Sleep duration and sleep disturbances as predictors of healthy and chronic disease-free life expectancy between ages 50 and 75: a pooled analysis of three cohorts

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ABSTRACT

Background: The aim of this study was to examine the associations of sleep duration and sleep disturbances with healthy and chronic disease-free life expectancy (LE) between ages 50 and 75.

Methods: Data were drawn from repeated waves of three occupational cohort studies in England, Finland and Sweden (n=55,494) and the follow-up ranged from 6 to 18 years. Self-reported sleep duration was categorized into <7h, 7-8.5h and ≥9h and sleep disturbances into no, moderate, and severe. Health expectancy was estimated with two health indicators: healthy LE based on years in good self-rated health and chronic disease-free LE based on years without chronic diseases. Multistate life table models were used to estimate healthy and chronic disease-free LE from age 50 to 75 years for each category of sleep measures in each cohort. Fixed-effects meta-analysis was used to pool the cohort-specific results into summary estimates.

Results: Persons who slept 7-8.5 hours could expect to live 19.1 (95% CI 19.0-19.3) years in good health and 13.5 (95% CI 13.2-13.7) years without chronic diseases between ages 50 and 75. Healthy and disease-free years were 1-3 years shorter for those who slept less than 7 hours or slept 9 hours or more. Persons who did not have sleep disturbances could expect to live 20.4 (95% CI 20.3-20.6) years in good health and 14.3 (95% CI 14.1-14.5) years without chronic diseases between ages 50 and 75. Healthy and disease-free years were 6-3 years shorter for those who reported severe sleep disturbances.

Conclusions: Sleeping 7-8.5 hours and having no sleep disturbances between ages 50 to 75 are associated with longer healthy and chronic disease-free LE.

Key words: aging, cohort study, health expectancy, healthy life expectancy, life expectancy, sleep, sleep duration, sleep disturbance

Insufficient sleep and sleep difficulties are common in a modern society (1). Poor sleep has deleterious effects on physiology, including the metabolic, endocrine and immune systems (2-4). Moreover, growing evidence suggests that both short and long sleep duration are associated with adverse health outcomes, including cardiovascular disease (5), type 2 diabetes (6), functional decline (7), and mortality (8). Similarly, sleep disturbances are associated with an increased risk of various chronic diseases (6, 9), including depression (10), and mortality (11-13).

One approach to evaluate health consequences of poor sleep is to estimate health expectancy according to sleep duration and sleep disturbances. Health expectancy is a useful summary measure of a population's health that expresses the average number of years that a person can expect to live in "full health" by taking into account years lived in less than full health due to disease and/or disability (14). As health expectancy captures both the "quantity" and "quality" of lived years by considering simultaneously both health and years of life lost (15, 16), it is more informative than life expectancy alone and allows comparing proportion of life spent in good health across different population groups. There are a variety of ways to express health expectancy, depending on the health indicators available, and commonly used terms are healthy life expectancy, disease-free life expectancy and disability-free life expectancy. To give an example, one person aged 50 years can expect to live 25 years of which 20 years without chronic diseases and another person aged 50 years can expect to live 20 years of which 10 without chronic diseases. For these persons the proportion of disease-free life years would be 80% and 50%, respectively. To our knowledge, there are no previous studies examining the extent to which sleep duration and sleep disturbances are associated with health expectancy.

This study examines the association of sleep duration and sleep disturbances with health expectancy between ages 50 and 75 using two indicators: healthy life expectancy based on years in good self-rated health and chronic disease-free life expectancy based on years without chronic

diseases. To obtain robust estimates for lost health expectancy attributable to poor sleep, we used a 3-cohort design with individual data from 56,510 men and women living in England, Finland and Sweden.

METHODS

Study population

In all three cohorts, we included participants aged 50 to 75 years at the first wave for which valid survey data on health and sleep were available.

The Finnish data comprise participants from the Finnish Public Sector study (FPS). The FPS was established in 1997 and involves 151,901 employees with ≥6 month job contract in any year from 1991-2000 to 2005 in 10 towns and 5 hospital districts in Finland. Survey data have been collected at 4-year intervals on all 103,866 cohort members, who were at work in the participating organizations (in 1997-1998, 2000-2002, 2004, 2008, and/or 2012) or had retired or left the organizations after 2000-02 (in 2005, 2009, and 2013). Of those, 84,848 participants responded at least once (response rate 82%). For the analysis, we used data from 40,205 participants, who were followed up to 16 years (mean follow-up time 6.8 years).

Data for Sweden consisted of five postal questionnaire waves of the Swedish Longitudinal Occupational Survey of Health (SLOSH) (17). The first wave of SLOSH in 2006 was a follow-up of all respondents of the 2003 Swedish Work Environment Survey (SWES), in turn based on a random stratified sample of gainfully employed Swedish residents aged 16–64 years. At wave 2 in 2008, the sample was supplemented with the respondents from the 2005 SWES, yielding an overall sample of n=18,915 women and men originally representative of the working population in Sweden in 2003 and 2005. These people were surveyed again in 2010, 2012 and 2014. In total, 77% responded at least once. For the present study, we used data from 8,267 (for the healthy LE

outcome) and 8,152 (for the chronic disease-free LE outcome) participants who were followed up to 8 years (mean follow-up time 6 years).

The English data comprise participants from the Whitehall II study (WHII), a prospective cohort of British civil servants established in 1985-88 when 10,308 participants aged 35-55 years were recruited into the study (18). Since then, follow-up surveys have taken place approximately every 2 to 3 years with response proportions ranging between 61-79 %. For the present study, we used data from 7,022 participants, who were followed up to 18 years (mean follow-up time 12.0 years).

In all cohorts, participants gave informed consent and ethical approvals were given in each of the countries from relevant ethical committees/boards.

Measurement of Sleep

Sleep duration. In the FPS, sleep duration was measured by asking participants: ”How many hours do you usually sleep per 24 hours?”, in the WH II “How many hours of sleep do you have on an average week night?” and in the SLOSH study, participants were asked regarding working/weekdays “At what time do you normally go to bed (turn the lights out)?” and “At what time do you normally get up?”. In all cohorts participants were categorized into short sleepers (< 7 hours), mid-range sleepers (7–8.5 hours) and long sleepers (≥ 9 hours). Details of the questions and response options are provided in the Supplementary Table 1.

Sleep disturbances. In the FPS and WH II sleep disturbances were measured with four questions using the Jenkins’ sleep problem scale (19) and with four similar questions in the SLOSH study with the Karolinska Sleep Questionnaire (20, 21). The four items inquired about difficulties falling

asleep, difficulties maintaining sleep during the night, waking up too early in the morning and non-restorative sleep. In all cohorts participants were categorized into having no, moderate or severe sleep disturbances. Details of the questions and response options are provided in the Supplementary Table 1.

Outcome measures

Our life expectancy (LE) analyses were conditional on reaching the age of 50 and truncated at age 75, thus instead of estimating total LE, we estimated partial LE between ages 50 and 75 in each study cohort. This was done to permit comparable time frames across the cohorts. Partial LE was further divided into healthy and unhealthy LE. In each study cohort, we defined two health expectancy outcomes: 1) healthy LE using self-rated health and 2) chronic disease-free LE based on the occurrence of chronic diseases between ages 50 and 75. In addition, we took into account of mortality when modelling health expectancies.

Self-rated health. In each cohort, participants were asked to rate their general health on a 5-point Likert scale and they were categorized as 'good health' 'sub-optimal health' at each wave. Details of the questions and response options are provided in the Supplementary Table 1. Health expectancy based on years in good self-rated health is labeled 'healthy LE'.

Chronic diseases. The presence of the following chronic diseases was inquired with questionnaires in each cohort: heart disease, stroke (not separately available in SLOSH), chronic lung disease (chronic bronchitis or asthma) and diabetes. Information on cancer was obtained from registers for all cohorts. Individuals were defined as having a chronic disease if they reported one or more of the abovementioned conditions. To ensure comparability across studies the data for SLOSH on chronic conditions came from the 2008-2014 waves, as the 2006 wave did not collect information on all chronic conditions. The presence of chronic diseases at baseline (first observation

included in analysis) included any chronic diseases reported before the age of 50 from available information on respondents. Details of the questions and response options are provided in the Supplementary Table 1. Health expectancy based on years without chronic diseases is labeled 'chronic disease-free LE'.

Mortality was ascertained from linked register data for each study cohort with follow-up censored on 31 December of the year in which data collection last took place for each study cohort.

Covariates

Age and sex were obtained from self-reports or registers. Occupational position was categorized into higher, intermediate and lower occupational positions. In SLOSH, occupational position was based on self-reported job title; in FPS and WH II occupational position was obtained from the employers' records.

Statistical analyses

Characteristics of the participating cohorts are measured at the first observation point, which refers to the date each participant was included in the dataset.

We applied discrete-time multistate life table models to longitudinal data (22). For both outcome measures, three health states were defined: healthy, unhealthy, and dead. For healthy LE, there were four possible transitions between the health states, namely: healthy to sub-optimal health (onset), sub-optimal health to healthy (recovery), healthy to death, sub-optimal health to death. For chronic disease-free LE, there were only three possible transitions (no disease to disease, no disease to death and disease to death) as, by definition, recovery was not possible.

In the first step of the multistate life table analyses, multinomial logistic regression models were fitted separately for each cohort. Odds ratios for the associations of sleep duration and sleep disturbances with transitions between health states were estimated from these multinomial logistic models with age (in years), sex and socioeconomic position as covariates. Parameter estimates from these models were used to calculate age-specific transition probabilities between disease states by sex, sleep duration and sleep disturbances.

In the second step of analyses, partial LE, healthy LE and chronic disease-free LE from ages 50 to 75 (in total 26 years) were calculated based on these estimated transition probabilities using a stochastic (micro-simulation) approach (22). For each study, individual trajectories for a simulated cohort of 100,000 persons were generated with distributions of covariates at the starting point based on the observed study-specific prevalence by five-year age group, sex, sleep duration and sleep disturbances. Partial LE, healthy LE and chronic disease-free LE from age 50 to 75 were then calculated as the average from these trajectories for sleep duration, sleep disturbances and sex. Computation of 95% confidence intervals (CI) (from 2.5^{th} and 97.5^{th} percentiles) for these multistate life table estimates was performed using a bootstrap method with 500 replicates for the whole analysis process (multinomial analysis and simulation steps). As sleep-related transitions to poor health and death may differ by sex, we repeated analyses including interactions between sex and sleep duration and sex and sleep disturbances in the multinomial logistic models. Finally, we calculated the proportion of life spent in good health between ages 50 and 75 by dividing the healthy LE with partial LE. Similarly the proportion of life spent without chronic diseases between ages 50 and 75 was calculated by dividing the chronic disease-free LE with partial LE.

All analyses were conducted in SAS 9.2 using the SPACE (Stochastic Population Analysis of Complex Events) program (23, 24). After separate analyses among men and women in all cohorts, we used fixed-effects meta-analysis (25) to pool the cohort- and sex-specific results into summary

estimates with the R (version 3.3.2) library Meta (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Table 1 shows characteristics of each study cohort at the time of first observation. The distribution of sleep duration and sleep disturbances varied across cohorts. In FPS and SLOSH, about two thirds and in WH II about a half of the participants reported sleeping 7-8.5 hours. Severe sleep disturbances were the most common in the FPS (23% in men and 27% in women), then in WH II (13% in men and 19% in women) and least common in the SLOSH (6% in men and 11% in women).

Sleep and healthy life expectancy

Short sleep (< 7-hours), but not long sleep (≥ 9 hours) was associated with slightly shorter partial LE compared to mid-range sleep (7-8.5 hours) (Table 2). Mid-range sleepers could expect to live longer in good health compared to those with short or long sleep. The difference was 1.1 year between short and mid-range sleepers and 2.5 years between mid-range and long sleepers. In proportions, mid-range sleepers could expect to live 77% of their life between ages 50 and 75 in good health, whereas in short sleepers and long sleepers the proportions were 74% and 67%, respectively (Figure 1). Men had slightly longer healthy LE than women, but there was no sex difference in the association between sleep duration and healthy LE (Supplementary Table 2).

Persons with moderate and severe sleep disturbances had only slightly shorter partial LE compared to those with no sleep disturbances, but there was a steep gradient towards shorter healthy LE with more severe sleep disturbances (Table 2). Persons without sleep disturbances could expect

to live 81% of their life between ages 50 and 75 in good health. The corresponding figures for moderate and severe sleep disturbances were 71% and 57%, respectively (Figure 2). In terms of absolute number of years, those without sleep disturbances could expect to live more than six additional years in good health compared to those with severe sleep disturbances. No sex difference was observed in the association between sleep disturbances and healthy LE (Supplementary Table 2).

Sleep and chronic disease-free life expectancy

Similarly to healthy LE, mid-range sleepers could expect to live longer without chronic diseases compared to those with short or long sleep (Table 3). Mid-range sleepers could expect to live 54% of their life between ages 50 and 75 without chronic diseases, whereas the proportions were 50% for short sleepers and 49% for long sleepers (Figure 1). In terms of absolute number of years, mid-range sleepers could expect to live 1.1 to 1.4 years longer without chronic disease compared to those with short or long sleep. Women had slightly longer chronic disease-free LE than men, but there was no sex difference in the association between sleep duration and chronic disease-free LE (Supplementary Table 3).

The proportion of years without chronic diseases between ages 50 to 75 was 57% for those who did not report sleep disturbances and the corresponding proportions for those with moderate and severe sleep disturbances were 50% and 45%. In terms of absolute number of years, those without sleep disturbances could expect to live more than three additional years without chronic diseases compared to those with severe sleep disturbances. No sex difference was observed in the association between sleep disturbances and healthy LE (Supplementary Table 3).

Cohort specific differences

In terms of cohort-specific results are shown in Supplementary Tables 4-7. We found that long sleep was consistently associated with shorter healthy and chronic disease-free LE in all cohorts. Results for short sleep varied slightly so that in SLOSH short and mid-range sleepers did not differ from each other. Also in the WH II the prevalence of long sleep was very low (2%) and especially in men the chronic disease-free LE was much lower than in other cohorts. There was a gradient towards a shorter healthy or disease-free LE with increasing sleep disturbances in all cohorts. The difference between "no" and "severe" sleep disturbances in the association with healthy LE was most pronounced in FPS and SLOSH. In terms of chronic-disease free LE there were no marked differences across cohorts.

To provide more detailed information on the magnitude of risk, the associations between sleep measures and each possible transition are shown in Supplementary Tables 8-11. Likelihood of moving from healthy to unhealthy state was higher in persons with short sleep duration (especially in FPS and WH II) and severe and moderate sleep disturbances (all cohorts) compared to mid-range sleepers and those with no sleep disturbances. Sleep disturbances were also associated with higher likelihood of moving from disease-free to disease state in all cohorts.

Finally, we tested the interactions between sex and the sleep measures on LE outcomes in each cohort in multinomial logistic models. In most cases, this did not significantly improve model fit. However, there was a statistically significant sex interaction for sleep disturbance and risk of transition from unhealthy to healthy state in SLOSH, where the lower likelihood of recovery from unhealthy to healthy state associated with severe and moderate sleep disturbance was more pronounced in men than in women (p=0.014).

DISCUSSION

This study examined how sleep duration and sleep disturbances were associated with healthy and chronic disease-free life expectancy in over 56,000 men and women from three independent occupational cohort studies from Europe. We found that men and women with mid-range sleep duration could expect to live one to two years longer in good health or without chronic diseases between ages 50 and 75 compared to those with long or short sleep duration. In addition, people who did not have sleep disturbances could expect six additional healthy years and three more disease-free years than those with severe sleep disturbances between ages 50 and 75.

To our knowledge, this is the first prospective study to provide health expectancy estimates for both self-rated health and chronic diseases in different levels of sleep duration and sleep disturbances. We applied multistate models to longitudinal data to obtain transition probabilities between health states and found robust associations between sleep and health expectance which are consistent with earlier research related to impaired sleep and other health measures. In agreement with our findings, previous studies have reported that mid-range sleep and non-disturbed sleep are associated with better health (5, 6). Our study extends previous studies by examining how sleep quantity and quality are associated with health outcomes by using health expectancy analysis, which combines information on health, morbidity and mortality. The findings of the study are very relevant because sleep problems are increasingly common and at the same time life expectancy has continuously increased in Western countries (26, 27). The important question is how many of the gained years of life will be spent in good health or without chronic disease. We showed consistent results across four different European countries suggesting that sleep problems, in addition to other life style factors (28), are likely to considerably decrease the proportion of life that is spent in good health.

In our study, we used two health expectancy outcomes, namely healthy LE, based on self-reported health, and chronic disease-free LE. We found that, in general, healthy LE was longer than chronic disease-free LE. For example, when we compared individuals reporting "no" and "severe" sleep disturbances, differences in years and proportions were larger with healthy LE than with chronic disease-free LE. The reason why healthy LE is longer and shows greater variability than chronic disease-free LE may be because self-rated health is a holistic measure and it captures a wider range of health-related phenomena beyond chronic disease, i.e. people can still perceive their health relatively good despite having a chronic disease (29).

We utilized data from three European cohorts and in addition to reporting pooled estimates, we also presented results for each cohort separately. In general we found consistent results across all study cohorts in spite of some heterogeneity in the measurement of sleep duration and sleep disturbances across the cohorts. In these data, long sleep and a higher level of sleep disturbances were associated with shorter healthy and chronic disease-free LE. However, the absolute difference in years varied slightly between cohorts and by the health expectancy indicator since sleep duration and sleep disturbances were measured with different instruments in SLOSH compared to FPS and WH II. For example in SLOSH the time going to bed and waking up was inquired separately, whereas in FPS and WH II the participants were asked about their total sleep time. This may have led small differences in reporting accuracy, but by using a relatively crude three-level categorization, the influence on our results is likely to be small. Although the prevalence of sleep disturbances was lower in SLOSH than in FPS and WH II, the health expectancy estimates were very similar across the cohorts. In addition, there was some variability in the definitions of health and chronic diseases between cohort studies and the cohorts were also different in terms of representativeness and age (30). Pooling the results across studies allowed us to assess the

similarities and differences of the associations across different contexts, an important point concerning the generalizability of our findings.

The current study has a number of strengths. Our data were based on large prospective cohorts from three European countries with multiple measurements of self-rated health and chronic diseases enabling longitudinal modeling to estimate health expectancy over an extended time period from age 50 to 75 years. We used microsimulation to estimate healthy LE and chronic disease-free LE, which provided consistent results for each cohort. In addition, we used two different indicators of impaired sleep and two different health expectancy outcomes proving a broader picture of the relationship between sleep and health expectancy.

The study also has limitations that need to be considered. First, we assessed sleep duration and sleep disturbances using self-report, which is not the gold standard but nonetheless the most common method in large-scale research; self-reported information on sleep also forms the basis for diagnosing insomnia in sleep clinics (31). In future studies, measurement with, for example, accelerometers might be a feasible method for a more accurate and objective assessment of sleep duration and quality. Second, a limitation inherent in the study design is that we will have to assume that poor sleep is either new (i.e. a recent onset) or that it precedes development of chronic diseases before age 50. We attempted to examine the potential reverse causality by calculating transition probabilities between different health states and found that moving from healthy to unhealthy state or moving from disease-free to disease state were more likely in persons with severe and moderate sleep disturbances compared to those with no sleep disturbances. This suggests that it is likely that sleep disturbances precede health problems and not vice versa. However, we do not know whether moving from disease-free to disease state is driven by poor sleep or a subclinical disease affecting sleep and developing later to a clinical disease state. Third, we assessed a selected range of chronic diseases (heart disease, stroke, chronic lung disease, cancer and diabetes) not encompassing

osteoarthritis and depression, for example. Therefore, our measure of healthy LE may not have captured all life dimensions of non-fatal health and functional limitations. Fourth, due to the observational nature of the study, our study does not permit definite causal inferences.

Since our health expectancy analyses were conditional on reaching the age of 50 and truncated at age 75, future studies are needed to investigate the association of sleep duration and sleep disturbances with healthy and chronic disease-free LE starting at younger ages and extending follow-up beyond the age of 75. Our study was based on occupational cohort studies. Thus, it is possible that health-related selection may have led to underestimation of the association between sleep and health expectancy, since individuals who are not working or are disabled are not represented and they are known to have more sleep problems and poorer health (32). Further research is needed to examine whether our findings are generalizable to general populations.

In conclusion, we found that short or long sleep and severe sleep disturbances were associated with slightly lower partial life expectancy between ages 50 and 75, but markedly less years in good health and less years without chronic-diseases compared to mid-range sleep or no sleep disturbances. Finding ways to support healthy sleeping habits in midlife may substantially increase the time spent in good health with advancing age.

Supplementary Data

Supplementary information is available at journal's website.

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Conflict of interest

SS currently serve on the editorial board for the Journal of Gerontology: Medical Sciences. All other authors have no conflicts of interest to disclose.

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Figure legends.

Figure 1. Proportion (95% CI) of life spent in good health and without chronic disease between ages 50 and 75 by sleep duration. Pooled analysis of men and women in FPS, SLOSH and Whitehall II Studies.

Figure 2. Proportion (95% CI) of life spent in good health and without chronic disease between ages 50 and 75 by sleep disturbances. Pooled analysis of men and women in FPS, SLOSH and Whitehall II Studies.

Table 1. Characteristics of the study cohorts at the time of first observation *.

	FPS		SLOSH		Whitehall II	
	Men	Women	Men	Women	Men	Women
Sample size	7894	32311	3771‡	4496‡	4946	2076
Age (mean, SD)	53.7(3.2)	53.3(2.9)	57.1(5.5)	56.5(5.4)	56.9 (5.5)	57.5 (5.7)
Occupational position (%)						
High grade	41.4	27.0	22.5	16.9	41.5	14.2
Middle grade	24.4	56.7	36.7	51.7	52.1	44.3
Low grade	34.2	16.3	40.8	31.4	6.4	41.6
Suboptimal self-reported health (%)	37.2	34.2	23.7	20.6	11.8	18.0
Chronic health conditions (%)†	26.0	26.4	21.6	17.3	37.5	37.3
Sleep duration (%)						
< 7 hours	30.8	25.7	25.1	14.4	39.9	44.4
7-8.5 hours	67.2	71.3	67.0	73.7	58.8	53.5
≥ 9 hours	1.9	3.0	7.9	11.9	1.3	2.1
Sleep disturbances (%)						
Severe	23.0	26.9	5.9	10.6	13.1	19.3
Moderate	23.9	25.1	10.8	15.3	23.0	25.9
No	53.1	47.9	83.3	74.1	64.0	54.8

* The first observation point refers to the date each participant is for the first time included in the data set. † Presence of chronic diseases includes illness reported at or before the first observation point. ‡ Number of participants included in the analysis regarding chronic disease-free LE is 3748 men and 4445 women.

Table 2. Partial life expectancy, healthy life expectancy and unhealthy life expectancy in years based on self-reported health between ages 50 and 75 by sleep duration and sleep disturbances. Pooled analysis of men and women in FPS, SLOSH and Whitehall II Studies.

	Partial life expectancy	95% CI		**Healthy life expectancy**	95% CI		**Unhealthy life expectancy**	95% CI	
Sleep duration									
< 7	24.8	24.7	24.9	18.0	17.8	18.2	6.6	6.4	6.8
7-8.5	25.0	25.0	25.1	19.1	19.0	19.3	5.6	5.5	5.7
≥ 9	25.0	24.8	25.2	16.6	16.1	17.2	8.3	7.8	8.8
Sleep disturbances									
Severe	24.7	24.6	24.8	14.2	13.9	14.5	10.6	10.4	10.8
Moderate	24.9	24.8	25.0	17.5	17.3	17.8	7.1	6.9	7.3
No	25.0	24.9	25.1	20.4	20.3	20.6	4.6	4.5	4.7

Table 3. Partial life expectancy, chronic disease-free life expectancy and life expectancy with chronic diseases in years between ages 50 and 75 by sleep duration and sleep disturbances. Pooled analysis of men and women in FPS, SLOSH and Whitehall II Studies.

	Partial life expectancy	95% CI		Chronic disease-free life expectancy	95% CI		Life expectancy with chronic diseases	95% CI	
Sleep duration									
< 7	24.7	24.6	24.8	12.4	12.1	12.7	12.2	12.0	15.5
7-8.5	24.9	24.9	25.0	13.5	13.2	13.7	11.5	11.3	11.7
≥ 9	25.0	24.8	25.3	12.1	11.3	12.9	12.7	11.9	13.5
Sleep disturbances									
Severe	24.7	24.6	24.8	11.1	10.8	11.4	13.6	13.3	13.9
Moderate	24.9	24.8	25.0	12.5	12.2	12.8	12.4	12.1	12.7
No	24.9	24.9	25.0	14.3	14.1	14.5	10.6	10.4	10.8

Figure 1.

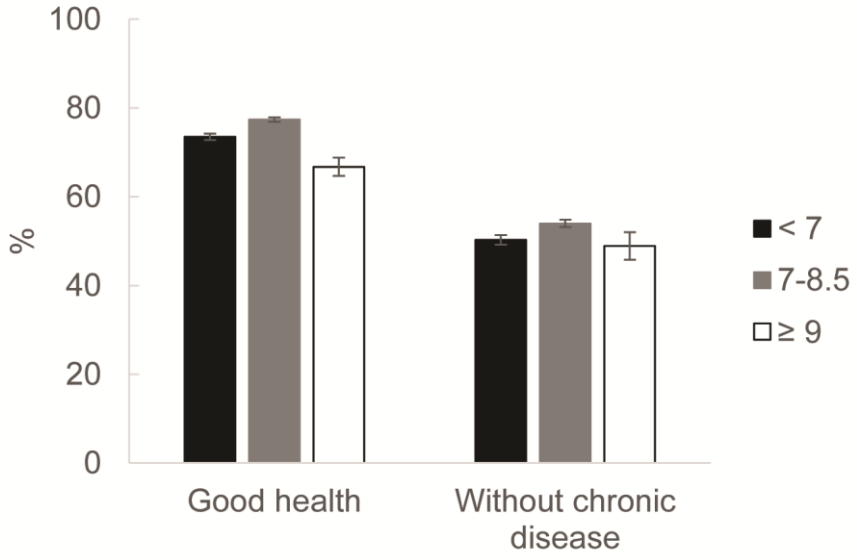

Figure 2.