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ORIGINAL PAPER

Effects of the living environment in a model of social determinants of health focusing on the cognitive mechanism of urban residents

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Abstract
We investigated the effects of living environment on the health status of urban residents using a quantitative model of social determinants of health, focusing on the cognitive mechanism of urban residents. A cross-sectional survey through an online questionnaire was conducted in Koto Ward, Tokyo, Japan ($n = 1553$). We developed a "social determinants of health" model based on the hypothetical model in the field of social epidemiology by structural equation modeling, which has three layers: social infrastructure layer (macro), community layer (meso), and personal layer (micro). The model also has five main latent factors: social environment, living environment, social capital, self-efficacy, and health status. We estimated the standardization total effects of all the latent factors for investigating the effect of urban living environment on the health status of the residents. We determined that the latent factors, social environment (0.606), living environment (0.723), social capital (0.156), and self-efficacy (0.356), affect the health status with regard to the standardization total effects. The urban living environment had the greatest effect on the health status of the residents among other latent factors. Furthermore, living environment (0.530) affected social capital the most, and social environment (0.500) affected self-efficacy the most. We conclude that improving the urban infrastructure, especially the urban living environment, can promote the health status of urban residents most effectively.

Keywords Social environment · Built environment · Natural environment · Social capital · Self-efficacy · Health states

Introduction

The importance of social and living environment for health in urban areas

World Health Organization (WHO) (2010b) declared that "typical urbanites have more choice and opportunity than their ancestors ever had before. […] At the same time, cities concentrate certain risks and health hazards." They also stated that improving social infrastructures such as the social and living environment in urban areas is of great importance. In addition, the Japan National Institute of Population and Social Security Research (2020) estimated that urban population ratio of total population in Japan in 2015 was 91.4%. This means that more than 100 million of the total population of 120 million in Japan live in the urban area. Based on the above background, the Japanese government has proposed a new policy guideline that links the "guidelines for promoting community development focused on healthcare, medical care, and social welfare" formulated by the Ministry of Land, Infrastructure, Transport and Tourism (2014) and the "Healthy Japan 21 2nd edition" declared by the Ministry of Health Labour and Welfare (2012) to concurrently improve the health status and social infrastructures in urban areas.

Hanibuchi et al. (2011) showed that neighborhood parks and green spaces could facilitate leisure-time sports activities for elderly people. As a study outside Japan, Vlahov and Galea (2002) concluded in their review study that the social environment, the physical environment, and access to health and social services are the most important factors that affect

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the health of residents. Considering the built environment in urban areas, Gordon-Larsen et al. (2006) suggested that inequality in the availability of facilities for physical activities may contribute to ethnic and Socio-economic Status (SES) disparities in physical activities and overweight patterns. Mitchell and Popham (2008) revealed that the relationship between income deprivation and mortality differ significantly across groups according to their exposure to green spaces for mortality from all causes and circulatory disease. From these cited studies, we infer that the living environments, including the built and natural environments, in the urban areas are one of the most fundamental factors that influence the health condition of the residents. In addition, in previous studies examining the relationship between living environment and health condition, objective evaluations, such as green coverage or access to green space and other facilities for physical activities, are often used as definitions and indicators of the living environment (Mitchell and Popham 2008; Maas et al. 2006, 2009; Hanibuchi et al. 2011). In short, these studies focused on "quantitative" measures of the urban living environment. On the other hand, relatively few studies have adopted subjective evaluations, such as satisfaction with the living environment, as definitions and indicators of the living environment (Grahn and Stigsdotter 2010; Stigsdotter and Grahn 2011). Measuring the living environment through objective evaluations is undertaken so that when examining the relationship between the living environment and health status from the perspective of public health, sources that provide objective indicators established by databases, such as GIS, can be used. In addition, investigating the relationship between satisfaction with the living environment and subjective health status from the perspective of public health has high economic costs because it is necessary to distribute a large number of questionnaires to the residents of a survey area. To our knowledge, no previous studies have established a comprehensive cognitive mechanism for measuring urban resident satisfaction with the living environment, subjective health status, and many other cognitions regarding the social environment and other self-evaluated scale indexes. Therefore, we have defined the index of the living environment in this study as the degree of satisfaction with the living environment, and explored the relationship between the living environment and health status from the viewpoint of the cognitive mechanism of the urban residents. In short, we investigate "social determinants of health (SDH)" as a "qualitative" measure of the urban living environment.

The models of social determinants of health

By contrast, as a global trend in public health, the SDH in "The Solid Facts" advocated by Wilkinson and Marmot (2003) and Marmot (2005) has attracted considerable attention. According to "The Solid Facts," SDH involves 10 factors mainly related to the social environment, including psychological, social, and economic factors, which are closely related to health status. As the most representative SDH conceptual framework, the WHO (2010a) assumes that the conceptual model of SDH has a hierarchical structure consisting of four layers: the globalization environment, public policies (macro-level), community (mesa-level), and individual interaction (micro-level). In addition, as a famous example of other conceptual SDH layer structures, the model proposed by Göran and Whitehead (1991) also assumes a four-layer structure for SDH. In this model, factors related to SDH are positioned in the following order: (1) general socio-economic, culture and environmental conditions, (2) living and working conditions, (3) social and community networks, and (4) individual lifestyle factors. Braveman et al. (2011) also envisioned a four-layer structure as a conceptual framework for SDH. This structure consists of the following from upstream factors: (1) economic and social opportunities and resources, (2) living and working conditions in homes and communities, (3) medical care and personal behavior, and (4) health. The Bay Area Regional Health Inequities Initiative (BARHII 2020) also provided a detailed model of the SDH conceptual framework. The model in BARHII assumes the following six layers from upstream to downstream for the SDH layer structure: (1) social inequities, (2) institutional inequities, (3) living conditions, (4) risk behaviors, (5) diseases and injury, and (6) mortality. Furthermore, Berkman et al. (2000) proposed a layered structure model for health effects based on social networks. The goals for the conceptual framework on SDH are detailed in Sugisawa (2012). Several recent studies employed social networks (Kjellstrom and Mercado 2008; Srinivasan et al. 2003; Maas et al. 2006, 2009). Mohnen et al. (2011) focused on the relationship between health and social capital (SC), and Waverijn et al. (2016) investigated the relationship between health literacy skills and SC. Putnam (1993) defined SC as "features of social organizations, such as networks, norms, and trust that facilitate action and cooperation for mutual benefit". Kondo et al. (2018) envisioned a structural model focusing on the macro-to-micro three-layer structure of SDH from the perspective of gerontological research and life course approaches in Japan. In this structure, the following factors were assumed: (1) society as environment (eg SC), (2) individual socio-economic factors (eg family and marital status), and (3) individual bio-behavioral factors (e.g., health behaviors). The four common trends in the study of the above conceptual model of SDH in public health and social epidemiology are as follows: (1) SDH has a main three-to-four-layer structure from upstream to downstream; (2) the layered structure model has the social environment as the most upstream factor; (3) the layered structure model has lifestyle and health behavior as the most downstream factor; and (4) the common layered structure of SDH can be summarized as follows: "social infrastructure" as the macro-layer, "community" as the meso-layer, and "personal factors" as the micro-layer.

In recent years, Hanazato (2019) reported "the primordial prevention by improving neighborhood environment", which highlights the efforts to prevent the urban residents from getting sick by integrally improving the social and the living environments. As mentioned above, with the current trend in public health and related research areas, there is an increase in the research on exploring the social infrastructure, especially the living environment, that nurtures social networks.

The purpose of this study

From the above-cited previous studies, we can assume that the health status of urban residents is a result of various SDH entwined in a hierarchical and complex manner. Social epidemiologists proposed conceptual models to determine the comprehensive relationship of SDH with a focus on the field of public health (Kondo et al. 2018; Berkman et al. 2000), but only a few studies have quantitatively estimated the structure of SDH. In addition, it is estimated that not only can the urban living and social environments be objectively measured, but also the effect of the living and social environments based on the cognition of the urban residents on the health condition of these residents. For this reason, there is a need to (1) express the relationship between social infrastructure (macro-level), community (meso-level), and personal factors (micro-level) of urban residents in one quantitative and hierarchical model of their cognitive mechanism and (2) estimate the impact of urban living environments on the health status considering the interaction between various factors as SDH. The purpose of this study is to (1) develop a comprehensive model for SDH on cognitive mechanism of urban residents and (2) investigate the effect of urban living environments on the health status of the residents considering the relationship with other factors in SDH.

Materials and methods

Relevance to a previous study and the originality of this study

To achieve the objective of this study, we decided to refer to the theoretical hypothesis proposed by Otsuka et al. (2016). Otsuka et al. (2016) conducted two-step verification to measure the health-promoting effect of urban green spaces. As a first step, they constructed the association between SDH and health-related quality of life (QOL) of urban residents via structural equation modeling. As a second step, they measured the health-promoting effect associated with the usage of urban green spaces via multiple-group structural equation modeling. However, the theoretical hypothesis in Otsuka et al. (2016) lacked the concept of community (mesa-level) such as SC that mediates social infrastructure (macro-level) and personal factors (micro-level). This was a major challenge associated with the verification of SDH from the perspective of public health. There are two reasons for the lack of the community level (meso) layer in the theoretical hypothesis of Otsuka et al. (2016). First, previous studies did not consider the concepts of social infrastructure level factors when investigating the association between individual level lifestyles (such as activities in public parks) and subjective health status (Stigsdotter and Grahn 2011). Therefore, Otsuka et al. (2016) first constructed a model that included macro-level factors located at the top of the causal relationship regarding SDH, such as social and living environments, from the viewpoint of the cognitive mechanism of urban residents. Second, although in the theoretical hypothesis of Otsuka et al. (2016) they assumed that self-efficacy (including social support of SDH) acts as an intermediate and intervening factor (meso) that connects social and living environments (macro) to health status (micro), they revealed that self-efficacy was only an intermediate factor between social environment and health status. This suggests that self-efficacy is inadequate as a factor in the community layer (meso) in the three-layer structure for SDH. Therefore, we added 17 items related to SC to the model of Otsuka et al. (2016) to more strongly explain the concept of community layer (meso) in the three-layer structure of SDH. Therefore, this study reconstructs a highly valid model for verifying SDH from the viewpoint of public health using the same data set as that considered by Otsuka et al. (2016). The originality of this study is that we attempt to build a basic model to verify the effects of intervention for promoting health. In future studies, multiple-group structural equation modeling using the reconstructed model in this study will help us to identify more effective interventions for improving the health status of urban residents. The details of the data used in this study are described below.

Data collection

We conducted a cross-sectional study through an online questionnaire survey using QuickMill of Macromill Co., Ltd. An online questionnaire survey is one of the questionnaire survey methods through which responses are obtained from a registered monitor in the survey outsourcing company. This type of survey has the advantages that (1) sample sizes and distribution of the participants' demographic data can be adjusted according to the arbitrary setting of the investigator and (2) the bias due to the interest in the research objectives is reduced compared to mail surveys. According to Hanibuchi et al. (2015), online questionnaire surveys have improved the quality and reliability of data for setting countermeasures against impersonators and satisficing on response behaviors. However, according to Ohsumi (2002), it is not possible to verify whether the sample obtained from online questionnaires reflects the demographic target population because the participants are limited to those who can connect or use the internet. We adopted an online survey because it can yield more accurate answers to privacy-related questions, such as health status, and adjusts the participants' demographic data according to the target population. We set the participants as the residents of Koto Ward, Tokyo, Japan, and requested to collect 1500 responses from Macromill Co., Ltd. In addition, we requested to collect responses according to the population ratio, sex, and age of each district in Koto Ward to MacroMill Co., Ltd. After the survey, we collected 1553 responses.

Site and participants

We set the survey site as Koto Ward, Tokyo, Japan, and the survey period from November 1 to 17, 2014. Figure 1 shows the aerial photograph of Koto ward posted on the official website modified by the authors (Koto ward 2018). We chose Koto Ward as the survey site because it composed of the various regions as regards its living environment, including the old city area in the north, dotted with large-scale public housing complexes, and the Waterfront redevelopment area in the south (Koto ward 2007). Koto Ward has a diverse social environment based on the demographics (Koto ward 2017). As of November 1, 2014, the population of Koto Ward is 493,525 and the number of households is 248,990 (Koto ward 2021a). Figure 2 shows the changes in the population of Koto Ward by age group over the past 20 years (Koto Ward 2021b, created by the authors with reference to the data posted on the official website of Koto Ward). The population age composition of Koto Ward is centered around the baby boomer generation born in 1947–1949 and the second baby boom generation peaked in 1971–1974. With a declining birthrate and aging population rapidly advancing throughout Japan, Koto Ward has seen a large increase in the elderly population (65 years of age or older), but the young population (0–14 years old) has also begun to increase after hitting the lowest levels in 2000. In recent years, the proportions of young and old populations in Koto Ward have increased, but that of the working-age population (15–64 years old) has decreased. However, only the number of late middle-aged people (35–54 years old) in the working-age population has increased. This caused an increase in the young population in Koto Ward. With reference to the national population census conducted in 2015, the changes in the youth population in Koto Ward were 13.1% in 1995, 11.5% in 2000, 11.4% in 2005, 12.1% in 2010, and 12.6% in 2015 (Koto ward 2019). On the other hand, the transition of the elderly population in Koto Ward was 12.2% in 1995, 15.2% in 2000, 17.3% in 2005, 19.1% in 2010, and 21.2% in 2015. However, the working-age population is exceptionally increasing between the ages of 35 and 54 due to the influx of child-rearing generations from other regions. The current situation regarding the demographics of Koto Ward can be summarized into the following two features: First, the proportion of the child-rearing population is increasing. Second, Koto Ward still has a high elderly population and aging rate. In particular, the large influx from other areas is concentrated in the redevelopment area in the south. Therefore, it is predicted that the differences in population and age distributions between the redevelopment area and other existing urban areas will increase in future. Based on the current demographics, Koto Ward appears to have diverse social environments in comparison with Japan's basic demographics regarding urban areas.

Table 1 shows the demographics of the 1553 participants (Otsuka et al. 2016). To verify the deviation of the demographics in the four (Shirakawa–Toyo–Kiba, Kameido–Oshima, Sunamachi–Minami sunamachi and Toyosu) and nine regions (Shirakawa, Tomioka, Toyosu, Komatsubashi, Toyo and Kiba, Kameido, Oshima, Sunamachi and Minami sunamachi) of Koto Ward, we performed Pearson's Chi-square test. There was no significant difference in the age group and gender of the participants. However, there were significant differences in the marital status, presence of children, individual and household income in the four and nine regions of Koto Ward. Table 1 shows that there were regional differences in the social status of the participants' demographics, which indicates that we successfully collected participants from the diverse social environment in Koto Ward. From these results, although we adopted an online questionnaire survey with concern about coverage error, the sample adequately reflects the population of Koto Ward.

Survey items

In this study, we set the subjective scale evaluation regarding the social environment, living environment, SC, self-efficacy, and health status. For the measurement of the social environment and self-efficacy, we originally created 14 items, which followed the socio-economic factors on SDH according to WHO, including the social gradient, stress, social exclusion, work, unemployment, and social support (Wilkinson and Marmot 2003; Marmot 2005). We defined these items as the SDH index (see Table 2). In the measurement of the living environment and health status, we employed the Satisfaction Index of Health-Related Quality of Life (SI-HRQOL) by Nakajima et al. (2003) and revised it from a four- to a five-scale measure (see Table 3). SI-HRQOL employs 15 items and 5 factors to evaluate health

Fig. 1 The aerial photograph of Koto ward (Koto Ward 2018)

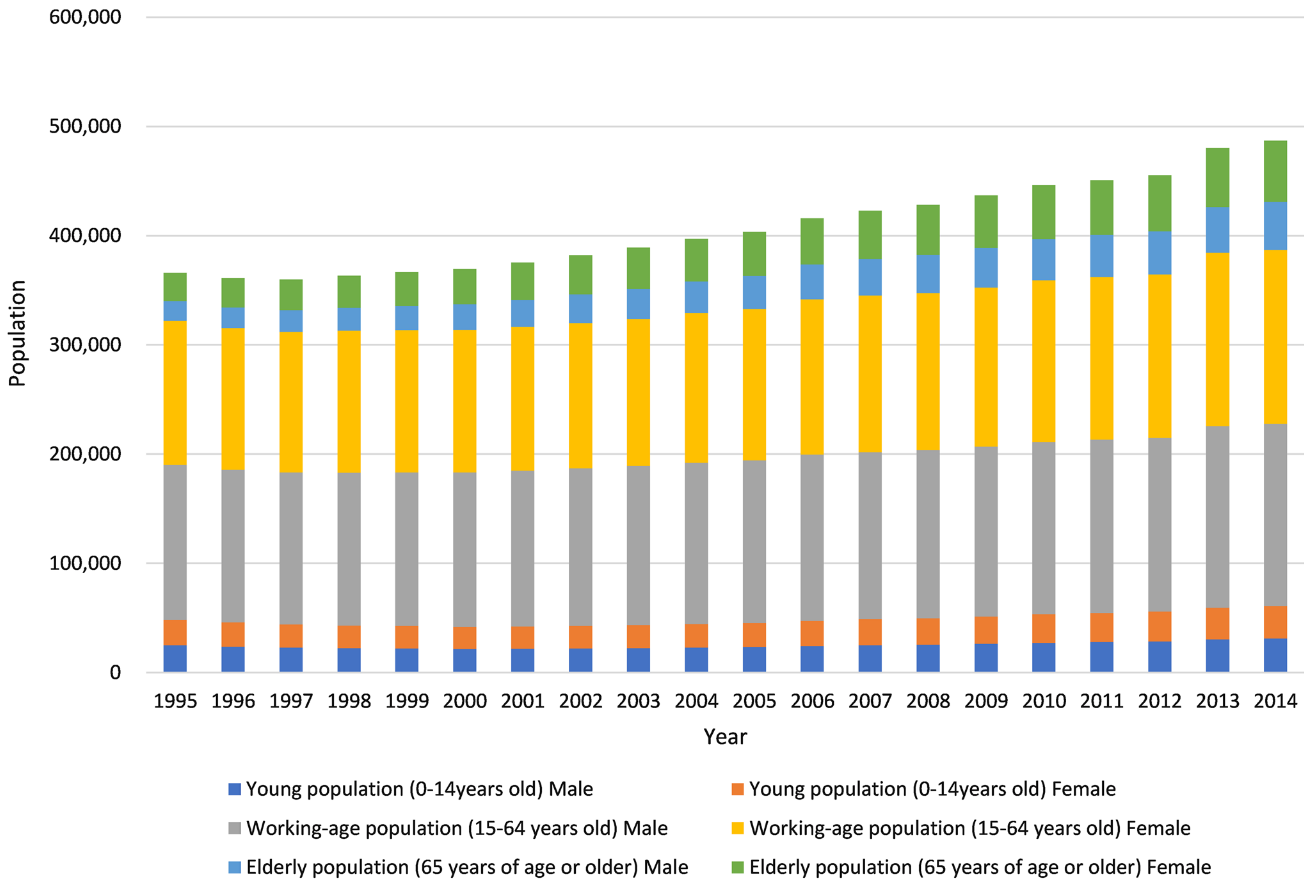


Fig. 2 Population trends by age group in Koto Ward (Koto Ward 2021b)

status, including the physical, mental, and social health, and the living environment, including convenience and comfort. Although the SI-HRQOL created by Nakajima et al. (2003) exists only in Japanese, the factor structure has been rigorously verified by a huge amount of data from more than 6000 participants and structural equation modeling. In addition, SI-HRQOL was verified to be associated with SF-12 developed by Ware et al. (1996, 1998), which is globally recognized as metrics for health-related quality of life (QOL). Therefore, SI-HRQOL is an appropriate index for measuring the health-related QOL (health status and satisfaction with the living environment in the neighborhood) of Japanese. In this study, we assumed that there were two factors; health status (micro-level) and living environment (macro-level), upstream of the five-factor structure in SI-HRQOL of Nakajima et al. (2003) (Table 3). For the measurement of SC, we set a total of 17 items as the SC index with reference to Putnam (1993) and Cabinet Office in Japan (2002) (see Table 4). In the 17 items in the SC index, we measured the three concepts of trust, network, and norm on a 4–7 Likert scale. In this study, the SC index was used to measure trust in four items, network in seven items, and norms in six items. We assumed that here was a factor, social capital (SC) (meso-level), upstream of the three-factor structure in the SC index (Putnam 1993; Cabinet Office in Japan 2002) (Table 4). In statistical analysis, we unified the scores of all the items such that the higher the score, the more socially desirable.

Statistical analysis

We employed structural equation modeling to build a comprehensive and quantitative model for the SDH on cognitive mechanism of urban residents using the three observed variables: SDH index, SI-HRQOL, and SC index. The procedure for developing the model is as follows.

1. We perform a factor analysis on the factor structure of each of the three observation variables.
2. Based on the result of 1, we performed confirmatory factor analysis using SEM on the SI-HRQOL and SC index and reconfirmed the factor structure.
3. As the theoretical hypothesis, we assume a causal model with a three-layer structure (social infrastructure, community, and personal layers).

Table 1 Demographics

	Items	%	*n* (1553)	Pearson's Chi-square test (*p* value)	
				Four regions	Nine regions
Age groups	20 s	10.6	164	0.539	0.075
	30 s	23.0	357		
	40 s	33.2	516		
	50 s	19.9	309		
	60 s	10.2	159		
	70 s or more	3.1	48		
Sex	Male	48.6	754	0.335	0.166
	Female	51.4	799		
Marriage	Unmarried	37.5	582	0.000	0.000
	Married	62.5	971		
Presence of children	Without	52.6	817	0.001	0.015
	With	47.4	736		
Occupation	Company employee/public employee	52.5	816	0.552	0.515
	Freelance/self-employed	7.7	120		
	Housewife	16.7	259		
	Part-time job	11.7	181		
	Student	2.3	36		
	Other	2.8	44		
	Unemployed	6.2	97		
Annual household income (10,000 yen)	0–400	21.0	295	0.000	0.000
	400–800	39.3	553		
	800–1200	20.9	294		
	1200–	9.1	128		
	Unknown/unanswered	9.8	138		
Individual annual income (10,000 yen)	0–400	55.6	780	0.001	0.022
	400–800	27.0	379		
	800–1200	8.8	123		
	1200–	3.3	47		
	Unknown/unanswered	5.3	74		

The four regions in the Koto Ward are Shirakawa–Toyo–Kiba, Kameido–Oshima, Sunamachi–Minami sunamachi, and the Toyosu area, and the nine regions are Shirakawa, Tomioka, Toyosu, Komatsubashi, Toyo and Kiba, Kameido, Oshima, Sunamachi, and Minami sunamachi

4. We construct the model by combining the factors of the three observation variables based on the theoretical hypothesis (WHO 2010a; Göran and Whitehead 1991; Braveman et al. 2011; BARHII 2020; Berkman et al. 2000; Kondo et al. 2018; Sugisawa 2012).
5. If the theoretical hypothesis is not supported, we refine the theoretical hypothesis of the model and revalidate the model.
6. We estimate the impact of the living environment on the health status of the urban residents based on the model.

As a concrete analysis procedure in 1 above, we first performed a factor analysis using the maximum likelihood method and Promax rotation to understand the factor structure of the observed variables of the participants. Second, we interpreted the factors of each of the observed variables after excluding items with an initial commonality of 0.3 or less in the analysis of the first factor. We also calculated the Cronbach's alpha confidence coefficient to verify the internal consistency of each factor. We obtained sufficient internal validity when the Cronbach's alpha coefficient was 0.7–0.8 or more. To develop the model, we employed structural equation modeling and calculated the standardized total effect to investigate the effects of SDH on the health status of urban residents. The total effect is defined as the sum of the direct and indirect effects. The direct effect refers to the path coefficient directly connected between the source and the destination variables

Table 2 Items of SDH index

No	Items	Abbreviation	Factor	Upstream factor
1	I have enough income and social status	Income and status	Social environment	No upstream factor
2	There is a large social and economic gradient with those around us	Social gradient	Social environment	
3	I can deal appropriately with stress and difficult events	Dealing with stress	Social environment	
4	I have a lot of stress over the long term	Long-term stress	Social environment	
5	I am subject to social discrimination and prejudice due to my circumstances and living conditions	Discrimination and prejudice	Social environment	
6	I feel lonely and isolated	Isolation and loneliness	Social environment	
7	I do not have proper evaluation and discretion in the workplace and labor environment	Labor environment	Social environment	
8	I am unemployed or unstable employment	Unemployment	Social environment	
9	I have good relationships with my family, friends, people at work and neighbors	Relationships	Self-efficacy	No upstream factor
10	I can get enough public support from the community and the local government	Public support	Self-efficacy	
11	I feel needed by the people around me	Needed	Self-efficacy	
12	I feel the importance of my existence	Importance of existence	Self-efficacy	
13	I am financially and socially independent	Independence	Self-efficacy	
14	I am playing the role I am expected to play	Role	Self-efficacy	

1. Not applicable, 2. Somewhat not applicable, 3. Neither applicable nor not applicable, 4. Somewhat applicable, 5. Applicable

Table 3 Items of SI-HRQOL

No	Items	Abbreviation	Factor	Upstream factor
1	My physical condition	Physical condition	Physical health	Health status (micro)
2	My physical strength	Physical strength		
3	My physical mobility	Physical mobility		
4	My mental composure	Mental composure	Mental health	
5	My intention	Intention		
6	My belief	Belief		
7	Relationships with my friends	Friends	Social health	
8	Relationships with my family and relatives	Family and relatives		
9	Relationships with my neighbors	Neighbors		
10	Convenience of living in the area where I live	Convenience	Convenience	Living environment (macro)
11	Ease of obtaining information necessary for living	Obtaining information		
12	Contents of welfare services in the area where I live	Welfare services		
13	Safety in the area where I live	Safety	Comfort	
14	Environmental hygiene in the area where I live	Environmental hygiene		
15	Natural environment of the area where I live	Natural environment		

We based the upstream factor structure on that of Nakajima et al. (2003)

1. Not satisfied, 2. Somewhat not satisfied, 3. Neither satisfied nor dissatisfied, 4. Somewhat satisfied, 5. Satisfied

of the path. The indirect effect refers to the product of the path coefficients between all the variables. Standardized total effect indicates the value obtained by standardizing the total effect. However, the factor analysis of SI-HRQOL in step 1 above produced the same results as those of Otsuka et al. (2016). On the other hand, for the results of the SDH index, factor analysis was performed with the same settings, but some items were excluded from the viewpoint of the initial value of commonality (Otsuka et al. 2016).

Theoretical hypothesis in the health determinants model

In this study, we modified the health determinants model as a theoretical hypothesis that infers the process of

Table 4 Items of social capital

No	Items	Abbreviation	Factor	Upstream factor
1	Do you think people can be trusted in general?	General trust	Trust	Social capital (meso)
2	Do you think your neighbors can be trusted?	Trust in neighbors		
3	Do you think your neighbors can work together to solve problems that need to be resolved locally, such as frequent crimes in your neighborhood?	Solving crime		
4	Do you think many of your neighbors will try to help others?	Cooperation between neighbors		
5	Interaction with my friends and acquaintances outside of school and work	Interaction with friends	Network	
6	Interaction with my family/relatives	Interaction with family		
7	Interact with my neighbors	Interact with neighbors		
8	Cooperation in daily life, such as consulting with each other and lending and borrowing daily necessities	Cooperation in daily life		
9	Everyday standing talk	Everyday standing talk		
10	Greeting	Greeting		
11	Number of neighbors interacting	Number of neighbors interacting		
12	Activities of territorial organizations	Territorial organizations	Norm	
13	Club/group activities related to sports/hobbies/entertainment	Sports club		
14	Activities of organizations related to volunteers, NPOs, and civic activities	Volunteers		
15	Activities of organizations related to society of commerce and Industry, business cooperatives, religions, politics, etc	Society of commerce and industry		
16	Activities of the Internet community related to the neighborhood	Internet community		
17	Events held in the neighborhood (festivals, athletic meet, concert, nature observation event)	Events		

No. 1–4: 1. Disagree, 2. Somewhat disagree, 3. Neither agree nor disagree, 4. Somewhat agree, 5. Agree

No.5–10: 1. Not at all, 2. Rarely (once a year–once every few years), 3. Occasionally (once a month–a few times a year), 4. Somewhat frequent (once a week–a few times a month), 5. Routine (every day–a few times a week)

No.11: 1. Acquaintance and interaction with quite a lot of people (generally 20 or more), 2. Acquaintance and interaction with some people (generally 5–19 people), 3. Acquaintance and interaction with only a few people (generally 4 people or less), 4. No interaction with neighbors

No.12–17: 1. Do not participate, 2. Less than once a year, 3. More than once every 6 months, 4. More than once a month, 5. Once a week, 6. 2–3 times a week, 7. Every day

determining the health status of urban residents based on the previous studies on SDH (WHO 2010a; Göran and Whitehead 1991; Braveman et al. 2011; BARHII 2020; Berkman et al. 2000; Kondo et al. 2018; Sugisawa 2012) and the results of the factor analysis mentioned in the previous section. We assumed that the theoretical hypothesis could divide the factors into three layers: the social infrastructure (macro) layer, community (meso) layer, and personal (micro) layer. In developing the model, we made some improvements to reflect factor and confirmatory factor analyses in the previous section. First, we set up three upstream factors (latent variables) in structural equitation modeling. For example, we established "health status" that summarizes the physical, mental, and social health, "living environment" that summarizes convenience and comfort in SI-HRQOL, and "social capital" that summarizes network, trust, and norm in the SC index. We set health status, living environment, and SC as latent variables in the

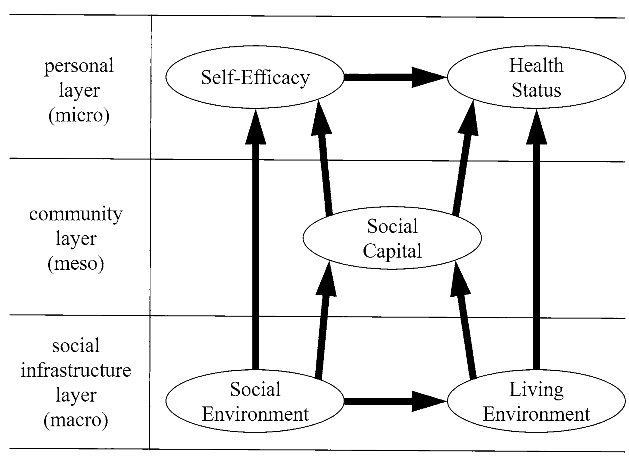


Fig. 3 Theoretical hypothesis for the health determinants model

personal, social infrastructure, community layers, respectively. Figure 3 shows the framework of the theoretical hypothesis in this study, wherein we hypothesized that the social and living environments exist as latent variables in the social infrastructure layer and directly or indirectly influence the latent variables in the personal layer such as self-efficacy and health status. Furthermore, we assumed that SC in the community layer directly affects the self-efficacy and health status in the individual layer and indirectly transfers the effects of social and living environments in the social infrastructure layer to the two factors in the personal layer. That is, in this theoretical hypothesis, we assumed that SDH determines the health status of the urban residents through the following process.

1. The social environment such as unemployment and work in SDH in WHO determines the comfort and convenience of the living environment (WHO 2010a; Göran and Whitehead 1991; Braveman et al. 2011; BARHII 2020; Berkman et al. 2000; Kondo et al. 2018; Sugisawa 2012).
2. The upstream two factors in social infrastructure create the community and the social capital according to the level of social and living environments.
3. Finally, the upstream three latent variables determine the self-efficacy and health status of urban residents.

While developing the model using the structural equation modeling, we adopted a model in which all the significant paths set in the theoretical hypothesis are 0.1% or less. When the paths set in the theoretical hypothesis were not significant, we sequentially removed the insignificant paths and revalidated the model. We employed Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Comparative Fit Index (CFI), and Root Mean Square Error of Approximation (RMSEA) to verify the suitability of the model. The model had good fitness when GFI, AGFI, and CFI were 0.9 or more and RMSEA was 0.05 or less. We used the standardized estimates to describe the path coefficients of the model.

There are two major differences between the theoretical hypothesis in this study and the study of Otsuka et al. (2016). First, the theoretical hypothesis of this model follows that of public health and social epidemiology for SDH (WHO 2010a; Göran and Whitehead 1991; Braveman et al. 2011; BARHII 2020; Berkman et al. 2000; Kondo et al. 2018; Sugisawa 2012). Therefore, the community layer (meso) and SC, which were not present in the model of Otsuka et al. (2016), were added to the model of this study. Second, this study and that of Otsuka et al. (2016) have very different research objectives. The purpose of the study by Otsuka et al. (2016) was to examine which path coefficient was affected by the difference in the frequency of use of public parks by multi-population path analysis.

Results

Factor structure of the observed variables

First, to understand the factor structure related to the psychological, social, and economic status of the participants, we performed a factor analysis on 14 items of the SDH index, and the results are shown in Table 5. We named the first factor "self-efficacy" because it contained the items that evaluated the sense of trust and ability toward oneself such as "the importance of existence". The second factor had items that evaluated the social exclusion in their groups such as the "labor environment". Since we reverse-coded these five items in the statistical analysis, we obtained that the higher the score in the five items, the better the socio-economic condition. Therefore, we named the second factor "social environment". The Cronbach's coefficient of confidence for each factor was 0.87 for the self-efficacy and 0.80 for the social environment. Note that we excluded the item "social gradient" in the analysis of the second factor because its initial value of commonality was less than 0.3 in the analysis of the first factor.

Next, to understand the factor structure related to the health status and living environment of the participants,

Table 5 Factor analysis of SDH index

Layer	Micro	Macro
Layer name	Personal layer	Social infrastructure
Factor	Factor 1	Factor 2
Factor name	Self-efficacy	Social environment
Importance of existence	0.85	− 0.09
Needed	0.85	− 0.15
Role	0.74	− 0.01
Dealing with stress	0.64	0.10
Relationships	0.63	0.10
Independence	0.55	0.05
Public support	0.51	0.07
Income and status	0.51	0.08
Labor environment	− 0.04	0.71
Isolation and loneliness	0.09	0.71
Discrimination and prejudice	− 0.08	0.69
Long-term stress	0.05	0.66
Unemployment	0.07	0.55
Factor correlations	Factor 1	Factor 2
Factor 1		0.44
Factor 2		
Cronbach's α	0.87	0.80

Table 6 Factor analysis of SI-HRQOL

Layer	Micro	Macro	Micro	Micro	Macro
Layer name	Personal layer	Social infrastructure	Personal layer	Social infrastructure	Personal layer
Factor	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Factor name	Physical health	Comfort	Social health	Mental health	Convenience
Upstream factor	Health status	Living environment	Health status	Health status	Living environment
Physical strength	1.00	− 0.02	0.00	− 0.08	0.00
Physical mobility	0.92	− 0.03	− 0.04	0.01	0.04
Physical condition	0.84	0.04	0.01	0.00	− 0.04
Mental composure	0.40	0.04	0.09	0.38	− 0.03
Environmental hygiene	− 0.03	1.02	− 0.04	0.01	− 0.07
Safety	0.01	0.85	− 0.01	0.01	0.00
Natural environment	0.00	0.72	0.05	0.01	0.01
Welfare services	0.06	0.40	0.07	− 0.05	0.31
Friends	0.01	− 0.08	0.86	0.08	− 0.04
Family and relatives	− 0.01	0.03	0.80	− 0.03	− 0.01
Neighbors	− 0.01	0.09	0.62	− 0.06	0.04
Intention	− 0.02	− 0.01	− 0.07	1.06	− 0.01
Belief	0.02	0.01	0.12	0.71	0.06
Obtaining information	− 0.01	0.03	− 0.03	0.01	0.92
Convenience	− 0.02	0.19	0.03	0.02	0.63
Factor correlations	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Factor 1		0.38	0.51	0.63	0.31
Factor 2			0.52	0.43	0.68
Factor 3				0.68	0.57
Factor 4					0.45
Factor 5					
Cronbach's α	0.91	0.88	0.82	0.88	0.82

we performed factor analysis on 15 items of SI-HRQOL, and the results are listed in Table 6. In this analysis, we hypothesized the five-factor structure following Nakajima et al. (2003). As a result, we obtained the same factor structure as Nakajima et al. (2003). Therefore, we named the first factor "physical health", the second "comfort", the third "social health", the fourth "mental health", and the fifth "convenience", and the Cronbach's coefficient of confidence for the factors was 0.91, 0.88, 0.82, 0.88, and 0.82, respectively. The results of factor analysis of the SI-HRQOL are the same as those of Otsuka et al. (2016) (Table 6).

Finally, to understand the latent structure related to SC of the participants, we performed factor analysis on 17 items in the SC index, as shown in Table 7. We named the first factor "network" because it contained the items related to the interaction with the neighboring residents such as "Everyday standing talk." We named the second factor "trust" because it contained the items related to the relationship between the neighboring residents such as "Trust in neighbors." We named the third factor "norm" because it contained the items related to participation in local activities such as the "Internet community". The Cronbach's coefficient of confidence was 0.85, 0.87, and 0.79 for network, trust, and norm, respectively. We excluded the four items in the SC index because their initial values of commonality were less than 0.3 in the first-factor analysis.

Although we performed factor analysis on all the three observed variables collectively, we found almost the same factors structures as the above.

Reconstruction of factor structure by confirmatory factor analysis

To build a model based on the theoretical hypothesis, we attempted to reconstruct the factor structure obtained by factor analysis in the SI-HRQOL and SC index. Figure 4 shows the results of confirmatory factor analysis in the SI-HRQOL and SC index. As a result, the most acceptable model in the SI-HRQOL models A-D from the viewpoint of model suitability was SI-HRQOL model B (GFI 0.973, AGFI 0.957, CFI 0.984, and RMSEA 0.042). On the other hand, SI-HRQOL models C and D, which include upstream factors of "health status" and "living environment" shown in Table 6,

Table 7 Factor analysis of social capital

Layer	Meso	Meso	Meso
Layer name	Community layer	Community layer	Community layer
Factor	Factor 1	Factor 2	Factor 3
Factor name	Network	Trust	Norm
Upstream factor	Social capital	Social capital	Social capital
Everyday standing talk	0.94	− 0.04	− 0.09
Interact with neighbors	0.86	0.02	− 0.04
Number of neighbors interacting	0.77	0.01	0.00
Cooperation in daily life	0.60	− 0.05	0.12
Trust in neighbors	0.01	0.88	− 0.07
General trust	-0.15	0.82	0.03
Cooperation between neighbors	0.07	0.74	0.05
Solving crime	0.07	0.73	− 0.03
Internet community	− 0.07	− 0.04	0.78
Volunteers	− 0.06	0.02	0.72
Society of commerce and Industry	− 0.04	− 0.06	0.69
Territorial organizations	0.18	0.07	0.57
Events	0.28	0.07	0.44
Factor correlations	Factor 1	Factor 2	Factor 3
Factor 1		0.50	0.47
Factor 2			0.22
Factor 3			
Cronbach's α	0.85	0.87	0.79

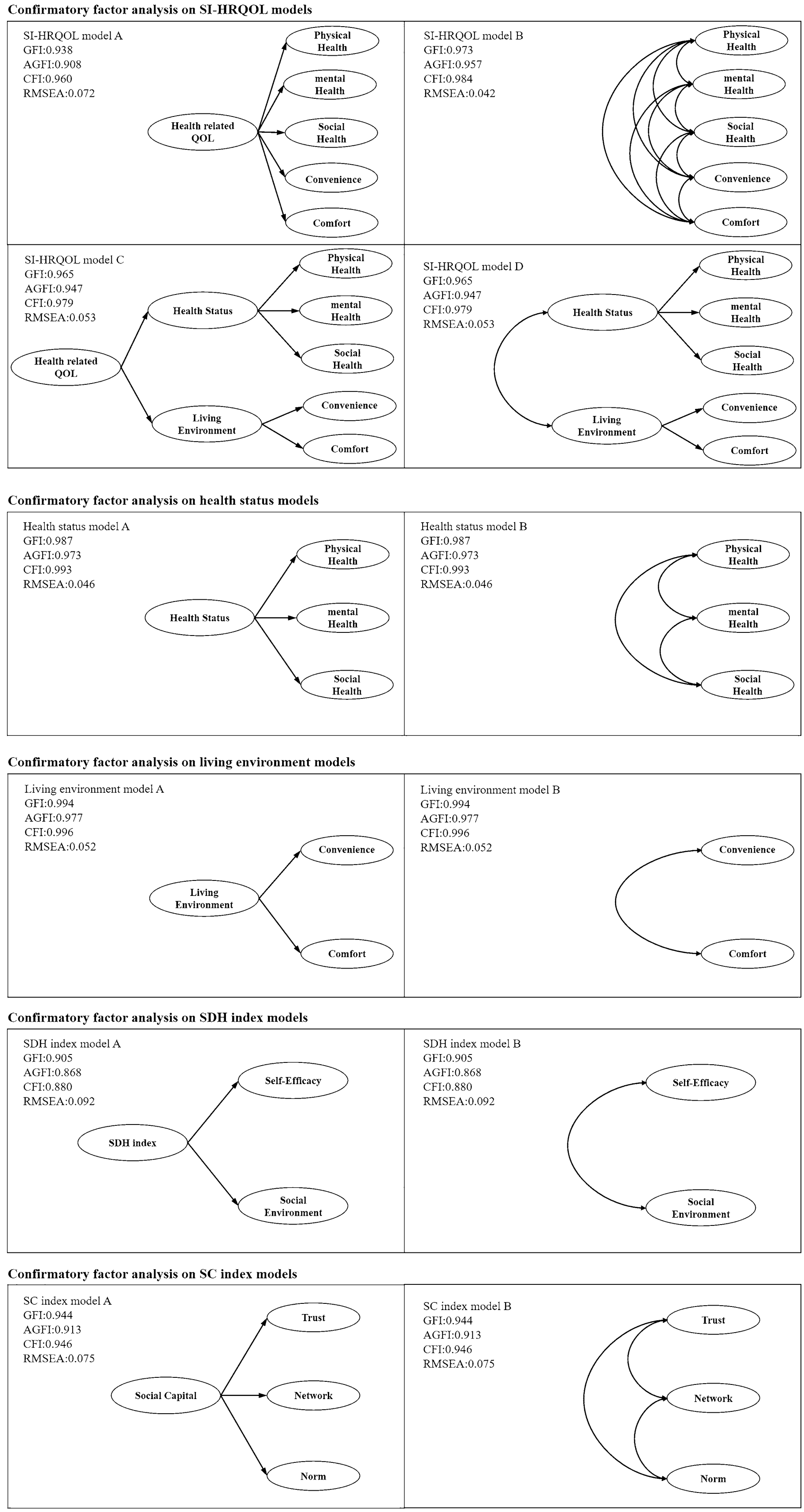
also had sufficient suitability to meet the set criteria. We adopted model D and built a new model based on the theoretical hypothesis. Furthermore, we performed confirmatory factor analysis on the respective factor structures of "health status" and "living environment." As a result, the suitability of health condition models A and B was GFI 0.987, AGFI 0.973, CFI 0.993, and RMSEA 0.046. On the other hand, the suitability of living environment models A and B was GFI 0.994, AGFI 0.977, CFI 0.996, and RMSEA 0.052. All four models were acceptable in terms of the suitability criteria set. We adopted model A for both the health status and living environment models. We also reexamined the factor structure of the SC index model by confirmatory factor analysis. As a result, the suitability of both SC index models A and B was GFI 0.944, AGFI 0.913, CFI 0.946, and RMSEA 0.075. In this study, based on the theoretical hypothesis, we summarized the three factors of the SC index shown in Table 7 by the upstream factor called "Social Capital."

Process of building hypothetical model: health determinants model

Building the health determinants model

Figure 5 shows the health determinants model based on the theoretical hypothesis by structural equitation modeling. For the model suitability, GFI was 0.913, AGFI 0.899, CFI 0.940, and RMSEA 0.043. The explanatory power (R^2) of the five main latent variables in the model was 43% for living environment, 28% for SC, 42% for self-efficacy, and 76% for health QOL. Regarding the relationship between the five main latent factors in the model, we describe the path flow below. First, "social environment," in which latent factors are located most upstream in the model, does not directly affect "health status," but indirectly affects health status through three routes. These three indirect effects branched into two routes, one via "self-efficacy" and the other via "living environment." Second, "living environment" had a direct effect and an indirect effect on "health status." The indirect effect of "living environment" went through social capital and self-efficacy. "Social capital" was only the indirect effect of "social capital- > self-efficacy- > health status. "Self-efficacy" had only a direct effect on "health status." The SI-HRQOL and sub-factor structures in the SC index in this model also supported the results of confirmatory factor analysis. However, two paths, that is, from the social environment to SC and from SC to health status, as assumed in the theoretical hypothesis were not established in the model. We excluded the former path from the model because it was not significant. On the other hand, the latter path was significant at the 5% level, but we excluded it from the model. This is because the p value generally tends to be lower when the sample size is larger, but the path is at the 5% level despite a sample size of 1,553. In addition, the significance of all other

Fig. 4 Analytical process in confirmatory factor analysis



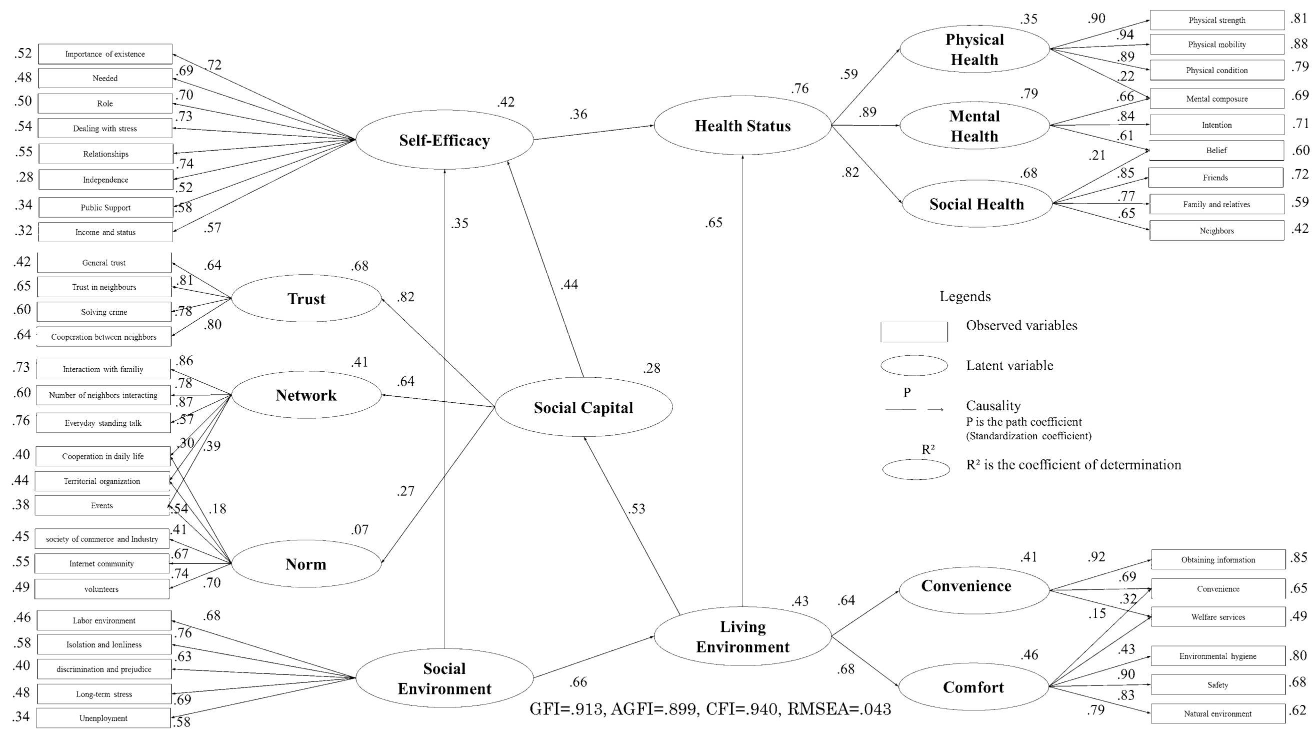


Fig. 5 Health determinants model

paths was at the 0.1% level. Therefore, we built a model with a unified significance level of 0.1% to not establish an exceptional path with a low significance level.

Inferring the effect of factors on health status

Table 8 lists the standardized total effect of each factor. The standardized total effect of the social environment was estimated to be 0.659 for living environment, 0.349 for SC, 0.500 for self-efficacy, and 0.606 for health status, that of the living environment was 0.530 for SC, 0.232 for

Table 8 Inferring the effect of factors on health status in the health determinants model

Major latent factors	Sub-latent factors	Affecting latent variables				
		Social environment	Living environment	Social capital	Self-efficacy	Health status
Affected latent variables						
Living environment		0.659				
	Convenience	0.422	0.640			
	Comfort	0.446	0.667			
Social capital		0.349	0.530			
	Trust	0.287	0.436	0.822		
	Network	0.223	0.338	0.637		
	Norm	0.093	0.142	0.267		
Self-efficacy		0.500	0.232	0.438		
Health status		0.606	0.723	0.156	0.356	
	Physical health	0.358	0.432	0.092	0.210	0.591
	Mental health	0.540	0.653	0.139	0.317	0.891
	Social health	0.499	0.603	0.128	0.293	0.824

self-efficacy, and 0.723 for health status, that of SC was 0.438 for self-efficacy and 0.156 for health status, that of self-efficacy was 0.359 for health status.

Discussion

Factor structures in the three observed variables

Table 5 indicates that the social gradient did not fit well into the two-factor structure of the SDH index. By contrast, social gradient is a representative indicator of SDH, so we infer that there is a hidden third factor related to the social gradient but independent of the self-efficacy and social environment in the SDH index. In future studies, this problem could be solved by adding the items to the SDH index that measures one's states of inequality such as subjective poverty, deprivation, and social gradient in detail.

Table 6 shows the results of factor analysis of SI-HRQOL from Otsuka et al. (2016). These results almost reproduced the factor structure assumed in Nakajima et al. (2003). Therefore, the appropriate factor structure for the health-related QOL of the participants can be obtained.

Table 7 shows the results of factor analysis of the SC index. After removing four items with an initial communality of less than 0.3 in the first-factor analysis, we obtained three factors in line with the definition of SC in Putnam (1993). Therefore, the appropriate factor structure for the SC of the participants can be obtained.

From the results of confirmatory factor analysis in Fig. 4, we confirmed that the upstream factors proposed in the theoretical hypothesis hold in the factor structures of SI-HRQOL and SC index. We found that even if we summarized the five factors in SI-HRQOL by the upstream factors of health status and living environment, as proposed in the theoretical hypothesis, SI-HRQOL model D showed sufficient suitability. In addition, we confirmed sufficient model suitability even when performing independently confirmatory factor analysis of both the health status and living environment in health status and living environment models. Therefore, we summarized the five factors of SI-HRQOL into the two following upstream factors: health status and living environment, in the theoretical hypothesis and positioned them in the personal (micro) and social infrastructure (macro) layers, respectively. We also performed a confirmatory factor analysis on the SC index. In conclusion, we found that the SC index model A, which summarizes the three factors shown in Table 7 by the upstream factor "social capital," is valid. Based on the results of the factor and confirmatory factor analyses, we constructed a three-layer model for SDH proposed in the theoretical hypothesis.

Health determinants model

Figure 5 shows the health determinants model built by structural equation modeling. Although this "Health determinants model" does not have some of the paths we have proposed in the theoretical hypothesis, we revealed that (1) the three-layer structure of SDH on cognitive mechanism of urban residents, (2) the relationship between the five main latent factors on SDH, and (3) the sub-factor structure of SI-HRQOL and SC index verified by confirmatory factor analysis are established as an integrated model of "Health determinants model." Therefore, this "Health determinants model" generally supported the three-layer structure of SDH and the structure of the five main latent factors in the theoretical hypothesis shown in Fig. 3. This means that even if we focus on the cognitive structure of urban residents, a causal relationship between the three-layer structure of SDH proposed and the major SDHs in public health and social epidemiology can be established. Therefore, the model could be acceptable with regard to suitability. Furthermore, many previous studies focus mainly on the relationship between living environment and health status, and the indicators and definitions of living environment are objectively measured such as the number or ratio of facilities and accessibility (Mitchell and Popham 2008; Maas et al. 2006, 2009; Hanibuchi et al 2011). Therefore, we considered that the "Health determinants model" provided a basic model for understanding the cognitive mechanism of SDH. However, the health determinants model in this study had a lower suitability index than the model constructed by Otsuka et al. (2016). On the other hand, the model suitability indicators met the set criteria. In the model, the social environment had no direct effect on the SC but indirect effect through the living environment. This indicates that even if a relationship had a direct causal relationship (path) in previous studies, it may be an indirect relationship via an intermediate factor. Alternatively, for models based on the cognitive mechanism of urban residents using subjective indicators, there may be a causal relationship different from the statistical model, including objective indicators. Berkman et al. (2000) and Sugisawa (2012) reported the possibility of confounding and intervening factors in health status, which is supported by the model developed herein. By contrast, the significance level of the path "SC → health" was 5%, which is poor compared to that of the other paths; hence, we excluded it to maintain the robustness of the model. This suggests that the relationship between SC and health status, which has been verified in previous studies (Maas et al. 2009), may actually be an indirect relationship mediated by self-efficacy. We note that it is strictly different from the study of Maas et al. (2009) because the model in this study focuses on the cognitive mechanism of urban residents. The explanatory power (R^2) of the five main latent variables in the model was 43% for the living environment, 28% for SC, 42% for self-efficacy, and 76% for health status. Therefore, the model can satisfactorily explain the health status of urban residents.

Living environment is the most influential variable of SDH on health status

From the results in Table 8, we conclude that the urban living environment, followed by the social environment, affect the health status of the residents the most, considering the SDH factors. In addition, the effect of the living environment on the health status is the most influential latent variable even with a model that employs the social environment as an upstream factor of the living environment. This indicates that improving the quality of living environment is the most effective way to promote the health of urban residents. However, because the social environment was the upstream latent variable that most affected all the latent and observed variables, including the living environment, improving the social environment could improve all the downstream variables.

This study revealed the relationships between the factors of SDH and health status and the estimated effect size of SDH to health status on the cognitive mechanism of urban residents for SDH. Therefore, improving the quality of living environment could also improve SC. These suggest that primordial prevention by improving the urban neighborhood living environment not only promotes the health condition of the residents but also revitalizes relationships in the community. In addition, SC had the second largest effect on self-efficacy, following the social environment. In other words, the relationships in the community contribute to the self-efficacy rather than the health status of the urban residents. In addition, the effect of self-efficacy on the health status was 0.356, which is less than that of other factors. However, the effects of self-efficacy on health status should not be ignored.

From the results of this study, we draw the following conclusions about the cognitive mechanism of urban residents for SDH:

1. Quality of urban living environments have the greatest effect on the health status of the residents considering the relationship with other factors of SDH such as social environment, SC, and self-efficacy in the health determinants model.
2. Improving the quality of urban living environment most promotes the health of the residents and regeneration of the neighboring community.
3. Social environments have not only a high impact on health status but also the highest effect on the self-efficacy of urban residents compared with various other factors of SDH.

Future studies should focus on the following:

1. Building more elaborate models to improve the investigation of the health status of urban residents
2. Evaluating the effect of the intervention on the urban living environment by longitudinal survey, cross-delay model, and simultaneous effect model in structural equitation modeling
3. Predicting the effect of intervention experiments on urban living environments, especially in populations with health risk factors, to close the health gap
4. Developing a comprehensive model to verify time-series changes that integrate both objective (quantity) and subjective (quality) indicators of SDH

This study has the following limitations. First, it is a cross-sectional study on Koto Ward, Tokyo Japan. Therefore, there is no confirmation as regards the reproducibility of the conclusions of this study. In addition, this study does not demonstrate the process and causal relationship between SDH on urban residents, but it deduces a framework for SDH.

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