The impact pathways of environmental, social, and behavioural factors on healthy ageing for urban dwellers aged 85+: Longitudinal study of the Tokyo Oldest Old Survey on Total Health (TOOTH)

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ABSTRACT

In the context of global population ageing and concentration in cities, the population aged 80 and over (80+) is growing rapidly. Japan has the fastest ageing population and longest healthy average life expectancy, while health decline becomes pronounced and care needs increase in the 85+ age group post the 'average life expectancy'. The healthy ageing of older urban community dwellers is a pressing issue in world initiatives for sustainable urbanisation. However, for the 85+ age group, less is known about how promoting/inhibiting factors and their pathways influence healthy ageing, and related longitudinal studies remain insufficient. Using data from a longitudinal cohort study conducted from 2008–2009 to 2014–2015 among independent dwellers aged 85+ in central Tokyo (men = 203, women = 232), this study analysed the impact pathways of environmental, social, and behavioural factors on health and survival to explore promoters and potential risks on healthy ageing by gender, with multi-group structural equation modelling (SEM) and Bayesian SEM. For both genders, there was a positive chained pathway starting from friends as facilitators through positive interactions between 'social participation' and 'active behaviour' to 'ageing-related health'. Additionally, their personal networks were small, suggesting that men with family-centred networks and women with non-family-centred networks require different approaches and supports. Implications of the results are discussed, and an organised social watch and support system, which becomes more important in the 'new normal' for urban dwellers aged 85+, is recommended.

1. Introduction

1.1. Older urban dwellers

Concerning global population ageing and urbanising (concentration in cities) trends, the population aged 80 and older (80+) has grown particularly fast. Japan, with the fastest ageing population, reached the 2050 world projection for ageing rate and 80+ population proportion about 30 years early, in 2019 (OECD, 2015; SBJ., 2020).

In Tokyo, the 80+ population exceeds one million (7.3% of the total population) (SBJ., 2020). The household size tended to be small, and in the central Tokyo wards of Shibuya, Shinjuku, and Minato, where this study was conducted, about half of elderly households with members

aged 65+ lived alone. The housing types were also distinctive, with more than 85% of total households located in residential complexes due to high land prices (T.M.G., 2018).

Older dwellers have been rarely considered in mainstream urban environment planning. However, many 85+ community dwellers in Tokyo preferred continuing to live and age at their home, with an attachment for the area where they currently lived and to reside with their family (T.M.G., 2019). While ageing in place may bring social and health benefits along with cost-effective solutions in sustainably aged societies (Van Dijk et al., 2015), we cannot overlook the possible downsides. Home in old age could be a place of negative experiences, such as isolation and loneliness, and could often have weaknesses in terms of informal support, social network, and the physical environment

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of the home and neighbourhood, consequently undermining a person's ability to live independently (Sixsmith et al., 2008).

1.2. Healthy ageing

The World Health Organisation (WHO) defines 'healthy ageing' as the process of developing and maintaining the functional ability that enables wellbeing in older age, which is focussed on through their 'Decade of healthy ageing' for 2020–2030 initiative. Functional ability comprises the intrinsic capacity of an individual, along with relevant environmental characteristics and the interaction between them. Relevant environments include the home, community, and broader society, as well as all factors within them, such as the built environment, people and the relationships with them, attitudes and values, health and social policies, and support systems and services (WHO, 2021a).

WHO's International Classification of Functioning, Disability and Health (ICF) describes and classifies information related to health, disability, and functioning based on the concept that individuals' levels of functioning and disability result from interactions between their health conditions, environmental factors, and personal factors (WHO, 2001). Based on this framework, we hypothesised that there were promoting/inhibiting environmental, social, and behavioural factors for ageing-related health and survival, and that the continuously positive interaction and effect of promotors, with preventing inhibitors, would mellow the health-decline process and enable healthy ageing. While Japan had the longest 'healthy average life expectancy' (HALE) (national average 74.1 years) in 2019 (WHO, 2021b), it was indicated that health decline was more pronounced and the need for nursing care became higher in the 85+ group post the 'average life expectancy' (national average 84.3 years in 2019) (Akiyama, 2020). Thus, since health conditions and environments are different in the early and late stages of old age, rather than combining all 65+ people into old age, we considered it important to focus on the 85+ age group and to clarify the factors that promote and inhibit their healthy ageing.

1.3. Health predictors and related mechanisms in old age

1.3.1. Social relationships

'Social network' is a concept focusing on the structural aspects of social relationships, where the personal (egocentric) network represents individual-centred connections among family and non-family members. Social relationships tend to dwindle in old age, and the decline in personal networks with ageing often begins with weak ties (Cornwell et al., 2015; Moore et al., 2016; Perry et al., 2012); this shrinking network could be attributed to external factors, such as physical decline, life events (e.g. bereavement), and prejudice (ageism; social attitudes and infrastructures that are not age-friendly) (Vitman et al., 2014), as well as to internal factors such as socioemotional selectivity, from the theory that older adults select relations favourable to themselves (Lang et al., 1998). Social networks are dynamic and operate within a variety of social settings. These contingencies have implications for health and wellbeing, necessitating the investigation of their intricacies when studying health in later life (Roth, 2020).

In addition to family, continuous relationships with friends and neighbours are considered to play important mental and practical roles for older urban dwellers to live in the community independently (Fischer, 1982; Suanet et al., 2013). Having more friends is associated with increased prosocial activities and improved health, in turn connected with closer relationships (O'Malley et al., 2012). Therefore, this study focussed on the relationships with family, close neighbours, and friends, who might be able to watch over and detect the health decline of older urban dwellers regularly. Since the assessment of network size and relationships is important to predict beneficial social resources for future health (Beller et al., 2018; Murillo et al., 2020), we assessed their relationship, size (number), and geographic proximity (residential location).

1.3.2. Predictors on health in old age

Social participation can help people maintain and build new connections. The effect may be strengthened by participation in diverse social activities, especially involving local community, hobby, or sports groups, which could be effective for decreasing disability risk (Kanamori et al., 2014; Tomioka et al., 2017).

Frequent outings are beneficial for older independent dwellers, and are correlated with reduced dysfunction and improved health measures (Jacobs et al., 2008). Outing frequency could predict changes in activities of daily living (ADL) (Kono et al., 2007). However, frequency reduces with ageing, and approximately one-third (30.8%) of 85+ community dwellers in Tokyo go out once a week or less (T.M.G., 2019).

Vigorous and moderate physical activity (PA) and adequate nutrition are also positively related to healthy ageing (Sowa et al., 2016). Practising a new exercise regimen in old age could improve health and cognition, even in previously inactive individuals (Hamer et al., 2014).

1.3.3. Mechanisms

Theories and models have been developed to understand the mechanisms by which social networks connect personal, social, and environmental contexts at multiple levels, and integrated into health sciences including biology and genetics. (Berkman et al., 2014; Pescosolido, 2006). Since various factors with influences of contextual variation affect health and longevity (Aida et al., 2018; Holt-Lunstad et al., 2010; Sowa et al., 2016), and ageing-related health has a complex decline, these effects should be comprehensively and simultaneously analysed to clarify the impact pathways on healthy ageing. Additionally, since there are gender differences in social relationships (e.g., networks, status, and roles) and other relevant environmental factors that influence health, these differences should be considered when analysing and interpreting the results of social health determinants in cohort studies (Moore et al., 2020; Nelson et al., 2011).

1.4. Study objectives

In Japan, the introduction of the Long-Term Care Insurance (LTCI) system in 2000 made it possible for people to receive social care and support at home. Meanwhile, older independent dwellers without officially certified care needs may be left to help themselves. Moreover, for urban dwellers aged 85+ with pronounced health decline, prediction and early detection are important, but may be hindered for members in aged-single and aged-couple-only households for several reasons (e.g., decline in cognitive function).

Studies focusing on home-based healthy ageing of 85+ independent urban dwellers remain insufficient. This study attempts to address this gap, aiming to clarify the promoting/inhibiting factors and impact pathways on healthy ageing in the urban community by gender.

Moreover, recently, older dwellers have been severely forced to restrict their social activities for coronavirus prevention, especially in urban areas with higher infections. We hoped that the results of this study would help to predict those restrictions' influence on the healthy ageing of older independent dwellers during the pandemic, and propose possible recovery strategies after the same.

2. Method

2.1. Study design and setting

Our data were derived from self-reported questionnaires and home-based interviews of the 'Tokyo Oldest Old Survey on Total Health' (TOOTH), a prospective observational cohort study: a longitudinal and multifaceted survey on life and health for 85+ independent community dwellers in central Tokyo. The TOOTH consisted of three waves: a baseline survey (Wave 1; 2008–2009) and two follow-up surveys for the remaining participants (Wave 2; 2010–2011 and Wave 3; 2014–2015), each of whom was examined according to the protocol followed in the

baseline. The study design, recruitment, measures, and procedure have been detailed in the TOOTH protocol (Arai et al., 2010). The TOOTH was approved by the ethical committee of XXX (ID:XXX) and registered in XXX (ID:XXX).

2.2. Analytic models

This study examined the interaction among personal, environmental, social, and behavioural factors and their impact pathways on health and survival days in the ageing process of dwellers aged 85–89 at baseline, using data for 6 years, until they reached their early 90s.

Fig. 1 illustrates two analytic models for this study, using 17 observed variables as structural variables, including four latent variables. In Model 1, we analysed the correlations among 'environmental factors:' seven observed variables regarding housing type, usage of care service, family and non-family relationships; 'behavioural factors:' two latent variables of social participants and active behaviour; and 'health:' two latent variables of ageing-related health status and independent living ability; using data of the eligible participants (n = 435) at Wave 1. Additionally, the impact pathways of these variables on 'survival days' observed for 6 years after Wave 1 were analysed. The eligible participants (n = 362) for Model 2 were those in Wave 2, conducted 3 years

after Wave 1. In Model 2, we analysed the correlations among environmental and behavioural factors at Wave 1, and the impact pathways of these variables on health at Wave 2 and survival days within the 3 years after Wave 2.

The heterogeneity or homogeneity between men and women were also analysed in both models. We did not analyse Wave 3 data (n = 187) because they were too few remaining participants for gender comparison analysis in structural equation modelling (SEM).

2.3. Study participants

As illustrated in Fig. 2, Model 1 had 435 participants (males (m): 203 [47%], females (f): 232 [53%]) out of the total 542 participants in Wave 1. Participants for Model 1 were selected based on the following criteria: At Wave 1 survey enrolment, they were aged 85–89 years (m: 86.67 ± 1.38, f: 86.84 ± 1.37), living independently, and having sufficient communication and memorisation abilities to complete the self-reported questionnaire during a home-based interview. As an objective assessment for these criteria, the Mini-Mental State Examination (MMSE) scores and officially certified long-term care levels were also used. The participants aged 85+, whose cognitive function generally tends to decline with ageing, scored 21 points or more in the 30-item MMSE,
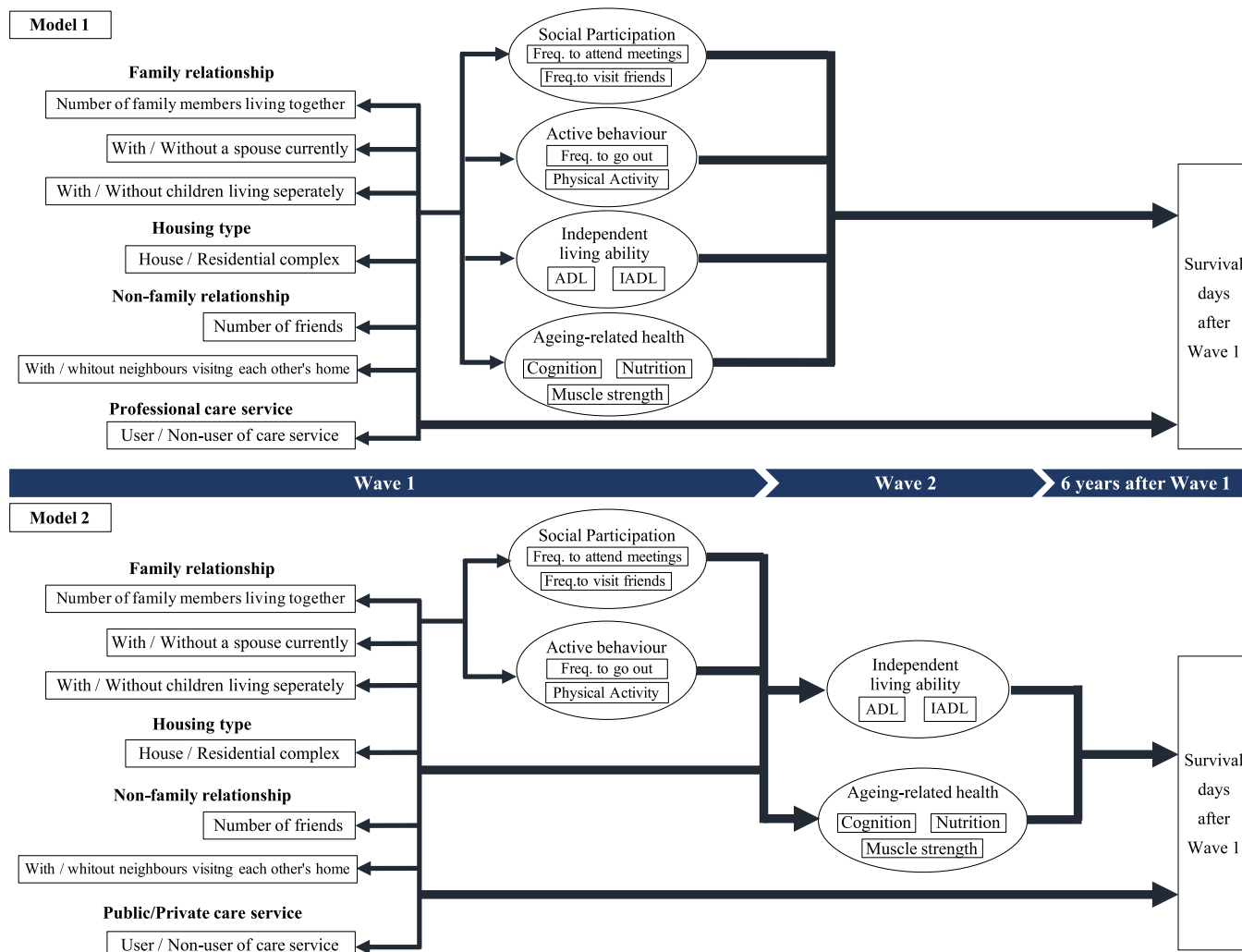
Notes) The rectangles are the observed variables and the ovals are the latent variables. The bold lines are the causal paths. The indicator observed variables are shown within the oval latent variable. To avoid confusing lines and make it easier to see the arrows, the arrows are grouped together, but meaning an arrow from each variable to each variable. Freq.: Frequency, ADL: Activities of daily living, IADL: Instrumental ADL

Fig. 1. Analytic model illustrating the paths from behavioural factors with environmental factors to health and survival.
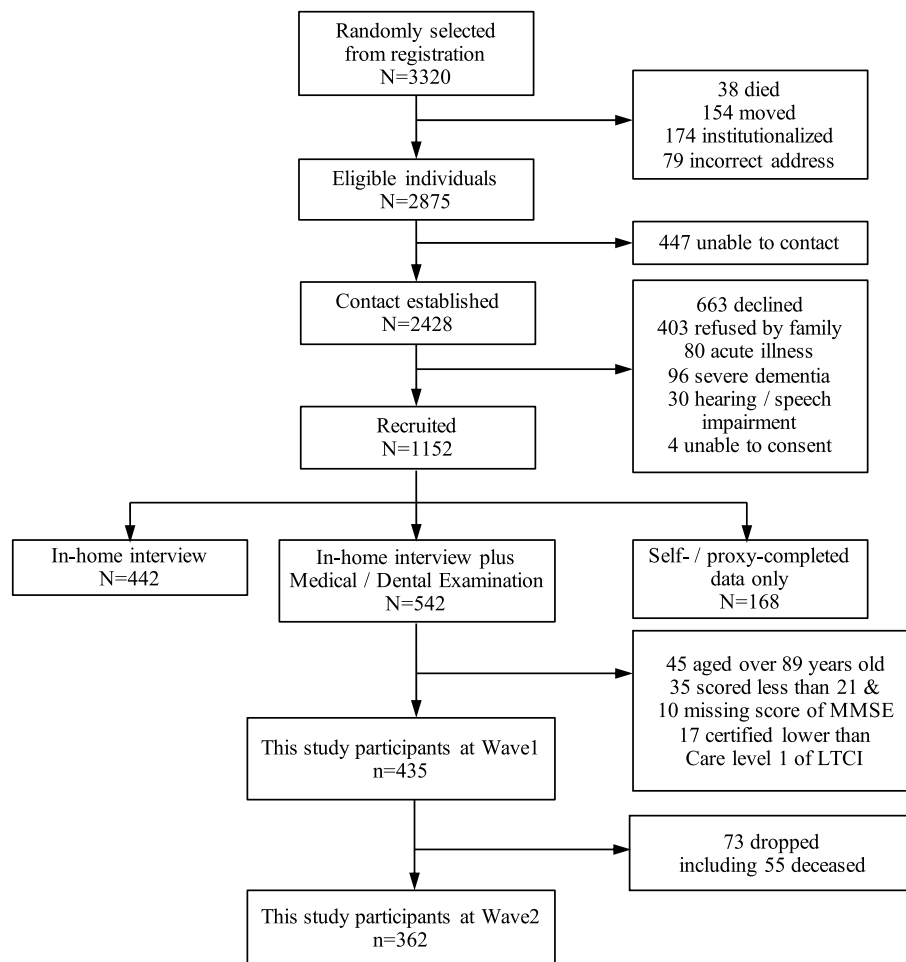
Notes) MMSE: Mini-Mental State Examination, LTCI: Japan's Long-Term Care Insurance Act

Fig. 2. Flowchart representing the selection criteria of the analytical participants.

which is commonly used to evaluate global cognitive function (Folstein et al., 1975; Ganguli et al., 2010). Given that 'Care level 1', as certified by Japan's LTCI Act, is equivalent to independence in ADL, with only partial support in instrumental ADL (IADL), a 'Care level 1 or better' was deemed to support HALE (Tomioka et al., 2020; Ueki, 2008). In other words, the eligible participants included those who were able to live in the community on their own, with only partial public support; or even with mild functional disability, who had not been certified by the LTCI.

Model 2 had 362 participants (m: 165 [46%], f: 197 [54%]), who survived for 3 years from Wave 1 and participated in the Wave 2 survey, out of the Model 1 participants.

2.4. Measures

2.4.1. Environmental factors

1)'Housing type' was binary: i) a single-family house or ii) a residential complex (multi-family house), and used to clarify related differences based on family and non-family relationships.

Family relationship was assessed by three observed variables: 2) 'Number of family members living together', 3) '1:With/0:Without a current spouse' and 4) '1:With/0:Without children living separately'. Non-family relationship was assessed by two observed variables: 5) 'Number of friends' and 6) '1:With/0:Without close relationship with neighbours who visit each other's home'. Among the above binary variables, 3), 4) and 6), were sub-grouped based on 'with' or 'without', and used to clarify the difference depending on them in family and non-family relationships, behaviours, and health.

While approximately 20% of the participants for Model 1 had required support/care certified by Japan's LTCI, only 16% reported the usage of care services. The binary variable of 7) 'with/without usage of public/private care services' was used to clarify the associated difference in other relevant environments, behaviours and health.

2.4.2. Behavioural factors

The latent variable 'social participation' was a common factor for two variables: 8) 'Frequency of visiting friends' and 9) 'Frequency of participating in meetings', and comprised data from six-point Likert scales, where higher frequency corresponded to higher scores. The meetings were gatherings of organisations and groups such as local communities, hobby/sports groups, retirees/alumni associations, and social activities. Another latent variable, 'active behaviours' representing being physically active in daily life, was a common factor for variables 10) and 11). 10) 'PA per week' (Metabolic equivalents (METs) hours/week) was calculated from the modified Zutphen PA questionnaire by PA intensity and duration, of which validity had been verified by comparison with the measurement result of the accelerometer (Oguma et al., 2017). 11) 'Outing frequency' was inversely coded from the original responses, such that a higher frequency indicated higher scores among five-point Likert scales.

2.4.3. Health and survival

We structured two latent variables to evaluate healthy ageing from the following four aspects: physical function, cognitive function, nutritional status, and independent living ability.

The first latent variable, 'ageing-related health', represented a common factor for three variables: 12) 'Handgrip strength' of the dominant hand, measured in duplicate using a hand-held dynamometer (Tanita 6103, Tanita co-operation, Tokyo, Japan), as a measure of physical function based on muscle strength (Arvandi et al., 2016); 13) score on the MMSE as a measure of cognitive function; and 14) 'Plasma albumin' (Corti et al., 1994) as a measure of nutritional status (Hirata et al., 2020). Another latent variable was 'independent living ability' by self-report, of which higher scores indicated lower needs for care-/assistance. This represented a common factor for two variables: 15) 'ADL', consisting of 10 items (meal, transfers to bed, toileting, grooming, bathing, dressing, walking, taking the stairs, bladder and bowel control), evaluated by the Barthel index (Mahoney et al., 1965); and 16) 'IADL', which was assessed by five items (using the phone, shopping, using transportation, managing medication and finances), which were selected from the Lawton measurement scale (Lawton et al., 1969).

Additionally, 17) 'survival days' were ascertained through telephone contact or mail surveys conducted every 12 months for 6 years post-Wave 1 until 2015 (maximum of 2,190 days).

2.4.4. Covariates (Personal factors)

2.4.4.1. Demographic characteristics (age, household budget, gender).
The demographic characteristics that could affect health were stratified or considered to be controlled as follows. The age range was limited to 85–89 years. In the household budget self-assessment, 86.4% of the participants responded 'neither straitened or easy', 'easy', or 'very easy', and the majority had socioeconomic status with cumulative advantages through their life course. There were no significant gender differences in age and household budget. This study took gender into account in the analysis and interpretation of results.

2.4.4.2. Medical history.
Medical history of cerebrovascular disease; cancer; heart disease; diabetes; lung disease; gastrointestinal, liver, or gallbladder disease; kidney disease; and thyroid disease was examined through medical interviews at Wave 1. The missing data for each disease was less than 10%. As a result of the χ^2 test, there were no gender differences in the distribution ratios of each disease except diabetes (m: 17.2%, f: 8.2%) and thyroid disease (m: 2.1%, f: 8.5%), whose prevalence rates were low. In addition, the Mann–Whitney U test indicated no significant difference in survival days by the presence of each disease. Therefore, medical history was considered to be of rather low impact for participants in this study, and was not used as a structural variable in our analytic models.

2.4.5. Analyses

2.4.5.1. Structural equation modelling/missing values/estimation method.
The multiple-group (gender-group) structural equation modelling (MG-SEM) with confirmatory factor analysis (CFA), using the maximum likelihood estimation (ML) method was used to analyse the related pathways among structural variables, and the homogeneity/heterogeneity between gender groups simultaneously.

Each missing value of the 17 observed variables was less than 5% for men and women at Wave 1. Each missing value of five observed variables (ADL, IADL, MMSE, Albumin, and Handgrip) at Wave 2, used for Model 2, was less than 20% for men and women. The Full Information Maximum Likelihood estimation (FIML) method was used to compensate for all missing values.

Because the observed variables used in this study were not normal distributions, to verify the ML estimation results, we also analysed same models using Bayesian SEM (BSEM) based on the Markov chain Monte Carlo algorithm, which has better properties than conventional SEM for non-normal distributions (Arbuckle, 2019).

In BSEM, the prior distribution of each variable was set as non-informative (diffused) uniform distribution; the burn-in period included 500 samples, which were considered sufficient to ensure that convergence in distribution was attained, and that the analysis samples were indeed samples from the true posterior distribution. The acceptable criterion of the convergence statistic was set at < 1.002, which was highly conservative compared to the value (≤ 1.10) suggested by (Gelman et al., 2004).

2.4.5.2. Model diagnostics/significant level/software.
A model fit for MG-SEM with ML estimation is considered good when the comparative fit indices (CFI) are >0.95, and the root mean square error of approximation (RMSEA) is < 0.05 (Hooper et al., 2008). The statistical significance level was set at $p < 0.05$.

The model fit of BSEM was assessed with posterior predictive p-values and the 95% credible interval (CI). A well-fitting model should have a p-value around 0.50, which implies a 50% concentration in the middle of the distribution. The Bayesian 95% CI, generated for all parameters, was interpreted as a probability statement about the parameter. It meant that there was a 95% probability that the true value exists within the interval.

IBM® SPSS® Statistics 26 and Amos TM 26 (IBM Corp., Armonk, NY, USA) software were used for analysis.

2.4.6. Procedure
We first verified the structure of the CFA by gender, assuming covariance among the four latent variables for the behavioural factor and health. Next, the model was revised, as necessary, by allowing only residual covariances based on existing theoretical evidence.

In the analysis of Models 1 and 2 by MG-SEM with ML estimation, after verifying the configural invariance between gender groups, we analysed the measurement invariant models (models with metric invariance), which were constrained to be equal to the factor loadings of four latent variables for behavioural factors and health between the groups, to ensure that the interpretive meaning of latent variables between the groups was consistent.

Moreover, Models 1 and 2, with metric invariance for both gender groups, were analysed by Bayesian SEM to verify the results with those by MG-SEM with ML estimation.

3. Results

3.1. Descriptive statistics

The participants' characteristics by gender are summarised in Table 1. In Wave 1, significant gender differences were found in housing type, number of family living together, having a current spouse, having children who live separately, usage of care services, and frequency of visiting friends. Women were more likely to live in residential complexes, have no spouse currently, live alone, use care services, and visit friends frequently. However, personal networks were small for both genders. Although many participants had children (m: 90%, f: 81%), the majority lived in the small household with single or 2 individuals (m: 76%, f: 74%). A median range of only 1–2 friends was observed, and only 5–15% had close relationships with neighbours.

In health, ADL was significantly lower among women than men in both Waves 1 and 2. Moreover, although both cognitive function and IADL showed no gender differences in Wave 1, both variables became significantly lower among women than men in Wave 2. Nevertheless, women significantly had more survival days than men.

3.2. Gender-group structural equation modelling

3.2.1. CFA and configural invariance
In the CFA of Model 1, assuming covariance among the four latent factors, all latent factors significantly affected each corresponding

Table 1

Descriptive statistics of participants by gender.

Observed variables	Male		Female		Gender difference
TOTAL n = 435	203	46.7%	232	53.3%	
n = 362	165	45.6%	197	54.4%	
Age	86	85–88	87	86–88	p = 0.176[a]
Household budget					p = 0.489[b]
Not straitened	171	84.2%	205	88.4%	
Housing type					p = 0.010[b]*
Residential complex	73	36.0%	113	48.7%	
Marital status					p < 0.001[b]***
Without a spouse currently	50	24.6%	198	85.3%	
Number of family members living together	2	2–2	1	1–2	p < 0.001[a]***
Living alone	35	17.2%	120	51.7%	
Children living separately					p = 0.014[b]*
Yes, I have	163	80.3%	161	69.4%	
Neighbours visiting each other's homes					p = 0.103[b]
Yes	17	8.4%	32	13.8%	
Number of friends	1	0–3	2	0–3	p = 0.547[a]
None	82	40.4%	82	35.3%	
Usage of care service					p = 0.019[b]*
User	23	11.3%	47	20.3%	
Frequency of visiting friends					p = 0.010[b]*
More than once a week	37	18.2%	78	33.6%	
No visit	60	29.6%	55	23.7%	
Frequency of attending meetings					p = 0.619[b]
More than once a week	40	19.7%	53	22.8%	
No participation	107	52.7%	102	44.0%	
Physical Activity (METs hours/week)	9.3	3.0–19.6	7.0	2.8–14.6	p = 0.146[a]
Outing frequency					p = 0.224[b]
More than once a day	133	65.5%	131	56.5%	
Infrequent	10	4.9%	11	4.7%	
Activities of daily living: ADL	100	100–100	100	100–100	p = 0.013[a]*
W2	100	95–100	100	90–100	p < 0.001[a]***
Instrumental ADL	5	5–5	5	4–5	p = 0.387[a]
W2	5	4–5	5	3–5	p = 0.005[a]**
Mini-Mental State Examination	28	26–29	27	25–29	p = 0.064[a]
W2	28	25–29	27	25–29	p = 0.045[a]*

Table 1 (*continued*)

Observed variables	Male		Female		Gender difference
Albumin (g/dL)	4.1	3.9–4.3	4.1	4.0–4.3	p = 0.258[a]
W2	4.1	3.8–4.3	4.1	3.9–4.4	p = 0.251[a]
Grip strength (kg)	24.8	21.5–27.5	16.5	14.1–19.0	p < 0.001[a]***
W2	22.0	18.9–24.6	15.0	12.5–17.8	p < 0.001[a]***
Survival days for 6 years	2,114	1,290–2,190	2,190	1,459–2,190	p = 0.027[a]*

Notes) Values are expressed as numbers and percentage or median and inter-quartile range, a: Mann–Whitney U test, b: χ^2 test, *: p < 0.05, **: p < 0.01, ***: p < 0.001, W2: Wave2, Wave not shown: Wave1.

observed variable in both men and women. Although both the models for men and women showed a good fit (CFI>0.95, RMSEA<0.05), in the model for men, the correlation coefficient between the latent variables of 'active behaviours' and 'independent living ability' was 1.09, which was slightly higher than 1.00 and improper. The model, assuming the residual covariance between 'outing frequency' (from 'active behaviours') and ADL (from 'independent living ability') was adopted based on the theoretical rationale of their association (Kono et al., 2007).

The configural invariance of Model 1 was verified between gender groups with a good fit for each group, as shown below:

Males: CFI = 1.000, RMSEA = 0.000
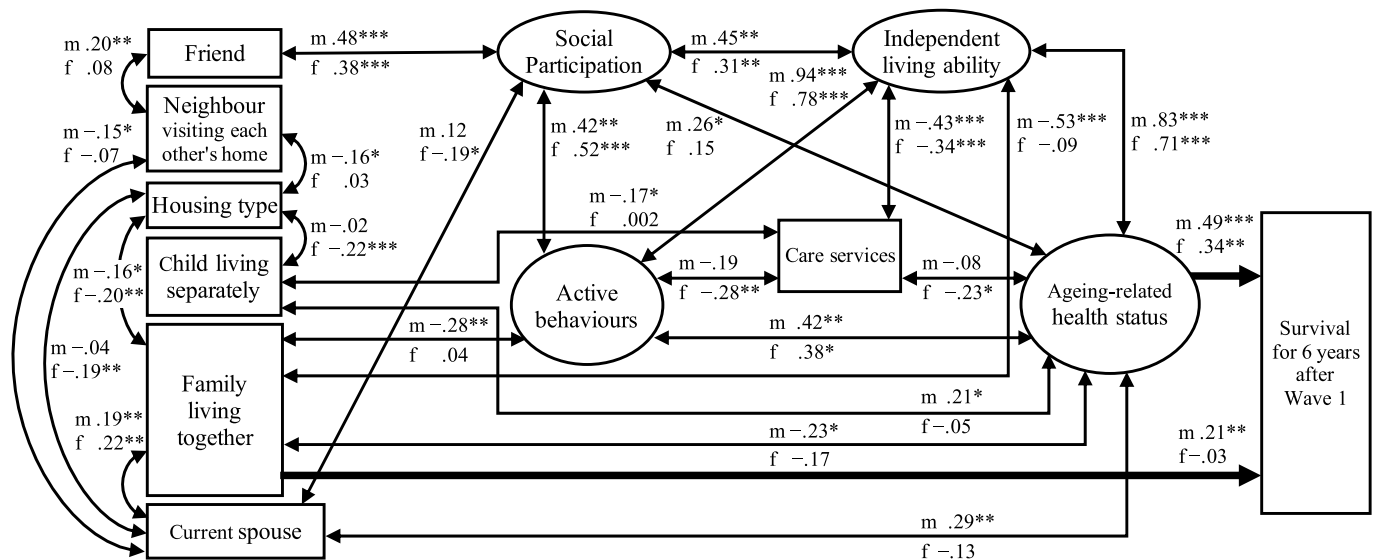
Females: CFI = 0.963, RMSEA = 0.021

3.2.2. Significant coefficients in Model 1

Appendix 1 presents the summative results of the unstandardised and standardised coefficients of significant pathways in both, or either, men and/or women in Model 1, comparing the MG-SEM by ML estimation with BSEM. The MG-SEM showed a good fit (CFI = 0.998 and RMSEA = 0.003 in configural invariance between gender groups, CFI = 0.997 and RMSEA = 0.004 in metric invariance). In the BSEM, each posterior predictive p-value for men and women was exactly 0.50, which showed a well-fit model. Since every estimate in the MG-SEM was within the 95% CI estimated by the BSEM as well as without positive or negative sign discrepancy, we illustrate the diagram of significant paths in Model 1 with standardised coefficients of the MG-SEM in metric invariance (Fig. 3).

3.2.2.1. Major gender homogeneity.
Participants who lived in single-family houses had a higher number of family members living together. Those with more friends tended to have greater social participation, leading to positive interaction with active behaviour and independent living ability. Those with higher active behaviour also had better ageing-related health and independent living ability. Those with low independent living ability tended to use care services. Those with better ageing-related health also lived longer, with a significant positive effect.

3.2.2.2. Male-specific significant paths.
Male participants had more family members living together when the levels of active behaviour, independent living ability, and/or ageing-related health were lower, leading to a positive impact on survival. Those with children who lived separately were less likely to use care services. Those with a spouse and/or those with greater social participation had better health. Those without a spouse and/or who lived in single-family houses were more likely to have close relationships with neighbours.

3.2.2.3. Female-specific significant paths.
Female participants tended to use more care services regardless of their family members when the levels of active behaviour and/or ageing-related health were lower.

Notes) Standardised coefficients by gender (m: for men, f: for women) in Model 1 are showed. The bold lines are causal paths.

All variables except Survival were data from Wave 1. *: p<0.05, **: p<0.01, ***: p<0.001, no astrisk: not significant.

Fig. 3. Significant paths in Model 1 of the MG-SEM with metric invariance.

Those without a spouse and/or without children who live separately tended to live in residential complexes. Those with a spouse had less social participation.
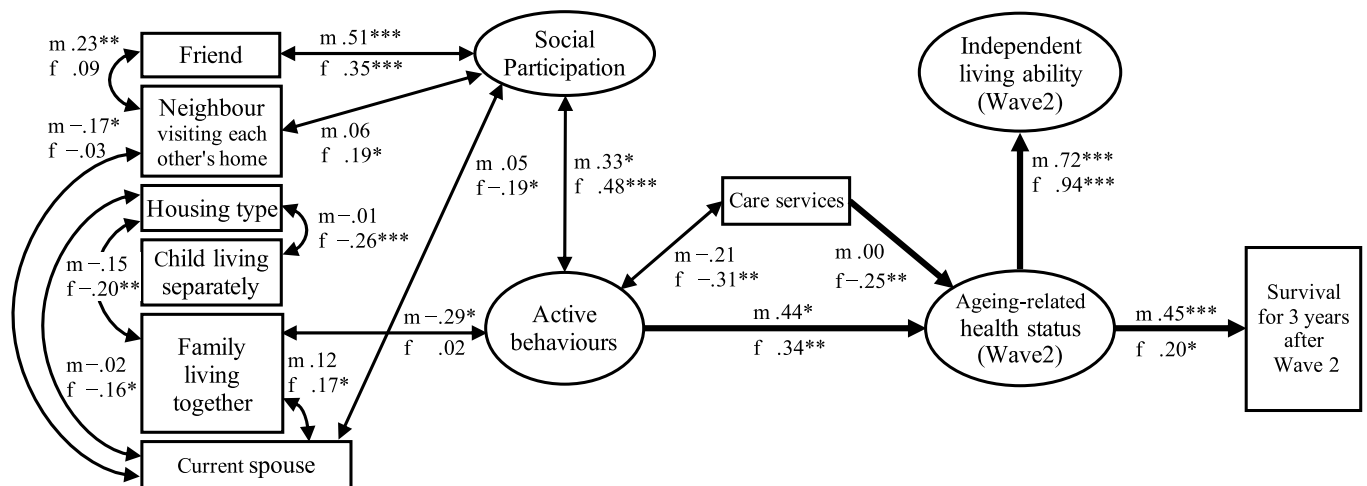
3.2.3. Significant coefficients in Model 2

As in Model 1, Appendix 2 presents the summative results in Model 2, comparing the MG-SEM by ML estimation with the BSEM. The MG-SEM showed a good fit (CFI = 0.989 and RMSEA = 0.010 in configural invariance between gender groups, CFI = 0.977 and RMSEA = 0.014 in metric invariance). In the BSEM, each posterior predictive p-value for men and women was 0.50, which showed a well-fit model. As in Model 1, since every estimate in the MG-SEM was within the 95% CI estimated by the BSEM, as well as without positive or negative sign discrepancy, we illustrate the diagram of significant paths in Model 2 with standardised coefficients of the MG-SEM in metric invariance (Fig. 4). Overall, Model 2 was a simpler route with fewer significant paths than Model 1.

3.2.3.1. Major gender homogeneity. As in Model 1, participants with more friends tended to have higher social participation, leading to higher active behaviour. A greater amount of active behaviour at Wave 1 had a positive effect on ageing-related health at Wave 2. Preferable ageing-related health positively affected independent living ability and survival.

3.2.3.2. Male-specific significant paths. As in Model 1, male participants tended to have more family members living together when active behaviour was less. Those without a spouse and/or having more friends were more likely to have close relationships with neighbours.

3.2.3.3. Female-specific significant paths. As in Model 1, female participants without a spouse and/or without children who live separately tended to live in residential complexes. Those having more family members tended to live in single-family houses. Those with a spouse had

Notes) Standardised coefficients by gender (m: men, f: women) in Model 2 are showed. The bold lines are causal paths.

No description of measurement period means data from Wave 1. *: p<0.05, **: p<0.01, ***: p<0.001, no astrisk: not significant.

Fig. 4. Significant paths in Model 2 of the MG-SEM with metric invariance.

less social participation, while those who had close relationships with neighbours had greater social participation. Those with less active behaviour used care services. Those using care services at Wave 1, whose health was already lower, tended to experience further decline in health at Wave 2.

4. Discussion

4.1. Gender common features

For both men and women aged 85+, personal networks were small, as previous studies indicated (Moore et al., 2016). However, one positive chained pathway was identified: the number of friends interacted with social participation; social participation interacted with active behaviour; active behaviour positively affected ageing-related health; and ultimately, ageing-related health affected independent living ability and survival; further, health and independence interacted with social participation and active behaviour in a cycle. Each relation among variables, that is, effects of participation on health (Kanamori et al., 2014; O'Malley et al., 2012), activity on health (Jacobs et al., 2008; Kono et al., 2007; Sowa et al., 2016), and social relationship on survival (Aida et al., 2018; Holt-Lunstad et al., 2010) was as shown in previous studies. This study clarified one circulating sequence common to 85+ males and females in the above-mentioned relations embedded in the mechanisms for environmental and behavioural factors on healthy ageing shown in previous studies (Berkman et al., 2014; Pescosolido, 2006). The results suggested that 'friends' were the starting point of this positive pathway and could facilitate healthy ageing for both genders, supporting that non-family ties were important for older independent dwellers in urban communities (Fischer, 1982; Suanet et al., 2013).

4.2. Gender heterogeneity

4.2.1. Female features

In this 85+ cohort, where husbands are often older than their wives, female participants were more likely to be widowed and live alone than males. Females visited friends more frequently and had stronger positive correlation between social participation and active behaviour than males. Moreover, having close relationships with neighbours directly interacted with social participation. Thus, it was further highlighted that there was a gender difference in the importance of social participation, which had a greater interaction with maintaining non-family relationships and activity affecting healthy ageing for females than for males, similar to previous studies in other age groups (Tomioka et al., 2017). Meanwhile, those with a spouse tended to have less social participation. Wives, even aged 85+, seemed to continue housework, take care of and prioritise their older husbands over their own social participation, despite social participation's mitigation of caregiving's negative impact on mental health (Oshio et al., 2016). Furthermore, females with low levels of activity/health/independent living ability tended to use care services rather than family networks. Given that females survived longer than males, they could have self-managed their healthy ageing well with non-family-centred networks.

While this self-management could be successful in normal times, the concern is that the recent COVID-19 pandemic makes it difficult to socialise with friends, attend meetings, and go out daily (Arai et al., 2021). Considering the downside of ageing in place (Sixsmith et al., 2008), older urban independent dwellers, such as female participants with self-managed healthy ageing, may experience higher risks of behavioural restraints, causing them to be home-bound (seclusion) and socially isolated, triggering a vicious chained influence on healthy ageing.

While most females can afford to use care services, our results suggested that, without early detection, single or couple-only households were at a potential risk of not receiving timely support if they are unaware of their own deteriorating health and are unable to seek help urgently.

4.2.2. Male features

Male participants without a spouse and/or living in single-family houses had significantly close relationships with neighbours. Those with neighbourhood relationships also tended to have more friends, supporting that social context pertaining to family composition and personality contributed to maintaining personal networks in old age (Lang et al., 1998). Those with such social relationships could have been watched over regularly.

When their activity, health, and independent living ability were lower, males tended to live with more family members, which positively affected their survival. Additionally, those with children living separately tended to maintain better health and use fewer care services. Males with a spouse tended to be in better health (Umberson et al., 2010), suggesting that wives managed husbands' health and could be their primary caregivers when the husbands' health declines. These results support that Japanese men tend to be supported by a family-centred network (Aida et al., 2018), suggesting that even if males' health started to decline, daily care from their family maintained their subsequent healthy ageing. It also implies that wives continue to play their domestic role without retirement, even when aged (Nelson et al., 2011). Considering the potential risks behind a shift to family-centred relationships associated with the inability to develop new non-family ties and/or health decline (Cornwell et al., 2015; Moore et al., 2016), wives who tend to prioritise their husbands over socialising could experience a great burden in caring for older husbands due to dwindling non-family ties (Oshio et al., 2016).

4.3. Limitations

This research has several limitations. First, the following biases were recognised in this study: 1) regional bias (central Tokyo area populated densely and designed for working generation, influencing social relationships and activities); 2) economic bias (about 86% of the participants were economically stable, impacting daily behaviours and support selection); 3) health bias (inconclusive relationship between medical history and survival as participants were healthy enough to take the survey); and 4) personality bias (cooperative and sociable participants, traits that could influence their social relationships and behaviours). Second, since this study used only a binary variable indicating the presence/absence of a current spouse, it did not consider whether there were any psychological differences that may affect behaviour and health among participants without a current spouse based on whether they never married or were divorced or widowed. Third, there were only 435 participants in this study, which was limited by the selection of analysis targets, thus limiting the generalisability of the results. Fourth, since the TOOTH baseline survey was conducted in 2008–2009, it is necessary to compare and verify these results with those of more recent surveys. Finally, it is necessary to compare and validate this study with research conducted in metropolitan areas in other countries to further clarify the research supporting sustainable ageing and urbanising societies worldwide.

4.4. Implications

Our findings indicated that certain individual qualities and contexts among older urban dwellers may have impacted their ability to live in the community. The results also shed light on contextual factors related to the COVID-19 pandemic. The time has come to provide opportunities and places for encounters and exchanges, to create new human relationships in an organised manner rather than leaving social connections to the spontaneous generation of individuals as in the past (Haseda et al., 2019).

Further, we believe that it is necessary to watch over and understand not only the health and living conditions of older urban dwellers and their informal caregivers, but also their psychological conditions, before they suffer mental crises (Oshio et al., 2016).

Lastly, considering the fact of the increase in crime targeting older people in urban areas, it would be necessary to build a support system for older adults, focusing on promoting social relationships and community ties in sustainable urbanisation, with the involvement and management of the government and related organisations, in consideration of crime prevention, rather than simply promoting interaction in the local community.

5. Conclusion

This study identified one circulating sequence common to 85+ males and females living independently in urban communities, which was linked from friends to health through social participation and active behaviours.

Given the gender-related social and health differences observed in our study, support approaches for the early detection, treatment, and improvement of health decline should be different between genders.

Ethics approval

The TOOTH was approved by the ethical committee of the Keio University School of Medicine (ID:20070047) and registered in the University Hospital Medical Information Network Clinical Trial Registry (ID:UMIN000001842).

CRediT authorship contribution statement

Natsuko Yoshida: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Yasumichi Arai:** Investigation, Resources, Data curation, Writing – review & editing, Funding acquisition. **Midori Takayama:** Investigation, Resources, Data curation, Writing – review & editing. **Yukiko Abe:** Resources, Data curation, Writing – review & editing. **Yuko Oguma:** Investigation, Resources, Data curation, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2022.101089.

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