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ORIGINAL INVESTIGATION

# Changes in physical functioning over 6 years in older women: effects of sitting time and physical activity

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**Abstract** The combined effects of physical activity (PA) and sitting time (ST) on physical functioning (PF) may be stronger than for each factor separately. This study examined associations between ST, PA, and PF over 6 years in older women. Data were from 6,611 participants in the Australian Longitudinal Study on Women's Health (mean age 78 ± 1.5 years). Activity pattern at baseline (2002) was categorized as one of 12 combinations of ST (<4, 4–7, or ≥8 h/day) and PA (<40, 40–450, 450–900, or ≥900 MET min/week). PF was measured using the SF-36 (range 0–100) in 2002, 2005, and 2008. General estimating equations for linear regression were used with adjustment for confounders. Baseline PF ranged from 40 to 74 in the least to the most active groups. PF was 6.3 (95 % confidence interval [CI] −7.6 to −5.0) points lower in participants sitting ≥8 h/day than in participants sitting <4 h/day, and 16.9 (CI 15.7–18.0) points higher in participants reporting ≥900 MET min/week than in participants reporting <40 MET min/week PA. Compared with the least active pattern, those in the most active pattern scored 24.5 (CI 22.5–26.4) points higher. The decline over 6 years was greater in the more active categories: 5 and 16 points in the least and most active categories. In conclusion, in women, both high physical activity and low sitting time are important for establishing a certain level of PF prior to age 76–81, but do not protect against decline in PF over time later in life. The combined effect of ST and PA did not differ from their individual effects on PF.

**Keywords** Physical activity · Sedentary behaviour · Physical functioning · Old age

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## Introduction

The association between physical activity and physical functioning in older adults has been well-described, and cross-sectional and empirical evidence shows that being physically active is associated with better physical functioning in older age (Visser et al. 2002; Gill et al. 2003; Landi et al. 2007). A growing body of evidence suggests that, in addition to being inactive, prolonged sitting time is a risk factor for many health problems including cardiovascular diseases, diabetes, and premature death (Thorp et al. 2011). Although an association between prolonged sitting time and physical functioning can be expected, to our knowledge, this association has not been examined before.

Sitting time and physical activity are measured and perceived as different but related aspects of behavior (Dunstan et al. 2012). Both prolonged sitting time and inactivity have been associated with poor health outcomes, but few studies have examined their combined effects. For example, three studies that examined associations between

prolonged sitting time and mortality included an interaction term with physical activity (Patel et al. 2010; Matthews et al. 2012; van der Ploeg et al. 2012). All three studies showed that mortality risks associated with higher levels of sitting time were higher in groups with lower levels of physical activity. These findings suggest that physical activity may (partly) off-set the negative effects of prolonged sitting time. Hence, the combined effects of sitting time and physical activity may be more important than their individual effects on health.

Compared with younger adults, older adults may be more likely to avoid physically challenging activities and increase their sitting time due to pain, fear of falling, or mobility limitations (Wijlhuizen et al. 2007; Rasinaho et al. 2007). Prolonged inactivity and immobility lead to bone loss and muscle weakness and subsequent decline in physical functioning, with increased risks of falls and fractures (DiPietro 2001; Stel et al. 2004; Visser et al. 2005; Booth et al. 2011). Hence, a downward spiral becomes apparent.

The aim was to examine associations between physical activity, sitting time (and their combined effects, referred to as "activity pattern") and the course of physical functioning over time in older women.

## Methods

### Participants

Data were from the Australian Longitudinal Study on Women's Health (ALSWH), a large population-based study of factors affecting the health and well-being in three generations of women (Lee et al. 2005). The study methods were approved by the Human Research Ethics Committees of the Universities of Newcastle and Queensland, and all participants signed informed consent. Detailed information on design, recruitment, and attrition can be found elsewhere (Brown et al. 1998; Lee et al. 2005). This study used self-completed questionnaire data from the oldest cohort born in 1921–1926. The first survey in 1996 included 12,762 women; since then, four follow-up surveys have been completed at 3-year intervals. Sitting time was measured in the third survey (2002) only, therefore, this survey was taken as the baseline for the current analyses, with the 2005 and 2008 surveys as follow-up. Of the 8,646 women who participated in the 2002 survey, 6611 (76.5 %) provided data on physical activity, sitting time, and physical functioning and were included in the analyses. Of these participants, 5,157 (78.0 %), and 3,873 (58.6 %) provided data on physical functioning in the fourth, and fifth surveys, respectively. Reasons for non-response are presented in Fig. 1.

### Measurements

#### *Physical functioning*

In 2002, 2005 and 2008, physical functioning was measured as a subscale of the SF-36 (Bohannon and DePasquale 2010; Ware and Sherbourne 1992). This subscale consists of ten items about whether health limits the participant in doing a range of activities, including vigorous and moderate activities, stair climbing, mobility and self-care. The score ranges from 0 to 100 with higher scores indicating better physical functioning related quality of life.

#### *Sitting time*

In 2002, sitting time was measured by asking "How many hours each day do you typically spend sitting down while doing things like visiting friends, driving, reading, watching television, or working at a desk or computer?" The validity and reliability of this question have not been evaluated, but a similar question in the International Physical Activity Questionnaire (IPAQ) has been shown to have good test–retest reliability ($r > 0.75$) (Rosenberg et al. 2008). The question was answered in hours, both for a typical week day and weekend day. Data were cleaned following protocols as described by van Uffelen et al. (2010). Hours spent sitting on a week day and a weekend day were averaged ([week day*5 + weekend day*2]/7) to estimate the mean sitting time in hours per day (range 0–16 h/d), and categorized using cut-points corresponding with those used in other studies: <4, 4–7, and ≥8 h/day (van der Ploeg et al. 2012; Pavey et al. 2012).

#### *Physical activity*

In 2002, physical activity was assessed from reported frequency and duration of walking briskly, moderate (e.g., social tennis, recreational swimming, dancing) and vigorous (activities that make you breathe harder or puff and pant, e.g., aerobics, competitive sport, vigorous cycling) leisure-time activities during the last week. These questions are based on the Active Australia survey, and have been found to have moderate test–retest reliability (ICC $\geq 0.56$) and concurrent validity against accelerometer data ($r = 0.52$) (Kanis et al. 2004; Brown et al. 2008). Time spent in each activity was multiplied by the metabolic equivalent (MET) score that reflects the average intensity of the activities in that category (Ainsworth et al. 2011): walking briskly = frequency*duration*3.0, moderate activities = frequency*duration*4.0, vigorous activity = frequency*duration*7.5. Scores in each activity category were summed (range 0–15,000 MET min/week). Based on the

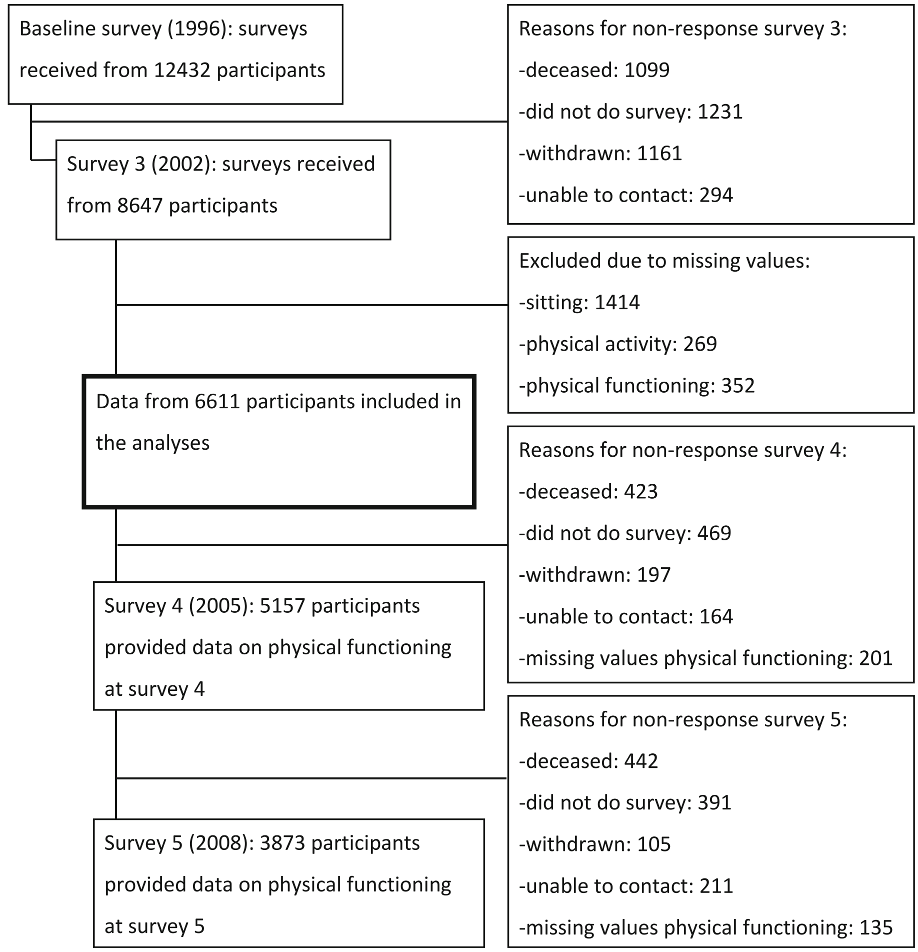


**Fig. 1** Flow chart of participants in 1921–26 cohort of the Australian Longitudinal Study on Women's Health

international recommendations to do 30 min of moderate activity on most days (5 or more) of the week (US Department of Health and Human Services 2008), physical activity was categorized as <40, 40–450, 450–900, and ≥900 MET min/week, corresponding to no, low, moderate, and high level of physical activity.

*Activity pattern*

The definition of activity pattern was based on time spent in both physical activity and sitting. Each category of physical activity was combined with each category of sitting time, resulting in the 12 categories described in Table 2.

*Descriptive variables and confounders*

Demographic, health status, and life style variables were measured as part of the mailed survey in 2002 (unless stated otherwise). The demographic variables were age, area of residence, marital status, education (assessed in the 1996 survey), and type of residence (community-dwelling/retirement village/nursing home or hostel). Health status variables were self-reported weight and height, body mass index [BMI, weight (kg)/height (m)$^2$], anxiety and depressive symptoms, chronic diseases, bodily pain, fall history, fracture history, and dizziness. Anxiety and depressive symptoms were assessed using the Goldberg Anxiety and Depression Scale (GAD), with scores ranging from 0 to 18 and higher scores indicating more symptoms (Goldberg et al. 1988). Number of chronic diseases was based on the presence of six major chronic conditions, i.e., cardiovascular diseases, diabetes, stroke, lung diseases, cancer, and arthritis. Bodily pain was measured as a subscale of the SF-36 (range 0–100) (Ware and Sherbourne 1992). Fall and fracture status were assessed by asking "In the past 12 months have you: (a) had a fall to the ground?; and (b) broken or fractured any bones?" (yes/no). Dizziness was assessed by asking "Have you had problems in the last 12 months with dizziness or loss of balance: never, rarely, sometimes, or often?". The categories never and rarely, and sometimes and often were collapsed for further analyses.

## Statistical analysis

Baseline characteristics were compared between the sitting time categories. Differences were tested using ANOVA for

near normally distributed variables, Kruskal–Wallis test for variables not normally distributed, and $\chi^2$ test for categorical variables.

The associations between sitting time, physical activity, and activity pattern at baseline (2002) and physical functioning at baseline and after 3 and 6 years of follow-up were studied using general estimating equations (GEE) for linear regression and with an exchangeable correlation structure. Crude unrestricted spline graphs showed that the associations between sitting time and physical functioning and between physical activity and physical functioning were not linear (data not shown). Therefore, analyses were done with sitting time and physical activity in categories. Analyses were conducted unadjusted and with adjustment for variables that were significantly associated with the exposures and outcome. To model the course of change in physical functioning over time, an interaction term between exposure and survey was added. To test potential collinearity between physical activity and sitting time, the Spearman correlation and variance inflation factor (VIF) were calculated (VIF > 10 indicates collinearity) (Chen et al. 2003). If collinearity is an issue, the two exposures cannot be put in one model. If no collinearity existed, potential interaction between sitting time and physical activity was tested. If the $p$ value for interaction was <0.10 (Aiken and West 1991), the product term sitting time*physical activity was added to the models for sitting time and physical activity. The lowest categories were used as the reference categories for sitting time and physical activity, whereas the least active category (sitting ≥8 h/day and <40 MET min/week) was used as the reference category for activity pattern. As 1,643 (24.8 %) participants had missing values on any of the confounding variables, multiple imputation by chained equations (MICE) was used to impute these values. $P$ values were based on two-sided tests and were considered statistically significant at $P < 0.05$. All analyses were done using Stata version 11.1 (StataCorp LP, US).

## Results

At baseline in 2002, the mean age of the 6,611 participants with complete data was 78 ± 1.5 years. Just under half the participants lived in urban areas and the majority lived in the community. Statistically significant differences were found between the three sitting time categories on most demographic and health characteristics (Table 1). In particular, the participants with the highest sitting time had poorer outcomes on all health characteristics. Compared with participants whose data were included in the analyses, those excluded due to missing values for sitting time and/or physical activity ($n = 2035$) were older, more likely to be divorced, separated or widowed; had lower levels of

**Table 1** Baseline characteristics (2002) of women in each of the sitting time categories

| | Sitting time | | | |
|---|---|---|---|---|
| | <4 h/day | 4–7 h/day | ≥8 h/day | $P$ value |
| N | 2796 | 2590 | 1225 | |
| Age[a] | 78.2 (1.4) | 78.2 (1.5) | 78.2 (1.4) | 0.85 |
| Living in urban areas (%) | 40.5 | 45.3 | 45.1 | 0.005 |
| Community dwelling (%) | 93.6 | 91.2 | 87.1 | <0.001 |
| Married/de facto relationship (%) | 50.9 | 43.6 | 38.4 | <0.001 |
| Education (%) | | | | 0.58 |
| No formal | 28.8 | 29.1 | 30.1 | |
| School certificate | 40.8 | 39.5 | 39.8 | |
| Higher school certificate | 12.5 | 13.4 | 12.7 | |
| Trade/apprentice/certificate | 13.6 | 12.7 | 13.1 | |
| University degree or higher | 4.4 | 5.4 | 4.2 | |
| Weight (kg)[b] | 64 [56–70] | 64 [57–72] | 67 [58–76] | <0.001 |
| BMI[a] | 24.8 (4.2) | 25.4 (4.4) | 26.4 (5.3) | <0.001 |
| Bodily pain[b,c] | 70 [41–84] | 62 [41–84] | 52 [31–80] | <0.001 |
| Faller (%) | 16.5 | 17.9 | 23.2 | <0.001 |
| Fractures (%) | 4.5 | 5.8 | 6.5 | 0.02 |
| Dizziness (%) | 19.9 | 22.6 | 29.1 | <0.001 |
| Number of chronic diseases[b] | 1 [0–1] | 1 [0–1] | 1 [0–2] | <0.001 |
| Depressive/anxiety symptoms[b] | 4 [2–7] | 5 [2–8] | 6 [3–9] | <0.001 |
| Physical activity (MET min/week)[b] | 270 [0–953] | 270 [0–945] | 0 [0–615] | <0.001 |

[a] Means (standard deviations), $P$ values based on ANOVA

[b] Medians [Interquartile ranges], $P$ values based on Kruskal–Wallis tests. Differences in proportions are tested with $\chi^2$ tests

[c] Lower scores indicate poorer quality of life resulting from bodily pain

**Table 2** General estimating equations: associations between sitting time, physical activity, activity pattern (i.e., the combination of sitting time and physical activity) and physical functioning in older women

| Sitting time (h/day) | Physical activity (MET min/week) | | Unadjusted[a] | | Adjusted[a] | |
|---|---|---|---|---|---|---|
| | | *n* | B | CI | B | CI |
| <4 | | 2796 | 0 | | 0 | |
| 4–7 | | 2590 | −4.5 | −5.8 to −3.2 | −1.9 | −2.9 to −0.9 |
| ≥8 | | 1225 | −15.1 | −16.8 to−13.5 | −6.3 | −7.6 to −5.0 |
| | <40 | 2522 | 0 | | 0 | |
| | 40–450 | 1533 | 18.4 | 17.0 to 19.9 | 10.8 | 9.6 to 11.9 |
| | 450–900 | 963 | 23.8 | 22.2 to 25.5 | 14.3 | 13.0 to 15.6 |
| | ≥900 | 1593 | 28.8 | 27.4 to 30.2 | 16.9 | 15.7 to 18.0 |
| ≥8 | <40 | 644 | 0 | | 0 | |
| 4–7 | <40 | 926 | 9.2 | 6.9 to 11.5 | 4.8 | 3.0 to 6.7 |
| <4 | <40 | 952 | 14.7 | 12.5 to 17.0 | 7.0 | 5.2 to 8.9 |
| ≥8 | 40–450 | 235 | 22.5 | 19.1 to 25.8 | 13.6 | 10.9 to 16.3 |
| 4–7 | 40–450 | 597 | 26.9 | 24.4 to 29.4 | 15.8 | 13.8 to 17.8 |
| <4 | 40–450 | 701 | 29.6 | 27.2 to 32.0 | 16.7 | 14.7 to 18.6 |
| ≥8 | 450–900 | 116 | 26.0 | 21.6 to 30.4 | 16.0 | 12.5 to 19.6 |
| 4–7 | 450–900 | 412 | 32.5 | 29.7 to 35.2 | 19.6 | 17.4 to 21.9 |
| <4 | 450–900 | 435 | 35.0 | 32.4 to 37.7 | 20.6 | 18.4 to 22.8 |
| ≥8 | ≥900 | 230 | 33.1 | 29.7 to 36.4 | 20.6 | 17.9 to 23.0 |
| 4–7 | ≥900 | 655 | 36.1 | 33.7 to 38.6 | 21.0 | 19.0 to 23.0 |
| <4 | ≥900 | 708 | 40.9 | 38.5 to 43.3 | 24.5 | 22.5 to 26.4 |

*B* regression coefficient, *CI* 95 % confidence interval

[a] Unadjusted models include survey, adjusted models additionally include age, education, housing situation, chronic conditions, BMI, bodily pain, fracture history, and dizziness

education, and had lower levels of sitting time as well as physical activity ($P < 0.01$).

Averaged over time, higher levels of sitting time were associated with lower scores for physical functioning (Table 2). Compared with participants sitting <4 h/day, participants who sat 4–7 h/day scored 4.5 (95 % confidence interval [CI] −5.8 to −3.2) points lower and participants sitting ≥8 h/day scored 15.1 (CI −16.8 to −13.5) points lower. This association remained statistically significant after adjustment for confounders. The interaction with survey was not significant ($P = 0.90$), suggesting that the association between sitting time and functioning is constant over time.

Higher levels of physical activity were associated with higher scores for physical functioning (Table 2). Compared with participants who spent <40 MET min/week, those with 40–450, 450–900, and ≥900 MET min/week scored 18.4 (CI 17.0 to 19.9), 23.8 (CI 22.2–25.5), and 28.8 (CI 27.4–30.2) points higher, respectively. This association remained statistically significant after adjustment for confounders. The interaction with survey was significant ($P < 0.001$), suggesting that the slope of the physical activity–physical functioning relationship changed over time.

The poor correlation between the sitting time and physical activity ($r = -0.15$, $P < 0.001$) and low variance inflation factor (VIF $\sim$ 1) suggest no collinearity. The interaction between sitting time and physical activity in the association with physical functioning was significant ($P = 0.05$). Compared with the least active pattern (i.e., ≥8 h/day sitting and <40 MET min/week), those sitting 4–7 h/day and spending <40 MET min/week scored 9.2 (CI 6.9–11.5) points higher on physical functioning (Table 2). This difference in physical functioning scores further increased with higher levels of activity and lower levels of sitting up to 40.9 (CI 38.5–43.3) points higher in participants sitting <4 h/day and spending ≥900 MET min/week. After adjustment for confounders, the associations attenuated, but remained statistically significant. In 2002, the predicted mean values ranged from 45.9 to 74.2 in the least to the most active activity patterns (Fig. 2). A decline in functioning over 6 years was observed in all activity patterns, and ranged from five points in the least active pattern to 16 points in the most active pattern. The interaction with survey was significant ($P < 0.001$), suggesting that the slope of the activity pattern–physical functioning relationship changed over time.

## Discussion

This is the first study to examine the combined effects of sitting time and physical activity on physical functioning in older women. Both higher levels of sitting time and lower levels of physical activity were associated with lower levels of physical functioning. The effects of the two measures combined seemed to be the sum of their separate effects. A decline in functioning over time was observed in all activity patterns, but the decline appeared

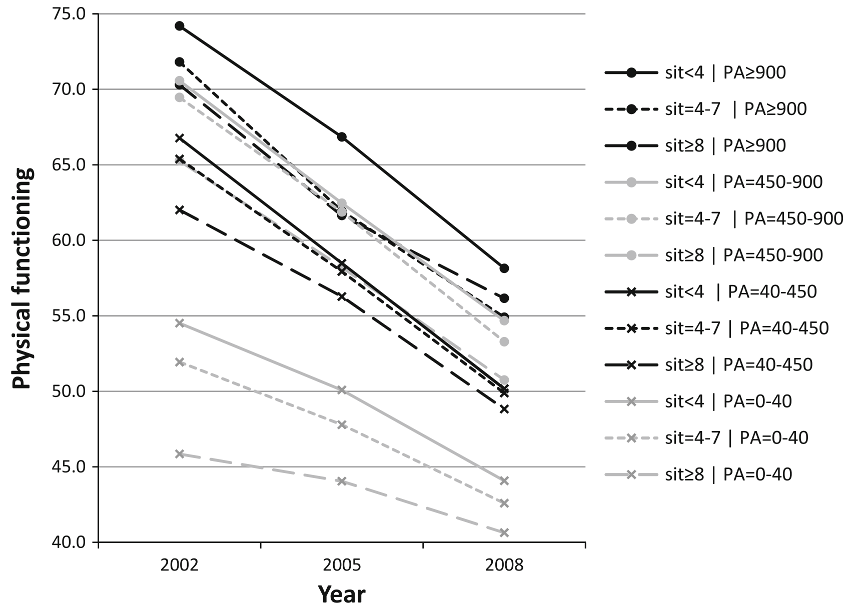


**Fig. 2** Physical functioning over time presented by activity pattern in older women predicted mean values for physical functioning are presented after adjustment for survey, age, education, housing situation, chronic conditions, BMI, bodily pain, fracture history, and dizziness. Activity patterns are based on times spent sitting (h/day) and in physical activity (PA, MET min/week)

to be greater among the women with more active patterns.

It is commonly known that active older people have better levels of physical functioning than inactive older people (Hillsdon et al. 2005; Peel et al. 2005). The current results add to existing knowledge by showing that time spent sitting, either alone or in combination with physical activity, impacts on physical functioning. These findings are in line with those of a cross-sectional study that found statistically significant associations between sedentary time (as measured with accelerometry) and measures of fitness (including strength and endurance) in older adults (Santos et al. 2012). Mechanisms behind this association are likely to be similar to those for physical activity, which is known to preserve muscle strength, reduce muscle fat infiltration (Visser et al. 2005; Tager et al. 2004), improve cardio-vascular and metabolic health (Haskell et al. 2007), and decrease risk of hip fractures (Gregg et al. 1998).

The interaction term between sitting time and physical activity was statistically significant. However, in Table 2, it can be seen that the combined effects of sitting time and physical activity on physical functioning were additive, suggesting no interaction. The discrepancy between the interaction *P* value and the combined effects may be caused by differential drop-out in the categories (i.e., drop-out is likely to be greater in less active categories). To test this, the models were repeated using data from participants with complete data only ($n = 3873$). In this subsample, the *P* value for interaction was 0.29, and there was slightly attenuated but still additive effects of sitting time and physical activity on physical functioning. The results were presented on the additive scale as absolute mean differences in physical functioning between categories (i.e., regression coefficients, Table 2). Although interaction on the additive scale may be more appropriate for public health and clinical decision making, interaction on the multiplicative scale (i.e., relative differences presented as risk ratios on the exponentiated scale) reflects the causal structure of interactions, because it explicitly relates to the hypothesised biologic interaction (Rothman et al. 1980; Knol et al. 2009). To provide insight into potential causal interaction between physical activity and sitting time, we repeated the analyses with results presented on the log-scale (i.e., as odds ratios; these values can be obtained by taking the exponent of the coefficients presented in Table 2). The odds ratios suggested that the combination of prolonged sitting time and inactivity did infer a greater impact on physical functioning than their individual effects (i.e., interaction on the multiplicative scale). To our knowledge, only one study has presented interaction effects of physical activity and sedentary behavior on both the additive and multiplicative scales. In that study, the out-come was mortality and the interaction existed on the multiplicative scale, but not the additive scale (Peeters et al. 2013). The existence of interaction on the multipli-cative scale may suggest biological interaction, but may also be an artefact of the scaling. Further research is needed to examine if these findings are consistent across cohorts and health outcomes.

Figure 2 shows that although the women in the more active patterns started at higher levels of functioning, their rate of decline was greater than in the women in the least active patterns. It seems likely that the level of functioning in the least active patterns already was low at the start of follow-up, limiting the range for further decline. Further-more, a decline in functioning was observed in all activity

patterns, suggesting that active lifestyles may result in higher levels of physical function for women in their mid-seventies, but that this does not protect against decline later in life. This also raises the question of causality: does decline in activity precede decline in functioning or vice versa? Findings from prospective studies suggest that physical activity has a positive effect on physical functioning (Gill et al. 2003; Landi et al. 2007; Visser et al. 2002; Cooper et al. 2011; Hillsdon et al. 2005). To our knowledge, however, only cross-sectional studies have examined the effect of physical functioning on physical activity and thus, from these studies, no conclusions can be drawn regarding the direction of the relationship (Harris et al. 2009; Kaplan et al. 2001; Rantanen et al. 1999).

The strengths of the current study include the large population-based sample of women and the tracking of changes in physical functioning over time. In addition, we used a novel approach to examine the combined effects of prolonged sitting time and physical activity. Limitations are that the classification of activity pattern was based on self-reported time spent sitting and in physical activity. The measures used were based on validated questionnaires and we used categories rather than continuous values to reduce the impact of measurement error. Finally, the sample included women in a specific age range, and results cannot be generalized to men or different age groups. Comparison of women included and excluded from the current analyses showed that excluded women had lower levels of sitting time and at the same time lower levels of physical activity, which may seem counter intuitive. However, the low correlation between sitting time and physical activity indicates that one can have high levels of sitting time and at the same time high levels of physical activity and support the theory that sitting time and physical activity are two distinct aspects of one's activity pattern (Dunstan et al. 2012). As the excluded women were older, more often divorced, widowed or separated, and more likely to be living alone, it may be that they had to do more chores in and around the house. They may have been fit enough to do these mainly light intensity activities, which could have resulted in reduced sitting time, but not fit enough to do more intense activities that counted toward the measure of moderate to vigorous physical activity used in this study. Overall, the sample used for the analyses may represent a sample of relatively active older women but with higher levels of sitting time.

In conclusion, both sitting time and physical activity were associated with physical functioning over time, with higher levels of functioning in women who sat less and were more active. The combined effect of sitting time and physical activity did not differ from their individual effects on physical functioning. High activity/low sitting time is important for establishing adequate physical functioning prior to age 76–81, but does not protect against decline in physical functioning over time later in life.

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