

**This is an electronic reprint of the original article.
This reprint *may differ* from the original in pagination and typographic detail.**

Author(s): Äijö, Marja; Kauppinen, Markku; Kujala, Urho; Parkatti, Terttu

Title: Physical activity, fitness, and all-cause mortality: An 18-year follow-up among old people

Year: 2016

Version:

Please cite the original version:

Äijö, M., Kauppinen, M., Kujala, U., & Parkatti, T. (2016). Physical activity, fitness, and all-cause mortality: An 18-year follow-up among old people. *Journal of Sport and Health Science*, 5(4), 437–442. <https://doi.org/10.1016/j.jshs.2015.09.008>

All material supplied via JYX is protected by copyright and other intellectual property rights, and duplication or sale of all or part of any of the repository collections is not permitted, except that material may be duplicated by you for your research use or educational purposes in electronic or print form. You must obtain permission for any other use. Electronic or print copies may not be offered, whether for sale or otherwise to anyone who is not an authorised user.

Original article

Physical activity, fitness, and all-cause mortality: An 18-year follow-up among old people

Marja Äijö ^{a,*}, Markku Kauppinen ^b, Urho M. Kujala ^b, Terttu Parkatti ^b

^a Unit of Health Care, Savonia University of Applied Sciences, Kuopio 70111, Finland

^b Department of Health Sciences, University of Jyväskylä, Jyväskylä 40014, Finland

Received 30 November 2014; revised 9 April 2015; accepted 25 May 2015

Available online 25 September 2015

Abstract

Background: Little is known about change in physical activity (PA) and its relationship to all-cause mortality among old people. There is even less information about the association between PA, fitness, and all-cause mortality among people aged 80 years and above. The objective is to investigate persistence and change in PA over 5 years as a predictor of all-cause mortality, and fitness as a mediator of this association, among people aged 80 and 85 years at the beginning of an 18-year mortality follow-up period.

Methods: Using Evergreen Project data (started in 1989), 4 study groups were formed according to self-reported changes in PA level, over a 5-year period (starting in 1989–1990 and ending in 1994–1995): remained active (RA, control group), changed to inactive (CI), remained inactive (RI), and changed to active (CA). Mortality was followed up over the 18-year period (1994–2012). Cox models with different covariates such as age, sex, use of alcohol, smoking, chronic diseases, and a 10 m walking test were used to analyze the association between change in PA level and mortality.

Results: Compared to RA, those who decreased their PA level (CI) between baseline and follow-up had higher all-cause mortality (hazard ratio (HR) = 2.09; 95%CI: 1.63–2.69) when adjusted for age, gender, and chronic diseases. RI showed the highest all-cause mortality (HR = 2.16; 95%CI: 1.59–2.93). In CA, when compared against RA, the risk of all-cause mortality was not statistically significant (HR = 1.51; 95%CI: 0.95–2.38). In comparison with RA, when walking speed over 10 m was added as a covariate, all-cause mortality risk was almost statistically significant only in CI (HR = 1.37; 95%CI: 1.00–1.87).

Conclusion: Persistence and change in PA level was associated with mortality. This association was largely explained by fitness status. Randomized controlled studies are needed to test whether maintaining or increasing PA level could lengthen the life of old people.

© 2016 Production and hosting by Elsevier B.V. on behalf of Shanghai University of Sport. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Keywords: All-cause mortality; Fitness; Follow-up study; Functional ability; Old people; Physical activity

1. Introduction

A regular, moderate-to-high level of physical activity (PA) is associated with reduced risk of mortality among people aged 65 or older.^{1–7} For example, analyses conducted among persons aged 75–79 and 80+ years showed lower mortality risk among those who participated in ≥ 15 min of strenuous activity daily, e.g., vigorous walking versus none, and in ≥ 6 h/day of physically less demanding activities, e.g., gardening versus less than 2 h.⁸ A recently published meta-analysis showed that a higher level of total and domain-specific PA was associated with reduced all-cause mortality.⁹ Similar results have also been obtained in some cohort studies.^{10–14}

Some of the previous studies on long-term changes in the level of PA over time in older people have suggested that increasing and maintaining PA levels can promote longer life among older women,^{15,16} although it is less beneficial for women aged at least 75 years or with poor health.¹⁵ Studying the association between PA, fitness, and mortality among older people is problematic. Normal aging processes, based on genetic factors, decline the body capability in such parameters as muscle strength, maximal oxygen uptake and vital capacity, and in increased breathing work. All these changes affect the ability to be physically active or to perform regular exercise. Decline in PA is an indicator of an individual's level of physical fitness, which, in turn, in older people is related to frailty. Diseases and their preliminary stages also have an effect on the level of PA.¹⁷ In addition, observational follow-up studies have found that physical fitness is a stronger predictor of death than PA level.¹⁸

Peer review under responsibility of Shanghai University of Sport.

* Corresponding author.

E-mail address: marja.aijo@savonia.fi (M. Äijö).

The aim of this follow-up study was to investigate change in PA as a predictor of all-cause mortality among people aged 80 or 85 years at the beginning of an 18-year mortality follow-up with special reference to physical fitness as a mediator of this association.

2. Methods

2.1. Study design and target group

This study is part of the Evergreen Project, which is a prospective, population-based study in the city of Jyväskylä in central Finland.¹⁹ A general description of the framework, design, and methodology of the study has been described earlier by Heikkinen¹⁹ and Schroll et al.²⁰ and hence mentioned only briefly here. In 1989, three hundred and fifty-five 75-year-olds (92.9% of all residents in this age group) and in 1990, two hundred and sixty-two 80-year-olds (91.9%) were interviewed. Altogether 558 interviewees at baseline and 371 at the 5-year follow-up (1994–1995) answered the question on PA. Over the 5-year period, the main reasons for dropout were impaired health, noninterest in participating, relocation outside of the city of Jyväskylä, living in an institution and decease. Of the target group, 357 answered the PA question at both measurement times. They were 80 or 85 years old at the time of measurement in 1994–1995, which is referred to as the baseline in this mortality follow-up paper. Those living in institutions were excluded from this study because their state of health often precluded the collection of data. The Ethical Committee of the University of Jyväskylä approved the study protocol and all of the subjects signed a written informed consent. The study was carried out according to the guidelines on the responsible conduct of research and good research ethics. The methods applied in the data collection conformed to the relevant scientific criteria and were ethically sustainable.

2.2. Data collection

Data were collected through structured home interviews, a health questionnaire and laboratory examinations. At the end of the home interview session, the health questionnaire was left with the target individuals to be completed and returned when they came to the laboratory for the health examinations. The home interview session was performed by female university students who had been specially trained for the purpose. One interview session lasted about 1.5–2 h. The structured home interviews comprised several sections: 1) social background, living conditions, lifestyle, and life-history; 2) a health status questionnaire; 3) social activities, social contacts and support; 4) ability to perform activities of daily living; and 5) depressiveness and loneliness. The questions were all closed-ended. The health status section included items on PA. The other items on health status concerned 1) use of alcohol, 2) smoking, 3) PA, and 4) eating habits. The health examinations, conducted in a laboratory environment at the University of Jyväskylä, included 1) an interview on health status and drug use, 2) anthropometric status, 3) physical performance, 4) sensory functions, 5) perceptual motor coordination, 6) cognitive capacity and metacognitions, and 7) neuropsychological functions. The data

collection was carried out in the same way using similar study protocols on both measurement occasions.

2.3. PA

Level of self-reported PA was assessed using a validated scale developed by Grimby²¹ and Frändin and Grimby²² on the basis of the original 4-graded scale of Saltin and Grimby.²³ For the analyses, the responses to the 6-scale question were reclassified into 2 groups: inactive (comprising response alternatives 1 = mainly sitting in 1 place, reading or watching TV, and 2 = light PAs such as easy household tasks, and as well as going for an occasional walk or doing easy gardening) and active (comprising response alternatives 3 = moderate PA of about 3 h/week, such as dusting, ordinary gardening, walking longer distances, and cycling, 4 = moderate PA over 4 h/week or intense PA up to 4 h/week, such as heavy gardening, home maintenance or heavy domestic activities involving some breathlessness, and sweating, 5 = active sports at least 3 h/week such as tennis, swimming, jogging, or heavy gardening or heavy leisure-time activities, and 6 = competitive sports, strenuous exercise several times a week involving considerable physical exertion, such as swimming or jogging a longer distance).

On the basis of self-reported changes in PA level during the 5-year period (starting 1989–1990 and ending 1994–1995) 4 study groups were formed: remained active (RA = control group; $n = 152$), changed to inactive (CI; $n = 122$), remained inactive (RI; $n = 62$), and changed to active (CA; $n = 21$). Table 1 shows the frequencies and percentage distributions in each study group for both gender and baseline age.

2.4. Covariates

All the covariates were measured in the years 1994–1995. The items on smoking and use of alcohol have been described in detail earlier,⁴ and were used as category variables in this study. The diagnoses of chronic diseases were based on self-report in the interview,²⁴ and were later confirmed by a medical doctor in a clinical setting. The group of cardiac diseases included myocardial infarction and angina pectoris, cardiac insufficiency and heart arrhythmia. Respiratory diseases included asthma, chronic bronchitis and emphysema, and musculoskeletal diseases included arthrosis, rheumatoid arthritis, and sciatica syndrome. Metabolic diseases comprised diabetes. The group of other diseases comprised insufficiency, anemia, mental illness, neurosis, depression, alcoholism, Parkinson's disease, epilepsy, cataract, glaucoma, gout, obesity, and dementia. Each disease group formed a variable, and the subjects were coded as having a disease or having no disease in the group.

Maximal walking speed over 10 m, used as a continuous variable, was measured at baseline using a stopwatch in the laboratory corridor.²⁵ At least 2 additional meters were allowed for acceleration and deceleration.

2.5. Mortality

Date of death was recorded for all subjects who had died during the 18-year (1994–2012) follow-up period. This information was obtained from official archives and from the

Table 1

Distribution of 80- and 85-year-old women and men in the study groups based on changes between the years 1989–1990 and 1994–1995 in physical activity and frequencies (*n*), percentages (%), and statistically significant differences (*p* value) of covariates by 4 study groups (χ^2 test) (*n* = 357, years 1989–1990; *n* = 335 at the baseline measurement time, years 1994–1995).

Variables	RA	CI	RI	CA	<i>p</i>
Years 1989–1990	152	122	62	21	
Baseline (years 1994–1995)	147	110	59	19	
80 years					
Women	66 (43.1)	59 (38.6)	21 (13.7)	7 (4.6)	^a
Men	38 (48.7)	18 (23.1)	14 (17.9)	8 (10.3)	^a
85 years					
Women	32 (34.0)	37 (39.4)	20 (21.3)	5 (5.3)	^a
Men	16 (50.0)	8 (25.0)	7 (21.9)	1 (3.1)	^a
Women	98 (64.5)	96 (78.7)	41 (66.1)	12 (57.1)	0.038
75-year-old	104 (68.4)	77 (63.1)	35 (56.5)	15 (71.4)	0.345
Chronic diseases					
Heart disease	71 (46.7)	86 (70.5)	40 (64.5)	12 (57.1)	0.001
Stroke	7 (4.6)	12 (9.8)	11 (17.7)	3 (14.3)	0.019
Cancer	17 (11.2)	12 (9.8)	8 (12.9)	0 (0)	0.391
Chronic musculoskeletal diseases	52 (34.2)	51 (41.8)	17 (27.4)	7 (33.3)	0.258
Chronic respiratory diseases	10 (6.6)	17 (13.9)	3 (4.8)	3 (14.3)	0.087
Diabetes	11 (7.2)	19 (15.6)	7 (11.3)	1 (4.8)	0.124
Other diseases	33 (21.7)	48 (39.3)	19 (30.6)	6 (28.6)	0.018
Health behavior					
Use of alcohol	25 (17.0)	10 (9.1)	8 (13.6)	6 (31.6)	0.050
Smoking	6 (4.1)	5 (4.5)	6 (10.2)	0 (0)	0.199

^a The study groups did not have statistically significant gender differences in either age group or age group differences in gender groups (χ^2 test). Abbreviations: CA = changed to active; CI = changed to inactive; RA = remained active; RI = remained inactive.

archives of hospitals and homes for the elderly. The mortality follow-up started from the date of the last follow-up measurement 1 January 1994 – 31 December 1995 and continued until death or the date 12 September 2012.

2.6. Statistical analysis

Changes in the level of PA were analyzed using the McNemar test, and the differences between the covariates using the χ^2 test, in the 4 groups. The analysis of variance and least-significant difference (LSD) analysis were used for comparisons of means between the groups with walking speed over 10 m. The Kaplan–Meier survival Log Rank analysis was used to detect differences in the 4 study groups. We assessed the assumption of proportionality of hazards both graphically and by testing the significance of interaction terms for the PA and cardiovascular disease score and years of follow-up. No evidence was found for departure from the proportional hazards assumption. All tests were 2-sided and statistical significance was set at $p < 0.05$. Cox regression analysis, with calculations of hazards ratios (HRs) and 95%CI, was used to investigate the relationship between the dependent variable (time of death) and change in PA. The relative risk of death was analyzed in the 4 groups, using the RA group as the reference group. The relationship between all the adjusted variables and all-cause mortality was tested separately in different analytical models, and variables with statistically significant relationships with all-cause mortality were included in the final models. Three models with a varying number of adjusted variables (age, gender, heart diseases, stroke, diabetes, other diseases and maximal walking speed over 10 m)

were used in the analysis process. The mortality rate per 100 person-years was calculated for each of the 4 study groups separately. Drop out analysis was not done, owing to the small number of survivors (*n* = 10) during the 18-year follow-up. The data were analyzed in the year 2014. All analyses were conducted using the SPSS Version 18.0 for Windows (IBM, Armonk, NY, USA).

3. Results

In years 1989–1990, 379 (68% of 558), and 5 years later (1994–1995) 178 (48% of 371), of the study population were coded as active. The final number of participants in this study was 357 since the participants who did not have physical activity information from the second measurement time were excluded. Among these participants 122 (45% of 357) changed to inactive, while the number who changed from inactive to active was quite low (McNemar test, $p < 0.001$).

Comparison of the 4 study groups at baseline revealed a higher prevalence of cardiac diseases and other diseases in the CI group, and stroke in the RI group, than in the other 2 groups. The lowest prevalence of cardiac diseases, stroke and other diseases was found in the RA group. Women were more frequent in the CI group, and the use of alcohol was more prevalent in the CA group than in the other groups (Table 1). Table 2 shows that mean walking speed over 10 m/s was statistically significantly slower in CI and RI compared to RA (both $p < 0.001$) and CA ($p = 0.002$, $p = 0.038$). No statistically significant differences were observed between RA and CA ($p = 0.100$) or between CI and RI ($p = 0.059$) groups with walking speed over the 10 m/s.

Table 2
Mean walking speed over 10 m/s and comparison between 4 study groups at the baseline measurement time (*t* test).

Group	Mean walking speed over 10 m/s
Remained active	1.50
Changed to inactive	1.12*,#
Remained inactive	0.97*,#
Changed to active	1.36

* $p < 0.001$, compared with remained active.

$p < 0.05$, compared with changed to active.

The total number of person-years in this study was 2945. During the 18 follow-up years, 97.2% ($n = 347$) of the subjects died. The mortality rate per 100 person years was 9 in RA, 14 in CI, 16 in RI, and 12 in CA. The Kaplan–Meier analyses showed that mortality was statistically significantly lower in the RA than CI (log rank = 29.00, $df = 1$, $p < 0.001$) or RI (log rank = 26.12, $df = 1$, $p < 0.001$). The difference between RA and CA was statistically almost significant (log rank = 3.40, $df = 1$, $p = 0.065$) (Fig. 1).

During the 18-year follow-up, the relative risk of death adjusted for age and gender was more than 2 times greater in CI and RI than RA. Adjustment for the covariates of stroke, diabetes, heart diseases and other diseases reduced the estimate, but did not change the interpretation of the results. When walking speed over 10 m/s was added as a covariate to model 2, all-cause mortality risk was higher only in CI compared to RA (Table 3). The statistical significance of this is on the borderline (lower limit 1.00).

4. Discussion

In this study we investigated persistence or change in PA as a predictor of all-cause mortality among 80- and 85-year-old people, over an 18-year follow-up period. The results show that persistent inactivity and changes to inactivity were associated with a higher mortality rate, and that this association was largely explained by fitness status.

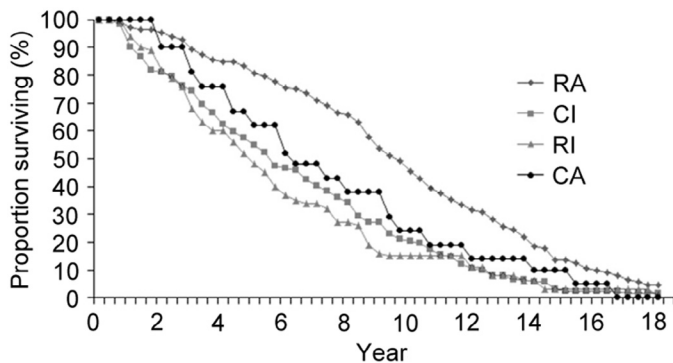


Fig. 1. Proportion of mean survival in 4 study groups according to baseline measurement. CA = changed to active; CI = changed to inactive; RA = remained active; RI = remained inactive.

Table 3
The relationship between the covariates and all-cause mortality in 4 study groups (HR and 95%CI) in 3 models (Cox regression-analysis).

Group	Model 1 ^a		Model 2 ^b		Model 3 ^c	
	HR	95%CI	HR	95%CI	HR	95%CI
RA	1	—	1	—	1	—
CI	2.09	1.63–2.69	1.96	1.51–2.53	1.37	1.00–1.87
RI	2.16	1.59–2.93	2.02	1.49–2.76	1.02	0.64–1.62
CA	1.51	0.95–2.38	1.36	0.86–2.16	1.04	0.63–1.74

^a Adjusted for age and gender.

^b Adjusted for age, gender, stroke, diabetes, cardiac diseases, and other diseases.

^c Adjusted for age, gender, stroke, diabetes, cardiac diseases, other diseases, and walking speed over 10 m/s.

Abbreviations: 95%CI = 95% confidence intervals; CA = changed to active; CI = changed to inactive; HR = hazard rate; RA = remained active; RI = remained inactive.

During the 5-year period PA decreased more than increased with only a minority of the participants reporting an increased level of activity. Compared to the results of Xue et al.,¹⁶ our participants were more often coded into the RA and RI groups. Comparison of the results between these 2 studies is, however, difficult because of differences in the measurements of PA.

In this study, PA was associated with a lower mortality rate, which is in line with earlier findings.^{4,9–12} In the groups that were physically inactive at the end of our baseline period (RI or CI), a higher mortality rate, slower walking time, and more cardiac diseases, stroke and other diseases were observed than in the physically active groups (RA or CA). This may be explained by the prevalence of diagnosed diseases and by undiagnosed pre-disease stages, which may reduce the PA level and fitness of older people, whereas healthy individuals are able to continue their vigorous level of activity. Furthermore, genetic factors might explain part of the association, as regular exercise behavior and health outcomes may be affected by the same genetic factors. Those with a favorable genetic profile may experience exercising as easy and at the same time may have lower morbidity and mortality.¹⁷ Among those with chronic diseases, however, change in health behavior is more difficult.²⁶ The results of this study support this view.

Some earlier studies have shown an association between increased PA and reduced all-cause mortality among younger populations.^{2,27} Studies have also shown that women aged 65 years or more who become active have a mortality rate similar to those who are already active, whereas active women who become inactive have a mortality risk similar to those who have been inactive all along.^{15,16} Among older people, increasing the level of PA may help to lower their mortality risk, if their fitness level is taken into account. The present results support the idea that the association between increased PA and all-cause mortality among older age groups (>65 years) might resemble that found for younger age groups (<65 years).^{2,27,28} In our study, the mortality difference between the RA and CA groups was statistically non-significant. When 10 m walking time was adjusted along with the other covariates in the analyzed model, a borderline significant increase in risk of all-cause mortality

appeared only in the CI group, showing that the fitness level of the subjects might explain much of the association between PA and mortality found in our study. Subjects with higher fitness levels were able to increase or maintain their higher PA level. As in earlier studies¹⁸ among younger people, physical fitness might be a stronger predictor of all-cause mortality among older people than level of PA. It might be that older men and women differ in their fitness level;²⁹ however, in this study, owing to the small number of participants, it was not possible to conduct mortality analyses for men and women separately.

The main strengths of our study are the 18-year longitudinal data, and the representativeness of the study population. The baseline participation rate, 93% of 75-year-olds and 92% of 80-year-olds, was higher. This study provided new information about a very old age group. At the end of the follow-up, the oldest group of subjects was 93 years or older. This age group has not been widely studied. This study also included both men and women, whereas earlier studies have focused exclusively on change in PA among women.^{15,16} In all phases of the study, the mortality data were collected using reliable records and the same study protocol. The research staff were well trained to minimize any systematic or occasional errors. PA was measured on the basis of a simple standardized question, which was easy for older subjects to answer. Furthermore, previous studies, such as Rantanen et al.,³⁰ have used the same classification in studying PA and changes in maximal isometric strength among old people. Our results are in line with theirs. Another strength of our study lies in the covariates used in the analyzed models. We used the main covariates associated with PA and mortality such as smoking, use of alcohol, and chronic diseases.^{31,32} In addition, the diagnoses of chronic diseases were based on medical examinations. The results of this study can be generalized to non-institutionalized older people of the same age living in cities in Finland and to similar populations of older people in western countries.

The study also has its limitations. PA level was based on self-reports, which is inherently prone to measurement error and the results of which may be affected by misclassification. However, the PA question²¹ used in this study has been used in earlier studies and it has been considered a reasonably valid measurement.¹ Among younger populations,³³ it has been shown that the level of PA can vary between active and inactive subjects during the follow-up years; this is also possible in our study. Also, other factors, such as intra-individual factors like acute illnesses or psychosocial attributes, and extra-individual factors like medication, other therapeutic regimens, external support or physical environment, have their own effect on the level of PA. Today, more validated and reliable measures of PA in older people are available.

5. Conclusion

Both a physically inactive life-style and a decrease in the level of PA were predictors of mortality. Even very old people can maintain and even increase their level of PA. Fitness level largely explained the association between the change in PA and all-cause mortality. As fitness level is strongly associated with both PA and mortality, randomized controlled studies are

needed to test whether maintaining or increasing PA levels could lengthen life among old people.

Authors' contributions

MÄ performed statistical analysis and drafted the manuscript; MK helped to perform the statistical analysis; UMK and TP helped to draft the manuscript. All authors have read and approved the final version of the manuscript, and agreed with the order of presentation of the authors.

Competing interests

None of the authors declare competing financial interests.

References

1. Sihvonen S, Rantanen T, Heikkinen E. Physical activity and survival in elderly people: a five-year follow-up study. *JAPA* 1998;**6**:133–40.
2. Wannamethee SG, Shaper AG, Walker M. Changes in physical activity, mortality, and incidence of coronary heart disease in older men. *Lancet* 1998;**30**:1603–8.
3. Glass T, Mendes de Leon C, Marttoli R, Berkman L. Population based study of social and productive activities as predictors of survival among elderly Americans. *BMJ* 1999;**319**:478–83.
4. Äijö M, Heikkinen E, Schroll M, Steen B. Physical activity and mortality of 75-year-old people in three Nordic localities: a five-year follow-up. *Aging Clin Exp Res* 2002;**14**(Suppl. 3):S83–9.
5. Stensvoll D, Nauman J, Nilsen T, Wisløff U, Slørdahl S, Vatten L. Even low level of physical activity is associated with reduced mortality among people with metabolic syndrome, a population based study (the HUNT 2 study, Norway). *BMC Med* 2011;**29**:109. doi:10.1186/1741-7015-9-109
6. Brown W, McLaughlin D, Leung J, McCaul KA, Flicker L, Almeida OP, et al. Physical activity and all-cause mortality in older women and men. *Br J Sports Med* 2012;**46**:664–8.
7. Sundquist K, Qvist J, Sundquist J, Johansson SE. Frequent and occasional physical activity in the elderly. A 12-year follow-up study of mortality. *Am J Prev Med* 2004;**27**:22–7.
8. Paganini-Hill A, Kawas C, Corrada MM. Activities and mortality in the elderly: the Leisure World cohort study. *J Gerontol A Biol Sci Med Sci* 2011;**66**:559–67.
9. Samitz G, Egger M, Zwahlen M. Domains of physical activity and all-cause mortality: systematic review and dose-response meta-analysis of cohort studies. *Int J Epidemiol* 2011;**40**:1382–400.
10. Ueshima K, Ishikawa-Takata K, Yorifuji T, Suzuki E, Kashima S, Takao S, et al. Physical activity and mortality risk in the Japanese Elderly. A cohort study. *Am J Prev Med* 2010;**38**:410–8.
11. Gulsvik A, Thelle D, Samuelsen S, Myrstad M, Mowe M, Wyller T. Ageing, physical activity and mortality—a 42-year follow-up study. *Int J Epidemiol* 2012;**41**:521–30.
12. Mok Y, Won S, Kimm H, Nam C, Ohrr H, Ha Jee S. Physical activity level and risk of death: the severance cohort study. *J Epidemiol* 2012;**22**:494–500.
13. Moore SC, Patel AV, Matthews CE, Berrington de Gonzalez A, Park Y, Katki HA, et al. Leisure time physical activity of moderate to vigorous intensity and mortality: a large pooled cohort analysis. *PLoS Med* 2012;**9**:e1001335. doi:10.1371/journal.pmed.1001335
14. Shaw BA, Agahi N. A prospective cohort study of health behavior profiles after age 50 and mortality risk. *BMC Public Health* 2012;**12**:803. doi: 10.1186/1471-2458-12-803
15. Gregg E, Cauley J, Stone K, Thompson TJ, Bauer DC, Cummings SR, et al. Relationship of change in physical activity and mortality among older women. *JAMA* 2003;**289**:2379–86.
16. Xue QL, Bandeen-Roche K, Mielenz TJ, Seplaki CL, Szanton SL, Thorpe RJ, et al. Patterns of 12-year change in physical activity levels in community-dwelling older women: can modest levels of physical activity help older women live longer? *Am J Epidemiol* 2012;**176**:534–43.

17. Kujala U. Physical activity, genes, and lifetime predisposition to chronic disease. *Eur Rev Aging Phys Act* 2011;**8**:31–6.
18. Lee DC, Sui X, Ortega YS, Church TS, Winett RA, Ekelund U, et al. Comparisons of leisure-time physical activity and cardiorespiratory fitness as predictors of all-cause mortality in men and women. *Br J Sports Med* 2011;**45**:504–10.
19. Heikkinen E. Background, design and methods of the Evergreen Project. *JAPA* 1998;**6**:106–20.
20. Schroll M, Steen B, Berg S, Heikkinen E, Viidik A. NORA-Nordic research on ageing. Functional capacity of 75-year-old men and women in three Nordic localities. *Dan Med Bull* 1993;**40**:618–24.
21. Grimby G. Physical activity and muscle training in elderly. *Acta Med Scand Suppl* 1986;**711**:233–7.
22. Frändin K, Grimby G. Assessment of physical activity, fitness and performance in 76-year-olds. *Scan J Med Sci Sports* 1994;**4**:41–6.
23. Saltin B, Grimby G. The physiological analysis of the middle-aged and former athletes. *Circulation* 1968;**38**:1104–15.
24. Äijö M, Parkatti T. Independent and combined association of physical activity and cardiac disease on mortality risk in the very old. *J Aging Health* 2011;**23**:70–85.
25. Aniansson A, Rundgren A, Sperling L. Evaluation of functional capacity in activities of daily living in 70-year-old men and women. *Scand J Rehabil Med* 1980;**12**:145–54.
26. Newsom JT, Huguet N, McCarthy MJ, Ramage-Morin P, Kaplan MS, Bernier J, et al. Health behavior change following chronic illness in middle and later life. *J Gerontol B Psychol Sci Soc Sci* 2012;**67**:279–88.
27. Byberg L, Melhus H, Gedeberg R, Sundström J, Ahlbom A, Zethelius B, et al. Total mortality after changes in leisure time physical activity in 50 year old men: 35 year follow-up of population based cohort. *BMJ* 2009;**338**:b668. doi:10.1136/bmj.b668
28. Talbot LA, Morrell CH, Fleg JL, Metter EJ. Changes in leisure time physical activity and risk of all-cause mortality in men and women: the Baltimore Longitudinal Study of Ageing. *Prev Med* 2007;**45**:169–76.
29. Gouveia ÉR, Maia JA, Beunen GP, Blimkie CJ, Fena EM, Freitas DL. Functional fitness and physical activity of Portuguese community-Residing older adults. *JAPA* 2013;**21**:1–19.
30. Rantanen T, Era P, Heikkinen E. Physical activity and the changes in maximal isometric strength in men and women from the age of 75 to 80 years. *J Am Geriatr Soc* 1997;**45**:1439–45.
31. Cohen-Mansfield J. Smoking and mortality among persons aged 75–94. *Prev Med* 2013;**56**:185–9.
32. Rizzuto D, Orsini N, Qui C, Wang HX, Fratiglioni L. Lifestyle, social factors, and survival after age 75: population based study. *BMJ* 2012;**29**:e5568. doi: 10.1136/bmj.e5568
33. Picavet H, Wendel-vos G, Vreeken H, Schuit A, Verschuren W. How stable are physical activity habits among adults? The Doetinchem Cohort Study. *Med Sci Sports Exerc* 2011;**43**:74–9.