6.9)	1695 (4.5)	3962 (08.9)	
Number of chronic diseases				
0	55,569 (67.5)	25,399 (67.5)	30,170 (67.5)	< 0.001
1–2	22,677 (27.5)	10,780 (28.7)	11,897 (26.6)	
≥ 3	4069 (4.9)	1441 (3.8)	2628 (5.9)	
Meeting physical activity recommended level				
Yes	52,793 (64.2)	25,259 (67.2)	27,534 (61.6)	< 0.001
No	29,469 (35.8)	12,322 (32.8)	17,147 (38.4)	

n (%) numbers and percentages

Table 3 The association between objectively measured built environments and physical activity using multilevel analyses (Republic of Korea 2013–2014)

	Model 0			Model 1			Model 2			Model 3		
	Total	Men	Women	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)
Gender (ref. women)												
Men				1.26 (1.20–1.32)						1.27 (1.22–1.33)		
Age (ref. ≥ 60)												
19–39				0.93 (0.88–0.98)	1.07 (0.99–1.17)	0.85 (0.78–0.92)				0.91 (0.87–0.96)	1.03 (0.95–1.11)	0.88 (0.82–0.95)
40–59				0.88 (0.84–0.92)	0.86 (0.80–0.92)	0.92 (0.86–0.98)				0.87 (0.83–0.91)	0.82 (0.77–0.88)	0.94 (0.88–1.00)
Education (ref. ≥ college)												
≤ High school				0.96 (0.92–0.99)	0.90 (0.85–0.95)	0.98 (0.93–1.04)				0.96 (0.93–1.00)	0.91 (0.86–0.96)	
Household income (ref. ≥ 3 million won)												
< 3 million won				1.02 (0.99–1.06)	1.03 (0.97–1.08)	1.01 (0.96–1.06)						
Job (ref. other)												
Non-manual labor				1.00 (0.96–1.05)	0.86 (0.80–0.92)	1.06 (1.00–1.12)				1.00 (0.96–1.05)	0.86 (0.80–0.93)	1.06 (1.00–1.12)
Manual labor				1.12 (1.07–1.17)	0.88 (0.82–0.94)	1.31 (1.24–1.38)				1.15 (1.10–1.20)	0.90 (0.85–0.96)	1.35 (1.28–1.42)
Living alone (ref. yes)												
No				0.96 (0.90–1.02)		1.01 (0.93–1.09)						
Smoking (ref. current smokers)												
Never smokers				1.17 (1.11–1.23)	1.13 (1.06–1.20)					1.17 (1.11–1.22)	1.13 (1.07–1.20)	
Former smokers				1.15 (1.09–1.21)	1.16 (1.10–1.23)					1.15 (1.10–1.20)	1.16 (1.10–1.23)	
Drinking (ref. current drinkers)												
Never drinkers				0.87 (0.83–0.91)	0.82 (0.74–0.90)	0.88 (0.83–0.93)				0.87 (0.83–0.91)	0.82 (0.74–0.90)	0.89 (0.84–0.94)

Table 3 (continued)

	Model 0			Model 1			Model 2			Model 3		
	Total	Men	Women	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)
Former drinkers				0.83 (0.79–0.88)	0.88 (0.81–0.95)	0.82 (0.78–0.88)				0.83 (0.79–0.87)	0.86 (0.79–0.93)	0.83 (0.78–0.88)
Perceived body image (ref. obesity)												
Non-obesity				1.10 (1.06–1.14)	1.15 (1.08–1.22)	1.09 (1.04–1.15)				1.11 (1.07–1.15)	1.16 (1.11–1.22)	1.09 (1.05–1.14)
Body mass index (ref. ≥ 25 kg/m^2)												
< 25 kg/m^2				1.02 (0.98–1.07)	1.03 (0.97–1.10)	1.00 (0.94–1.06)						
Subjective health status (ref. good)												
Poor				0.66 (0.63–0.69)	0.61 (0.57–0.66)	0.68 (0.64–0.73)				0.66 (0.63–0.69)	0.62 (0.58–0.66)	0.67 (0.63–0.71)
Stress perception (ref. yes)												
No				1.10 (1.07–1.14)	1.11 (1.05–1.17)	1.09 (1.04–1.14)				1.11 (1.07–1.15)	1.11 (1.06–1.17)	1.10 (1.05–1.15)
Depression (ref. yes)												
No				1.05 (0.99–1.12)	1.08 (0.96–1.20)	1.05 (0.97–1.13)						
Number of chronic diseases (ref. ≥ 3)												
0				1.01 (0.93–1.09)	0.92 (0.81–1.04)	1.07 (0.96–1.18)						1.06 (0.96–1.17)
1–2				1.06 (0.99–1.15)	0.96 (0.84–1.08)	1.14 (1.03–1.25)						1.14 (1.04–1.25)
Distance to public physical activity facilities [ref. Q4 (farthest)]												
Q1 (nearest)							1.16 (0.94–1.42)	1.18 (0.93–1.49)	1.16 (0.93–1.46)			
Q2							1.08 (0.89–1.32)	1.10 (0.88–1.37)	1.09 (0.88–1.35)			
Q3							0.98(0.84–1.15)	1.00 (0.83–1.19)	0.99(0.83–1.18)			

Table 3 (continued)

	Model 0			Model 1			Model 2			Model 3		
	Total	Men	Women	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)
Distance to public parks [ref. Q4 (farthest)]												
Q1 (nearest)							1.48 (1.19–1.85)	1.49 (1.15–1.92)	1.42 (1.11–1.82)	1.42 (1.16–1.75)	1.39 (1.10–1.76)	1.41 (1.12–1.77)
Q2							1.66 (1.35–2.04)	1.76 (1.39–2.24)	1.53 (1.22–1.92)	1.62 (1.33–1.96)	1.68 (1.34–2.10)	1.52 (1.23–1.88)
Q3							1.31 (1.09–1.58)	1.30 (1.05–1.61)	1.28 (1.04–1.57)	1.27 (1.07–1.52)	1.24 (1.02–1.51)	1.26 (1.04–1.52)
Distance to public transit [ref. Q4 (farthest)]												
Q1 (nearest)							0.99 (0.82–1.19)	0.97 (0.78–1.20)	0.99 (0.80–1.21)			
Q2							1.02 (0.86–1.22)	1.02 (0.83–1.24)	1.01 (0.84–1.22)			
Q3							0.95 (0.83–1.09)	1.01 (0.87–1.19)	0.88 (0.76–1.03)			
Population density [ref. Q4 (highest)]												
Q1 (lowest)							0.78 (0.60–1.00)	0.83 (0.62–1.11)	0.72 (0.55–0.96)	0.79 (0.64–0.97)	0.87 (0.68–1.10)	0.72 (0.57–0.90)
Q2							0.82 (0.68–0.98)	0.82 (0.67–1.00)	0.82 (0.67–1.00)	0.81 (0.70–0.94)	0.84 (0.71–1.00)	0.79 (0.67–0.92)
Q3							0.85 (0.74–0.97)	0.85 (0.73–0.99)	0.85 (0.73–0.98)	0.84 (0.74–0.96)	0.86 (0.75–1.00)	0.83 (0.72–0.95)
Street connectivity [ref. Q4 (highest)]												
Q1 (lowest)							1.20(1.00–1.44)	1.18 (0.95–1.45)	1.20 (0.98–1.47)			
Q2							1.14 (0.99–1.31)	1.15 (0.98–1.35)	1.13 (0.97–1.31)			
Q3							1.09 (0.96–1.24)	1.08 (0.94–1.25)	1.10 (0.95–1.26)			
Land-use mix [ref. Q4 (highest)]												
Q1 (lowest)							0.88(0.76–1.01)	0.86 (0.73–1.01)	0.89 (0.76–1.05)			

Table 3 (continued)

	Model 0			Model 1			Model 2			Model 3		
	Total	Men	Women	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)	Total OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)
Q2							1.00 (0.88–1.15)	0.97 (0.84–1.13)	1.03 (0.89–1.19)			
Q3							0.99 (0.87–1.13)	0.98 (0.84–1.13)	1.00 (0.87–1.15)			
Area level variance	0.270	0.300	0.292	0.269	0.296	0.291	0.236	0.265	0.261	0.245	0.272	0.265
(SE)	(0.019)	(0.027)	(0.025)	(0.020)	(0.027)	(0.025)	(0.019)	(0.026)	(0.026)	(0.019)	(0.027)	(0.025)
PCV				− 0.4%	− 1.3%	− 0.3%	− 12.6%	− 11.7%	− 10.6%	− 8.9%	− 8.1%	− 8.9%
MOR	1.64	1.69	1.67	1.64	1.68	1.67	1.59	1.63	1.63	1.60	1.65	1.63
ICC	0.075	0.083	0.082	0.076	0.082	0.081	0.067	0.074	0.074	0.069	0.076	0.075

OR, odds ratio; 95% CI, 95% confidence interval; Q, quantile; ref., reference category; SE, standard error; PCV, proportional change in variance; MOR, median odds ratio; ICC, intraclass correlations

Model 0 included only the intercept; Model 1 included selective individual factors; Model 2 included built environment features; and Model 3 included selective individual factors and built environment features

population density were more likely to engage in PA. Similar to men, the highest odds of PA in women were found for the second shortest distance to a park (OR 1.52, 95% CI 1.23–1.88 for Q2 vs. Q4). Living in a community with the lowest population density was associated with 28% decreased odds of PA in women compared with women living in a community with the highest population density (OR 0.72, 95% CI 0.57–0.90 for Q1 vs. Q4). Among individual factors, age, job, dinking, perceived body image, subjective health status, stress perception and the number of chronic diseases were significantly associated with PA in women.

Discussion

In the present study, using a large sample of the Korean population, distance to parks and population density were significantly associated with meeting the recommendations for PA. Evidence of a linear gradient was observed in the relationship. Thus, participants who lived in a community with a supportive built environment close to parks with high population density were more likely to be physically active. Moreover, gender-specific correlates associated with PA were observed.

Consistent with the literature (Bauman et al. 2012; Coombes et al. 2010; Sallis et al. 2016; Watts et al. 2013), our results demonstrated that distance to parks was significantly related to PA in both men and women. Although a study from the USA found no association between distance to the closest park and park use or park-based PA (Kaczynski et al. 2014), shorter distances to a park reduce inconvenience and cost to the individual in terms of time and effort required to be active (Kent and Thompson 2014). Our findings also support that proximity to parks is more likely to encourage sufficient PA across genders. Next to proximity to parks, high population density was associated with PA in women, whereas no significant relationship was found for men. High population density is needed to improve community physical environments associated with PA because a sufficient number of local residents are necessary to support frequent transport services, nearby parks and PA facilities and diverse destinations (Saelens et al. 2003; Sallis et al. 2016).

Although associations between population density and PA have been reported in many other studies (de Sa and Ardern 2014; Sallis et al. 2016; Witten et al. 2012), limited knowledge exists regarding differences in the association between built environments and PA based on gender. Two studies from Portugal reported gender differences in the association between objectively measured built environments and leisure-time PA among adults over 65 years of age (Ribeiro et al. 2013, 2015). Additionally, a study using pooled data from the USA, Australia and Belgium indicated a stronger association for women between perceived neighborhood environmental attributes and transport-related walking (Van Dyck et al. 2013). Previous studies suggested that variation in neighborhood effects by gender originated from differences in perception, exposure and vulnerability to contextual factors (Stafford et al. 2005), both in utilization of available neighborhood facilities (e.g., parks) (Cohen et al. 2006) and in how men and women view and value-specific social and physical environments (Burke et al. 2009). Although our findings revealed an association between objectively measured population density and PA in women, further studies are required to improve our understanding of the gender-specific correlates of built environments.

Distance to PA facilities or public transit was not significantly related to PA in the current study. These variables had significantly negative associations in the bivariate relationship but not in the full model. PA facilities are generally located within or around parks. Additionally, transportation services are determined according to the population density of each community. Therefore, the influence of distance to PA facilities or public transit on PA appears attenuated in multi-environment-variable models. Although most studies that examined the subcomponents of PA (i.e., transportation activities, walking or cycling) indicated positive associations with street connectivity and LUM (Christiansen et al. 2016; de Sa and Ardern 2014; Witten et al. 2012), our findings did not reveal significant associations between total PA and street connectivity and LUM. Similarly, an international study which included ten countries on five continents reported that street connectivity and LUM were not associated with moderate-to-vigorous-intensity PA (Sallis et al. 2016). Hence, more studies are needed to improve our understanding of the association between street connectivity, LUM and total PA, especially moderate-to-vigorous-intensity PA.

Regarding individual factors, men, manual workers, current drinkers and male never smokers were more likely to be active. Additionally, participants with good perceived body image and health status and low levels of perceived stress reported more PA. These findings are in agreement with previous research outcomes (Bauman et al. 2012; Hallal et al. 2012; Mama et al. 2015; Piazza-Gardner and Barry 2012; Serrano-Sanchez et al. 2012; Solomon et al. 2013). Although previous studies reported that older adults were less active (Hallal et al. 2012; Solomon et al. 2013), our findings showed that younger adults were less active than older adults. Men with a college education or beyond were more active than men with less education. In addition, a study on Spanish adults showed a positive association between education and PA in both men and women (Serrano-Sanchez et al. 2012). The present study also found that women with one or two chronic diseases were more active that women with more than three chronic diseases. Because one-third of Korean adults have hypertension, diabetes and/or dyslipidemia (Tran et al. 2017), the government has encouraged PA, which in turn increased adult PA.

The strengths of the present study included the use of objective measures for built environments, a large sample drawn from the KCHS and analyses that tested the association between built environments and total PA using a multilevel analysis model based on gender. Despite these strengths, limitations existed. Social desirability bias was possible because self-reported PA was used. Moreover, the IPAQ has been shown to overestimate PA (Lee et al. 2011); thus, actual prevalence rates are likely not as high as those reported in this study. Second, the influence of private PA facilities and parks was not assessed in the current study. Third, although psychosocial factors (i.e., self-efficacy, motivation, social support) contributed to a sufficient level of PA (Serrano-Sanchez et al. 2012), the present study did not investigate these associations due to a lack of available data. Fourth, residential mobility was not assessed despite its potential implications. Lastly, since this study measured built environment features based on administrative areas rather than based on each individual's home or daily travel space, the possibility of an ecological fallacy cannot be ruled out.

In summary, the results from the current study highlighted the importance of short distances to parks and high population density for supporting sufficient PA. Furthermore, these associations were more obvious in women than in men. Based on our findings, interventions that (1) empower individuals to be physically active through health education and services, (2) create a supportive environment that permits easy involvement in PA, including more parks in less populated areas and (3) provide gender-specific programs are recommended.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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