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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

Neighborhood environments, lifestyles and noncommunicable diseases in Sweden and Japan

KENTA OKUYAMA
CLINICAL SCIENCES, MALMÖ | FACULTY OF MEDICINE | LUND UNIVERSITY

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KENTA OKUYAMA completed Sports and Health Science studies at Hosei University in Japan in 2014. He then obtained a Master's degree in Public Health, Epidemiology at the Colorado School of Public Health in the US in 2016. His research interest is how the place where we live influences our lifestyles and chronic diseases. This thesis aimed to investigate if neighborhood environmental factors, such as accessibility to fast food outlets, hilliness and socioeconomic status are associated with obesity, physical activity, depressive symptoms and pain among the Swedish and Japanese populations.

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Kenta Okuyama

LUND UNIVERSITY

DOCTORAL DISSERTATION

Doctoral dissertation for the degree of Doctor of Philosophy (PhD) at the Faculty of Medicine at Lund University to be publicly defended on September 8th at 13.00 in Agardhsalen, Department of CRC, Jand Waldenström gata 35, Malmö

Faculty opponent
Ulf Ekelund, Professor
Department of Sports Medicine
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Abstract:

Background: Noncommunicable diseases (NCDs) account for more than 70 percent of global deaths. Research to identify neighborhood environmental factors can serve to modify our environment to be more health-promoting or target high-risk areas to reduce the risk of NCDs at the population level. This thesis work aimed to: investigate modifiable neighborhood environmental factors for obesity among Swedish adults, rural-specific neighborhood environmental factors for physical inactivity and depressive symptoms among Japanese older adults, and neighborhood socioeconomic status (SES) for pain among Swedish older adults. The thesis aims to highlight what neighborhood research and public health and clinical policies/practices could consider taking to tackle this global health issue.

Methods: Paper I investigated whether neighborhood availability of fast food (FF) outlets and physical activity (PA) facilities are associated with the risk of obesity among 1.7 million Swedish adults. Paper II investigated rural neighborhood environmental factors, e.g., hilliness and access to community centers for the risk of physical inactivity among 2,211 older adults in three rural municipalities in Japan. Paper III investigated if neighborhood hilliness was associated with depressive symptoms among 935 older adults in three rural municipalities in Japan. Paper IV investigated if neighborhood SES was associated with severe pain among 11,685 older adults in Sweden.

Results: Neither FF outlets nor PA facilities availability in neighborhoods were associated with obesity in Sweden. Neighborhood hilliness and access to community centers were associated with physical inactivity and depressive symptoms among rural Japanese older adults, but the associations varied across municipalities. Swedish older adults in low SES neighborhoods had higher odds of severe pain.

Conclusion: Neighborhood environmental factors for NCDs could differ from place to place due to social, cultural, and geographical contexts. Once high-risk areas are identified, public health and clinical practices could be directed to those areas. Further research to identify neighborhood environmental factors considering various contexts, as well as their mechanisms, would aid in effective public health practices and policies to reduce the burdens of NCDs.

Key words: Neighborhood, Noncommunicable diseases, Obesity, Physical inactivity, Depressive symptoms, Pain, Socioeconomic status

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MADE IN SWEDEN

To my family, Takako, Takashi, Mina, and Yoneko

Table of Contents

Abstract

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Popular science summary

Nowadays, many people are aware of what is good and bad for our health. For example, we try to eat healthier food and exercise more to maintain our health. It is not as easy as it sounds; in fact, more of us are becoming overweight or obese, physically inactive, and dying due to noncommunicable diseases (NCDs), which are all consequences of unhealthy lifestyles. This is more prominent in people who do not have high education, live in rural areas, and are of older age. One of the reasons is that the places where we live are encouraging us to choose certain lifestyles. It may be more difficult to eat healthily if there are only fast food (FF) restaurants in your area of residence. In contrast, it may be easier to go out for a walk if your neighborhood is affluent. A lot of research has found that neighborhood environments are playing important roles in our lifestyle behaviors as well as health outcomes. That suggests that changing the neighborhood environment, i.e., the place where people live, to be health-promoting could be an effective method to improve our health. However, research findings are not sufficient to initiate environmental changes, especially for certain settings and people, such as older people living in rural areas. Therefore, this thesis aimed to investigate neighborhood environments and NCDs and lifestyles – an area in which more research is needed.

Our first paper investigated if the availability of FF outlets and PA facilities in neighborhoods was associated with the risk of obesity among Swedish adults. Neither of them were related to the risk of obesity in Sweden, unlike other countries. Our second paper investigated if older people living in rural areas of Japan stop exercising due to neighborhood environmental factors such as the accessibility to public transportation, community centers and hilly terrains. People in hilly neighborhoods had a higher risk of stopping exercise and people living far away from community centers had a lower risk of stopping exercise, but the result was different across towns. Our third paper investigated if rural older people in Japan living in hilly neighborhoods had a higher risk of depressive symptoms, and we found they were at a higher risk. Our fourth paper investigated if Swedish older adults living in low socioeconomic status (SES) neighborhoods have a higher risk of severe pain; we found they were having a higher risk.

Research investigating neighborhood environments could tell us where there is a high-risk population that we need to act upon, as well as what we could change to improve health at the population level. It is important to note that a certain neighborhood environmental factor related to NCDs is not always the same across countries, regions, or even towns. More research is needed to identify what we can change in settings and populations where general health tends to be poor to reduce inequality and eventually reduce the burden of NCDs.

List of Papers

This thesis is based on the following four papers referred to in the text by Roman numerals. Reprinted with permission from the respective publishers.

Paper I

Okuyama, K., Li, X., Abe, T., Hamano, T., Franks, P. W., Nabika, T., & Sundquist, K. (2020). Fast food outlets, physical activity facilities, and obesity among adults: a nationwide longitudinal study from Sweden. *International Journal of Obesity*, *44*(8), 1703-1711.

Paper II

Okuyama, K., Abe, T., Li, X., Toyama, Y., Sundquist, K., & Nabika, T. (2021). Neighborhood environmental factors and physical activity status among rural older adults in Japan. *International journal of environmental research and public health*, *18*(4), 1450.

Paper III

Abe, T., **Okuyama, K.**, Hamano, T., Takeda, M., Yamasaki, M., Isomura, M., Kunihiko, N., Sundquist, K., & Nabika, T. (2021). Assessing the impact of a hilly environment on depressive symptoms among community-dwelling older adults in Japan: A cross-sectional study. *International Journal of Environmental Research and Public Health*, *18*(9), 4520.

Paper IV

Okuyama, K., Johansson, SE., Sundquist, K. Neighborhood socioeconomic status and pain among older adults – a cross-sectional study. *European Journal of Pain. Manuscript. Under review.*

Author's contribution to the papers

Paper I

K.O. designed the study, drafted the work, and interpreted the analysis results.

Paper II

K.O. designed the study, drafted the work, curated geographical and all data, conducted the statistical analysis, and interpreted the analysis results.

Paper III

K.O. contributed to the study design, curated geographical data, and interpreted the analysis results.

Paper IV

K.O. designed the study, drafted the work, curated data, conducted the statistical analysis, and interpreted the analysis results.

Abbreviations

BMI	Body mass index
CoHRE	Community-based Healthcare Research and Education
DeSO	Demographic Statistical Areas
EU-SILC	Statistics on Income and Living Conditions
FF	Fast food
GIS	Geographic information system
IPAQ	International Physical Activity Questionnaire
MVPA	Moderate or vigorous physical activity
NCDs	Noncommunicable diseases
NDI	Neighborhood deprivation index
PA	Physical activity
SAMS	Small area market statistics
SDS	Zung Self-Rating Depression Scale
SES	Socioeconomic status
ST	Sedentary time
UK	United Kingdom
US	United States
WHO	World Health Organization

Introduction

Noncommunicable diseases

Noncommunicable diseases (NCDs) are caused by a combination of genetic, physiological, environmental and behavioral factors (1). More than half of the annual global deaths are attributed to NCDs, e.g., cardiovascular diseases (CVD), cancers, chronic respiratory diseases and diabetes. Specifically, 36 million deaths (63% of 57 million deaths) were due to NCDs according to the estimates in 2008 and it is projected to increase to 55 million deaths by 2030 (2). The increasing trend was confirmed in the estimates of 2019; 41 million deaths (74% of all deaths) (3). Those numbers include premature deaths, which could be avoided by means of effective and equitable prevention and treatment strategies.

In 2013, the World Health Organization (WHO) endorsed a Global Action Plan for the Prevention and Control of NCDs and set nine global targets, e.g., 25% relative reduction in premature deaths, 10% relative reduction in physical inactivity, and to halt the rise of diabetes and obesity (2).

Epidemiological transition

It is not so long ago since NCDs started being a dominant cause of death in our societies. Infectious diseases, e.g., tuberculosis and diarrhea, used to be the major threat to our lives until the 19th century (4,5). They started declining along with the improvement of sanitary conditions, medical treatment and socioeconomical development. On the other hand, NCDs started emerging along with population aging, modernization, urbanization, globalization and technological development (Figure A) (5).

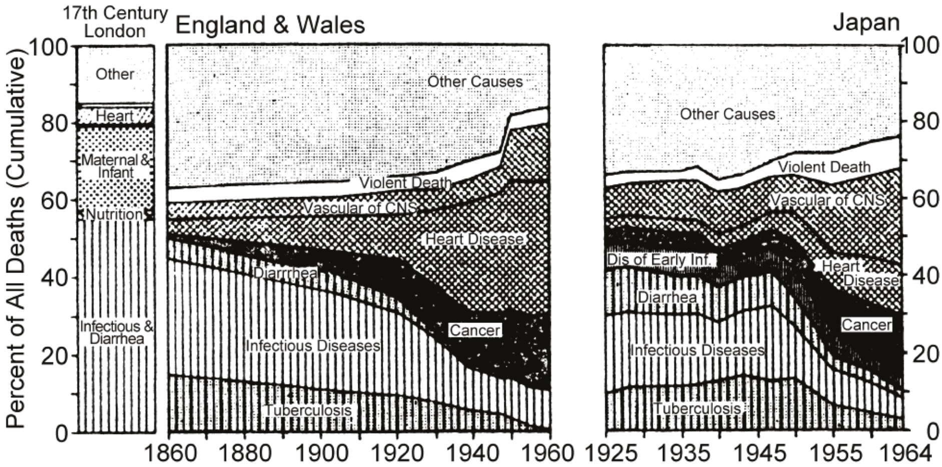

Figure A: Shift in the proportion of causes of death from infectious diseases such as tuberculosis and diarrhea to NCDs such as heart disease and cancer. Cited and partially modified from the 2nd revised version of Omran's paper: "The Epidemiologic Transition: A Theory of the Epidemiology of Population Change" (5).

Our lifestyles have changed to be more sedentary over time, and the consumption of high-calorie food has become more popular and prevalent worldwide. Physical inactivity and obesity are in the increasing trend in almost all parts of the world since 30 years (6,7). As of 2016, almost one-third of the population were obese in many parts of the world (Figure B) (8).

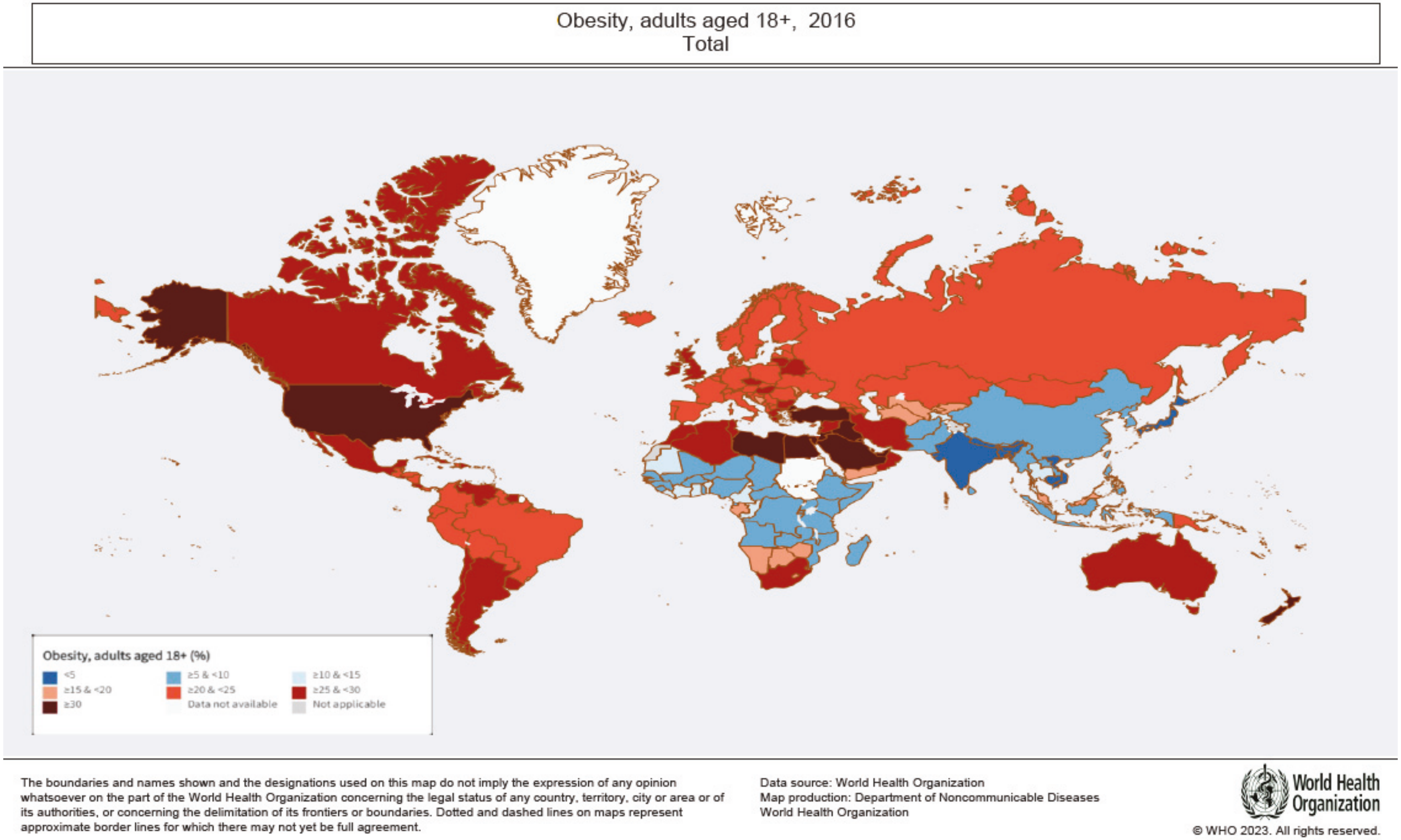

Figure B: Proportion of adults (18+ years old) who are obese (body mass index (BMI)>=30) in 2016. The prevalence of obesity is more than 20 % in the areas with orange, red, and dark red.

In addition to these metabolic-related outcomes, disabilities and mental health disorders have been increasing. Pain and depression are one of the major factors depriving our time that we can live without disabilities (9). Given that socioeconomic development continues, and we live longer, all these NCDs and related outcomes will continue increasing and incurring significant costs to our societies. And what we consistently see in the patterns is that vulnerable populations such as those who have low socioeconomic status (SES), and rural and older adults bear a higher prevalence of those outcomes (9). Such inequalities in health are unfair by themselves but also pose detrimental effects to the whole population by spillover effects (10). Therefore, we need an equity-based and multisectoral approach to tackle these public health issues (2).

Neighborhood environments, NCDs and lifestyles

In order to reduce the burdens of NCDs, one of the important measurements is to intervene in upstream factors. Upstream factors include multiple sectors such as environments and policies which encompass individuals and determine individuals' behavior (11). Since the late 20th century, neighborhood research has shown that health behaviors and outcomes are associated with neighborhood environmental factors (12,13). It started out with neighborhood poverty levels and mortality, and then other outcomes were investigated such as CVD, obesity and physical activity (PA) (12,13). For example, accessibility to fast food (FF) outlets and PA facilities was found to be strongly associated with the risk of obesity among adults living in the United Kingdom (UK) and United States (US) (14,15). Walkable environments with high street connectivity, residential density, bus stop density and presence of sidewalks were consistently found to be positive factors to promote physical activity among urban middle and older age adults (16–18). However, those factors are not always associated with obesity and PA in different settings. In fact, accessibility to FF outlets was not associated with the risk of obesity in New Zealand (19), and street connectivity or presence of sidewalks were not PA promoting factors among rural populations (20,21). These indicate that more evidence in different settings is needed to initiate effective policies or environmental interventions; modifying neighborhood environments to reduce the risk of those outcomes. Furthermore, as some areas or populations are understudied, some outcomes such as depression and pain have not been studied as much as obesity and PA (Table A). Advancing neighborhood research within all NCDs and related outcomes would facilitate effective public health strategies to reduce the healthcare burden of NCDs at the population level because they are interlinked and often share similar upstream factors.

Table A: Gradient of neighborhood research for different NCDs related outcomes

	Obesity	**PA**	**Depressive symptoms**	**Pain**
Amount of research	High	High	Medium	Low
Research gap	Non-UK, US	Rural	Rural	General population
Significance	Effective intervention	Vulnerable group	Vulnerable group	Effective intervention Vulnerable group

Note: Amount of research is based on subjective measures and the degree is defined as relativity to each other. Rural population is often vulnerable to the risk of NCDs due to a lack of health-promoting resources.

Obesity

Being obese would significantly increase the risk of CVD, type 2 diabetes and certain types of cancer, which are the major NCDs to cause premature deaths (1,22). In general, obesity is a consequence of an imbalance between energy intake and expenditure (23). The shift of our lifestyles from manual based to machine or computer-based, i.e., physically active to sedentary lifestyles, and the emergence of fast food enabled our energy intake to easily exceed energy expenditure, and as a result obesity has become a global epidemic (24,25). The potential role and effect of neighborhood environment are expected based on the previous studies which consistently showed people in low SES neighborhoods have a higher prevalence of obesity as well as the increasing trend of obesity, which cannot be explained solely by biological reasons (26). It is now useful for public health policymakers and practitioners to know what they could modify to reduce the risk of obesity at the population level (27). Neighborhood exposure to FF outlets and PA facilities gathered attention since they are relatively easy to modify compared to other physical environments such as street and city layouts (14). The association between those commercial facilities and obesity was studied in the UK and US, but not in other countries, and the findings are inconclusive whether modifying those outlets and facilities could effectively reduce obesity risk at the population level (14,15,28–30).

Physical activity (PA)

Insufficient PA is an important factor for obesity, major NCDs as well as mental and physical disorders, e.g., depression and pain, of older adults (2,31). Approximately 30% of the world population are physically inactive (6,32), and a 10% relative reduction of physical inactivity and 15% relative reduction by 2025, and 2030, respectively, are targeted (2,33). While these targets and their strategies are well framed, it seems difficult to achieve by 2025 (6,16). One of the reasons is that there is no sufficient evidence in terms of which factors are associated with PA in areas and populations (e.g., rural, older adults) that tend to have higher risk and prevalence of physical inactivity (34). Numerous studies were conducted to identify neighborhood environmental factors for PA among older adults (17,18). Several neighborhood factors were consistently found to be modifiable factors to promote PA, such as street or city layouts and access to recreational PA facilities (17,18). However, these findings are dominantly from urban areas and whether these factors could be important modifiable factors to promote PA in rural areas is uncertain (35). In fact, some studies did not find consistent associations between these factors and PA in rural areas (20,21,36).

Depressive symptoms

Depression is more prevalent among the older age population and that could lead to major NCDs, suicide, and cognitive decline, which significantly shorten healthy life expectancy (37–41). Social components of the neighborhood environment such as SES and social capital have been found to be associated with depressive symptoms among older adults (42). However, similar to the evidence of PA, there is insufficient evidence especially with respect to physical neighborhood environmental factors in rural areas even though rural residents have a higher risk and prevalence of depressive symptoms (42). Japan’s aging rate is accelerating in rural areas and undulating neighborhoods with hilly terrains are often reported by local older adults as barriers that prevent them from doing daily activities. Walking on slopes every day could cause excessive mechanical load on knees and back for older adults, and that could lead to physical pain or dysfunctions (43). That could undermine the quality of sleep, and subsequently increase the risk of depressive symptoms

(44,45). On the other hand, several studies found that older adults in hilly neighborhoods had a lower risk of diabetes and hypothesized that it is due to the improvement of exercise level and physical function by walking up and down the slopes (46,47). It is, therefore, debatable whether hilliness could be a positive or negative factor for health outcomes among older adults.

Pain

Pain is highly prevalent among the older age population and that could lead to falls, disability and significant loss of healthy life expectancy (48–51). Individual-level risk factors of pain are well reported such as low SES and insufficient PA (52). Although neighborhood SES and pain were studied previously, evidence is relatively scarce compared to other health outcomes (53,54). In particular, few studies have investigated neighborhood environment and pain among the older adult population who could be representative of the general population. As old age is one of the strongest biological risk factors for pain and older adults spend considerable time within their neighborhoods, it is important to advance research investigating neighborhood environment and pain among older adults so that population level prevention and management of pain would be possible (55–57).

Given these backgrounds, the thesis investigated neighborhood environmental factors and NCDs and related outcomes in different settings to fill each of the research gaps.

Aims

The specific aims of each study were as follows:

Our first paper aimed to investigate whether modifiable neighborhood environmental factors, i.e., availability of FF outlets and PA facilities were associated with obesity among Swedish adults. As aforementioned, those were strongly associated with obesity among UK and US adults and indicated that increasing accessibility to PA facilities be health promoting way would significantly reduce the risk of obesity. Furthermore, decreasing access to FF outlets will also reduce the risk of obesity. This paper would serve to examine if that could be an effective method to implement in different countries.

Our second paper aimed to investigate neighborhood environmental factors that could be associated with physical inactivity among rural older adults in Japan. The study focused on vulnerable groups, i.e., rural, older adults, who are often more physically inactive due to a lack of PA promoting resources. This paper would contribute to extending the discussion of which neighborhood environmental factors should be considered in rural settings as well as identifying high-risk groups that public health practices should be undertaken.

Our third paper aimed to investigate whether neighborhood environmental factors, specifically hilliness, was associated with depressive symptoms among rural older adults. The focus was again on rural older adults, and hilliness was specifically investigated as it was often reported as a barrier for doing daily activities among older residents in the study setting. On the other hand, several previous studies showed that living in a hilly neighborhood might be protective against type 2 diabetes or physical dysfunction among urban older adults (46,47). This paper would advance the debate of hilliness and whether it is a positive or negative factor for health among older adults and help local public health agencies to identify high-risk areas to intervene in.

Our fourth paper aimed to investigate whether neighborhood SES was associated with pain among older adults in Sweden. Although pain is highly prevalent and one of the top ten factors to deprive our lifetime without disabilities (9), neighborhood research has not been done much outside of clinical settings. Therefore, this paper would serve to identify high-risk areas where clinical and public health practice should be initiated, as well as facilitate more research to identify modifiable neighborhood environmental factors for pain.

Methods

Overview

The thesis work consists of observational studies utilizing Swedish and Japanese healthcare and geographic databases. Table B shows the summary of the methods of each study.

Table B: Summary of methods of each paper.

	Paper I	Paper II	Paper III	Paper IV
Outcomes	Obesity	Physical inactivity	Depressive symptoms	Severe pain
Neighborhood environmental factors	Availability of FF outlets Availability of PA facilities	Hilliness Distance to community center Street connectivity Residential density Bus stop density	Hilliness	Neighborhood SES
Neighborhood units	Small area market statistics (SAMS)	1000 m street network buffer	400 m street network buffer	Small area market statistics (SAMS)
Study design, area, and individuals	Retrospective cohort study Sweden Adults 22-55 years old N = 1,710,055	Retrospective cohort study Three towns in Shimane, Japan Older adults 60+ years old N = 2,211	Cross-sectional study Three towns in Shimane, Japan Older adults 65+ years old N = 935	Serial cross-sectional study Sweden Older adults 65+ years old N = 11,685
Major data source	Total population Register Swedish Hospital Discharge and Outpatient Register	Health and lifestyle survey (Shimane CoHRE) Annual health checkup	Health and lifestyle survey (Shimane CoHRE) Annual health checkup	Total population Register Living condition survey data
Covariates	Sex Age Marital status Family income Education Immigration Occupation Neighborhood deprivation	Sex Age Smoking Drinking BMI Musculoskeletal disorders Residential towns	Sex Age Smoking Drinking BMI Low back pain Education Residential towns Sleep quality PA Sedentary time	Sex Age Marital status Family income Education Country of birth Smoking BMI PA Survey year

Outcome

The outcome obesity was defined based on International Classification Disease Code (ICD-10) E65 and E66 which are a main or secondary diagnosis of obesity registered in the Swedish Hospital Discharge and Outpatient registers.

Neighborhood environmental factors

Neighborhood availability of FF outlets and PA facilities were defined as available or not available if one or more outlets or facilities were within the neighborhood units SAMS (58). SAMS is one of the most used neighborhood units in previous studies in Sweden, and there are 9,617 units with an average of 1,000 residents across the country (59–61). The data of FF outlets e.g., pizzerias and hamburger joints, and PA facilities, e.g., gyms, swimming pools and ski facilities were provided by the Swedish company Teleadress-Bisnode which created and administered geographical coordinates of services and resources across Sweden as of 2005. In the geographical information system (GIS), neighborhood availability of FF outlets and PA facilities in each SAMS were measured.

Study design

The study was designed as a retrospective cohort study with the time period between 2005 and 2015. Those who were diagnosed as obese between 2003 and 2005 were excluded to reduce the bias of reverse causality (n=3,220). That resulted in 1,710,055 adults who were between 22 and 55 years old living in Sweden.

Statistical analysis

Cox proportional hazard regression was used to examine the risk of obesity by neighborhood availability of FF outlets and PA facilities separately for women and men. Follow-up time (person-years) were calculated by censoring the first registration of obesity diagnosis, i.e., incidence of obesity, moving away from Sweden, or death during the study period. Hazard ratio (HR) and 95% confidence interval (95% CI) were estimated for the incidence of obesity by the neighborhood availability of FF outlets and PA facilities, respectively. Covariates to be adjusted in the regression model were age (birth year), marital status (married or not married/divorced/widowed), family income (low, middle-low, middle high, or high), educational attainment (<9, 10-12, or >12 years), immigration status (born in Sweden or other countries) and occupation (farmers/self-employed/others, professionals, white-collar workers, or blue-collar workers), which were derived from the Total Population Register. Neighborhood deprivation index (NDI) was also adjusted in the model that was constructed from the 2005 census data. The proportion of four deprivation indicators, i.e., low income, unemployment, low educational status and social welfare recipient status among the socioeconomically active age group (25-64 years old) were measured and standardized as z-score with the mean zero and standard deviation (SD) one for each SAMS. Those z-scores were then summed to make NDI for each SAMS. Low income was defined as those measured based on all-source incomes including interest and dividends, and less than 50% of individuals with median income. Unemployment was namely, not employed, except for those who were enrolled in full-time study, compulsory military services as well as those who were retired from work. Low educational status was defined as those with less than 10 years of education. NDI for each SAMS was then defined as low if the z-score was below one SD from the mean, moderate if the z-score was within one SD of the mean, and high if the z-score was above one SD from the mean (61,62).

Sensitivity analysis was conducted by recategorizing the availability of FF outlets and PA facilities into seven categories in order to assess the dose-response relationship.

Paper II

Outcome

The outcome physical inactivity was defined based on the response to the standardized health checkup questionnaire in Japan by the Ministry of Health, Labor and Welfare which was validated in a previous study (63). Those who responded “yes” to the question “Is walking or equivalent physical activity performed in your daily life for 60 minutes or more per day?” were coded as physically active. When the response changed to “no” over the study period, it was regarded as the incidence of being physically inactive.

Neighborhood environmental factors

Neighborhood environmental factors were measured by GIS within 1,000 meters (m) street network buffer of each study individual’s residential address which was a commonly used buffer size in previous studies (64). Hilliness was measured by mean land slope, the unit of degrees in angle, administered in the 50 m squared grid cells by the National Spatial Planning and Regional Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism of Japan (65). The grid cells’ polygon data were overlayed with the 1,000 m network buffer of each individual, and aggregated mean of land slope value was calculated for each individual. This method was used in previous studies and hilliness was found to be associated with type 2 diabetes and physical activity (46,66). Bus stop density was measured by the number of bus stops. Bus stop data were obtained from the Detailed Map, ArcGIS data collection that were stored as a point location by Esri corporation, Japan (67). The point location of bus stops was overlayed with the network buffer of each individual, and the aggregated sum of bus stops was calculated for each individual. Intersection density was measured by the number of intersections with three or more legs. Intersection data (point data) were obtained from the Street Network, Arc GIS data collection (67). The aggregated sum of intersections was calculated for each individual in the same way as bus stop density. Residential density was measured by the number of households. Household data were obtained from the Arc GIS data collection that were stored as the aggregated number of households within the smallest Japanese census areas (67). The sum of households was calculated in the same way as bus stop density and intersection density. Bus stop density, intersection density and residential density, which were measured using the same or similar methods, were found to be associated with physical activity among older adults (17,18). Distance to a community center was measured by physical distance along with the actual street network from a residential address point to a community center within the resident's district. Community center data were obtained from the National Land Numerical Information, administered as a point location by the National Spatial Planning and Regional Policy Bureau of Japan (65). For each individual residential address point, the distance to one community center was calculated. Community centers monitor and aim to maintain the health and well-being of residents by providing various activities and meetings. Community centers were found to be a health-promoting place for older adults in a previous study (68).

Study design

The study was designed as a retrospective cohort study. The time-period was between 2010 and 2019. Those who participated in the health and lifestyle survey along with the annual health checkup at least twice between 2010 and 2019 were included. In Japan, an annual free health checkup is provided at healthcare centers (e.g., hospitals, clinics), employers, or municipalities. For those who are retired or self-employed, participation is voluntary in the municipalities administered health checkup and is recommended from 40 years old onwards. The Center for Community-based Healthcare Research and Education (CoHRE) at Shimane University collaborated with three municipalities, i.e., Unnan City, Ohnan town and Okinoshima town in Shimane Prefecture (Figure C-F), and conducted an additional survey regarding health and lifestyle at the annual health checkup sites. This is known as the Shimane CoHRE Study that aims for the detection and prevention of NCDs by a health and lifestyle survey by linking with geographic information of the residents. The first participation in the Shimane CoHRE Study was defined as baseline for each participant and those who were physically inactive at the baseline were excluded from the analysis. Those with missing data in covariates, i.e., musculoskeletal disorders, n=17; hilliness, n=27 were further excluded. That resulted in 2,211 older adults aged 60 years or more (Figure G).

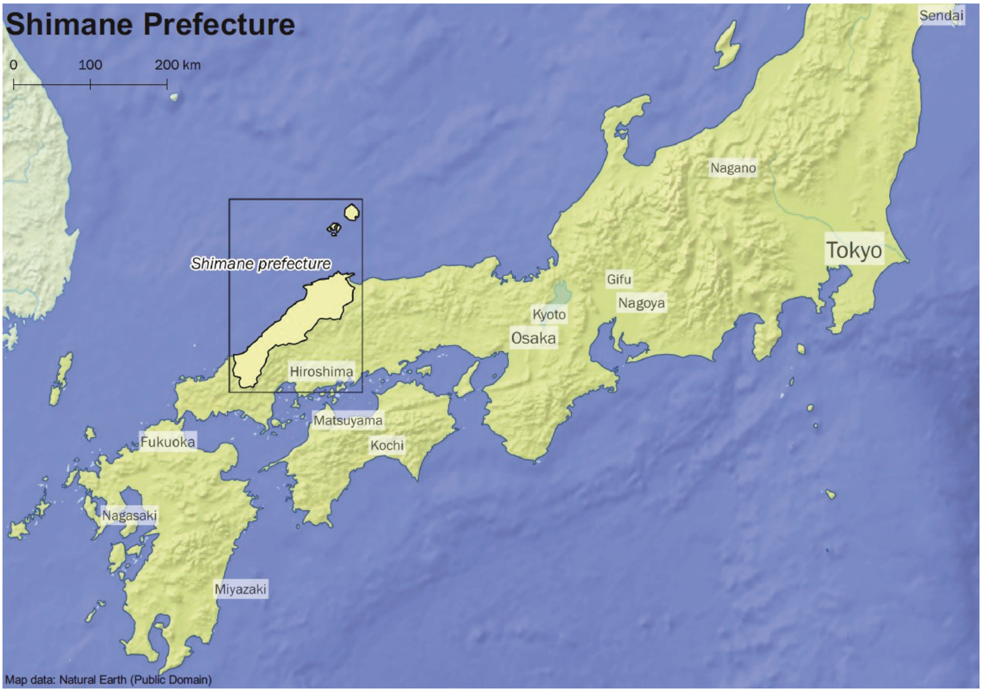

Figure C: Shimane Prefecture in Japan

(Made with Natural Earth. Free vector and raster map data. Available from: https://www.naturalearthdata.com/about/terms-of-use/)

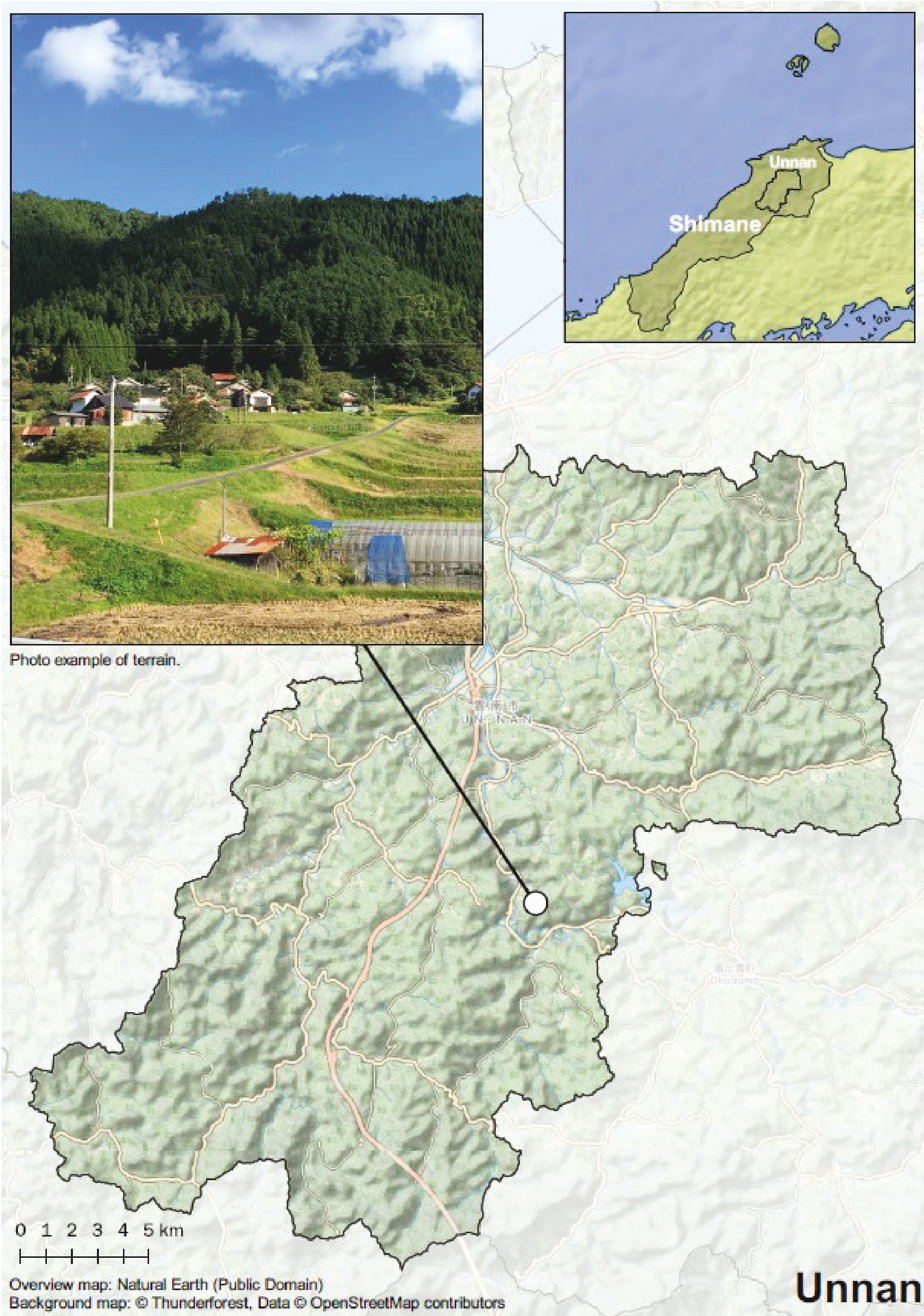

Figure D: Unnan city in Shimane prefecture

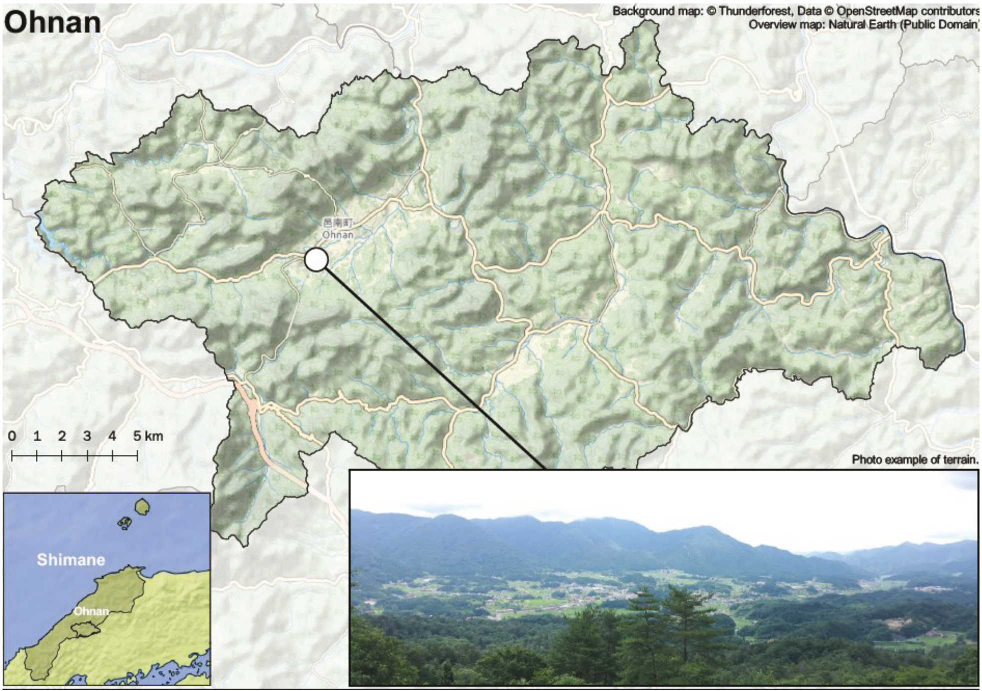

Figure E: Ohnan town in Shimane prefecture

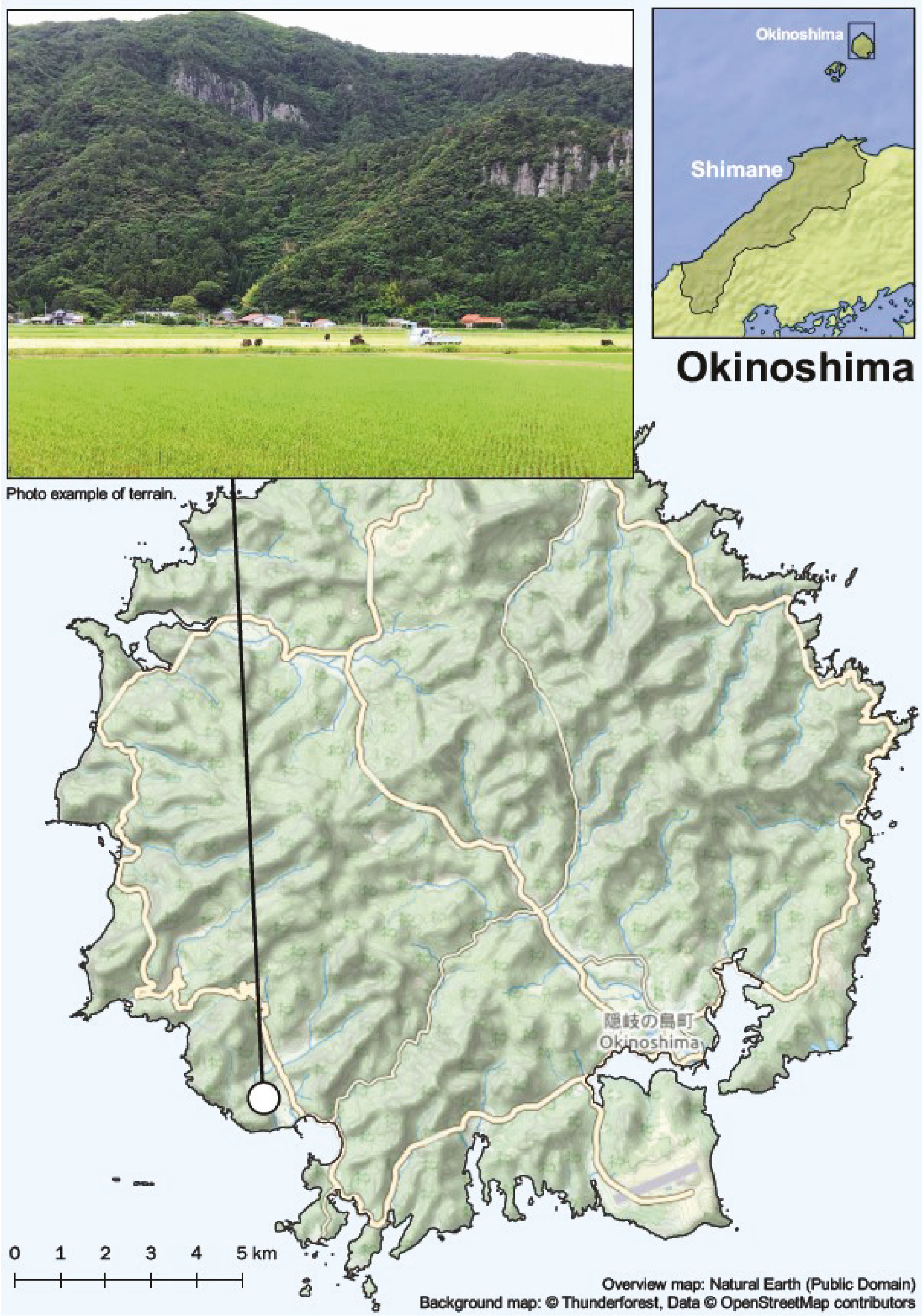

Figure F: Okinoshima town in Shimane prefecture

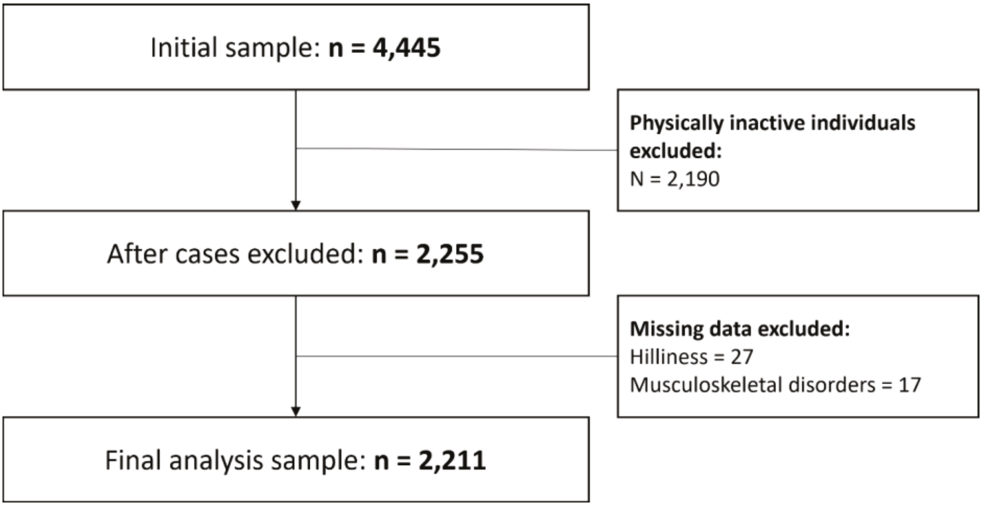

Figure G: Number of study individuals included in the study

Statistical analysis

Cox proportional hazard regression was used to examine the risk of physical inactivity by each neighborhood environmental factor. Follow-up time (person-years) was calculated by censoring the first record of the response indicating physical inactivity status and loss of follow-up during the study period. HR and 95% CI were estimated for physical inactivity by each neighborhood environmental factor in order to avoid multicollinearity across neighborhood factors. Covariates to be adjusted in the regression model were sex (male or female), age (60-69, 70-79, or 80+), smoking (yes or no), drinking (yes, occasionally, or no), BMI (continuous, based on height and weight measured at checkup), musculoskeletal disorders (yes or no) and residential municipalities, which were all measured or collected at the checkup and survey. After the overall analysis, stratified analysis was conducted by residential municipalities. Furthermore, stratified analysis by age (60-74 and 75+ years old) was conducted for each residential municipality. The age of 75 years old was used because this is a transition phase of health insurance type in Japan, which provides different services, as well as the age when older adults tend to decrease their PA and physical function (69–72).

Paper III

Outcome

The outcome depressive symptoms were defined based on the Zung Self-Rating Depression Scale (SDS). SDS is the validated questionnaire which consists of 20 questions to assess depressive symptoms (73). Each question is answered from scores 1 to 4, and the total score ranges from 20 to 80. A higher score indicates severe depressive symptoms, and SDS score >= 40 was defined as the presence of depressive symptoms in alignment with previous studies (74).

Neighborhood environmental factors

Neighborhood environmental factors, i.e., hilliness was measured by GIS within a 400m street network buffer of each study individual's residential address, which was another commonly used buffer size in previous studies (75). Hilliness was measured in the same way as that of Paper II.

Study design

The study was a cross-sectional study. The data were from 2012 when Shimane CoHRE investigated SES and lifestyles thoroughly by monitoring variables such as educational attainment, physical activity and sedentary behavior among residents in three municipalities in Shimane. Those with missing data, i.e., SDS, n=19; physical activity and sedentary time=93; lower back pain, n=2; years of education, n=495; GIS coordinates, n=7; were excluded. That resulted in a total of 935 older adults aged 65 years or more.

Statistical analysis

Binary logistic regression was used to examine the risk of depressive symptoms by neighborhood hilliness. Odds ratio (OR) and 95% CI were estimated for depressive symptoms by a continuous measure of neighborhood hilliness, i.e., land slope in degree. Covariates to be adjusted in the regression model were sex (male or female), age (65-74 or 75+), smoking (yes or no), drinking (yes, or no), BMI (<18.5, 18.5-22.9 or >=23), low back pain (yes or no), education (<12 or >=12), residential town, getting enough sleep (yes or no), moderate or vigorous physical activity (MVPA, <150 minutes or >=150 minutes per week) and sedentary time (ST, <3 hours or >= 3 hours per day).

MVPA and ST were measured by the validated short version of the International Physical Activity Questionnaire (IPAQ) (76,77). The category of MVPA was based on the current international PA recommendations (78,79). The category of ST was based on the median value of the study individuals.

Sensitivity analysis was conducted by categorizing the land slope into quartiles.

Paper IV

Outcome

The outcome severe pain was defined based on the response to the questions regarding pain in back, hip, neck, shoulder, arms, hands, legs or feet that were asked in the Statistics on Income and Living Conditions (EU-SILC) survey. Those who responded “yes” to the question: “Do you suffer from pain, ache in back or hip?” (same question for the other parts of the body) and then responded “severe” to the follow-up question: “Would you say the ailments are severe or mild?” were regarded as those with severe pain. Severe pain was chosen as the outcome because it has a higher relevance in clinical practice. In addition, it is less susceptible to individual perceptions.

Neighborhood environmental factors

Neighborhood SES (low, medium or high) was defined for each SAMS based on NDI that was constructed in the same way as Paper I. For ease of interpretation, NDI was rephrased as low neighborhood SES when NDI is high, and high neighborhood SES when NDI is low.

Study design

The study was a cross-sectional study and the data were from 2008 to 2013 when EU-SILC collected the status of pain data in a consistent manner. EU-SILC is the survey conducted by Statistics Sweden to keep track of the health and living conditions of residents in Sweden (80). The survey is conducted annually for a randomly chosen sample of the Swedish population between 16 and 84 years old. Cross-sectional surveys of the year between 2008 and 2013 were pooled and used in the study. Those with missing data, i.e., pain, n=440; neighborhood SES, n=134; education, n=50; BMI, n=118; exercise, n=21 and those with non-response data, i.e., pain, n=7; exercise, n=8, and those with outlier, i.e., BMI, n=193 were excluded. That resulted in a total of 11,685 older adults aged 65 years or more (Figure H).

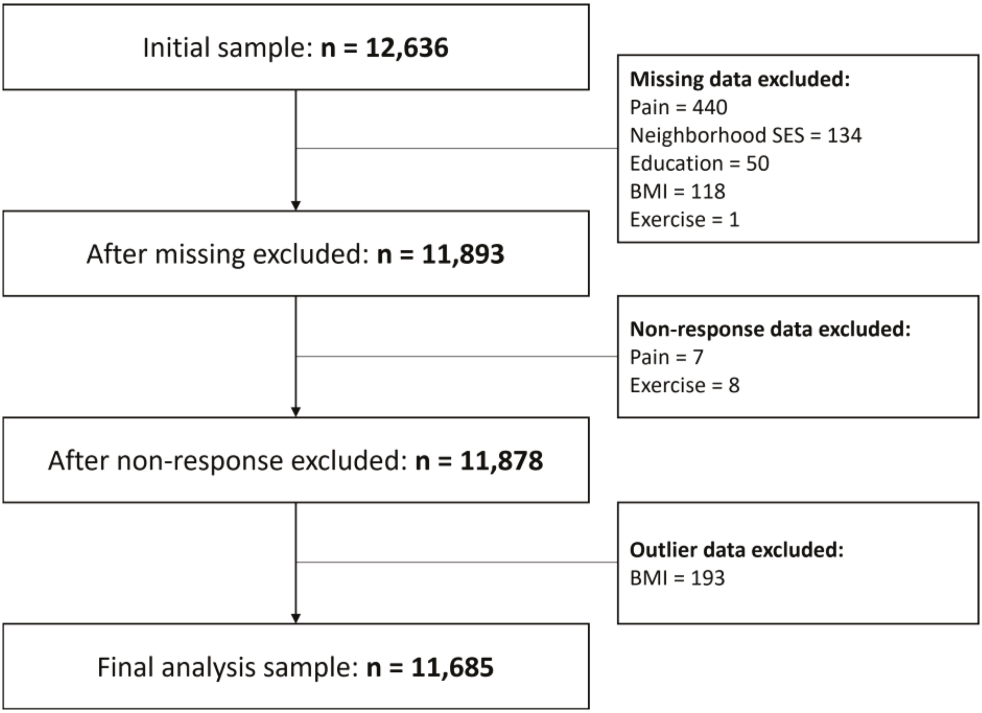

Figure H: Number of study individuals included in the study

Statistical analysis

Binary logistic regression was used to examine the risk of severe pain by neighborhood SES. OR and 95% CI were estimated for severe pain by three categories of neighborhood SES (low, medium or high). Covariates to be adjusted in the regression model were sex (male or female), age (65-69, 70-74, 75-79 or 80-84 years), marital status (married/cohabiting or single living), family income (high, medium or low), education (<10 or >=10 years), country of birth (Sweden or foreign), smoking (never or former/current), BMI (continuous, based on self-reported height and weight), exercise (basically never/a little now and then or once a week/more) and survey year. Sex, age, marital status, family income, education and country of birth were derived from the Total Population Register in the same way as Paper I. Smoking, BMI and exercise were derived from EU-SILC data.

Covariates were included in the analysis models step-by-step. Individual behavioral and health characteristics, i.e., smoking, exercise and BMI, were added in the final model as those were assumed more as mediators between neighborhood SES and pain.

In order to adjust for potential residual confounding across neighborhoods, i.e., SAMS, a multilevel analysis model was considered. However, there were not enough study individuals in each SAMS to effectively apply multilevel analysis. Of the 4,946 SAMS in the study, 2,162 (43.6%) of SAMS had only one individual and 1,242 (25.0%) of SAMS had two individuals. A between-group variance was calculated although the value was negligibly small, i.e., 1.49×10^{-30}. In addition, the log-likelihood ratio test was conducted between the models with and without multilevel structure, but the result indicated that the multilevel model does not improve the model (chi-square value: 0.00).

Ethical considerations

Paper I and IV

The studies utilized national register and survey data which were administered with high integrity by Swedish authorities. For the national survey, participants were informed about how the data would be used in the survey and participation in the survey was deemed as indirect consent. For the national register, the use of data was advertised in newspapers so that people could opt-out. The studies were approved by the Regional Ethical Review Board in Lund.

Paper II and III

The studies were approved by the Ethics Committee of Shimane University (Reference number; Paper II: 3912, Paper III: 2888), Japan. A detailed explanation of the study was given to all individuals participating in the survey and written informed consent was obtained from all study participants prior to the study. All data were collected and administered anonymously. All data analyses, e.g., using geographic location of study individuals, were conducted using the highly secured computer at the Center for Community-based Healthcare Research and Education at Shimane University, Japan. No analyses were conducted in Sweden on paper II and III.

Results

Paper I

Table 1-1 shows the baseline characteristics and obesity events of study individuals. The cumulative incidence of obesity was higher among those who live in neighborhoods with high deprivation (26.7 per 1000) compared to moderate and low deprivation (18.8 and 11.8, respectively). The trend was consistent, i.e., cumulative incidence of obesity was highest among those who lived in neighborhoods with high deprivation across all individual characteristics.

Table 1-1: Baseline characteristics of study individuals, the number and proportion of obesity events by characteristics, and cumulative incidence (per 1000 individuals) of obesity by neighborhood deprivation level and characteristics.

	Population		**Obesity events**		**Neighborhood deprivation**		
	N	%	N	%	Low	Moderate	High
Total population	1710055				334049 (19.5%)	1138652 (66.6%)	237254 (13.9%)
						Cumulative incidence (per 1000 individuals)	
Total cases of obesity			31671		11.8	18.8	26.7
Birth year							
1950-59	429266	25.1	6163	19.5	10.6	14.7	18.8
1960-69	616733	36.1	12537	39.6	12.5	20.9	31.0
1970-79	537207	31.4	11067	34.9	12.7	20.6	29.4
1980-85	126849	7.4	1904	6.0	7.3	14.2	21.7
Gender							
Males	1167449	68.3	14488	45.7	8.3	12.7	16.5
Females	542606	31.7	17183	54.3	18.3	32.5	48.2
Marital status							
Married	708621	41.4	12731	40.2	11.2	18.9	29.1
Not married/divorced/widowed	1001434	58.6	18940	59.8	12.5	18.7	25.8
Family income							
Low	426911	25.0	9293	29.3	13.2	22.0	27.8
Middle low	426975	25.0	8444	26.7	13.3	19.7	28.5
Middle high	426776	25.0	7627	24.1	11.6	18.0	26.9
High	429393	25.1	6307	19.9	10.0	15.4	22.0
Educational level							
≤ 9 years	196460	11.5	5134	16.2	18.6	24.7	35.0
10-12 years	533828	31.2	12165	38.4	15.7	22.7	31.2
> 12 years	979767	57.3	14372	45.4	9.7	15.2	21.3
Immigration status							
Born in Sweden	1604249	93.8	28978	91.5	11.5	18.5	26.0
Born in other countries	105806	6.2	2693	8.5	18.1	23.6	30.6
Occupation							
Farmers/self-employed/others	774190	45.3	14865	46.9	11.7	19.0	27.3
Professionals	72395	4.2	638	2.0	6.5	10.0	11.9
White collar workers	271924	15.9	3505	11.1	9.2	13.7	20.1
Blue collar workers	591546	34.6	12663	40.0	15.4	21.5	28.4
FF outlets							
Not accessible	1006925	58.9	18844	59.5	12.1	19.4	27.6
Accessible	703130	41.1	12827	40.5	11.0	18.0	25.9
PA facilities							
Not accessible	1031015	60.3	19265	60.8	11.8	19.0	27.1
Accessible	679040	39.7	12406	39.2	11.8	18.6	25.9

Table 1-2 shows the association between neighborhood availability of FF outlets, PA facilities and incidence of obesity among women and men. Except for a weak association between the availability of fast food and obesity among women (Table 1-2: HR: 0.95, CI: 0.92, 0,98), no significant association was observed.

Table 1-2: Association between neighborhood availability of fast food (FF) outlets or physical activity (PA) facilities and obesity among Women and Men.

	Women						Men					
	FF outlets			PA facilities			FF outlets			PA facilities		
	HR	95% CI		HR	95% CI		HR	95% CI		HR	95% CI	
FF outlets (ref. Non)	0.95	0.92	0.98				0.98	0.95	1.01			
PA facilities (ref. Non)				0.98	0.95	1.01				0.99	0.95	1.02
Birth year	1.04	1.04	1.04	1.04	1.04	1.04	0.98	0.98	0.99	0.98	0.98	0.99
Marital status (ref. Married)	1.09	1.05	1.12	1.09	1.05	1.12	1.23	1.19	1.28	1.23	1.19	1.28
Family income (ref. High)												
Low	1.14	1.09	1.20	1.14	1.09	1.20	1.26	1.20	1.32	1.26	1.20	1.32
Middle low	1.06	1.02	1.11	1.06	1.02	1.12	1.25	1.19	1.31	1.25	1.19	1.31
Middle high	1.11	1.06	1.16	1.11	1.06	1.16	1.07	1.02	1.13	1.07	1.02	1.13
Education (ref. > 12 years)												
≤ 9 years	1.68	1.60	1.76	1.68	1.60	1.76	1.84	1.74	1.93	1.84	1.75	1.93
10-12 years	1.46	1.41	1.51	1.46	1.41	1.51	1.74	1.67	1.82	1.75	1.67	1.82
Immigration status (ref. Born in Sweden)	0.77	0.74	0.81	0.77	0.73	0.81	1.10	1.01	1.20	1.10	1.01	1.20
Occupation (ref. Professionals)												
Farmers/self-employed/others	1.66	1.43	1.92	1.66	1.43	1.92	1.17	1.05	1.29	1.17	1.05	1.29
White collar workers	1.14	0.98	1.32	1.14	0.98	1.32	1.05	0.95	1.17	1.05	0.95	1.17
Blue collar workers	1.78	1.54	2.07	1.79	1.54	2.07	1.22	1.11	1.36	1.23	1.11	1.36
Neighborhood deprivation (ref. Low)												
Moderate	1.56	1.48	1.63	1.55	1.48	1.62	1.36	1.29	1.43	1.36	1.29	1.43
High	2.09	1.98	2.21	2.07	1.96	2.19	1.73	1.63	1.84	1.73	1.63	1.84

Table App 1-1 shows the result of a sensitivity analysis when neighborhood availability of FF outlets and PA facilities were categorized into seven categories. While there was no significant association among men, the risk of obesity was significantly lower among women living in neighborhoods with seven or more FF outlets (HR: 0.83, 95% CI: 0.73, 0.95) and in neighborhoods with six, seven or more PA facilities (HR: 0.73, 95% CI: 0.60, 0.89, and HR: 0.83, 95% CI: 0.72, 0.96, respectively).

Paper II

Table 2-1 shows the baseline characteristics of study individuals by the status of becoming physically inactive. Among 2,211 individuals, a total of 994 (45.0%) of them became physically inactive over time. There was a higher proportion of the oldest age category (80+) among those who sustained PA compared to those who became physically inactive (9.1 and 3.9%, respectively).

Table 2-1: Baseline characteristics of study individuals by the status of becoming physically inactive

Variables	**Became physically inactive**	
	No (%)	**Yes** (%)
N	1217	994
Gender		
Male	520 (42.7)	424 (42.7)
Female	697 (57.3)	570 (57.3)
Age		
60-69	538 (44.2)	521 (52.4)
70-79	568 (46.7)	434 (43.7)
80+	111 (9.1)	39 (3.9)
Municipality of residence		
Unnan	482 (39.6)	481 (48.4)
Oki	379 (31.1)	189 (19.0)
Onan	356 (29.3)	324 (32.6)
Smoking		
Yes	86 (7.1)	88 (8.9)
No	1131 (92.9)	906 (91.1)
Drinking		
Yes	320 (26.3)	278 (28.0)
Occasionally	238 (19.6)	213 (21.4)
No	659 (54.1)	503 (50.6)
BMI (mean (SD))	22.4 (2.8)	22.4 (3.0)
Musculoskeletal disorders		
Yes	213 (17.5)	164 (16.5)
No	1004 (82.5)	830 (83.5)

Figure 2-1 shows the association between distance to a community center and physical inactivity among those who live in Ohnan town. Older adults who live far from a community center had a lower risk of becoming physically inactive (HR: 0.66, 95% CI: 0.47, 0.93) in Ohnan town.

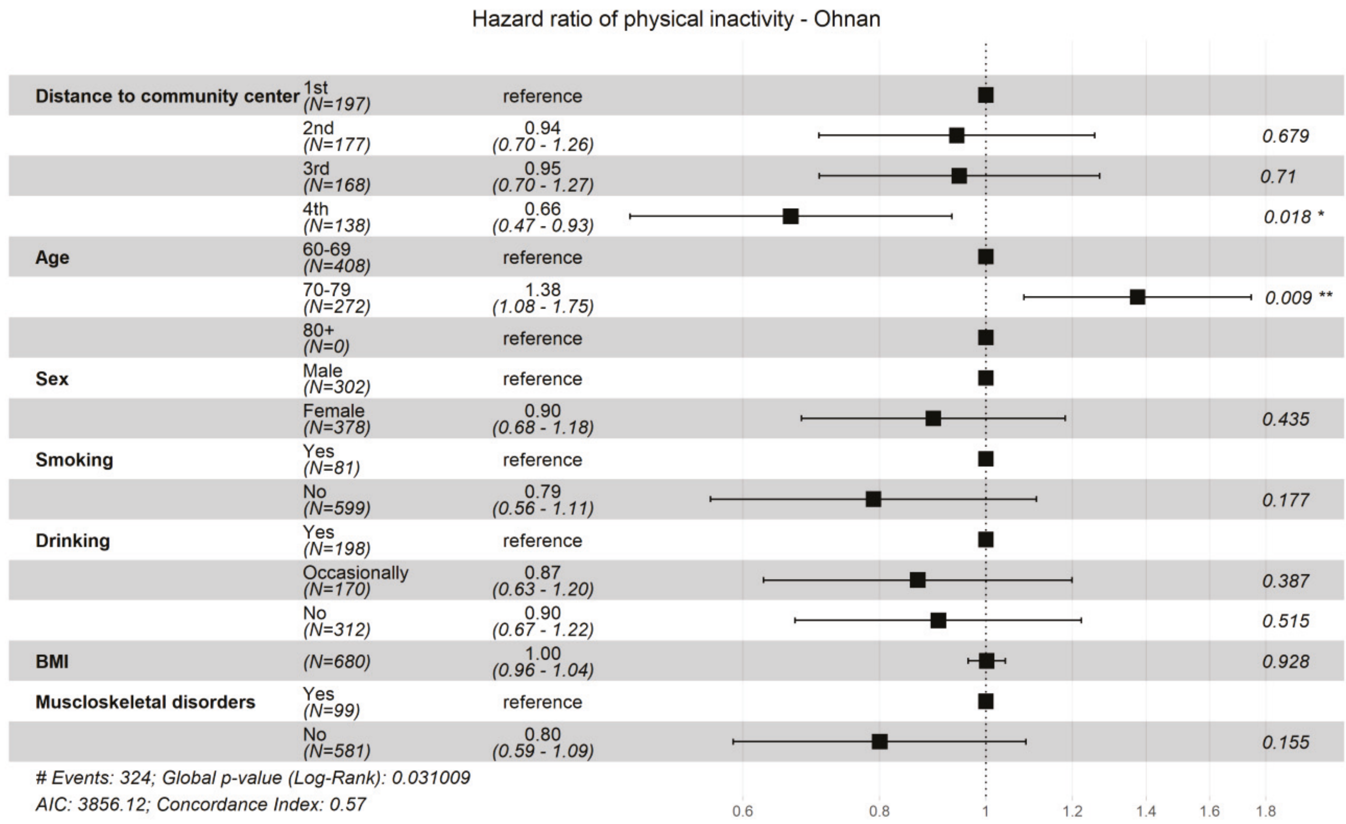

Figure 2-1: Association between distance to a community center and physical inactivity adjusted for covariates for those living in Ohnan town (Notes: There were 0 individuals aged over 80 years old and therefore, it is shown as reference, but that was not used in the analysis)

Figure 2-2 shows the association between hilliness and physical inactivity among those who live in Okinoshima town. Older adults living in hilly areas had a higher risk of becoming physically inactive (2nd quartile's HR: 1.55, 95% CI: 1.01, 2.4, and 3rd quartile's HR: 1.66, 95% CI: 1.08, 2.5) in Okinoshima town.

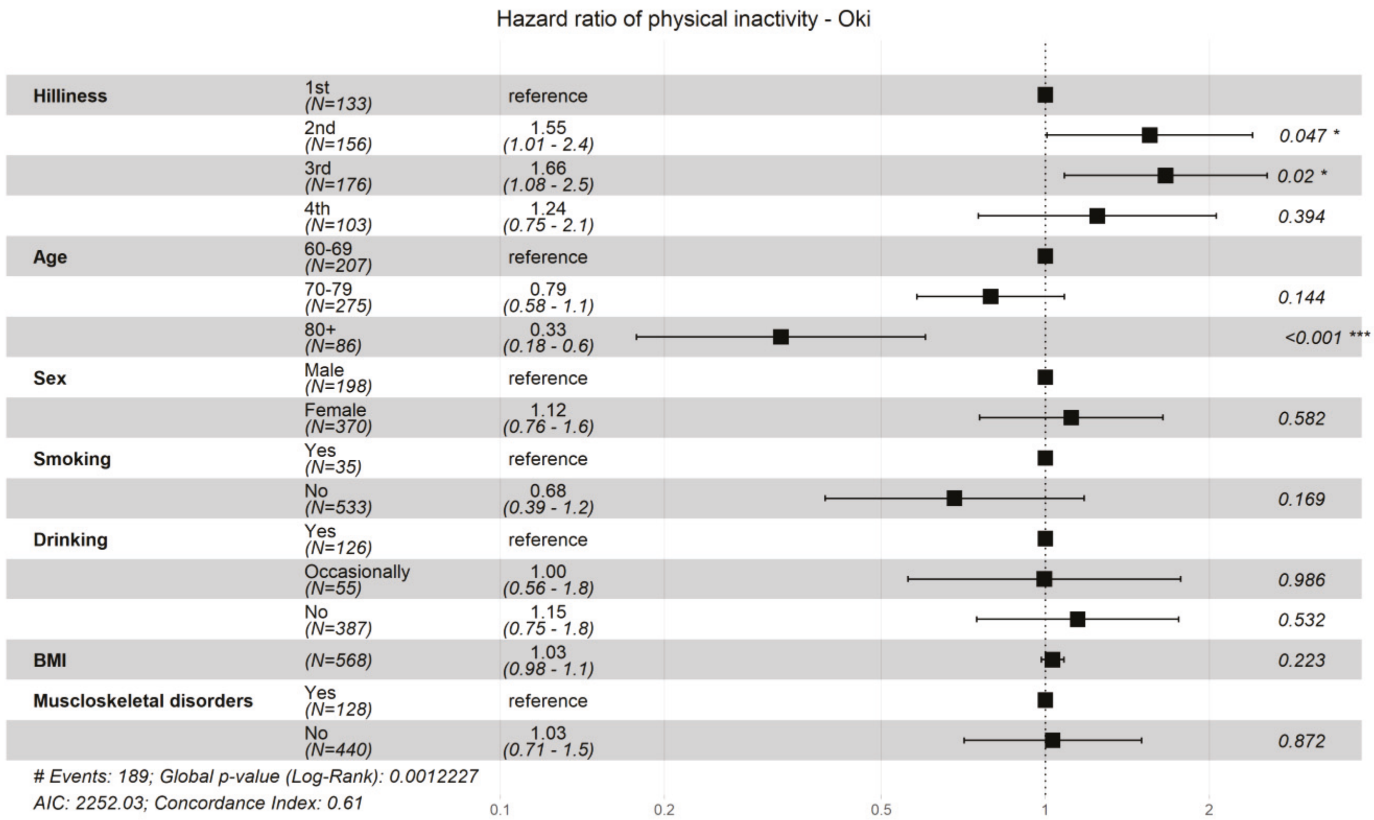

Figure 2-2: Association between hilliness and physical inactivity adjusted for covariates for those living in Okinoshima town

Table App 2-1 shows the results of the overall analysis before stratifying by residential municipalities. In model 2, before adjusting for residential municipalities, older adults who lived in neighborhoods with more bus stops had a higher risk of physical inactivity (3rd quartile's HR: 1.18, 95% CI: 1.01, 1.36) and those who lived far from a community center had a lower risk of physical inactivity (4th quartile's HR: 0.75, 95% CI: 0.57, 0.93).

Table App 2-2 shows a sensitivity analysis by stratifying the individuals further at the age of 75 years old. In Okinoshima town, older adults aged 60-74 years who live in hilly neighborhoods had a higher risk of becoming physically inactive (2nd quartile's HR: 1.55, 95% CI: 1.08, 2.02, and 3rd quartile's HR: 1.74, 95% CI: 1.27, 2.21). However, those in the hilliest neighborhoods did not have an increased risk of physical inactivity (4th quartile's HR: 0.89, 95% CI: 0.27, 1.50). In contrast, older adults aged more than 75 years who lived in the hilliest neighborhoods had a higher risk of physical inactivity (4th quartile's HR: 3.13, 95% CI: 2.09, 4.16).

Paper III

Table 3-1 shows the characteristics of study individuals by total and depressive symptoms. Among 935 individuals, there were 215 (23.0%) individuals who had depressive symptoms. Those who were without enough sleep had a higher proportion of depressive symptoms compared to those with enough sleep (46.2 and 17.2 % respectively). Those with low back pain had a higher proportion of depressive symptoms compared to those without lower back pain (28.6 and 17.8 % respectively). The land slope value was higher among those with depressive symptoms compared to those without depressive symptoms (10.49 and 8.84 degrees respectively).

Table 3-1: Characteristics of study individuals by total and depressive symptoms

Variables	Total	No Depressive Symptoms	Depressive Symptoms	*p*-value
***n* (%)**	**935**	**720 (77.0)**	**215 (23.0)**	
Sex				
Male	360 (38.5)	276 (76.7)	84 (23.3)	0.85
Female	575 (61.5)	444 (77.2)	131 (22.8)	
Age				
65–74 years old	718 (76.8)	552 (76.9)	166 (23.1)	0.87
≥75 years old	217 (23.2)	168 (77.4)	49 (22.6)	
Body mass index (Asian cut-off)				
Underweight, <18.5 kg/m^2	69 (7.4)	51 (73.9)	18 (26.1)	0.44
Normal weight, 18.5–22.9 kg/m^2	502 (53.7)	381 (75.9)	121 (24.1)	
Overweight, ≥23.0 kg/m^2	364 (38.9)	288 (79.1)	76 (20.9)	
Current smoking				
No	874 (93.5)	675 (77.2)	199 (22.8)	0.54
Yes	61 (6.5)	45 (73.8)	16 (26.2)	
Current alcohol drinking				
No	505 (54.0)	389 (77.0)	116 (23.0)	0.99
Yes	430 (46.0)	331 (77.0)	99 (23.0)	
Physical activity				
≥150 min/week	795 (85.0)	615 (77.4)	180 (22.6)	0.54
<150 min/week	140 (15.0)	105 (75.0)	35 (25.0)	
Sedentary time				
<3 h/day	388 (41.5)	297 (76.5)	91 (23.5)	0.78
≥3 h/day	547 (58.5)	423 (77.3)	124 (22.7)	
Getting enough sleep				
Yes	749 (80.1)	620 (82.8)	129 (17.2)	**<0.01**
No	186 (19.9)	100 (53.8)	86 (46.2)	
Low back pain				
No	488 (52.2)	401 (82.2)	87 (17.8)	**<0.01**
Yes	447 (47.8)	319 (71.4)	128 (28.6)	
Educational years				
≥12 years	375 (40.1)	284 (75.7)	91 (24.3)	0.45
<12 years	560 (59.9)	436 (77.9)	124 (22.1)	
Municipality of residence				
Okinoshima town	114 (12.2)	92 (80.7)	22 (19.3)	0.06
Unnan city	365 (39.0)	292 (80.0)	73 (20.0)	
Ohnan town	456 (48.8)	336 (73.7)	120 (26.3)	
Land slope, degree, median (IQR)	9.19 (5.89, 12.65)	8.84 (5.71, 12.47)	10.49 (6.50, 16.94)	**0.01**

Table 3-2 shows the association between hilliness and depressive symptoms. Those who lived in hilly neighborhoods had higher odds of having depressive symptoms (OR: 1.04, 95% CI: 1.01, 1.08). There were 1.04 times increased odds of depressive symptoms by every one degree of land slope. Older adults without enough sleep had 4.24 times higher odds of depressive symptoms than those with enough sleep (OR: 4.24, 95% CI: 2.94, 6.13). Older adults with low back pain had 1.66 times higher odds of depressive symptoms than those without low back pain (OR: 1.66, 95% CI: 1.19, 2.30).

Table 3-2: Association between neighborhood hilliness (land slope) and depressive symptoms

	Crude model			Adjusted model		
	OR	**95% CI**	***p*-value**	**OR**	**95% CI**	***p*-value**
Land slope	1.04	(1.01, 1.08)	0.01	1.04	(1.01, 1.08)	0.02
Sex (ref Male)						
Female				0.88	(0.60, 1.31)	0.54
Age (ref 65–74)						
≥75				1.55	(0.95, 2.52)	0.08
BMI (ref Normal)						
Underweight				1.19	(0.65, 2.20)	0.58
Overweight				0.81	(0.57, 1.15)	0.24
Smoking (ref No)						
Yes				1.21	(0.64, 2.31)	0.56
Drinking (ref No)						
Yes				0.91	(0.62, 1.33)	0.63
PA (ref ≥150)						
<150				1.01	(0.64, 1.59)	0.96
ST (ref <3)						
≥3				0.95	(0.68, 1.32)	0.74
Sleep (ref Yes)						
No				4.24	(2.94, 6.13)	<0.01
Low back pain (ref No)						
Yes				1.66	(1.19, 2.30)	<0.01
Education (ref ≥12)						
<12 years				0.82	(0.59, 1.14)	0.24
Residential municipalities (ref Okinoshima)						
Unnan				0.75	(0.42, 1.35)	0.34
Ohnan				1.44	(0.78, 2.66)	0.25

Table App 3-1 shows a sensitivity analysis by categorizing land slope into quartiles. Those who live in the hilliest neighborhoods had a higher risk of depressive symptoms (4th quartile's OR: 1.72, 95% CI: 1.08, 2.73).

Paper IV

Table 4-1 shows the characteristics of study individuals by total and neighborhood SES. Among 11,685 individuals, there were 2,883 (24.7%) individuals who had severe pain. The proportion of severe pain was higher among individuals who lived in low SES neighborhoods compared to medium or high SES neighborhoods (30.1, 25.1, and 19.6% respectively). As for individual characteristics, the proportion of older age groups, those with low income, low education, foreign-born, smoking, and no exercise habit was higher in low SES neighborhoods compared to medium or high SES neighborhoods.

Table 4-1: Characteristics of study individuals by total and neighborhood socioeconomic status (SES)

	Neighborhood SES						Total	
	High		Medium		Low			
	No.	%	No.	%	No.	%	No.	%
Pain								
No/Mild	2203	80.4	5248	74.9	1351	69.9	8802	75.3
Severe	538	19.6	1763	25.1	582	30.1	2883	24.7
Year of survey								
2008/2009	776	28.3	2112	30.1	550	28.5	3438	29.4
2010/2011	955	34.8	2437	34.8	691	35.7	4083	34.9
2012/2013	1010	36.8	2462	35.1	692	35.8	4164	35.6
Sex								
Male	1340	48.9	3281	46.8	858	44.4	5479	46.9
Female	1401	51.1	3730	53.2	1075	55.6	6206	53.1
Age								
65-69	1027	37.5	2401	34.2	626	32.4	4054	34.7
70-74	771	28.1	1901	27.1	498	25.8	3170	27.1
75-79	548	20	1523	21.7	447	23.1	2518	21.5
80-84	395	14.4	1186	16.9	362	18.7	1943	16.6
Married/Cohabiting status								
Married/Cohabiting	2594	94.6	6518	93.0	1796	92.9	10908	93.4
Single living	147	5.4	493	7.0	137	7.1	777	6.6
Family income								
High	967	35.3	1392	19.9	222	11.5	2581	22.1
Medium	1229	44.8	3169	45.2	814	42.1	5212	44.6
Low	545	19.9	2450	34.9	897	46.4	3892	33.3
Education								
High (>=10 years)	2082	76	4314	61.5	1105	57.2	7501	64.2
Low (<10 years)	659	24	2697	38.5	828	42.8	4184	35.8
Birth country								
Sweden	2526	92.2	6384	91.1	1665	86.1	10575	90.5
Foreign	215	7.8	627	8.9	268	13.9	1110	9.5

Smoking								
No	2551	93.1	6296	89.8	1652	85.5	10499	89.9
Yes	190	6.9	715	10.2	281	14.5	1186	10.1
Exercise								
A little now and then or basically never	568	20.7	1870	26.7	625	32.3	3063	26.2
About once a week or more	2173	79.3	5141	73.3	1308	67.7	8622	73.8
BMI								
Mean (SD)	25.9	(3.2)	25.5	(3.6)	25.9	(3.9)	26.3	(4.3)
BMI squared								
Mean (SD)	661.8	(192.7)	687.8	(216.4)	708.8	(244.2)	685.2	(216.5)

Table 4-2 shows the association between neighborhood SES and severe pain. Those who live in low SES neighborhoods had higher odds of severe pain than those in high SES neighborhoods after adjusting for all potential confounders and mediators (OR: 1.30, 95% CI: 1.12, 1.50).

Table 4-2: Association between neighborhood socioeconomic status (SES) and severe pain

	Crude model			Sociodemographics adjusted			Full model		
	OR	**95%CI**		**OR**	**95%CI**		**OR**	**95%CI**	
Neighborhood SES (Ref=High)									
Medium	1.38	1.23	1.53	1.21	1.08	1.35	1.15	1.03	1.29
Low (low ses)	1.76	1.54	2.02	1.43	1.24	1.64	1.30	1.12	1.50
Year of survey (Ref=2008/2009)									
2010/2011	0.90	0.81	1.00	0.93	0.84	1.04	0.93	0.83	1.04
2012/2013	0.95	0.85	1.05	1.01	0.91	1.12	1.01	0.90	1.13
Sex (Ref=Male)									
Female	1.72	1.58	1.88	1.61	1.48	1.77	1.70	1.55	1.87
Age (Ref=65-69)									
70-74	1.20	1.07	1.34	1.10	0.98	1.23	1.12	1.00	1.25
75-79	1.36	1.22	1.53	1.15	1.02	1.30	1.17	1.03	1.33
80-84	1.48	1.31	1.67	1.18	1.03	1.34	1.17	1.02	1.35
Married/Cohabiting status(Ref=Married/Cohabiting)									
Single living	1.02	0.87	1.21	0.99	0.83	1.18	1.01	0.85	1.21
Family income (Ref=High)									
Medium	1.73	1.53	1.96	1.51	1.33	1.72	1.45	1.28	1.66
Low	2.33	2.05	2.64	1.72	1.50	1.98	1.56	1.35	1.80
Education (Ref=High)									
Low (<10 years)	1.45	1.33	1.58	1.29	1.18	1.41	1.20	1.09	1.31
Birth country (Ref=Sweden)									
Foreign	1.52	1.33	1.74	1.45	1.27	1.67	1.39	1.21	1.60
Smoking (Ref=No)									
Yes	1.24	1.08	1.42				1.12	0.97	1.29
Exercise (Ref=Never)									
About once a week or more	0.43	0.39	0.47				0.51	0.46	0.56
BMI (continuous)	1.08	1.07	1.09				0.99	0.91	1.08
BMI squared (continuous)	1.00	1.00	1.00				1.00	1.00	1.00

Discussion

Main findings and perspectives

Paper I found that neighborhood availability of fast food and PA facilities were not significant factors for the risk of obesity among the Swedish adult population, which was in contrast to the UK and US findings. Paper II found that rural neighborhood environmental factors, such as hilliness and access to community centers, were associated with the risk of physical inactivity among rural residents, while the association differed between towns with different local hubs of employment, e.g., fishing and farming. Paper III found that hilliness was a risk factor for depressive symptoms among rural older adults while previous studies found a beneficial effect of hilliness on other health outcomes. Paper IV found that those in low SES neighborhoods were at a higher risk of having severe pain in the general representative older adult population in Sweden.

One of the major perspectives from these studies is that neighborhood environmental factors for NCDs and related outcomes vary from place to place. This could be due to the difference in social, cultural and geographic contexts across countries, and even regions or smaller area units. This indicates that modifying or intervening in certain neighborhood environmental factors, which were effective to reduce NCDs in one place, may not be effective in another place. Another perspective is that our findings suggest the idea of which area or population should be targeted for intervention in public health and clinical practices. While the former perspective is a caveat for naïve implementation of environmental or political interventions, the latter is practically useful for public health and clinical practices at both local and national levels.

Neighborhood environment and obesity

Modifying FF outlets and PA facilities may not have much effect to reduce the obesity burden in Sweden. A previous Swedish study found that there were more health-damaging resources such as FF outlets in deprived neighborhoods (62). FF outlets are more available than health-promoting resources such as stores selling healthy groceries in deprived neighborhoods in the US as well (15,29). Although our study did not account for the degree of concentration of FF outlets in deprived neighborhoods, that is assumed to be greater in the US (15,29). As a result, in the US, those unhealthy food options are assumed to become the primary option for people who live in deprived neighborhoods and thus perpetuating their unhealthy diet and lifestyle. In Sweden, FF may not be a primary or affordable food option compared to the US as other options also exist. This indicates that taxation on FF may be an effective way to reduce access to FF, promote a healthier diet and consequently reduce obesity risk. However, there is not yet decisive evidence whether taxation on FF could reduce obesity risk except for certain populations such as those who are severely obese or with low SES (81–83).

The null association between PA facilities and obesity is supported also by the previous findings that such health-promoting resources were more available in deprived neighborhoods in Sweden (62). In addition, the association between neighborhood deprivation and accessibility of PA facilities is unclear or depends on local policies (84,85), e.g., some places initiate plans to increase health- promoting resources in deprived neighborhoods. It is possible that other PA promoting facilities or infrastructure such as sidewalks, bike paths or city layouts are associated with obesity.

Neighborhood environment and PA

Improving street connectivity (intersection density) and public transportation access may not be effective to improve PA of older adults in rural areas. Unlike previous studies in urban areas, higher bus stop density was associated with a higher risk of physical inactivity. Public transportation is encouraged as an active form of transportation to benefit individuals’ health by increasing time to walk or bike between home, destinations and public transit stops (33,86,87). However, it can be difficult for people to use it as a primary mode of transportation in rural or remote settings. In fact, car ownership and driving status were found to be PA promoting factors among rural older adults (88). Furthermore, good access to public transportation was found to be beneficial for PA only for those without driving status in rural areas (89). It may be easier for rural residents to access places where they can engage in PA, such as gyms, parks and nature reserves by driving. Nevertheless, it is important to sustain public transportation systems in rural areas, and if possible, alter transportation modes from driving to other active modes, i.e., walking, biking and public transportation for individuals' health as well as for environmental reasons.

Another contrasting finding in urban areas was the association between access to community centers and PA. In Japan, community centers serve as a place for community residents to interact through various social events, e.g., cooking, crafting, singing, and exercising. Social interaction has been well-reported to be beneficial for PA and many health outcomes among older adults (90). Therefore, good accessibility to community centers was expected to be beneficial for maintaining PA, but the opposite direct association was found. This could be explained by the negative effect of excessive social ties, which sometimes require obligatory roles or participation in community events, which can lead to a psychological burden among community residents (91). On the other hand, it is possible that those who live far away from community centers had more active social activities within the smaller units of residence communities to compensate for their remoteness.

Neighborhood hilliness was associated with the risk of physical inactivity among the residents in Okinoshima town only. It is interesting to contrast this finding to the local lifestyles of each town; the fishing industry is the main source of employment in Okinoshima town while it is crop farming in Unnan and Ohnan towns. Many older adults engage in farming in Unnan and Ohnan towns and farming fields are often located in hilly terrains. The findings from the previous study indicate that perception towards neighborhood hilliness could vary depending on how much people are used to such terrain through their daily lifestyles (92). Residents in Unnan and Ohan towns may not be affected by hilly terrains as much as those living in Okinoshima town. Additionally, the risk of physical inactivity was highest among residents aged 75 or more years old living in the hilliest neighborhoods in Okinoshima town. This could be because the majority of individuals stop working after this age (general retirement age is 60-65 years old) and perceive hilly terrains as greater barriers.

However, hilliness was often reported as a barrier for older adults to go out or exercise when we were interviewing the residents in all three towns. While previous studies reported that hilly neighborhoods accompanied by hiking trails and beautiful outlooks could encourage rural residents to be more active (93), the residents may perceive the hilliness as a barrier that causes physical exertion (94). Whether neighborhood hilliness is a health-promoting or damaging factor is debatable since some studies found that it was a risk factor for weight gain and physical inactivity (66,95) and other studies found that it was a health-promoting factor to prevent or control type 2 diabetes (46,47). It is important to note that it could vary between urban and rural areas, and even between towns with different lifestyles.

Neighborhood environment and depressive symptoms

Similar to the risk of physical inactivity, those who live in hilly neighborhoods were at the highest risk of depressive symptoms. Although we cannot assert that a hilly neighborhood is a cause of depressive symptoms, it is reasonable to ascribe such a neighborhood as a high-risk area based on previous findings Therefore, older adults living in hilly neighborhoods should be targeted for public health and clinical practices for preventing depressive symptoms. Studies that investigated neighborhood hilliness found that hilliness was associated with physical inactivity, weight gain, hypertension, depression and suicide (66,95–98). One study investigated neighborhood elevation and found that higher elevations, which often have sloped landscapes, were associated with knee pain, which is a common risk factor for depressive symptoms (99). Given these findings, we can conjecture one of the mechanisms; hilly terrain hinders older adults from going out and engaging in PA or gives mechanical loads on their body, and that results in an increased risk of pain, disturbance of sleep quality and depressive symptoms. On the other hand, several studies claim that neighborhood hilliness can be a health-promoting factor by strengthening the physical function of the residents by walking in sloped neighborhoods in their daily lives (46,47). However, such findings are relatively few and often in settings where the level of hilliness is gentle. For example, while our study area had 9.62 degrees of mean land slope, the other study area had 3.03 degrees (66). What is useful to investigate is whether there is a cut-off point where hilliness becomes a negative factor in health accounting for urban/rural and local lifestyle differences.

Neighborhood environment and pain

Similarly to numerous health outcomes, older adults living in low SES neighborhoods may bear a higher risk of pain and thus, should be targeted for prevention and treatment strategies for pain. Living in low SES neighborhoods tends to be psychologically burdensome due to lack of security, littering and poor access to public services or resources (26,100–102). Although the association could be bidirectional, psychological stress, anxiety and depression are well-reported as risk factors for pain (57). A few studies specifically found that psychological stress was a mediator between low SES neighborhoods and pain (103,104). In addition to psychological stress, unhealthy behaviors such as physical inactivity due to poor access to PA-promoting resources in low SES neighborhoods may play a role. PA is a well-known beneficial factor to prevent and manage pain (105). Low SES neighborhoods tend to lack parks, bike paths and sidewalks that can promote PA (106). Poor access to those PA promoting facilities or infrastructure is associated with low PA and subsequently pain (107). Considering these findings, improving neighborhood conditions such as security or access to PA facilities could be an effective strategy to reduce the risk of pain among these residents (104). However, in Sweden, health-promoting facilities including PA facilities are not lacking in low SES neighborhoods (62). In addition, the effect of neighborhood SES remained after adjusting for exercise habits in our analysis. This suggests that there may be other pathways within the association between low SES neighborhoods and severe pain. That could be poor management of pain due to social norms, conditions or lack of access to healthcare in low SES neighborhoods (104). In that case, telemedicine and eHealth to educate and deliver information or treatment to the residents could be an effective intervention (108).

Strengths and Significance

One of the strengths of the four projects was that GIS was used to objectively measure specific neighborhood environmental factors. Objective measures of neighborhood environments could be useful to contrast the findings to other studies, investigate clinically meaningful cut-off points and be less variable across individuals than subjective measures (109). Another strength was that the studies investigated individuals who could be representative of the general population of national or local communities. In particular, Paper I investigated nationally representative adults in Sweden and Paper IV investigated nationally representative older adults in Sweden, which has not previously been done in studies of neighborhood environment and pain.

The significance of Papers II, III and IV was that they investigated rural and older adults who are often more vulnerable to NCDs' risk. Even though those are at higher risk of NCDs, they have been understudied relative to their other counterparts such as urban population (110,111). This is often because more data on neighborhood environmental factors and health status as well as funding are available in urban settings (111). Studies investigating neighborhood environmental factors in vulnerable areas or populations should be conducted more to implement environmental interventions in order to prevent an increase in health inequalities.

Limitations

Measurement of neighborhood environmental factors

Although GIS was used to objectively measure neighborhood environmental factors for each project, the measured values could not be specific properties of each factor. For instance, neighborhood availability of FF outlets and PA facilities could also be a proxy of high or low population density. This could be explained by one of the sensitivity analyses that found women who lived in neighborhoods with more than seven FF outlets, or six PA facilities had a lower risk of obesity. The neighborhoods with more FF outlets and PA facilities could be urban areas with high population density. Given that the risk of obesity tends to be higher in rural areas due to lack of PA, unhealthy diet and other factors (112), our methods might not have captured the exposure to FF outlets and PA facilities as we intended.

Neighborhood hilliness in Papers II and III could have been a proxy of other factors as well. In the study areas, hilly neighborhoods are usually less populated and thus, socially isolated situations could have been a factor in increasing the risk of physical inactivity and depressive symptoms among older adults (113,114).

The use of administrative neighborhood units for Papers I and IV was problematic unless the space of units were matching where individuals are exposed to neighborhood environmental factors in their daily lives (115).

Furthermore, there are newer neighborhood units that were proposed by Statistics Sweden in 2018, i.e., Demographic Statistical Areas (DeSO). DeSOs have been proposed as potentially better measures for several reasons (116). First, the boundaries of DeSOs follow spatial barriers, such as streets, waterways and railways and, therefore, the boundaries should reasonably represent the activity space of residents. Second, this method is now used in all municipalities across Sweden, for consistency. Third, DeSOs account for updated demographic compositions, such as segregation and socio-economic development. In contrast, SAMS was created in 1994 and was used inconsistently in municipalities. One of the strengths of using administrative neighborhood units is that findings could become relevant for located policy interventions; thus, using newer administrative units reflecting updated neighborhood contexts would have been more suitable (117). However, since we did not have access to DeSO data, we judged that there is still an advantage of using SAMS; we could contrast and discuss our findings based on previous studies using SAMS. Papers II and III attempted to relax the administrative boundaries by using street network buffers, but that still leaves concerns that the buffer size, e.g., 1000m or 400m is not applicable to every individual's daily activity space. In order to improve this, activity space for each individual should be identified by using the global positioning system (118).

Measurement of outcomes

Outcomes were also subjected to be biased. Obesity diagnosis in Paper I could have been influenced by many factors between patients and clinicians. Information regarding the process of obesity diagnosis was not available in the register data. While we could assume that the bias could be non-differential, it is possible that some doctors in certain areas have more tendency to diagnose obesity than others, and that could be affected by patients' characteristics as well.

Self-reported PA, depressive symptoms and pain in Papers II, III and IV could have been biased across individuals. Although we used definitions and criteria which were used or validated in previous studies, unspecific measurement of outcome hinders us from discussing the findings robustly. For example, PA in Paper II was not measured specifically by domains, e.g., transportation, recreation, occupation, and household. As different domains of PA were found to be associated with different neighborhood environmental factors in previous studies (119), that should have been taken into account. Especially, as a rural-specific PA, farming activity was not distinguished from other types of PA, and that could have been associated with neighborhood environmental factors differently.

Severe pain in Paper IV was not distinguished between acute and chronic pains. As chronic pain is found to be more associated with psychosocial factors than physical trauma or injuries in recent evidence (57), the association between neighborhood SES and acute or chronic pain could have differed.

Mechanism

Measurement bias of neighborhood environmental factors and outcomes leads to another limitation; difficulties to discuss mechanisms. Even though we could refer to previous findings and subjective expertise, unbiased measurements for specific neighborhood environmental factors and outcomes are needed to effectively discuss the mechanisms.

For example, in Paper I, if attitudes to diagnose obesity to patients among doctors are heterogeneous between neighborhoods, the association between the number of FF outlets and PA facilities in neighborhoods and the risk of obesity could have been biased towards the null even though there actually were significant associations. Even though our findings were in alignment with previous research, the measurements which are more robust to misclassification bias, e.g., BMI, waist circumference, street network-based distance to FF outlets and PA facilities would improve the internal validity to discuss the mechanism.

In Paper II, if domain-specific PA was measured and farming activity was separately assessed, neighborhood hilliness could have been associated with domain-specific PA, e.g., transportation, across all municipalities. Since hilliness could have been perceived differently due to local work practices, in addition to specific measures for PA, information regarding perception for hilliness and engagement in farming or fishing would improve the discussion for the mechanism between neighborhood environmental factors and PA.

In Paper III, whether neighborhood hilliness is a barrier for older adults to engage in PA and that leads to depressive symptoms, or depressive symptoms are primarily driven by social isolation by living in hilly and remote areas is unclear. Similar to Paper II, perceptive measures for hilliness and whether residents regard it as barrier would help explain the uncertainty.

In Paper IV, if neighborhood SES was associated with only chronic pain but not acute pain, poor management of pain among those who live in low neighborhood SES could have been an issue. That could be due to accessibility to healthcare for pain management or health literacy and certain interventions such as telemedicine could be an effective intervention (120,121). In addition, the aggregated measure of neighborhood SES limits our discussion of how factors are operating between neighborhood SES and pain. Even though we could discuss the possibilities of psychological stress, as well as PA between neighborhood SES and pain, by referring to the previous findings, measuring more specific factors, which can lie between neighborhood SES and pain, would give more clues to public health policymakers and healthcare practitioners. For example, specific measurements of neighborhood safety, accessibility to PA facilities or healthcare centers, social capital and a number of other neighborhood factors could help us identify why people in low SES neighborhoods have a higher risk of pain.

While it was not the aim of each study, identifying the mechanism will advance the implications of neighborhood studies. By knowing why and how neighborhood environmental factors are driving health outcomes, we could devise effective intervention strategies to modify neighborhood environments. To know the mechanism, specific and precise measurement of both neighborhood environmental factors and outcomes is needed.

Internal validity

There were limited possibilities of causal inferences; in other words, a potential lack of internal validity for each study. Paper I was a longitudinal study and the temporal order of exposures and outcomes was considered. However, due to the nature of observational studies, exposures were not randomly assigned. That did not ensure one of the fundamental assumptions of causal inference; exchangeability (122). Another important assumption, i.e., consistency, was not assured as the measurement of exposures may not have been specific enough as aforementioned. Paper II did not have a random assignment of exposures either and thus, exchangeability did not hold. The measurement of exposures was, however, more specific than that of Paper I because of the use of street network buffers rather than neighborhood units, albeit not perfect. The temporal order of exposures and outcomes was considered by excluding the subjects with the outcomes in question at baseline and then following the incidence of the outcomes in both studies. However, the most common bias in neighborhood research, “residential selection”, cannot be ignored (122). Since there was no explicit time point when individuals started being exposed to the neighborhood characteristics of interest, individuals with certain health characteristics might have settled in certain neighborhoods. To overcome that problem, experimental or quasi-experimental studies should have been employed by explicitly assigning the starting time of the exposure or, as it is often difficult due to reasons of ethics and cost, repeated measures of exposures, outcomes, and confounders should have been employed to account for changes over time, which partly would have helped us to elucidate causal relationships in a more robust way (122). Papers III and IV were cross-sectional and, therefore, interpretations are limited to mere descriptions of the associations between neighborhood environmental factors and outcomes.

External validity

Although there was a potential lack of internal validity due to the observational study design, the external validity should have been relatively high despite the risk of selection bias due to the use of surveys. Paper I, however, utilized a large nationally representative cohort from national register data and, therefore, the findings should be generalizable to the Swedish population. On the other hand, papers II and III were subject to "healthy participant" bias. As the study individuals were those who participated in voluntary annual health checkups within the municipalities and Shimane CoHRE survey, they could have been healthier than the general population. Therefore, the external validity of the findings was affected so that we could not generalize the findings to the whole local population. However, the annual free health checkup is one of the unique public health initiatives in Japan. Public health practitioners and policymakers are engaged in the checkups and Shimane CoHRE study and the findings should be practically useful for incorporation into practices and policies. Paper IV was also subject to selection bias, i.e., nonresponse bias. Even though the study individuals were randomly sampled from the national population for the survey, those who did not respond to the survey might have been different in certain characteristics from the respondents. That could have limited the generalizability of the findings to the entire older Swedish population.

Methodological considerations

Besides the limitations common to the four papers as mentioned above, there are methodological limitations for each paper.

Paper I did not consider clustering within neighborhoods. In the neighborhood studies using administrative neighborhood units, individual data are nested in the neighborhood units. In the study, characteristics of individuals related to obesity or obesity itself could have been similar to each other among individuals in the same neighborhood. This dependency should be taken into account by applying a multilevel analysis model in order to avoid overestimation of the association between primary explanatory variables, i.e., neighborhood availability of FF outlets and PA facilities and outcome, i.e., obesity.

Paper II attempted to measure the incidence of physical inactivity over time, but it was self-reported and physical inactivity status could change to be active again. We assumed that individuals who become physically inactive at an older age are unlikely to be active again, in fact, there was a higher proportion of older aged adults (70-79 and 80+ years old) who maintained PA than 60-69 years old adults (Table 2-1) and the risk of physical inactivity was lower among older aged adults than 60-69 years old adults (Figure 2-2). However, other analysis models such as the generalized linear mixed model, which accounts for time-dependent outcomes, could have been more suitable to apply.

Paper III had many individuals with missing data, e.g., education. Since we conducted only a complete case analysis, the findings could have been biased. While multiple imputations might have been difficult due to the large proportion of missing data, other methods could have been applied to reduce the bias (123,124). In addition, covariates included in the analysis were not distinguished between confounders, mediators, effect modifiers and colliders. Including all covariates without distinct knowledge might have led to overadjustment bias (125).

Paper IV tried to conduct a multilevel analysis, assess missing data patterns and address the difference between confounders and mediators. However, more robust methodologies should be applied to discuss the mechanism between neighborhood SES and severe pain. For example, directed acyclic graphs could be used to select an adjustment set of variables to answer the research questions effectively (125).

Future directions

In research, more robust methodologies are warranted to identify neighborhood environmental factors that may affect the risk of NCDs among vulnerable populations. Such methodologies include quasi-experimental studies followed by modification of neighborhood environment or longitudinal studies accounting for time-dependent variables as well as residential mobility that ensure temporal order from exposure to outcome (126). Not only the methodologies of causal inference, but consideration of local contexts, e.g., social, cultural and geographic features are important. That will prevent naïve implementation of environmental or political interventions that may be effective only in certain areas. Furthermore, the mechanism between neighborhood environmental factors and outcomes should be investigated with more comprehensive data on behavioral and biopsychosocial factors. That will help us identify what we need to modify or intervene as regards considering cost effectiveness.

Conclusions

Neighborhood environmental factors that are associated with the risk of NCDs may be different across countries, regions and communities. Which neighborhood environmental factors are associated with the risk of NCDs among vulnerable areas and populations are understudied, and more research should be done to provide evidence-based public health and clinical practices to those high-risk groups. Effective intervention in those groups will reduce the global burden of NCDs by alleviating the inequality in health. Furthermore, research identifying neighborhood environmental factors perpetuating the risk of NCDs in certain places is useful on a practical level for local public health and clinical practices. However, albeit imperfect, the present thesis has helped to point out several important and novel associations that will guide the direction in future research.

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Appendix

Table App 1-1: Association between neighborhood availability of FF outlets and PA facilities and obesity

	Men			Women		
	HR	**95% CI**		**HR**	**95% CI**	
No. of fast food outlets (ref. Non)						
1	0.99	0.95	1.03	0.97	0.94	1.01
2	1.00	0.95	1.06	0.93	0.88	0.98
3	0.93	0.85	1.01	0.92	0.85	1.01
4	0.97	0.86	1.10	0.90	0.80	1.01
5	0.98	0.84	1.15	0.87	0.73	1.02
6	0.99	0.84	1.17	0.96	0.81	1.13
7 or more	0.88	0.77	1.00	0.83	0.73	0.95
No. of physical activity facilities (ref. Non)						
1	0.99	0.95	1.03	0.98	0.94	1.02
2	0.97	0.92	1.03	0.96	0.91	1.01
3	1.01	0.94	1.08	1.08	1.01	1.15
4	1.00	0.90	1.11	0.94	0.85	1.04
5	1.02	0.87	1.20	1.06	0.91	1.22
6	0.99	0.84	1.18	0.73	0.60	0.89
7 or more	0.92	0.79	1.06	0.83	0.72	0.96

Note: All covariates were adjusted.

Table App 2-1: Association between neighborhood environmental factors and physical inactivity

	Model 1[a]	Model 2[b]	Model 3[c]
	HR (95%CI)	**HR (95%CI)**	**HR (95%CI)**
Slope (ref. 1st, lowest)			
2nd	1.12 (0.95, 1.30)	1.12 (0.94, 1.29)	1.14 (0.97, 1.32)
3rd	1.10 (0.93, 1.28)	1.10 (0.92, 1.28)	1.13 (0.95, 1.30)
4th (highest)	1.00 (0.82, 1.17)	0.99 (0.81, 1.17)	0.98 (0.80, 1.16)
Bus stop density (ref. 1st, lowest)			
2nd	1.15 (0.99, 1.32)	**1.16 (1.00, 1.33)**	1.09 (0.92, 1.26)
3rd	**1.18 (1.01, 1.36)**	**1.18 (1.01, 1.36)**	1.14 (0.96, 1.31)
4th (highest)	1.11 (0.93, 1.29)	1.12 (0.95, 1.30)	1.04 (0.86, 1.22)
Intersection density (ref. 1st, lowest)			
2nd	0.94 (0.76, 1.12)	0.93 (0.75, 1.11)	0.94 (0.76, 1.13)
3rd	1.06 (0.89, 1.23)	1.06 (0.89, 1.23)	1.03 (0.86, 1.20)
4th (highest)	1.08 (0.91, 1.26)	1.09 (0.92, 1.26)	1.07 (0.90, 1.25)
Residential density (ref. 1st, lowest)			
2nd	1.06 (0.90, 1.23)	1.06 (0.90, 1.23)	1.07 (0.90, 1.24)
3rd	1.07 (0.90, 1.24)	1.06 (0.89, 1.23)	1.07 (0.90, 1.24)
4th (highest)	0.96 (0.78, 1.13)	0.96 (0.78, 1.13)	0.95 (0.78, 1.13)
Distance to community center (ref. 1st, lowest)			
2nd	0.94 (0.77, 1.11)	0.93 (0.76, 1.10)	0.96 (0.79, 1.13)
3rd	0.90 (0.73, 1.08)	0.90 (0.73, 1.07)	0.90 (0.73, 1.08)
4th (highest)	**0.75 (0.57, 0.93)**	**0.75 (0.57, 0.93)**	0.82 (0.64, 1.01)

Note: [a] Model 1: adjusted for age and sex; [b] Model 2: adjusted for age, sex, smoking, drinking and BMI. [c] Model 3: adjusted for age, sex, smoking drinking, BMI, musculoskeletal disorders and city of residence.

Table App 2-2: Association between neighborhood environmental factor and physical inactivity – stratified by residential municipalities and age groups.

	Unnan 60-74 n = 706	Unnan 75+ n = 257	Oki 60-74 n = 365	Oki 75+ n = 203	Onan 60-74 n = 680
	HR (95%CI)	**HR (95%CI)**	**HR (95%CI)**	**HR (95%CI)**	**HR (95%CI)**
Slope (ref. 1st, lowest)					
2nd	1.17	1.30	1.55*	1.89	0.88
	(0.89, 1.46)	(0.76, 1.85)	(1.08, 2.02)	(0.82, 2.97)	(0.57, 1.20)
3rd	0.88	1.27	1.74*	1.61	1.18
	(0.60, 1.17)	(0.72, 1.81)	(1.27, 2.21)	(0.58, 2.65)	(0.86, 1.50)
4th (highest)	0.91	1.49	0.89	3.13*	0.82
	(0.60, 1.23)	(0.99, 1.99)	(0.27, 1.50)	(2.09, 4.16)	(0.53, 1.10)
Distance to community center (ref. 1st, lowest)					
2nd	1.17	0.55	1.09	0.48	0.94
	(0.89, 1.45)	(0.03, 1.06)	(0.59, 1.60)	(-0.58, 1.54)	(0.70, 1.26)
3rd	0.95	0.69	1.06	0.52	0.95
	(0.66, 1.23)	(0.25, 1.14)	(0.50, 1.62)	(-0.60, 1.64)	(0.70, 1.27)
4th (highest)	0.92	0.72	1.03	0.73	0.66*
	(0.60, 1.25)	(0.17, 1.27)	(0.55, 1.51)	(-0.08, 1.54)	(0.47, 0.93)

Note: All models for each municipality and age group adjusted for sex, smoking drinking, BMI, musculoskeletal disorders. *p<0.05. There were no subjects >= 75 years old in Onan.

Table App 3-1: Association between neighborhood hilliness and depressive symptoms – land slope by quartiles (n=935).

	OR	95%CI
Slope (ref. 1st, lowest)		
2nd	1.27	0.79, 2.05
3rd	1.36	0.72, 2.21
4th (highest)	1.72	1.08, 2.73

Note: All covariates were adjusted.