


RESEARCH

Open Access



# 24-hour movement behaviors and changes in quality of life over time among community-dwelling older adults: a compositional data analysis

Lotta Palmberg<sup>1,2,3\*</sup> , Kristin Suorsa<sup>2,3</sup>, Antti Löppönen<sup>1</sup>, Laura Karavirta<sup>1</sup>, Taina Rantanen<sup>1</sup> and Timo Rantalainen<sup>1</sup>

## Abstract

**Background** Favorable movement behavior patterns, comprising more physical activity, less sedentary behavior, and sufficient sleep, may promote the maintenance of good quality of life (QoL) with advancing age. The aim of the present study was to investigate whether movement behaviors predict future changes in QoL among community-dwelling older adults over a four-year follow-up.

**Methods** Participants were 75-, 80- and 85-year-old community-dwelling older adults ( $n=203$ ) followed up for 4 years. Participants wore thigh- and trunk-mounted accelerometers for 3–7 days at baseline. Proportion of time-use in physical activity, standing and sedentary behavior were assessed based on body posture and movement intensity. Time in bed was determined using an automated algorithm. QoL was assessed during a home interview using the short Older People's Quality of Life Questionnaire at baseline and follow-up (range 13–65, higher scores indicate higher QoL). Compositional linear regression analysis was used to study whether baseline time-use composition predicts changes in QoL.

**Results** Over the 4-year follow-up, QoL scores decreased by 5% on average. Higher physical activity in relation to the other movement behaviors was associated with increase in QoL over time ( $\beta_{irr}$  0.94,  $p=0.013$ ), but this association attenuated after adding baseline physical function into the model. Sedentary behavior, standing, and time in bed were not associated with changes in QoL. Theoretical reallocation of 30 min of physical activity into sedentary behavior, standing or time in bed was estimated to decrease QoL by 0.5 (CI 95% -0.6 to -0.4), 0.6 (-0.7 to -0.5) and 0.4 (-0.5 to -0.3) points, respectively.

**Conclusions** Theoretical reallocation of physical activity into sedentary behavior, standing, and time in bed was found to be associated with prospective decline in QoL among older adults. Engaging more in physical activity and less in more passive activities may promote better QoL with advancing age.

**Keywords** Physical activity, Sedentary behavior, Sleep, Wellbeing, Compositional data analysis

\*Correspondence:

Lotta Palmberg  
lotta.m.palmberg@jyu.fi

<sup>1</sup>Gerontology Research Center and Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland

<sup>2</sup>Department of Public Health, University of Turku and Turku University Hospital, Turku, Finland

<sup>3</sup>Centre for Population Health Research, University of Turku and Turku University Hospital, Turku, Finland



© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

## Background

Quality of life (QoL) is a multidimensional and broad concept that reflects elements of life that hold significance to an individual. World Health Organization defines quality of life as an individual's perception of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards, and concerns [1]. It encompasses various domains such as physical and mental well-being, and interpersonal connections. Alas, aging is often accompanied with the increase of multimorbidity and loss of physical functioning, that may negatively impact QoL [2].

Movement behaviors, comprising physical activity, sedentary behavior, and sleep, can affect the maintenance of QoL with advancing age. Especially higher moderate-to-vigorous physical activity has been consistently linked with better QoL in previous studies [3, 4]. Better sleep quality has also been associated with better QoL [5], but findings on whether sleep duration is also associated with QoL are somewhat inconsistent. Particularly extreme sleep durations (short or long) may be associated with poorer QoL [3, 6, 7]. Furthermore, prolonged sedentary time may also decrease QoL with advancing age [3, 8–10], but findings are inconclusive with other authors not reporting an association between sedentary behavior and QoL [3, 6, 11].

Most of these earlier studies focusing on movement behaviors and QoL in old age, however, study physical activity, sedentary behavior, and sleep as individual behaviors rather than codependent behaviors that all happen within the constraints of the 24-hour day. In time-use epidemiology, the focus has shifted from individual behaviors into finding the optimal balance between all movement behaviors [12, 13]. Increasing time-use in one movement behavior (e.g., physical activity) will necessarily decrease time-use in at least one other movement behavior (e.g., sedentary behavior), and thus, many of the health benefits of physical activity are likely explained by simultaneous changes in several movement behaviors. Although there is a growing body of literature targeting the association of daily composition of movement behaviors with health outcomes [14–19], to our knowledge only one previous cross-sectional study explored the association between QoL and the entire time-use composition in movement behaviors in old age [20]. Therefore, the aim of the present study is to explore whether 24-hour movement behavior composition can predict longitudinal changes in QoL among community-dwelling older adults over a four-year follow-up period.

## Methods

The present study is part of the Active aging - resilience and external support as modifiers of the disablement outcome (AGNES) project and involves individuals aged 75, 80, and 85 residing in the Jyväskylä region of Central Finland. The initial sample was drawn from the Digital and Population Data Services Agency. In 2017–2018, all people born in 1942, 1938, and 1933 were invited to participate. In 2018, an additional sampling was done and people born in 1943, 1939, and 1934 were also invited to participate. Among the younger cohorts, we randomly selected approximately half of them, while all of those in the oldest cohort were invited. In total, 2791 people were invited to participate [22]. Inclusion criteria were willingness to participate and ability to communicate [21]. From 2017 to 2018, a total of 1021 individuals underwent a home interview, of whom 495 agreed to wear two tri-axial accelerometers for 7–10 consecutive days following the interview, of whom 433 had at least 3 days of data on both accelerometers [22]. Four-year follow-up data collection was conducted from 2021 to 2022. Of the 433 participants who wore both accelerometers at baseline, 68 did not want to participate the follow-up measurements, 16 were deceased, and 29 were excluded for other reasons (not reached, missing data etc.). Participants with valid accelerometer data from both devices for a minimum of 3 days, accurate detection of bed- and wake times for at least 3 nights, and complete data on QoL in both time points formed the analytical sample of the present study ( $n=203$ ).

### 24-hour movement behaviors

One accelerometer was attached to the participants' dominant thigh (UKK RM42; UKK Terveyspalvelut Oy, Tampere, Finland,  $\pm 16$  g range, 13-bit analog-to-digital conversion, sampled at 100 Hz), while the other was placed on the chest (either sternum or the left side of the chest if sternum placement was uncomfortable due to e.g., soft tissues. eMotion Faros 180, Bittium Corporation, Oulu, Finland,  $\pm 16$  g range, 14-bit, sampled at 100 Hz). Accelerometer data were processed in non-overlapping 5-second epochs. Angle of the device with respect to the orientation during walking was estimated (0=aligned with the orientation during walking,  $\pi/2=90$  degree tilt,  $\pi$ =upside down), and used for posture estimation as follows: lying if both accelerometers indicated an angle  $> \pi/4$ , sitting if the thigh-worn accelerometer indicated an angle  $> \pi/4$  and the trunk-worn accelerometer indicated an angle of  $\leq \pi/4$ , and upright if both accelerometers indicated an angle of  $\leq \pi/4$  [23]. From the data collected by the accelerometers, the mean amplitude deviation ( $MAD = 1/n \cdot \sum |r_k - r|$ ) of each 24-hour period was calculated based on the vector magnitude (Euclidean norm) of the resultant acceleration ( $\sqrt{x^2 + y^2 + z^2}$ ) in

non-overlapping 5-second epochs, following the methodology outlined in previous studies [24].

Bedtimes and arising times were estimated using accelerometer recordings using an automated algorithm by van der Berg and colleagues [25] and they were used to calculate time in bed (TIB). The algorithm has been described in detail elsewhere [25]. Briefly, bedtimes were determined by summing up consecutive bouts of lying down and comparing them against pre-set time-based cut-off values which depended on the start of the first bout. When the sum exceeded the pre-determined cut-off value, bedtime was determined at the start of the first bout. Similarly, arising times were determined based on summing up active bouts and comparing them against pre-set cut-off values. The original algorithm was slightly modified, so that TIB was restricted to lying down rather than allowing either sitting or lying down postures. All bedtimes and arising times that we derived utilizing the modified algorithm were visually confirmed. Bed- and arising times, that were deemed as invalid based on visual inspection (13% of bedtimes and 9% of arising times), were excluded from further analysis. Waking hours were also determined based on bedtimes and arising times, and then categorized into physical activity, standing and sedentary behavior based on posture and signal intensity. Physical activity was determined as epochs with a MAD threshold of  $\geq 0.035$  units of gravity (g) and upright posture, standing as epochs  $< 0.035$  g and upright posture, and sedentary behavior as epochs in sitting or lying posture [23]. The threshold of 0.035 g was determined through laboratory experimentation [26].

### Quality of life

Quality of life was assessed at baseline and follow-up with the short version of the Older People's Quality of Life Questionnaire (OPQOL-brief) which has been found to be a reliable and valid measure of QoL among older adults [27]. The questionnaire includes 13 items on perceived satisfaction with prospects, health, social relationships, financial situation, activity, home, safety, leisure, and life overall. All questions are assessed with the scale from 1 to 5 (strongly disagree to strongly agree). Individual scores were summed up into a sum score ranging from 13 to 65 (higher scores indicate better QoL).

### Covariates

Participants' sex and age were drawn from the Finnish Digital and Population Data Services Agency. Education was assessed as self-reported years of education. Morbidity was measured as the number of chronic diseases diagnosed by a physician and assessed using a self-reported questionnaire [21]. Depressive symptoms was measured with the Center for Epidemiologic Studies Depression Scale (CES-D) [28]. The range for CES-D is 0–60

and higher scores indicate more depressive symptoms. Physical function was assessed with the Short Physical Performance Battery (SPPB) which includes tests of balance, walking speed and chair stands [29]. The range for SPPB is 0–12 and higher scores indicate better physical performance.

### Statistical analysis

#### Descriptive statistics

Participant characteristics were described as means with standard deviations for continuous variables and percentages for categorical variables. Differences in the descriptive characteristics of participants according to tertiles of QoL at follow-up were studied with Chi-Square test for categorical variables and Kruskal-Wallis test for continuous variables. To address the effect of loss to follow-up and missing data on our findings, we compared the descriptive characteristics of our analytical sample with excluded participants from the original sample wearing both accelerometers at baseline ( $n=433$ ).

#### Compositional analyses

Compositional geometric means of the movement behaviors were calculated to describe the average composition of 24-hour movement behaviors. For the compositional multivariate linear regression analyses, time spent in PA, standing, SED and TIB were transformed into three isometric log-ratio (ilr) coordinates according to the following equations [14, 30]:

$$z_1 = \sqrt{\frac{3}{4}} \ln \frac{PA}{\sqrt[3]{STA \times SED \times TIB}}$$

$$z_2 = \sqrt{\frac{2}{3}} \ln \frac{STA}{\sqrt{SED \times TIB}}$$

$$z_3 = \sqrt{\frac{1}{2}} \ln \frac{SED}{\sqrt{TIB}}$$

The first ilr-coordinate  $z_1$  represents PA in relation to the compositional average of the remaining movement behaviours. The second ilr-coordinate  $z_2$  represents the balance between standing and the compositional average of SED and TIB. The final ilr-coordinate  $z_3$  represents the balance between SED and the compositional average of TIB. In total, four sets of ilr-coordinates were formed in a way that each component was put in the first position of the composition.

The daily composition expressed as ilr-coordinates were then used as predictors of QoL at baseline and follow-up in the compositional linear regression models. Model 1 was adjusted for age and sex, model 2 for age, sex, education, chronic conditions, and depressive

symptoms, and model 3 for age, sex, education, chronic conditions, depressive symptoms, and physical function. All prospective models were additionally adjusted for baseline QoL. The linear regression model was repeated for all sets of ilr-coordinates to study the relative importance of each part of the composition in relation to the remaining movement behaviors. The associations were presented as beta coefficients and their 95% confidence intervals. The beta coefficients indicate the change in QoL for each one-unit ilr increase, thus pointing out to presence of association but effect sizes cannot be drawn directly from the beta coefficients.

To illustrate the range of optimal time-use composition for the maintenance of QoL over time, a heat map was plotted for different combinations of time in physical activity, sedentary behavior and standing when TIB was fixed to 8 h following an approach by Chastin and colleagues and McGregor and colleagues [12, 31]. Again, different combinations of movement behaviors were transformed into ilr-coordinates and QoL was estimated based on the regression model adjusted for age, sex, and baseline QoL score. The range of values were based on the distribution of physical activity, sedentary behavior and standing among the study group.

Finally, to aid interpretation of the findings, isothermal substitution models were used to estimate the effect of one-to-one time reallocations between daily movement behaviors on QoL over the follow-up [32]. Reallocations between movement behaviors were calculated based on the mean composition at baseline (100 min of physical activity, 228 min of standing, 536 min of TIB, 556 min of sedentary behavior), and calculated as reallocations of 10, 30 and 60 min between each movement behavior. The hypothetical reallocated compositions were transformed into ilr-coordinates and changes in QoL after each reallocation were estimated based on the fully adjusted regression model (model 3). The results are shown as estimated changes in QoL and their 95% confidence intervals (CI). Statistical analyses were performed using the SPSS statistical software package (IBM SPSS Statistics Version 28.0, IBM Corp, Armonk, NY) and the “R” statistical environment (version 4.3.1).

## Results

The participants mean age at baseline was 77.5 (SD 2.8) years and 62% were women. During the 4-year follow-up, QoL scores decreased by 5% (Mean  $-2.8$ , SD 4.5 points) on average. The mean follow-up time for participants was 3.9 (SD 0.3) years. Descriptive characteristics of participants are presented in Table 1 according to QoL tertiles at follow-up. Participants in the low QoL group at follow-up were more likely women ( $p=0.034$ ), had lower education ( $p=0.019$ ), more chronic diseases ( $p=0.012$ ), more depressive symptoms ( $p<0.001$ ), and lower physical function ( $p<0.001$ ) at baseline than those with higher QoL. The mean composition of participants was 100 min of physical activity, 228 min of standing, 536 min of TIB and 556 min of sedentary behavior per day. Compared to the excluded participants of the full sample wearing both accelerometers at baseline ( $n=433$ ), the participants included in the present analyses were younger ( $p<0.001$ ), more years of education ( $p=0.046$ ), fewer depressive symptoms ( $p=0.001$ ), better physical function ( $p=0.024$ ), and better QoL at baseline ( $p=0.023$ , Supplementary Table 1).

The results of compositional linear regression analyses are presented in Table 2. In the cross-sectional analyses, higher proportion of physical activity ( $\beta_{ilr}$  1.30,  $p=0.001$ ) and TIB ( $\beta_{ilr}$  2.72,  $p=0.005$ ) relative to the remaining movement behaviors were associated with better QoL. The associations remained after adjusting for education, depressive symptoms, and chronic conditions. Conversely, higher standing ( $\beta_{ilr}$   $-1.99$ ,  $p<0.001$ ) and sedentary behavior ( $\beta_{ilr}$   $-2.13$ ,  $p=0.004$ ) relative to remaining behaviors were associated with lower QoL. In the final model including physical function, all associations attenuated. In the longitudinal analyses, higher baseline physical activity relative to remaining behaviors was associated with better maintenance of QoL at follow-up ( $\beta_{ilr}$  0.94,  $p=0.013$ ) and the association remained after adjusting for education, depressive symptoms, and chronic conditions. However, after adding physical function into the model the association attenuated ( $\beta_{ilr}$  0.66,  $p=0.094$ ). Standing, sedentary behavior and TIB were not associated with changes in QoL in the longitudinal analyses.

**Table 1** Descriptive characteristics of participants according to QoL tertiles at follow-up

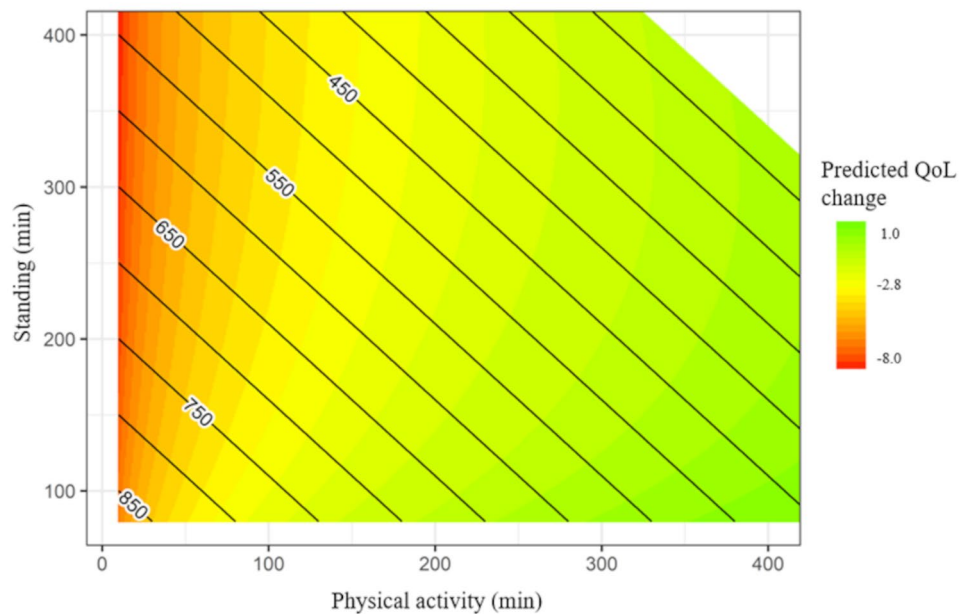
	All ( $n=203$ )	Low tertile ( $n=70$ )	Middle tertile ( $n=65$ )	High tertile ( $n=68$ )	$p$ -value
Women, % ( $n$ )	62 (125)	71 (50)	63 (41)	50 (34)	<b>0.034</b>
Age at BL, years, mean (SD)	77.5 (2.8)	78.0 (2.8)	77.5 (3.0)	76.9 (2.4)	0.167
Education, years, mean (SD)	12.2 (4.5)	11.2 (4.2)	11.9 (4.2)	13.4 (4.8)	<b>0.019</b>
Chronic diseases, $n$ , mean (SD)	3.1 (1.9)	3.6 (1.9)	2.8 (1.8)	2.8 (1.9)	<b>0.012</b>
CES-D, score, mean (SD)	6.5 (5.6)	8.8 (6.3)	6.2 (5.4)	4.4 (4.0)	<b>&lt;0.001</b>
SPPB, score, mean (SD)	10.6 (1.6)	9.8 (2.0)	10.9 (1.3)	11.2 (1.1)	<b>&lt;0.001</b>
QoL at BL, mean (SD)	56.2 (4.9)	52.9 (4.4)	56.4 (4.2)	59.3 (3.8)	<b>&lt;0.001</b>

Note: BL=baseline, CES-D=Center for Epidemiologic Studies Depression Scale, SPPB=Short Physical Performance Battery; Low QoL tertile  $\leq 51$ , Middle tertile  $= 52-55$ , High tertile  $>= 56$

**Table 2** Compositional linear regression analyses on cross-sectional and longitudinal associations between baseline time-use composition and QoL

Cross-sectional	Model 1			Model 2			Model 3		
	$\beta$ lir	95% CI	p-value	$\beta$ lir	95% CI	p-value	$\beta$ lir	95% CI	p-value
PA vs. other behaviors	1.30	0.52 to 2.09	<b>0.001</b>	0.83	0.10 to 1.56	<b>0.025</b>	0.03	-0.66 to 0.73	0.924
Standing vs. other behaviors	-1.99	-2.88 to -0.90	<b>&lt;0.001</b>	-1.39	-2.28 to -0.49	<b>0.003</b>	-0.70	-1.47 to 0.07	0.074
Sedentary vs. other behaviors	-2.13	-3.57 to -0.70	<b>0.004</b>	-1.63	-2.92 to -0.33	<b>0.014</b>	-0.41	-1.58 to 0.76	0.494
TIB vs. other behaviors	2.72	0.82 to 4.62	<b>0.005</b>	2.18	0.47 to 3.89	<b>0.013</b>	1.08	-0.42 to 2.58	0.158
<b>Longitudinal</b>									
PA vs. other behaviors	0.94	0.20 to 1.67	<b>0.013</b>	0.81	0.05 to 1.57	<b>0.036</b>	0.66	-0.11 to 1.42	0.094
Standing vs. other behaviors	-0.79	-1.73 to 0.15	0.098	-0.71	-1.65 to 0.22	0.137	-0.68	-1.62 to 0.25	0.151
Sedentary vs. other behaviors	-0.70	-2.05 to 0.64	0.305	-0.62	-1.97 to 0.73	0.369	-0.42	-1.77 to 0.94	0.543
TIB vs. other behaviors	0.56	-1.22 to 2.34	0.536	0.52	-1.26 to 2.30	0.565	0.45	-1.32 to 2.22	0.619

Note; Results shown only for the first ilr-coordinate, i.e. the identified behaviour versus all the others. Model 1 adjusted for age and sex, Model 2 adjusted additionally for education, baseline chronic conditions and depressive symptoms, All prospective analyses additionally adjusted for baseline quality of life, Model 3 additionally adjusted for baseline physical function, PA=physical activity, TIB=time in bed



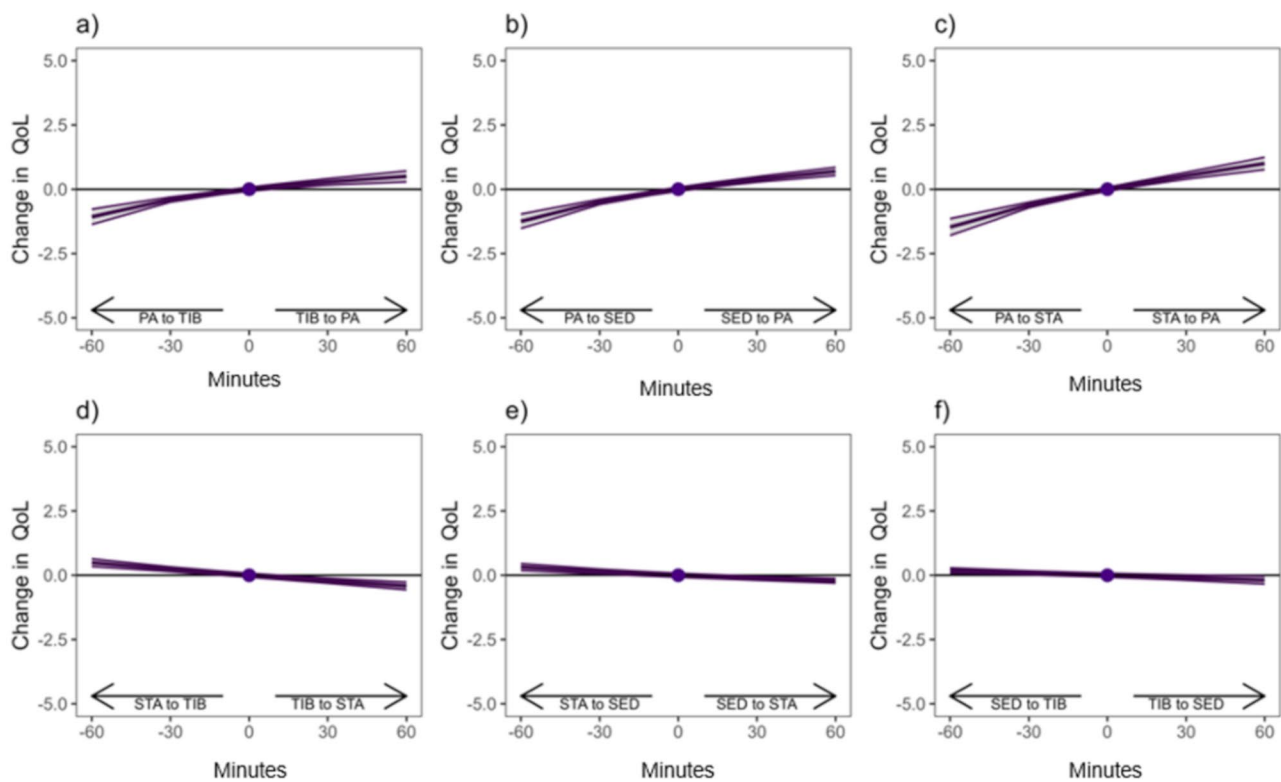
**Fig. 1** Heatmap showing estimated QoL change at follow-up with different balances between PA, STA, and SED

Note; x-axis: physical activity (PA) minutes, y-axis: standing (STA) minutes, contour lines: sedentary behavior (SED) minutes. Red color reflects greater than average estimated decrease in QoL (-2.8 units), yellow color average estimated decrease, and green color lower than average estimated decrease or increase in QoL

Figure 1 illustrates estimated QoL at follow-up with a range of different combinations of physical activity, sedentary behavior, and standing. The risk for poorer QoL was the highest with combinations including low physical activity and high standing, or sedentary behavior, but changes in QoL seem to be especially driven by changes in physical activity minutes. A lower-than-average estimated decrease in QoL scores was achieved with different daily combinations including high daily physical activity minutes and low-to-moderate standing and sedentary behavior.

Finally, the effects of theoretical one-to-one time reallocations between each movement behavior on QoL at follow-up are illustrated in Fig. 2. Theoretical reallocation

of time from physical activity into any other behavior was associated with an estimated decrease in QoL (Fig. 2a-c). Similarly, reallocating time into physical activity from any other behavior was associated with an estimated increase in QoL, but the changes in QoL were slightly smaller in absolute terms when compared to reallocation of time away from physical activity. Furthermore, reallocating time from standing into TIB and sedentary behavior was associated with a small estimated increase in QoL at follow-up (Fig. 1d & f).



**Fig. 2** One-to-one reallocations of physical activity, standing, sedentary behavior, and time in bed  
Note; PA = physical activity, STA = standing, SED = sedentary behavior, TIB = time in bed. The dot represents the mean baseline composition of 100 min of PA, 228 min of STA, 556 min of SB, 536 min of TIB and QoL score of 52.6

## Discussion

The main finding of the study was that theoretical time reallocation from physical activity into any other movement behavior predicted decrease in QoL over time among community-dwelling older adults, while reallocating time into physical activity was associated with better maintenance of QoL. Theoretical reallocation of time from physical activity into stationary waking behaviors, namely sedentary behavior and standing, was associated with slightly greater decreases in QoL than reallocating time into TIB. Time reallocation from physical activity into other movement behaviors was associated with slightly greater change in QoL than reallocating time from other behaviors into physical activity. Furthermore, the association of physical activity relative to all remaining movement behaviors in the linear regression models attenuated after adding physical function into the model suggesting it may explain the observed associations. Although the estimated changes on QoL were rather modest, we postulate that preventing decline in physical activity with advancing age may support the maintenance of better QoL over time. Since QoL reflects elements of life that individuals' hold significance to, even small changes in it can be considered important. The findings of this study extend previous cross-sectional findings

on the association between 24-hour movement behaviors and QoL by replicating the findings in a prospective investigation.

Our findings suggest that the proportion of physical activity rather than sedentary behavior, standing or time in bed predicts changes in QoL. This was also seen in the heat map which illustrated that different combinations of daily waking time-use including high level of physical activity was associated with more favorable changes in QoL. The finding is consistent with previous cross-sectional findings showing that a theoretical reallocation of 30 min into physical activity was associated with better QoL in old age [20]. The cross-sectional association between physical activity and QoL was explained mainly by baseline physical function, and the longitudinal association of physical activity relative to all other behaviors also attenuated after adding physical function into the model. However, the longitudinal one-to-one theoretical time reallocations the association remained in the fully adjusted regression model. These observations suggest that the longitudinal associations may also be explained by maintenance of physical function and health. While better physical function enables engagement in higher levels of physical activity, physical activity is also an important in the maintenance of better physical

function with advancing age [33]. Furthermore, we found that decreasing time-use in physical activity with respect to any other movement behavior was associated with a higher estimated change in QoL than increasing time-use in physical activity, which is parallel to earlier findings [20]. This observation is likely explained in part by the relatively high proportion of physical activity in the mean composition (100 min), which may partly be due to the short epoch length in the accelerometry analysis. Older individuals that already engage in relatively high level of physical activity may be less likely to receive additional benefits of further increasing daily time-use in physical activity on their QoL than older adults who accumulate low physical activity levels. This, however, need to be confirmed in future studies including more inactive older adults.

In the present analyses, standing seemed to be the movement behavior with the most detrimental association with QoL. Notably, standing is often included as light physical activity due to the upright posture and increased energy consumption [34, 35]. QoL is a broad concept, and different factors contribute to QoL between individuals based on factors which they hold value to. Activities that take place while standing may often include household chores that may be seen as obligatory routines rather than enjoyable activities, thus potentially decreasing QoL. Moreover, although apparently light, standing may decrease the likelihood of engaging in other more intensive activities later on in the day. Replacing sedentary behavior and TIB with standing was associated with an estimated decrease in QoL in the isothermal substitution models, but this change was minimal and unlikely to have any real-life significance. Whether or not standing displaces more intensive movement behavior remains to be explored in future studies.

The main strengths of the study include the longitudinal study design and continuous monitoring of physical activity, sedentary behavior and TIB for 3–7 days, which allowed us to account for day-to-day variations in 24-hour movement behaviors. Another strength was the availability of two concurrently worn tri-axial accelerometers. This allowed us to gain valid information of a larger variety of body postures and separate lying down from sitting, which would not be reliable using a single wearable sensor. There are also limitations that should be considered when interpreting the findings. First, we only accounted for the 24-hour movement behaviors at baseline, and thus, time reallocations were based on estimated changes, and not actual changes, in the daily time-use composition. Furthermore, although physical activity has been consistently associated with improved quality of life [3], we cannot be certain whether higher QoL may also lead to higher physical activity levels. Second, although we used a validated algorithm to identify

bed- and wake times, we were not able to separate actual sleep state from wake. Thus, our estimate of TIB can also include periods of wake time while lying in bed. Furthermore, we did not assess sleep quality, which may be more important with regards to QoL than sleep duration [5]. Third, it should be noted that the COVID-19 pandemic occurred during the follow-up period of the study. During the first wave and social distancing physical activity temporarily increased [36] while QoL slightly decreased [37], which may have impacted our findings. Finally, the older adults included in the present analyses had better physical functioning and were physically more active compared with the entire AGNES sample [22] which limits the generalizability of the present findings.

## Conclusions

In conclusion, the findings indicate that reallocating time from physical activity into other movement behaviors is associated with a decrease in QoL over time among older adults. In contrast, engaging more in physical activity and less in stationary activities may promote better QoL with advancing age. Especially preventing reduction in physical activity and simultaneously decreasing time-use in more passive waking behaviors could be encouraged for older adults and might warrant further exploration in a randomized controlled trial.

## Abbreviations

AGNES	Active agingresilience and external support as modifiers of the disablement outcome
CES-D	Center for Epidemiologic Studies Depression Scale
CI	Confidence interval
MAD	Mean Amplitude Deviation
PA	Physical activity
SED	Sedentary behavior
SPPB	Short Physical Performance Battery
STA	Standing
TIB	Time in bed
QoL	Quality of Life

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12966-024-01681-9>.

Supplementary Material 1

Supplementary Material 2

## Acknowledgements

We would like to thank all the participants of the AGNES study for their time and effort. The Gerontology Research Center is a joined effort between the University of Jyväskylä and University of Tampere.

## Author contributions

Conceptualization (L.P., Ti.R.), formal analysis (L.P., K.S.), investigation (L.P., A.L., L.K., Ta.R., Ti.R.), visualization (L.P., K.S.), funding acquisition (L.K., Ta.R., Ti.R.), drafting the manuscript (L.P.), review and editing of the manuscript (K.S., A.L., L.K., Ta.R., Ti.R.).

### Funding

This work has been supported by the European Research Council (693045 to Ta.R.); the Academy of Finland (339391 and 346462 to L.K., 321336, 328818, and 352653 to Ti.R. and 310526 to Ta.R.). This study was also supported by funding from the Juho Vainio Foundation in Finland (Grant to A.L.). The content of this manuscript does not reflect the official opinion of the European Union. Responsibility for the information and views expressed in the manuscript lies entirely with the authors.

### Data availability

After completion of the study, data will be stored at the Finnish Social Science Data Archive without potential identifiers (open access). Until then, pseudonymized datasets are available to external collaborators subject to agreement on the terms of data use and publication of results. To request the data, please contact Professor Taina Rantanen (taina.rantanen@jyu.fi).

### Declarations

#### Ethics approval and consent to participate

Both baseline and follow-up studies were given a positive endorsement by the Central Finland Hospital County Ethics Committee (Dnro 14U/2017, Dnro4U/2021), adhered to ethical principles outlined in the Declaration of Helsinki, and all participants provided written informed consent.

#### Consent for publication

Not applicable.

#### Competing interests

The authors declare that they have no competing interests.

Received: 17 June 2024 / Accepted: 5 November 2024

Published online: 12 November 2024

### References

1. The Whoqol Group. The World Health Organization quality of life assessment (WHOQOL): development and general psychometric properties. *Soc Sci Med.* 1998;46(12):1569–85.
2. Fusco O, Ferrini A, Santoro M, Lo Monaco MR, Gambassi G, Cesari M. Physical function and perceived quality of life in older persons. *Aging Clin Exp Res.* 2012;24:68–73.
3. Hakimi S, Kaur S, Ross-White A, Martin LJ, Rosenberg MW. A systematic review examining associations between physical activity, sedentary behaviour, and sleep duration with quality of life in older adults aged 65 years and above. *Appl Physiol Nutr Metab.* 2023;48(2):97–162.
4. Vagetti GC, Barbosa Filho VC, Moreira NB, de Oliveira V, Mazzardo O, de Campos W. Association between physical activity and quality of life in the elderly: a systematic review, 2000–2012. *Brazilian J Psychiatry.* 2014;36:76–88.
5. Sella E, Miola L, Toffalini E, Borella E. The relationship between sleep quality and quality of life in aging: a systematic review and meta-analysis. *Health Psychol Rev.* 2023;17(1):169–91.
6. Atkins J, Naismith SL, Luscombe GM, Hickie IB. Psychological distress and quality of life in older persons: relative contributions of fixed and modifiable risk factors. *BMC Psychiatry.* 2013;13(1):249.
7. Faubel R, Lopez-García E, Guallar-Castillón P, Balboa-Castillo T, Gutiérrez-Fisac JL, Banegas JR, et al. Sleep duration and health-related quality of life among older adults: a Population-based cohort in Spain. *Sleep.* 2009;32(8):1059–68.
8. Bayán-Bravo A, Pérez-Tasigchana RF, Sayón-Orea C, Martínez-Gómez D, López-García E, Rodríguez-Artalejo F, et al. Combined impact of traditional and non-traditional healthy behaviors on Health-Related Quality of Life: a prospective study in older adults. *PLoS ONE.* 2017;12(1):e0170513.
9. Choi JJ, Cho YH, Kim YJ, Lee SY, Lee JG, Yi YH, et al. The relationship of sitting time and physical activity on the quality of life in elderly people. *Int J Environ Res Public Health.* 2021;18(4):1459.
10. Rosenkranz RR, Duncan MJ, Rosenkranz SK, Kolt GS. Active lifestyles related to excellent self-rated health and quality of life: cross sectional findings from 194,545 participants in the 45 and up study. *BMC Public Health.* 2013;13(1):1071.
11. Vallance JK, Eurich D, Marshall AL, Lavalley CM, Johnson ST. Associations between sitting time and health-related quality of life among older men. *Ment Health Phys Act.* 2013;6(1):49–54.
12. Chastin SF, McGregor DE, Biddle SJ, Cardon G, Chaput JP, Dall PM, et al. Striking the right balance: evidence to inform combined physical activity and sedentary behavior recommendations. *J Phys Activity Health.* 2021;18(6):631–7.
13. Dumuid D, Pedišić Ž, Palarea-Albaladejo J, Martín-Fernández JA, Hron K, Olds T. Compositional Data Analysis in Time-Use Epidemiology: what, why, how. *Int J Environ Res Public Health.* 2020;17(7):2220.
14. Chastin SF, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: a novel compositional data analysis approach. *PLoS ONE.* 2015;10(10):e0139984.
15. del Pozo Cruz B, Alfonso-Rosa RM, McGregor D, Chastin SF, Palarea-Albaladejo J, del Pozo Cruz J. Sedentary behaviour is associated with depression symptoms: compositional data analysis from a representative sample of 3233 US adults and older adults assessed with accelerometers. *J Affect Disord.* 2020;265:59–62.
16. Janssen I, Clarke AE, Carson V, Chaput JP, Giangregorio LM, Kho ME, et al. A systematic review of compositional data analysis studies examining associations between sleep, sedentary behaviour, and physical activity with health outcomes in adults. *Appl Physiol Nutr Metab.* 2020;45(10):S248–57.
17. McGregor DE, Carson V, Palarea-Albaladejo J, Dall PM, Tremblay MS, Chastin SFM. Compositional analysis of the associations between 24-h Movement Behaviours and Health Indicators among adults and older adults from the Canadian Health measure survey. *Int J Environ Res Public Health.* 2018;15(8):1779.
18. Suorsa K, Gupta N, Leskinen T, Andersen LL, Pasanen J, Hettiarachchi P, et al. Modifications of 24-h movement behaviors to prevent obesity in retirement: a natural experiment using compositional data analysis. *Int J Obes (Lond).* 2023;47(10):922–30.
19. Von Rosen P, Dohrn I, Hagströmer M. Association between physical activity and all-cause mortality: a 15-year follow-up using a compositional data analysis. *Scandinavian Med Sci Sports.* 2020;30(1):100–7.
20. Verhoog S, Braun KVE, Bano A, van Rooij FJA, Franco OH, Koolhaas CM, et al. Associations of Activity and Sleep with Quality of Life: a compositional data analysis. *Am J Prev Med.* 2020;59(3):412–9.
21. Rantanen T, Saajanaho M, Karavirta L, Siltanen S, Rantakokko M, Viljanen A, et al. Active aging—resilience and external support as modifiers of the disablement outcome: AGNES cohort study protocol. *BMC Public Health.* 2018;18(1):565.
22. Portegijs E, Karavirta L, Saajanaho M, Rantalainen T, Rantanen T. Assessing physical performance and physical activity in large population-based aging studies: home-based assessments or visits to the research center? *BMC Public Health.* 2019;19(1):1570.
23. Rantalainen T, Koivunen K, Portegijs E, Rantanen T, Palmberg L, Karavirta L, et al. Is complexity of Daily Activity Associated with physical function and life-space mobility among older adults? *Med Sci Sports Exerc.* 2022;54(7):1210–7.
24. Vähä-Ypyä H, Vasankari T, Husu P, Suni J, Sievänen H. A universal, accurate intensity-based classification of different physical activities using raw data of accelerometer. *Clin Physiol Funct Imaging.* 2015;35(1):64–70.
25. van der Berg JD, Willems PJ, van der Velde JH, Savelberg HH, Schaper NC, Schram MT, et al. Identifying waking time in 24-h accelerometry data in adults using an automated algorithm. *JSports Sci.* 2016;34(19):1867–73.
26. Skantz H, Rantalainen T, Karavirta L, Rantakokko M, Palmberg L, Portegijs E, et al. Associations between Accelerometer-based free-living walking and self-reported walking capability among Community-Dwelling Older people. *J Aging Phys Act.* 2021;1(aop):1–8.
27. Bowling A, Hankins M, Windle G, Bilotta C, Grant R. A short measure of quality of life in older age: the performance of the brief older people's quality of life questionnaire (OPQOL-brief). *Arch Gerontol Geriatr.* 2013;56(1):181–7.
28. Radloff LS. The CES-D scale: a self-report depression scale for research in the general population. *Appl Psychol Meas.* 1977;1(3):385–401.
29. Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol.* 1994;49(2):85.
30. Hron K. Linear regression with compositional explanatory variables. [cited 2024 Apr 5]. <https://www.tandfonline.com/doi/epdf/10.1080/02664763.2011.644268?needAccess=true>



31. McGregor DE, Palarea-Albaladejo J, Dall PM, Stamatakis E, Chastin SFM. Differences in physical activity time-use composition associated with cardiometabolic risks. *Prev Med Rep.* 2019;13:23–9.
32. Dumuid D, Pedišić Ž, Stanford TE, Martín-Fernández JA, Hron K, Maher CA, et al. The compositional isotemporal substitution model: a method for estimating changes in a health outcome for reallocation of time between sleep, physical activity and sedentary behaviour. *Stat Methods Med Res.* 2019;28(3):846–57.
33. Paterson DH, Warburton DE. Physical activity and functional limitations in older adults: a systematic review related to Canada's Physical Activity guidelines. *Int J Behav Nutr Phys Activity.* 2010;7(1):38.
34. Mansoubi M, Pearson N, Clemes SA, Biddle SJ, Bodicoat DH, Tolfrey K, et al. Energy expenditure during common sitting and standing tasks: examining the 1.5 MET definition of sedentary behaviour. *BMC Public Health.* 2015;15(1):516.
35. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary behavior research network (SBRN)—terminology consensus project process and outcome. *Int J Behav Nutr Phys Activity.* 2017;14(1):75.
36. Lindeman K, Karavirta L, Eronen J, Kajan N, Portegijs E, Rantanen T. Physical activity changes from before to during the First Wave of the COVID-19 pandemic among Community-Dwelling older adults in Finland. *J Aging Phys Act.* 2023;1(aop):1–9.
37. Rantanen T, Eronen J, Kauppinen M, Kokko K, Sanaslahti S, Kajan N, Portegijs E. Life-space mobility and active aging as factors underlying quality of life among older people before and during COVID-19 lockdown in Finland—a longitudinal study. *Journals Gerontology: Ser A.* 2021;76(3):e60–7.

### **Publisher's note**

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.