Title: Daily steps and diet, but not sleep, are related to mortality in older Australians

Running title: Steps and diet related to mortality

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Abstract

Objectives: Supporting healthy ageing is a key priority worldwide. Physical activity, diet quality and sleep are all associated with health outcomes, but few studies have explored their independent associations with all-cause mortality in an older population in the same model. The study aim was to examine associations between step-count, self-reported diet quality, restless sleep, and all-cause mortality in adults aged 55-85 years.

Design: A prospective cohort study of adults in Newcastle, New South Wales, Australia.

Method: Data were from 1697 participants (49.3% women; baseline mean age 65.4±7.1 years). Daily steps (measured by pedometer), diet quality (from a modified Australian Recommended Food Score), and frequency of restless sleep (by self-report) were assessed in relation to all-cause mortality using Cox proportional hazard regression with adjustment for sex, age, household income and smoking. Baseline data were collected between January 2005 and April 2008, and last follow-up was in March 2017 (median follow-up 9.6 years).

Results: Higher step count (HR: 0.93, 95%CI: 0.88-0.98 per 1000-step increment) and higher diet quality (HR: 0.86, 95%CI: 0.74-0.99 per 8-point increment in diet quality score) were associated with reduced mortality risk. Restless sleep for ≥3 nights/week was not associated with mortality risk (HR: 1.03, 95%CI: 0.78-1.39). Sensitivity analyses, adjusting for chronic disease and excluding deaths <1 year after baseline, did not change these estimates.

Conclusions: Increased daily steps and consumption of a greater variety of nutrient-dense foods every week would result in substantial health benefits for older people. Future research should include a greater variety of sleep measures.

Keywords

Ageing, physical activity, nutrition, mortality, insomnia

Introduction

The average age of almost every country's population is increasing and this trend is expected to continue[1]. Promoting healthy ageing is therefore a key priority worldwide[1]. The majority of health concerns in older age relate to non-communicable diseases, and the burden associated with living with disease[1]. Health-promoting behaviours like sufficient physical activity and good quality diet and sleep are important for the prevention of chronic disease[1,2]. While the inverse association between higher self-reported physical activity and lower risk of all-cause mortality is well established[1], several recent studies have used objective activity measures, such as step-counts, to confirm this inverse association. [3-6]. Self-reported physical activity, diet quality and sleep duration have all been found to have associations with all-cause mortality when entered in the same model, with independent hazard ratios presented[7]. Although some step-count studies have accounted for the fact that physical activity commonly cluster with diet and sleep behaviours in individuals by adjusting for diet quality[5] and sleep duration,[6] they have not presented the hazard ratios associated with these measures, making it difficult to interpret the independent effects of different risk factors.

Understanding the unique associations of step-count, diet quality and restless sleep with all-cause mortality may assist in the development of public health campaigns, services and policies to support healthy ageing. Therefore, the aim of the current study was to examine the relationships between step-count, diet quality and frequency of restless sleep, with all-cause mortality in men and women aged 55-85 years after adjusting for a range of socio-demographic, behavioural and health variables as possible confounders.

Materials and methods

The Hunter Community Study (HCS) is a prospective population-based cohort study of community-dwelling (i.e. not in aged-care facility) men and women aged 55-85 years residing in Newcastle, New South Wales, Australia. The HCS is a collaborative study between the University of Newcastle's School of Medicine and Public Health and the Hunter New England Area Health Service. The University of Newcastle Human Research Ethics Committee granted ethics approval (reference H-820-0504a). Participants were randomly selected from the NSW electoral roll between December 2004 and December 2007. Baseline data were collected between January 2005 and April 2008. A total of 9784 individuals were sent invitation letters, 7575 responded (77.4%), 3877 agreed to participate via written informed consent, and 3253 (39.6%) completed the study. Consent for medical record linkage was given by 2938 participants. Of these, 739 were missing data for one or more of the health behaviours and 468 were missing data for the socio-demographic variables. The final sample available for analysis comprised 1697 participants after excluding implausible pedometer data (n=34) (Figure 1). Further details regarding recruitment has been published elsewhere[8]. All-cause mortality was obtained from the NSW Centre for Health Record Linkage (CHeReL). The last follow-up was performed on 31st of March 2017.

Physical activity was measured by a Digiwalker SW-200 pedometer (Yamax Corp, Tokyo, Japan) which was found to not differ significantly ($p<0.05$) from measured steps at five walking speeds (range 54 -107 m/min) and was within ±1% of measured steps above 80m/min[9]. The pedometer was worn on the waist belt during waking hours for 7 days. Participants recorded the start and end time for pedometer-wear each day, and step-count each evening, but did not reset the counter. Days with fewer than nine hours of wear, mean step count beyond the 1st (<941 steps) and 99th (>15,303 steps) centiles, and participants with fewer than any three days of measurement, were excluded from analysis. Methods and description of the activity patterns found in the HCS has been described elsewhere[10]. Mean step-count per day was calculated, and 1000-step increments were used in analysis.

Dietary intake was measured via a 145-item food frequency questionnaire modified for Australian diet and language norms with test re-test reliability (r=0.67-0.96)[11] and concurrent validity for nutrient intake compared with estimates from a weighed food diary in older Australian adults[12]. The FFQ-estimated intake of fruits and vegetables, Vitamin E and carotenoids classified ≥68% of individuals correctly within the same or adjacent quintile for these measures compared with their plasma biomarkers[12]. Diet quality was scored via the Australian Recommended Food Score adapted for the Hunter Community study (HCS-ARFS), comprising seven sub-scales that focus on dietary variety within core food groups[13]. Ten items from the full ARFS were not included and could not be scored (two vegetables; three meats/vegetarian alternatives; five cereals), and alcohol consumption (two items) was included as a separate covariate. The maximum total HCS-ARFS score was 62 points (Supplemental Table 1)[11]. The diet quality score was transformed into a Z-score for analysis, and a one standard deviation change equalled 8 points. Diet quality sub-scores for those in the highest versus the lowest tertile for total diet quality score were compared using a t-test, and effect size calculated.

Restless sleep was assessed by item-11 on the CESD-20[14]: "My sleep was restless". The following options were given: <1 day/ 1-2/ 3-4/ 5+ nights of restless sleep per week. Frequency of restless sleep was categorised as '0-2' or '3-7' nights per week. Three nights or more per sleep is considered the frequency threshold for clinical significance of sleep symptoms in insomnia diagnosis as used in other studies of sleep health[15], though the CESD single-item has not been validated for use in this manner. The Epworth Sleepiness Scale (ESS) has internal consistency (Chronbach's alpha=0.73-0.86), test re-test reliability (p=0.82) and concurrent validity against the 'maintenance of wakefulness test' (p=-0.43)[16]. It includes 8 items with 4-point response scales, and scores range from 0 to 24, and ≥11 points categorises excessive daytime sleepiness[16].

Smoking status was categorised as ‘never smoked’ (<100 cigarettes in lifetime), ‘former smoker’ (>100 cigarettes in lifetime, not current smoker) or ‘current smoker’ (smokes sometimes/every day). Alcohol consumption was categorised as ‘non-drinker’, ‘low risk’ (≤2 standard drinks per day on average and ≤4 standard drinks per occasion) or ‘high ‘risk’ (>2 standard drinks per day on average or >4 standard drinks per occasion) in line with Australian alcohol consumption guidelines. Marital status was categorised as ‘married or de-facto’, ‘non-partnered’ (never married/divorced/separated) or ‘widowed’. Highest attained educational level was categorised as: ‘primary/secondary school’, ‘trade qualification/TAFE’ (Technical and Further Education College) or ‘university/other tertiary’. Annual household income was categorised as ‘low’ (<AUD$30,000), ‘medium’ (AUD$30,000-70,000) or ‘high’ (>AUD$70,000).

Self-reported chronic conditions (Table 1) were summed and the total number of conditions was used in analysis. Mental health was measured via the SF-36 Mental Health sub-score from five items (score range 0–100) which has internal consistency (Chronbach’s alpha=0.83) but may overestimate depressive symptoms in those aged >75 years[17]. Item-14 on the Centre for Epidemiological Studies Depression Scale (CESD) was used as an indicator of loneliness: “I feel lonely”[14]. Participants were given the options <1 day/ 1-2/ 3-4/ 5+ days per week, and responses were categorised as ‘0-2’ or ‘3-7’ days per week.

All statistical analyses were conducted using Stata (version 14.0). Descriptive statistics comprised means with standard deviations and frequencies with percentages for continuous and categorical variables respectively. Comparisons between men and women for population characteristics and diet quality scores were made via Chi-square tests and t-tests. A series of Cox proportional hazard models were used to examine the relationships between physical activity, diet quality and restless sleep with time to death or administrative censoring. All participants alive at final follow-up (31st of March 2017) were treated as rightcensored. Models were adjusted for potential sociodemographic and behavioural confounders measured at baseline, and were treated as time-invariant in the models. Univariate analyses were performed to assess the relationships between physical activity, diet quality, restless sleep, and potential confounders, which were identified a-priori. Variables were included in the multivariable analyses if they had p<0.25 as a conservative cut-off to avoid excluding variables which may not be statistically significant but still influences estimates. The proportional hazard assumption was assessed via testing Schoenfeld residuals, and Martingale plots were constructed to assess the functional form of the continuous covariates steps and diet quality. A multivariate regression model was then fitted with the confounders identified in the univariate analysis. To maintain a more parsimonious model, variables were excluded from the multivariate analysis if p<0.25 after inclusion in the multivariate model and removal did not alter estimates by more than 10%. Interaction terms between sex and diet quality, and sex and physical activity were examined. Tertiles of mean steps and diet quality were calculated to plot Kaplan-Meier survival curves. To account for the effects of pre-existing disease two sensitivity analyses were performed by: 1) adjusting for number of chronic diseases and 2) excluding participants who died within 1 year of baseline data-collection, as has been done in other studies[5,6].

Results

Sociodemographic, health and behaviour characteristics for the participants are summarised in Table 1. There were similar proportions of men (50.7%) and women in the final sample. The mean age was 64.4 (SD7.1) years, approximately three quarters of participants were married or in a de-facto relationship, nearly half had a low household income (<$30k per annum) and the majority had at least one chronic disease diagnosis. The study population had a similar gender distribution to that found in the Australian population aged 55-85 years, but was slightly younger and more likely to be married (Supplemental

Table 2). Participants whose data could not be included (Figure 1) were older, less likely to have a university degree, had more chronic conditions, lower SF-36 scores and higher levels of excessive daytime sleepiness than the included sample. There were no significant differences in sex, average daily step-count, diet quality, or restless sleep (data not shown).

Mean daily step-count was 6898 (SD 2969) steps per day, and the mean diet quality score was 28.3 (SD 8.0) out of 62 points. The difference in diet-quality sub-scale scores between those in the highest and lowest tertile for diet quality was greatest for vegetables, fruit, and meat and alternatives (effect size=1.8 and 1.7 and 1.4 respectively) (Supplemental Table 3). Two thirds of the study sample reported three or more nights with restless sleep per week, but only one participants (0.1%) scored ≥11 points on the Epworth Sleepiness Scale to indicate excessive daytime sleepiness.

There were 204 deaths recorded by the end of the follow-up period. The total number of person-years of follow up was 16,443 with a median of 9.6 years per participant (range: 0.2-13.1 years). Both step-count and diet quality scores satisfied the proportional hazards assumption. The results of the univariate and multivariate models for all-cause mortality models are displayed in Table 2. Higher daily step-count and higher diet quality were both associated with lower all-cause mortality, while restless sleep did not, as observed in the Cox proportional hazards regression curves (Figure 2 a, b, c). Overall, men had a higher risk of all-cause mortality than women. A formal test found no interaction between sex and diet quality score (HR: 0.85, 95%CI: 0.64 to 1.14), nor sex and daily steps (HR: 1.01, 95%CI: 0.92 to 1.13). Never smoking and past smoking was associated with lower mortality risk, as was a high (≥$70k/annum) and medium ($30k-$70k/annum) income. Sensitivity analyses adjusting for chronic diseases (count of diagnosis) and excluding those who died within the first year of baseline data collection (n=6), did not noticeably change estimates (Supplemental Table 4).

Discussion

The aim of the current study was to examine the association between step-count, diet quality and restless sleep with all-cause mortality in older Australian adults. Each additional 1000 steps/day was associated with a lower risk of all-cause mortality by 6%. A higher diet quality score, quantified by the consumption of an additional eight different nutrient-dense, core foods per week was associated with a 15% lower risk for all-cause mortality. Daily steps in the study population (6898 steps/day) were lower than has been reported in a slightly younger Tasmanian cohort[3] (8781 steps/day), but comparable with estimates from an older Japanese[4] (6470 steps/day) cohort, but slightly higher than those from older US female[5] (5499 steps/day) and British male[6] (4938 steps/day) cohorts. Higher daily steps were associated with reduced risk of mortality in all these studies, and while the Australian study found similar risk-reduction as our study (6%)[3], the risk reduction was higher in the US and British studies (14-16%)[5,6].

The current study did not measure cadence, however in the large cohort of older US women, overall step-count was more consistently associated with all-cause mortality than cadence[5]. Similar findings were reported for the British male cohort which used accelerometer-counts to determine activity levels[6]. They concluded that total volume of activity had the greatest influence on mortality, and that any activity, from light intensity upwards, was beneficial[6]. This is encouraging for older cohorts, as irrespective of intensity, increasing physical activity is associated with numerous improved health outcomes [6,18]. Some studies have shown that the benefit of higher step-count on reducing mortality risk levels off after approximately 7400 steps[5], while other studies have suggested a linear association between step-count and mortality-risk[3]. One study, found that while a quadratic model was marginally better fit than a linear model, the difference was minimal.[6] In the current study, Martingale plots for step-count vs. mortality indicated a linear relationship. Dose-response relationships may differ depending on population characteristics, and this merits further investigation.

Our finding of a 14% lower risk of all-cause mortality associated with a greater variety of nutrient-dense foods is consistent with other studies[19]. A review of diet quality measures found that associations between diet quality and all-cause mortality ranged from 17-42%, but comparison is challenging given the diversity in methods and populations[19]. However, a longitudinal study using the full Australian Recommended Food Score found one point on the diet quality score was associated with significantly fewer health care claims and lower health care costs over 10 years[20]. The greatest differences between those the lowest and highest tertiles of dietary scores in the present study were found within the vegetable, fruits, and meat and vegetarian protein alternatives sub-scales. This indicates that particular efforts to increase the amount and variety of fruits and vegetables consumed may be warranted, as well as increasing the variety in meat and alternative protein sources consumed.

Restless sleep did not show an association with mortality, perhaps because the measure used may not have captured the properties of sleep salient to health outcomes. A previous study reported a 31% increased risk of all-cause mortality from short/long sleep duration and all-cause mortality in a model that included self-reported physical activity, diet quality, prolonged sitting, smoking, and alcohol use[7]. This is higher than in a meta-analysis of 21 studies, which reported a 6% and 13% increased risk of all-cause mortality associated with short and long sleep respectively[21]. The research on sleep disturbances and mortality is sparse, but in a younger French cohort, men (but not women) who reported one or more sleep disturbances were at increased risk of all-cause mortality by 17-38%[22]. Furthermore, despite two thirds of the current study sample reporting frequent restless sleep, the prevalence of excessive daytime sleepiness was only 0.1%, well below the reported prevalence in 50-80+ year old Australians (12.0-29.0%)[23] and other prevalence estimates globally (4-20.6%)[24], all measured using the ESS. The sleep disturbances reported may therefore be related to normal age-related sleep changes rather than chronic sleep disorders[25]. To capture the multidimensional nature of sleep, a greater variety of measures, such as sleep duration and sleep disturbance, which can now be measured with an accelerometer, sleep latency and perceived quality should be used in future longitudinal studies. Addition of measures would improve our understanding of how sleep characteristics, in combination with other health behaviours, are associated with health outcomes.

High income was strongly associated with reduced mortality risk (Table 2), suggesting a social gradient in this relationship. Furthermore, the association between cigarette smoking and increased risk of mortality was strong, and it is well known that smoking rates are highest in populations with lower socioeconomic status[26]. Although significant health benefits can be obtained from ceasing smoking, the prevalence of smoking among older people is low. In terms of Population Attributable Risk, we feel it is therefore justifiable to focus on improving physical activity[27,28] and diet[29], at this life stage[30]. However, barriers to behaviour change in low socioeconomic groups must be carefully considered if the burden of chronic disease and all-cause mortality in this population is to be reduced.

Study strengths include a community-based sample of older adults with similar age and gender distribution to the Australian population aged 55-85 years. Other strengths include the use of a comprehensive diet quality index that aligns with national dietary guidelines, and the inclusion of a range of potential confounders. Although the associations were robust to adjustment for possible confounding, and sensitivity analysis indicated that findings were not due to reverse causality, the possibility of this cannot be ruled out completely. The response rate of 39.6% is considered excellent compared to other Australian cohorts such as the '45 and Up' Study with a response rate of 11%[7]. Potential limitations include that the findings may not be generalizable to other countries and the relatively small sample size. Inherent limitations such as recall bias and social desirability are associated with self-report of health behaviours and may result in inaccurate estimates of associations. Pedometers also have a risk of error from incorrect data-logging, and possibly underestimating steps taken by frail elderly with a slow, shuffling gait.

Conclusion

A clear association between pedometer steps, diet quality, and all-cause mortality was found in this community representative sample of older Australians. Taking 1000 more steps per day was associated with a 7% reduced risk of mortality, and an additional 8 points on the diet quality score was associated with a 14% reduction in mortality. Substantial benefits are potentially available if this age group became more active, and consumed a greater variety of nutrient-dense core foods. A potential focus could be the consumption of a greater amount and variety of vegetables and fruits, and a greater variety in protein sources consumed. Restless sleep did not predict mortality, and future research should include a greater variety of measures. The expected health gains from improved physical activity and diet support enhanced community-wide efforts to improve health-behaviours.

Practical implications

- Higher step count and higher diet quality were both associated with lower mortality risk in older adults.
- Self-reported restless sleep was not associated with mortality risk; a more detailed assessment of sleep may provide greater insight into how sleep influences health.
- The expected health gains from improved physical activity and diet support enhanced community-wide efforts to improve both health behaviours.

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Table 1. Study Sample Characteristics: Health Behavior, Socio-demographic and Health Status (n=1731)

		Mean (SD)
Age	Years	65.4 (7.1)
Physical activity	Steps per day	6898 (2970)
(pedometer)	Median (IQR)	6,678 (4,689 – 8,850)
Diet quality score	Points (0-62)	28.3 (8.0)
(HCS-ARFS[1])	Median (IQR)	28 (23 – 34)
Epworth Sleepiness Scale	Score (0-24)	0.89 (1.00)
Chronic disease[2]	Count (0-12)	1.9 (1.5)
Mental health (SF-36)[3]	Score (0-100)	80.8 (14.7)
		Count (%) (n=1697)
Sex	Men[4]	858 (50.7)
Restless sleep	3-7 nights/week[5]	1049 (61.8)
Marital status	Married or de-facto	1316 (77.5)
	Non-partnered	229 (13.5)
	Widowed	152 (9.0)
Feelings of loneliness	3-7 days/week[6]	122 (7.2)
Annual household income	High (≥$70k)	338 (19.9)
	Medium ($30k-$70k)	604 (35.6)
	Low (<$30k)	755 (44.5)
Highest level of completed education	University	435 (25.6)
	TAFE/Trade college	493 (29.0)
	Primary/Secondary	770 (45.4)
Smoking status	Never	934 (55.0)
	Past smoker	644 (38.0)
	Current smoker	119 (7.0)
Alcohol consumption	Low risk	1158 (68.2)
	Never drink	332 (19.6)
	High risk	207 (12.2)
Chronic disease[2]	None	293 (17.3)
	One or more	1404 (82.7)

[1]HCS-ARFS: Hunter Community Study- Australian Recommended Food Score; [6] Asthma, atrial fibrillation, bronchitis/ emphysema, diabetes, heart attack, high cholesterol level, high blood pressure, osteoarthritis, osteoporosis, rheumatoid arthritis, stroke and thyroid problems; [3]36-item Short Form Survey; [4]Compared to women; [5]Compared to 0-2 nights/week; [6]Compared to 0-2 days per week;

Table 2. Cox Proportional Hazard Analysis, Univariate and Adjusted Associations With All-cause Mortality (n=1697)

		Model 1 Univariate HR (95%CI)	Model 2 Adjusted HR (95%CI)
Age	Per year increase	1.11 (1.09 to 1.13)	1.09 (1.07 to 1.11)
Sex	Men[2]	2.15 (1.61 to 2.86)	1.95 (1.43 to 2.65)
Physical activity pedometer	Per 1000 steps per day	0.83 (0.79 to 0.87)	0.93 (0.88 to 0.98)
Diet quality score	Per 8 points[3]	0.75 (0.66 to 0.87)	0.86 (0.74 to 0.99)
Restless sleep	0-2 nights/ week[4]	0.89 (0.69 to 1.17)	0.99 (0.75 to 1.32)
Epworth sleepiness scale	Score, 0-24	1.07 (0.97 to 1.18)[7]	Excluded[9]
Mental health SF-36[5]	Score, 0-100	1.00 (0.99 to 1.01)[8]	-
Marital status	Widowed	1	Excluded[9]
	Non-partnered	0.73 (0.45 to 1.18)[7]	-
	Married or de-facto	0.52 (0.35 to 0.76)[7]	-
Loneliness	0-2 days/ week[6]	0.92 (0.54 to 1.59)[8]	-
Annual household income	Low, <$30k	1	1
	Medium, $30k-$70k	0.43 (0.32 to 0.60)[7]	0.70 (0.50 to 0.99)
	High, ≥$70k	0.20 (0.11 to 0.35)[7]	0.43 (0.26 to 0.85)
Education	Primary/ Secondary	1	Excluded[9]
	TAFE/Trade college	0.99 (0.72 to 1.35)	-
	University/ other tertiary	0.85 (0.60 to 1.20)	-
Smoking status	Current smoker	1	1
	Past smoker	0.73 (0.47 to 1.14)[7]	0.50 (0.31 to 0.80)
	Never	0.46 (0.30 to 0.73)[7]	0.39 (0.24 to 0.63)
Alcohol consumption	High risk consumption	1	Excluded[9]
	Never drink	1.17 (0.75 to 1.85)[7]	-
	Low risk consumption	0.83 (0.56 to 1.24)[7]	-

Model 1: univariate analysis; Model 2: multivariate analysis; Model 3: Model 2+chronic disease status; [1]Compared to women; [2]Hunter Community Study-Australian Recommended Food Score, 8 points=1SD for mean diet quality score= 8 additional nutrient-dense, core foods per week; [3]Compared to 3-7 nights/week; [4]36-item Short Form Survey; [5]Compared to 3-7 days/week; [6]Covariate qualifies for inclusion in multivariable adjusted model, p<0.250; [7]Loneliness (p=0.770) and mental health (p=0.932) not included in multivariable model; [8]Epworth (p=0.451), marital status (p=0.491-0.547), education (p=0.322-0.359) and alcohol consumption (p=0.345-0.677) were excluded from multivariable model (p>0.250 and removal did not change estimates by >10%) for a more parsimonious model.

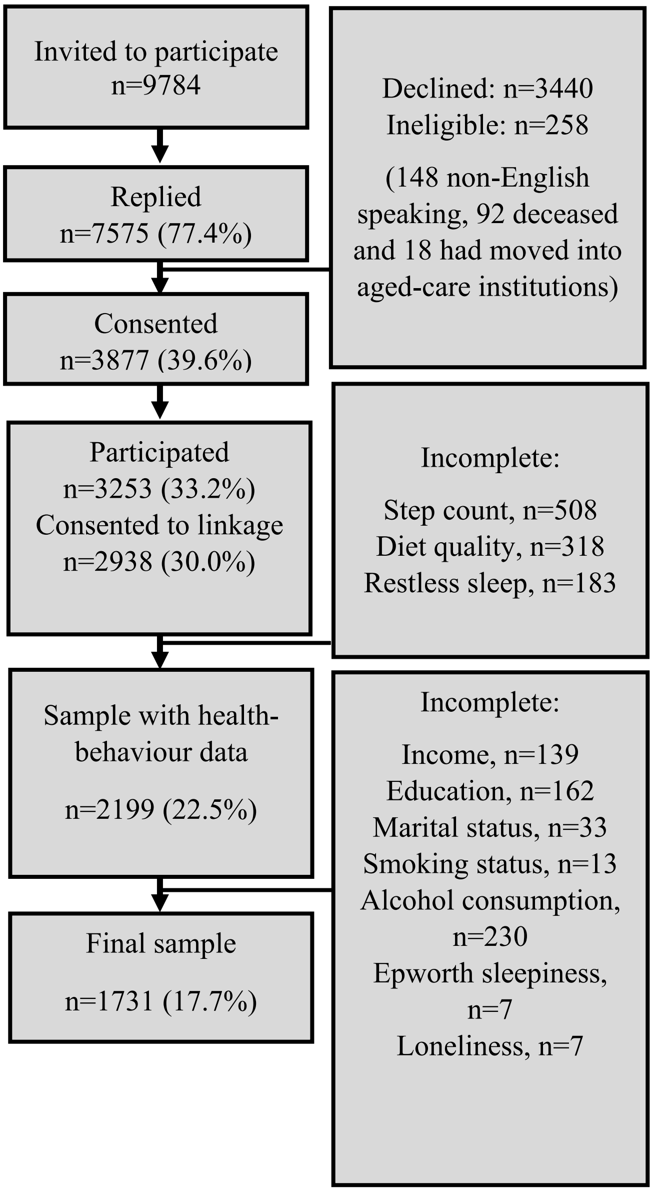

Figure 1. Recruitment and Data collection flowchart for the Hunter Community Study. Baseline data for community-dwelling 55-85 year olds in the Hunter-region of New South Wales, Australia was collected January 2005 and April 2008 and final follow-up was on the 31st of March 2017.

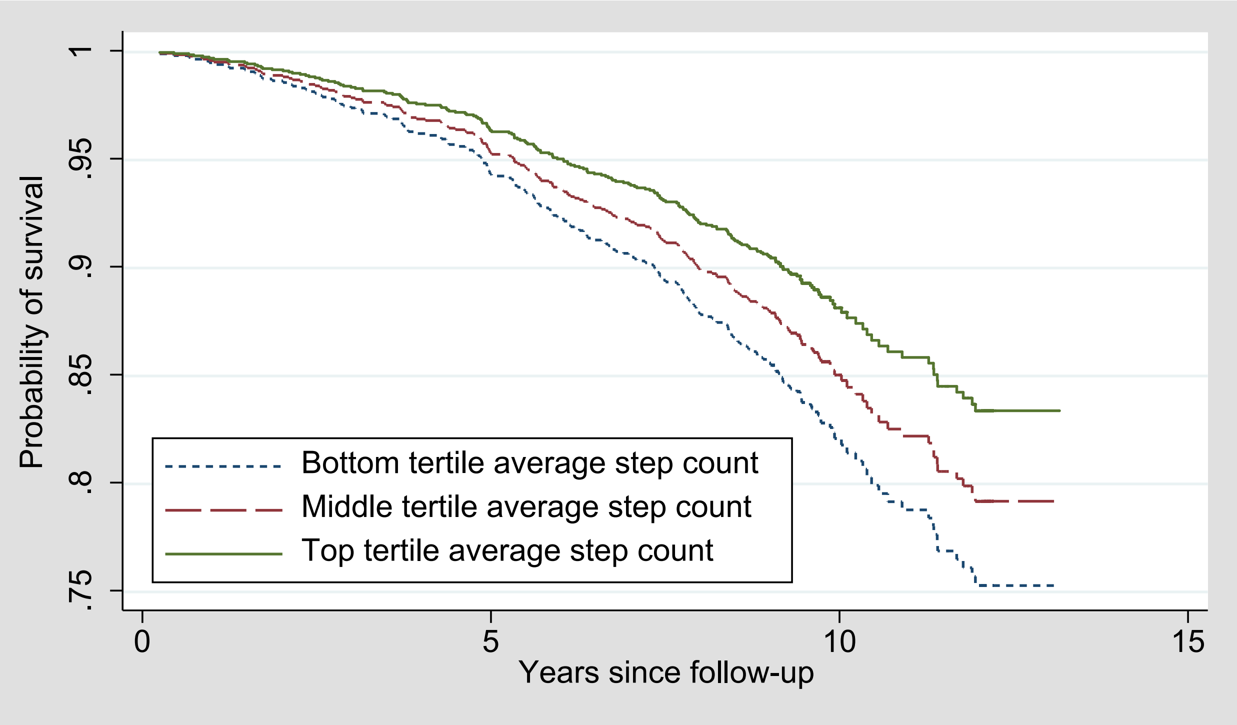

Figure 2a: Cox proportional hazards regression by step-count tertiles adjusting for mean age and diet quality score, and reference categories 'low income' and 'current smoker'. Step tertile 1 (941-5391 steps, n=560), step tertile 2 (5392-7985 steps, n=577), step tertile 3 (7985-15303 steps, n=560).

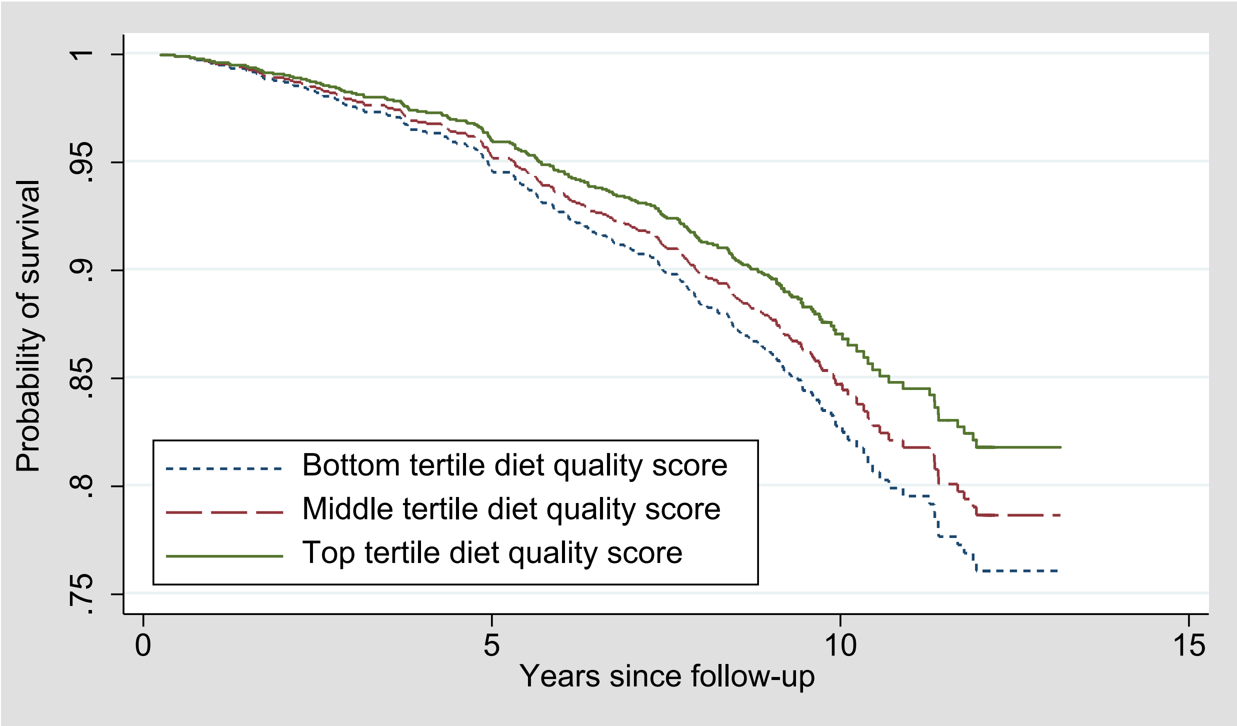

Figure 2b: Cox proportional hazards regression by diet quality tertiles (Hunter Community – Australian Recommended Food Score) adjusting for mean age and step count, and reference categories 'low income' and 'current smoker'. Diet quality tertile 1 (4-24 points, n=540), diet quality tertile 2 (25-31 points, n=573) and diet quality tertile 3 (32-54 points, n=584).

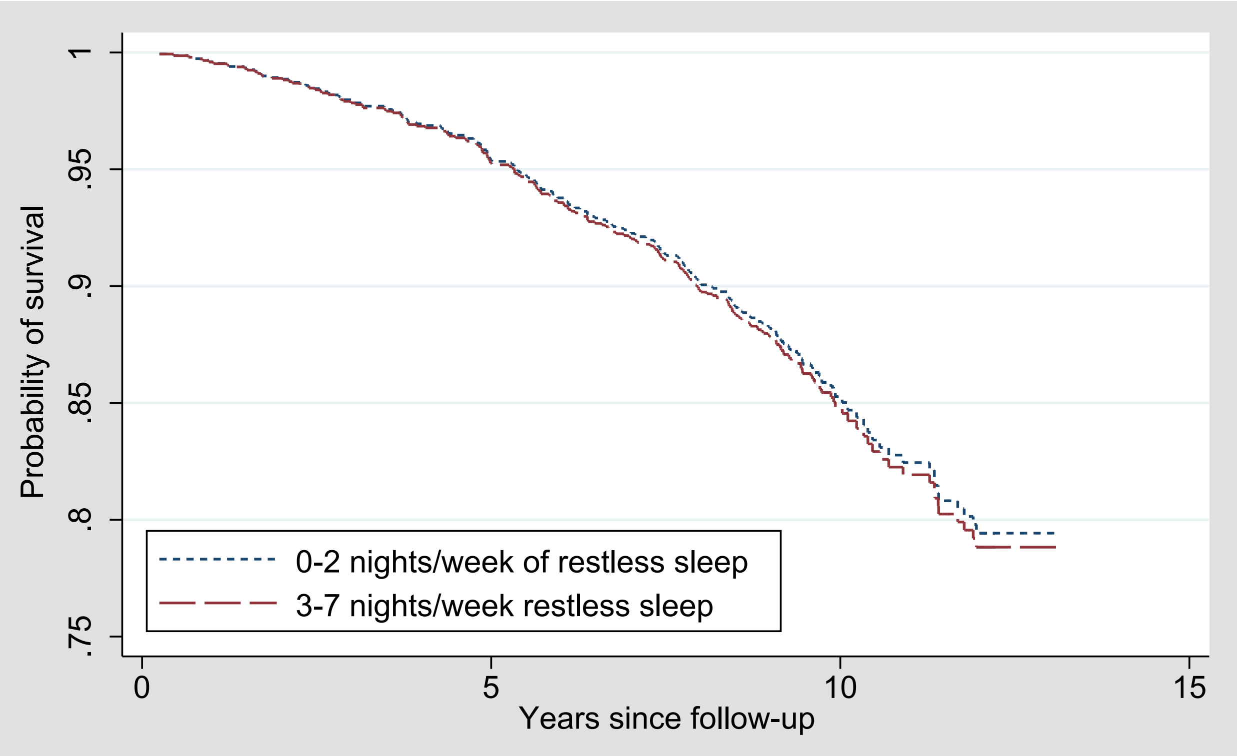

Figure 2c: Cox proportional hazards regression by restless sleep category adjusting for mean age, diet quality (Hunter Community – Australian Recommended Food Score) and step-count, and reference categories 'low income' and 'current smoker'. Restless sleep 0-2 nights/week (n=648, 38.2%) and restless sleep 3-7 night/week (n=1049, 61.8%).