Comparing the differences in three measures of healthy life expectancy, effects of mortality, and proportions of unhealthy people according to prefectures in Japan: An Ecological study

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Abstract

Objective

Ecological study using open data collected, compiled, and published in government statistics in Japan was conducted. The study aimed to verify the differences in these three measures of healthy life expectancy (HLE), namely disability-free life expectancy without activity limitation (DFLE-AL), life expectancy with self-perceived health (LE-SH), and disability-free life expectancy without care need (DFLE-CN), in relation to appropriate policymaking.

Results

Using data from 47 prefectures in 2010, 2013, and 2016, the three types of HLE were extended over time. There were strong correlations between DFLE-AL and LE-SH ($r = 0.69–0.83$) as well as LE and DFLE-CN ($r = 0.75–0.98$) in both sexes. However, the other correlations were either weak or not significant. Regression analysis examining the association between the aging rate, mortality, the proportion of unhealthy people and three types of HLE showed that the “subjective unhealthy rate” was significant (the standardized partial regression coefficients = -0.56– -0.34) in models with DFLE-AL and LE-SH as dependent variables. Therefore, DFLE-CN was suggested to be a different indicator from the other two HLEs. The “subjective unhealthy rate” had a significant influence on the prefectural DFLE-AL and LE-SH.

Introduction

The healthy life expectancy (HLE) has been one of the important goals of “Health Japan 21 (the second term)”, which was a national health policy formulated in 2013.¹ The HLEs that local governments have set as the target value were calculated using the Sullivan method,² taking data from government statistics according to target areas, namely, population, the number of deaths, a life table, and the number of unhealthy people. There are several definitions of “unhealthy,” and three measures of HLE that differed according to the definition of “unhealthy” have been used as target values.³ These three measures of HLE were selected for this study and comprised the following: (i) disability-free life expectancy without activity limitation (DFLE-AL), (ii) life expectancy with self-perceived health (LE-SH), and (iii) disability-free life expectancy without care need (DFLE-CN) (Additional file.1).
Some studies on the factors for the extension of these HLE measures\textsuperscript{4-6} and survey or studies of local government\textsuperscript{7-8} have been reported, but these studies referred only to a single HLE, and few reports have mentioned the differences between and characteristics of different measures of HLE. Furthermore, even in studies in which sub-concepts, such as frailty and ADL, were set as objective variables instead of HLE, it was concluded that they contributed to HLE extension. Moreover, the three measures of HLE were not distinguished and tended to be treated as a single indicator.\textsuperscript{9-12}

It has also been reported that while LE and HLE are consistently linearly extended in both sexes, the percentage of unhealthy periods in LE has also increased;\textsuperscript{13} therefore, the extension of HLE is strongly influenced by the extension of LE. In policymaking, it is important to clarify the relationships between length of HLE, mortality, and the proportion of unhealthy people. This study aimed to compare LE and three measures of HLE and to clarify the association between mortality, the proportion of unhealthy people, and each measure of HLE.

**Methods**

**Study design and data resource**

We conducted an ecological study using open data collected, compiled, and published as government statistics for 2010, 2013, and 2016 by prefecture. The data used for analysis were LE, three measures of HLE, population by age, number of deaths, and number of unhealthy people. The values of the three measures of HLE and LE were obtained from the “Healthy Life Report from Japan.”\textsuperscript{3} All other variables were derived from the government statistics website “e-Stat.”\textsuperscript{14} The population by age was derived from the 2010 population census and population estimates from 2013 and 2016. The number of deaths was derived from official vital statistics. There are three measures of “number of unhealthy people,” as they vary according to the method of HLE (Additional file1). In DFLE-AL, the people who answered “Yes” to the question “Do health problems currently affect your daily life in some way? (Yes/No)” were regarded as unhealthy, and in LE-SH, the people who answered “Not very good” or “Not good” to the question “What is your current state of health?”, which is rated on a 5-point scale (range, not good–very good), were regarded as unhealthy. The numbers of unhealthy persons in
DFLE-AL and LE-SH were derived from a comprehensive survey of living conditions. In DFLE-CN, the people requiring long-term care (level 2 or higher) were determined to be unhealthy in a survey of long-term care benefit expenses.

Main outcome
LE and three measures of HLE were used as outcome variables.

Main predictors
The predictor variables were converted to the following rates or ratios: aging rate, mortality and proportion of unhealthy people. Proportion of unhealthy people was used as main predictor. In this paper, we define the proportion of unhealthy people for three measures of HLE as the restriction rate for DFLE-AL, the subjective unhealthy rate for LE-SH, and the care need rate for DFLE-CN. The restriction rate and the subjective unhealthy rate were calculated by dividing the number of people who responded as being unhealthy to an anonymous self-administered questionnaire by the number of all survey respondents. The care need rate was calculated through dividing the number of persons requiring long-term care (level 2 or higher) by the number of persons aged ≥ 40 years who were eligible for long-term care insurance.

Other variables
Mortality, aging rate and data year were used as the other predictor variables. Mortality was calculated by dividing the number of deaths by the total population. Aging rate was calculated by dividing the population aged ≥ 65 years by the total population. Data year was used after converting from 1 to 3 in the order of 2010, 2013, and 2016. To assist with interpretation, all variables except data year were expressed in “per 1000 persons.”

Statistical analyses
First, Spearman’s rank correlation coefficients for LE and for the three measures of HLE were calculated to confirm their similarity. Then, regression analysis was performed using a generalized linear mixed model (GLMM), in which three measures of HLE were used as dependent variables. Data year, aging rate, mortality, and proportion of unhealthy people were included as independent variables. The random effects of prefectures were assumed for data year and the intercept.

In the regression analysis according to the GLMM, data of 47 prefectures in 2010, 2013, and 2016
were combined for all variables and treated as variables of 140 samples (the data for Kumamoto Prefecture in 2016 are missing due to an earthquake). For the independent variables, the model was constructed after the evaluation of multicollinearity using a variance inflation factor (VIF). Models with both aging rate and mortality as independent variables had a high VIF value of 8.4–15.2, which could lead to multicollinearity problems. Therefore, Model 1, with data year, aging rate, restriction rate, subjective unhealthy rate, and care need rate as independent variables, and Model 2, with mortality as an independent variable used instead of the aging rate, were developed. In these two models, regression analysis assuming random effects of prefectures for data year and the intercept was conducted according to sex and HLE (Figs. 1 & 2).

For estimation of the parameters, simulated draws from the posterior were obtained for each parameter using the Markov chain Monte Carlo (MCMC) method. MCMC is a method of deriving an estimate according to a desired distribution by combining a chain in which the next state is determined only from the previous state (Markov chain) and an algorithm for generating random numbers (Monte Carlo method). \(^{17-18}\) The simulated draws were preceded with 2500 “burn in” draws, which were discarded from the analysis. To reduce temporal auto-correlation among the draws, the MCMC chain was thinned by including only every second draw, yielding 5000 simulated posterior observations. Then, Rhat was calculated to confirm the convergence of the simulation. Rhat is an index of the divergence between chains, and in the case of three or more chains, if it is 1.1 or less by convention; it is considered to have converged. The calculation formula is as follows:

\[
Rhat = \sqrt{\frac{\text{var}^+}{\text{W} \cdot (\text{var}^+)}},
\]

Analysis was performed using Open source statistical software R (ver. 3.6.2)\(^{19}\) and Rstan\(^{18}\) package was used for the parameter estimation by MCMC.

Results
The correlations between DFLE-AL and LE-SH were high for both males and females (males, 0.74–0.83; females, 0.69–0.79) in all data years. However, the correlation between DFLE-CN and the other
two measures of HLE was moderately correlated at 0.46–0.57 in males but not significantly correlated (or weakly correlated) at 0.31 in females. Furthermore, for the correlation between LE and three measures of HLE, DFLE-CN showed a strong correlation with 0.97–0.98 for males and 0.75–0.85 for females. However, concerning DFLE-AL and LE-SH, the correlation was moderate at 0.42–0.55 for males and not significant (or weak) at 0.30 for females. (Additional file 2, Table 1)

The GLMM results for the standardized partial regression coefficients ($\beta$) in males (Figure 1) showed that, for all models with DFLE-AL and LE-SH as dependent variables, data year ($\beta = 0.74–1.11$) and subjective unhealthy rate ($\beta = -0.43– -0.34$) were significant factors. Among the models with DFLE-CN as the dependent variable, data year ($\beta = 0.46$) and care need rate ($\beta = -0.50$) were significant in Model 1. Moreover, in Model 2, data year ($\beta = 0.55$), care need rate ($\beta = -0.19$), and mortality ($\beta = -0.28$) were all significant factors.

The GLMM results for the standardized partial regression coefficients in females (Figure 2) showed that, for models with DFLE-AL as the dependent variable, data year ($\beta = 0.47–0.53$) and subjective unhealthy rate ($\beta = -0.55– -0.54$) were significant factors. As independent variables in each model, the aging rate ($\beta = 0.35$) in Model 1 and mortality ($\beta = 0.39$) and the restriction rate ($\beta = 0.11$) in Model 2 were significant. For models with LE-SH as the dependent variable, data year ($\beta = 1.01–1.02$) and subjective unhealthy rate ($\beta = -0.56$) were significant in both models; in Model 2, mortality ($\beta = 0.20$) was also significant. For models with DFLE-CN as the dependent variable, data year ($\beta = 0.18–0.23$) and care need rate ($\beta = -0.22– -0.27$) were significant in both models; in Model 1, the aging rate ($\beta = 0.18$) was also significant.

Finally, values of Rhat equaled to 1.0 for all parameters, indicating convergence across the four chains initiated from disparate starting values (i.e., the separate chains arrived at the same destination from different starting points). All indications pointed to the fact that the MCMC algorithm achieved convergence for all parameters, meaning that the simulated posterior values were drawn from the true posterior for each parameter.

**Discussion**

The GLMM results showed that data year had the greatest influence on all three measures of HLE for
both sexes, suggesting the LE extension over time might be significant. In addition, from the results of Spearman's correlation coefficient of LE and three types of HLE, DFLE-AL and LE-SH had strong correlated with $r = 0.69–0.83$ for all “Data years,” indicating that these indices are similar. Nevertheless, DFLE-CN showed a strong correlation ($r = 0.75–0.98$) with LE rather than the other two HLEs; therefore, DFLE-CN appeared to be an indicator more closely aligned to LE than the other two measures of HLE.

In DFLE-AL, a third-party judges the state of health based on the physical condition, which depends on the nursing care insurance system, so that the physical aspects are strongly reflected. The other two HLEs are questionnaire-based unhealthy judgments, but women are considered to have no correlation because they judge health in other aspects, such as psychological and social aspects. Hence, qualitative research is needed to determine how health is judged across sexes.

Furthermore, the GLMM result show that the “subjective unhealthy rate” influenced the prefectural two measures of HLE, namely DFLE-AL and LE-SH, that used subjective health scales involving an anonymous self-administered questionnaire to calculate the proportion of unhealthy people. This finding supports previous studies that subjective health related to reducing mortality and the incidence of cardiovascular diseases.\(^{20-23}\)

Among the prefectures in Japan, LE-SH, calculated using the “subjective unhealthy rate,” was the least used as a target value among the three measures of HLE, but it was suggested that improving the "subjective unhealthy rate" was important to not only raise LE-SH but also DFLE-AL.

**Conclusion**

HLE was most associated with increased life expectancy over time. The three measures of HLE, DFLE-AL, and LE-SH strongly correlated and excluding the effect of LE for the evaluation of DFLE-AL is necessary. Further, the subjective unhealthy rate had a significant influence on the prefectural DFLE-AL and LE-SH.

**Limitations**

This study had some limitations that need to be considered. This ecological study was conducted on a prefectural basis and could not assess HLE at an individual level. Further, the care need rate was
calculated by dividing the population aged ≥ 40 years; however, the rate might have been underestimated due to the large denominator, as people aged between 40 and 65 years and eligibility for long-term care insurance are limited to those with certain diseases.

**Abbreviations**

LE  
Life expectancy

HLE  
Healthy life expectancy

DFLE-AL  
Disability-free life expectancy without activity limitation

LE-SH  
Life Expectancy with self-perceived health

DFLE-CN  
Disability-free life expectancy without care need

ADL  
Activities of daily living

IADL  
Instrumental activities of daily living

GLMM  
Generalized linear mixed model

MCMC  
Markov chain Monte Carlo method

**Declarations**

**Ethics approval and consent to participate**

Not applicable

**Consent for publication**

Not applicable

**Availability of data and material**

The data used in this study are those that have been researched by the Japanese government and made publicly available on the website.

**Competing interests**
The authors declare that they have no competing interests.

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**Authors' contributions**

KT planned the study, performed all analyses, and wrote the paper. SO and KK supervised the data analysis and contributed to revising the paper.

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Tables

Table 1. Correlation coefficients for life expectancy and three measures of healthy life expectancy according to year
| Year | LE | DFLE-AL | LE-SH | DFLE-CN |
|------|----|---------|-------|---------|
| 2010 | LE | 1.00    |       |         |
|      | DFLE-AL | 0.43** | 1.00  |         |
|      | LE-SH | 0.44** | 0.83**| 1.00    |
|      | DFLE-CN | 0.97** | 0.48**| 0.50**  | 1.00    |
| 2013 | LE | 1.00    |       |         |
|      | DFLE-AL | 0.43** | 1.00  |         |
|      | LE-SH | 0.51** | 0.74**| 1.00    |
|      | DFLE-CN | 0.98** | 0.48**| 0.57**  | 1.00    |
| 2016 | LE | 1.00    |       |         |
|      | DFLE-AL | 0.42** | 1.00  |         |
|      | LE-SH | 0.55** | 0.81**| 1.00    |
|      | DFLE-CN | 0.98** | 0.46**| 0.56**  | 1.00    |

*p < .05, **p < .01

†The data for Kumamoto Prefecture in 2016 is missing due to an earthquake

**Abbreviations:** DFLE-AL, disability-free life expectancy without activity limitation; DFLE-CN, disability-free life expectancy without care need; LE, life expectancy; LE-SH, life expectancy with self-perceived health

**Supporting Information**

Additional supporting information may be found in the online version of this article at the publisher’s web-site: https://www.editorialmanager.com/envh/download.aspx?id=25624&guid=58e4c40d-ed2f-
Table S1. The definition of three measures of HLE in Japan

Figures
Regression analysis of the generalized linear mixed model of males with three measures of HLE. Abbreviations: DFLE-AL, disability-free life expectancy without activity limitation; DFLE-CN, disability-free life expectancy without care need; LE, life expectancy; LE-SH, life expectancy with self-perceived health.
Figure 2

Regression analysis of the generalized linear mixed model of females with three measures of HLE. Abbreviations: DFLE-AL, disability-free life expectancy without activity limitation; DFLE-CN, disability-free life expectancy without care need; HLE, healthy life expectancy; LE, life expectancy; LE-SH, life expectancy with self-perceived health

Supplementary Files
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