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**Associations of Frailty and Physical Function with a Daily Activities Measured by  
a Pattern-Recognition Activity Monitor: An Isotemporal Substitution Analysis in  
the IMPACT65+ study.**

Sara Higuera-Fresnillo<sup>1</sup>, Miguel Ángel de la Cámara<sup>1</sup>, Verónica Cabanas-Sánchez<sup>1,2</sup>,  
and David Martínez-Gómez<sup>3,4,5</sup>

<sup>1</sup> Department of Physical Education, Sport and Human Movement, Faculty of Teacher  
Training and Education, Autonomous University of Madrid, Madrid, Spain

<sup>2</sup> Research Centre in Physical Activity, Health and Leisure (CIAFEL), Faculty of Sport,  
University of Porto, Porto, Portugal

<sup>3</sup> Department of Preventive Medicine and Public Health, School of Medicine,  
Autonomous University of Madrid/IdiPaz, Madrid, Spain

<sup>4</sup> CIBER of Epidemiology and Public Health, Madrid, Spain

<sup>5</sup> IMDEA Food Institute. CEI UAM+CSIC, Madrid, Spain.

**Correspondence to:** Sara Higuera-Fresnillo. Department of Physical Education, Sport  
and Human Movement. Facultad de Formación de Profesorado y Educación.  
Universidad Autónoma de Madrid. Ctra. de Colmenar Km 11. E-28049. Madrid  
(Spain). E-mail: sara.higuera@uam.es

## 1 ABSTRACT

2 **Objectives:** The aims of this study were (i) to examine the independent associations of  
3 the time spent in daily activities measured by multi-sensor pattern-recognition with  
4 frailty and physical functioning (PF); and (ii) to analyze how relocating time between  
5 these daily activities is associated with frailty and PF in a sample of older adults.

6 **Design:** Cross-sectional study

7 **Setting and participants:** The study sample consists of 436 (287 women) high-  
8 functioning community-dwelling older adults, aged 65 to 92 years, who participated in  
9 the IMPACT65+ Study

10 **Measurements:** Frailty was calculated as a continuous measure; based on the five  
11 widely recognized Fried's criteria. PF was assessed using the SF-12 questionnaire. The  
12 time in daily activities was assessed by the Intelligent Device for Energy expenditure  
13 and Activity (IDEEA). Independent associations of daily activities with frailty and PF  
14 were examined using linear regression models adjusting for potential confounders. The  
15 isothermal substitution models for estimate the effect of replacing time in one activity  
16 with the same amount of time in another activity while holding wake time constant.

17 **Results:** Time spent lying was directly associated, while time in walk at average and  
18 brisk pace was inversely associated with frailty. The independent associations for PF  
19 were similar to lying, walk at average pace and walk at brisk pace. Isothermal  
20 substitution analyses revealed a clear beneficial effect of hypothetically replacing 30  
21 min/day of sedentary behaviors or light physical activity by the same amount of  
22 moderate-to-vigorous physical activity for frailty and FP.

23 **Conclusion:** This is the first study examining the activity-specific and isothermal  
24 association of daily activities with frailty and PF in older adults. Isothermal  
25 substitution analyses showed that replacing sedentary behaviors (lie, recline, passive sit)

by light-intensity activities (active sit, stand and walk at slow pace), as well as light-intensity activities by activities at MVPA such as walk at brisk pace, may produce theoretical improvements in frailty and PF. These findings are important for the development of effective interventions focused on reducing age-related frailty and declines in PF.

**Keywords:** IDEEA; frailty; physical function; sedentary behaviors; physical activity; walking;

## 1    **Introduction**

2            The increase in life expectancy is reflected in a progressive and rapid aging of  
3    the world population. For example, in Spain, data from the National Institute of  
4    Statistics show that in 2050 it is expected that there will be 21 million people over 65  
5    years of age (1). Healthy aging is the process of developing and maintaining functional  
6    capacity that allows well-being in elderly (1). Maintaining adequate physical  
7    functioning is considered to be one of the most important criteria for a healthy aging (2)  
8    and therefore, the identification of its modifiable determinants, and how to control its  
9    effects on the physical health of older adults, should be a public health priority. In older  
10   adults, certain evidence suggests that a less sedentary and more physically active  
11   lifestyle might be crucial to attenuate the age-related physical functioning decline. Too  
12   much time in sedentary behaviors has been associated with a greater deterioration in  
13   walking speed, increase of falls, and development of fragility (3–7). Conversely,  
14   physical activity (PA) has been related with a positive effect on mobility, limitations in  
15   activities of daily living, frailty and functional disability in elderly (8–11). Despite this  
16   evidence, older adults are still the least physically active and the most sedentary age  
17   group (12), which suggest that more effective strategies should be developed for this  
18   population.

19           The scientific literature in this topic is mainly limited to self-reported  
20   measurements of sedentary behaviors and PA. A few studies have used accelerometers,  
21   but their outputs are only based on intensity, which do not differentiate between  
22   postures or types of daily activities (11,13). Moreover, previous studies have  
23   independently explored these activity-specific without taking in account that they are  
24   co-dependent among them, so that the increase of time in one behavior implies  
25   decreasing time in another activity. Measuring the theoretical effects of substituting

time among behaviors while maintaining constant the total daily time can be key to developing more effective lifestyle-based interventions in older adults (14). Hence, the aims of this study were (i) to examine the independent associations of the time spent in daily activities (i.e., lie, recline, passive sit, active sit, stand, walk at slow pace, walk at average pace, walk at brisk pace, and other activities) measured by multi-sensor pattern-recognition with frailty and physical functioning; and (ii) to analyze by the isotemporal substitution technique, how relocating time between these daily activities is associated with frailty and physical functioning in a sample of older adults.

## Methods

### *Participants*

The study sample consists of 607 (383 women) high-functioning community-dwelling older adults, aged 65 to 92 years, who participated in the IMPACT65+ (Objectively assessed PA and its impact on frailty, quality of life and health in population aged 65 and older) study. The IMPACT65+ is a study aimed to examine the relationships of objectively measured PA with frailty, health-related quality of life and other health indicators in Spanish people aged 65 and over. Data from this study was collected from April 2015 to June 2017, and participants were recruited from wellness and senior centers (15). The study was approved by the Ethics Committee of the Autonomous University of Madrid (Madrid, Spain). Prior to data collection, all participants were informed of the nature of the study, and participants provided written informed consents.

### *Daily Activities*

PA and sedentary behaviors according to postures and intensities were assessed by the multi-sensor pattern-recognition Intelligent Device for Energy Expenditure and Activity (IDEEA, Minisun, Fresno, CA). The IDEEA consists of a small and lightweight main data recorder device (70x44x18mm, 59g) that can be worn on the belt and connected by wires and wirelessly to five sensors, which are biaxial accelerometers detecting angular acceleration and displacement in two orthogonal planes. Acceleration and position information obtained from the sensors is integrated in the microprocessor within the main recorder device. Participants were asked to wear the IDEEA for two consecutive days, without removing the device at any time. The sensors were adhered with a medical tape to the anterior sternum (i.e. just below the sternal angle), the anterior side of each thigh (i.e. midpoint between anterior superior iliac spine and knee

joint), and the plantar surface under each foot (i.e. under the foot arch). Devices were located and removed by trained personnel, and they were initialized and individually calibrated following the IDEEA software instructions (16).

The IDEEA is able to accurately assess more than 40 type of activities (16) and it has shown high levels of accuracy for estimating energy expenditure, and temporal and spatial gait parameters (17). For this study, all activity types were merge in 9 major daily activities, which were also classified into three intensity categories: (i) Sedentary behaviors: lie, recline, and passive sit (sitting posture characterized by an energy expenditure  $\leq 1.5$  METs). (ii) Light PA: active sit (sitting posture characterized by an energy expenditure  $> 1.5$  METs), stand, walk at slow pace ( $< 2$  miles per hour, mph), and walk at average pace (2-2.49 mph); and (iii) moderate-to-vigorous physical activity (MVPA): walk at brisk pace ( $\geq 2.5$  mph), and other activities (step up, step down, run, and jump).

The time spent in each daily activity was calculated as the mean of time during the valid days; we considered participants as valid for analyses when having at least 1 day with 10 hours of wake time (15). Since it was necessary to eliminate the sleep period to establish time in each activity, the sleep period time for each participant was identified and eliminated using a validated automated algorithm (18). This algorithm (algorithm #7) has demonstrated a high accuracy to detect sleep period compared with self-report (95.3%) and expert visual analysis of raw data (97.7%) (18).

### *Physical Frailty*

For this study, frailty was calculated as a continuous measure. This type of score has been used previously because it reduces random error, minimizes floor and ceiling effects, and tends to be normally distributed (19,20). However, the use of a continuous score in populations with a low prevalence rate in the outcome of interest (i.e. frailty



among high-functioning older adults) would require a large sample size to conduct association studies. The frailty score was based on the five widely recognized Fried's criteria (21). 'Weight loss' was calculated as the self-reported amount of kilograms lost during the last year. 'Exhaustion' was assessed by asking the participants two questions taken from the CES-D scale (22): "during the past week and to this day, at some point, you have felt that everything you did was a great effort; and, you did not feel like doing anything." The answers for both were: 1 point (less than a day), 2 points (1 to 2 days), 3 points (3 to 4 days), and 4 points (5 to 7 days). The answers to both questions were added to create a score ranging 2 to 8. 'Low physical activity' was assessed using a question from the European Prospective Investigation into Cancer and nutrition (EPIC) questionnaire: "During a typical week how many hours do you physical exercise (e.g. running, soccer, aerobic, swimming, tennis, gymnastics, etc.)?" (23). 'Slowness' was assessed in seconds using the 8-foot gait speed test (2.44 meters). Finally, 'weaknesses' was measured by grip strength measure with a hand dynamometer (TKK 5101 Grip D, Takey, Tokio, Japan). Two attempts were performed, and the average was calculated in kg. All the criteria used for the frailty score were harmonized so that a higher score indicated a worse frailty status. The final frailty score was obtained by standardizing each of the measurements to t-values. First, the z-values of each criteria were established using the mean and standard deviation of the total sample. Second, the z-score of each component was converted into t-values with a mean of 50 and standard deviations of 10. Third, t-values of the 'low PA' and 'weaknesses' criteria were multiplied by -1. Finally, the final score was calculated by the average of the five criteria in t-values, in order to have both outcome measures, frailty and physical functioning, in same units. The frailty score showed a strong dose-response relationship across the original Fried's categories (Supplementary Figure 1). Furthermore, another

frailty score was also calculated after excluding the PA variable, which allows to examine whether the beneficial effect of PA on frailty is independent of improvements in the ‘low physical activity’ criterion as suggested previously (24).

#### *Physical Functioning*

Overall physical functioning was assessed using the Spanish version of the SF-12 questionnaire, which has shown good reproducibility and validity in the Spanish population (25). This instrument consists of 12 items summarized using standardized procedures to obtain two scores indicating the physical and mental dimensions of health, but for the present study only the physical dimension was taken into account. This variable was standardized to a national norm with a mean of 50 and standard deviations of 10 (i.e. t-values), and the highest score represented a better level of physical functioning.

#### *Covariates*

Sex (men or women), age, and the highest educational level attained (illiterate, primary studies, secondary studies, medium university studies and vocational training, or higher university studies) were recorder. Smoking and alcohol drinking were reported as currently, former and never. Body weight and height were measured following standardized procedures, and body mass index was calculated as weight in kg divided by squared height in meters. Overweight was established for those who had a BMI  $\geq 25$  kg/m<sup>2</sup>, and obesity for those who had a BMI  $\geq 30$  kg/m<sup>2</sup> (26). Information on the following chronic conditions diagnosed by a physician and reported by the participants were recorded: coronary heart disease, stroke, rheumatism, hip fracture, cancer at any site, diabetes, Parkinson, and dementia/Alzheimer.

#### *Statistical Analysis*

Descriptive characteristics of the study participants are presented as a mean  $\pm$  standard deviations or percentages. The independent associations of daily activities with frailty and physical functioning were examined using linear regression models. Four models were fitted: model 1 was adjusted for age (years), sex (men, women) and wake time monitoring (h/day). Model 2 was adjusted as model 1, plus educational level (primary studies or lower, secondary studies or higher), BMI ( $\text{kg}/\text{m}^2$ ), smoking (current, former, never), alcohol drinking (current former, never) and chronic conditions (none, one or more). Model 3 was further adjusted for time (h/day) in other activities within the same category (e.g. within the sedentary category, the model for lie was additionally adjusted for time spent in recline and in passive sit). Finally, model 4 was adjusted as model 3, plus time in MVPA for sedentary behaviors and light PA, and plus time in light PA for MVPA activities. Associations were reported as unstandardized regression coefficients with 95% confidence intervals.

Isotemporal substitution analyses were used to estimate the effect of replacing time in one daily activity for the same amount of time spent in another activity, while awake time was kept constant (14). For example, when we examined the effect of replacing lying with standing, we dropped lying from the model but retained the time in the rest of activities, total wake time and other covariates in the model; thus, the coefficient of standing represents the consequence of substituting reclining instead of standing while other activities remain constant. Associations of daily activities with frailty and physical functioning were reported for 30 minutes reallocated. All analyses were performed using STATA v.14.1. Statistical significance was set at  $p < 0.05$ .

## Results

Descriptive characteristics of the study sample are shown in Table 1. A total of 436 participants (287 women; aged  $71.65 \pm 5.28$  years), with valid data on daily monitoring, outcomes and covariates were included in the analyses. Most reported primary studies or lower as educational level (57.34%). The average of BMI was  $28.69 \pm 4.48$  kg/m<sup>2</sup>, and 31.19% were obese. The most prevalent chronic conditions were rheumatism (17.89%) and diabetes (15.83%). Moreover, most of participants were currently alcohol drinkers (35.55%), and never smokers (56.18%). The mean waking time was 14.90 h/day and the most prevalent activity was passive sit (5.12 h/day), while other activities (i.e. step up and down, run, and jump) was the less prevalent (0.08 h/day).

Independent associations of daily activities with frailty and physical functioning are presented in Table 2. After adjustment for main covariates (model 2), total time in SB was only directly associated with frailty [ $\beta$  (95%CI): 0.61 (0.06, 1.15)], while the time spent in MVPA was inversely associated with frailty [ $\beta$  (95%CI): -4.63 (-6.51, -2.76)] and positively associated with physical functioning [ $\beta$  (95%CI): 6.10 (2.37, 9.82)]. When analyzed by daily activities, time spent lying was directly associated, while time in walk at average and brisk pace was inversely associated with frailty, in models 3. Nevertheless, in fully adjusted analyses, only the association between time spent in walk at brisk pace and frailty remained significant [ $\beta$  (95%CI): -4.72 (-6.75, -2.71)]. Similarly, using the frailty score without the 'low physical activity' criteria, the inverse associations between total MVPA time and walk at brisk pace were also significant in the full adjusted model ([ $\beta$  (95%CI): -3.59 (-5.74, -1.44)] and [ $\beta$  (95%CI): -4.04 (-6.32, -1.76)], respectively) (Supplementary Table 1). The independent associations for physical functioning were similar, but association of lying [ $\beta$  (95%CI):

-1.92 (-3.78, -0.06)], walk at average pace [ $\beta$  (95%CI): 8.95 (2.53, 15.38)] and walk at brisk pace [ $\beta$  (95%CI): 6.20 (2.18, 10.23)] with physical functioning remained significant in full adjusted analyses (Table 2).

Figure 1 shows the isotemporal substitution models for 30 minutes time reallocation between main intensities categories. Replacing the time in sedentary behaviors and light PA by 30 minutes of MVPA results in a decrease from -4.76 to -4.39 t-values for frailty, and an increase from 5.82 to 6.24 t-values for physical functioning. Specifically, it is observed that replacing 30 minutes of lying, reclining, passive sitting, active sitting, standing or walk at slow pace with walk at brisk pace results in a decrease ranging -3.80 to -4.68 t-values for frailty (all  $p < 0.01$ ) (Table 3). For physical functioning replacing 30 minutes of these activities with walk at average pace or walk at brisk pace results in an increase from 7.67 to 10.11 and 3.85 to 6.29 t-values, respectively (all  $p < 0.001$ ) (Supplementary Table 3). Conversely, the reallocation of 30 minutes of walking at brisk pace with lying or walk at slow pace were the strongest inverse associations (4.68 and 4.56 t-values, respectively) for frailty (Supplementary Table 2). The strongest inverse association for physical functioning were the reallocation of 30 minutes for walk at brisk or at average pace with walk at slow pace and active sitting (ranging from -6.28 to -10.11 t-values) (Table 3).

## 1    **Discussion**

2            This study examined the independent associations and isothermal substitution  
3    analysis of daily activities that considered body postures and movements with frailty  
4    and physical function in older adults. The results show that the time that older adults  
5    spent doing MVPA, which is mainly derived from brisk walking, was associated with a  
6    lower levels of frailty and higher physical function scores. The time spent in light PA,  
7    specially walking at an average pace, was also independently associated with better  
8    scores in physical function. In addition, overall sedentary behavior was not associated  
9    with frailty or physical function in older adults but lying was related with worse scores  
10   in physical functioning. Finally, isothermal substitution analyses revealed a clear  
11   beneficial effect of hypothetically replacing 30 min/day of sedentary behaviors or LPA  
12   by the same amount of MVPA for frailty and physical functioning.

13           The present findings are in line with those of previous research on the  
14   importance of PA at moderate and vigorous intensities on the physical health of the  
15   elderly. There is a strong scientific evidence about the favorable relationship of MVPA  
16   and frailty, physical function, disability or mortality (3,24,27–31). A meta-analysis in  
17   frail older adults found beneficial effects of moderate exercise-based interventions on  
18   strength, gait speed, and balance (32). Moreover, low MVPA has been independently  
19   associated with higher levels of frailty, poor self-reported health and high ADL  
20   disability, among others (3,33). Our results show a negative association of MVPA with  
21   frailty and better physical function, independently of SB and light PA. However, other  
22   moderate-vigorous intensity activities, such as step up, step down, run and jump, do not  
23   have a significant effect; this may be due to the low prevalence of this type of activities.

24           Recent studies have focused on the role of light PA on physical health of older  
25   adults (34–39). For example, some authors have shown that any increase in light PA

1 may cause beneficial effects in the physical function, frailty-related morbidities, and  
2 disability, regardless of MVPA (11,35–38). Our results indicated that time spent  
3 walking at an average pace was directly related to physical function. These results are  
4 important since older population spend most of their time in sedentary behaviors,  
5 whereas light PA is the predominant PA intensity (12).

6         Similar to what formerly indicated (3), the total time in sedentary behavior was  
7 not related to frailty and physical function, independently of MVPA. However, we  
8 observed that the time spent lying, which is a specific type of sedentary behavior, was  
9 associated with a decreased physical function in our sample. These results are in line  
10 with previous studies (11,40,41). A recent review that included 9 studies in older adults  
11 found that hip-worn accelerometer-measured sedentary behavior showed a strong  
12 association with some of the components of the physical performance (41). However, as  
13 in our results, sedentary time was not associated with frailty. By contrast, one study  
14 with self-reported measures has shown that older adults who were more sedentary had  
15 higher levels of frailty (42). Although, the evidence of the health benefits of reducing  
16 sedentary behaviors is wide; this association with frailty is unclear. The use of different  
17 scales of frailty, self-reported measures of sedentary time and cross-sectional designs,  
18 might yield more robust conclusions from future longitudinal and clinical trials are  
19 necessary. In addition, future research should confirm the negative role of lying on these  
20 and other physical health outcomes in older adults.

21         Isotemporal substitution models may explore the theoretical effects of  
22 substituting time spent in one behavior for another while keeping the total time fixed  
23 (14). In a recent cross-sectional study with 886 (70% women) older adults who used  
24 wrist-worn accelerometers to measure sedentary behavior, light PA and MVPA, the  
25 authors found that replacing 30 min of sedentary behaviors with an equivalent amount

of light PA reduced a 16% the risk of frailty in elderly [(OR (95%CI): 0.84 (0.78, 0.90)] (35). In this regard, another study conducted in the Toledo Study of Healthy Aging Study (11) with 628 participants over 65 years found similar results. PA was also measured with wrist-worn accelerometry and frailty was measured using the Frailty Trait Scale, and the results showed that PA at any intensity was associated with lower levels of frailty. However, just as in our results, only replacing 30 minutes of sedentary time with MVPA was associated with a decrease in frailty [ $\beta$  (95%CI): -2.46 (-3.78, -1.14)]. Light PA also had certain benefits in those older adults who had comorbidities [ $\beta$  (95%CI): -0.57 (-1.05, -0.09)] (11).

On the other hand, hypothetical benefits on physical function when sedentary time is substituted for light PA have been described. For example, Lerma et al. (2017) examined the associations of sedentary time with light PA and MVPA on physical function in older adults. The results showed that replacing 30 minutes of sedentary behaviors by the same amount of PA (light or moderate-vigorous) has beneficial effects on physical function, measured by the 400-m walk test (38). Nevertheless, as our results show, not all types of PA produce the same benefit in older adults. In our study, the isotemporal replacement of sedentary behaviors as lie, recline and passive sit by light PA, like walk at average pace, reported greater benefits [ $\beta$  (95%CI): -9.68 (-16.22, -3.14), -8.80 (-15.36, -2.24), and -7.83 (-14.37, -1.29) respectively (all  $p < 0.05$ )], than the substitution for other light activities such as: active sit, stand or walk at slow pace (all  $p > 0.05$ ). Our results, therefore, suggest that achieving healthy lifestyle changes in older adults, such as replacing the time spent in lie, recline or passive sit with walking at average pace, could be a primary effective approach to improve physical health among older adults.



Strengths of this study were data collection with validated and standardized methods, analyses adjusted for numerous potential confounders, and activity data assessed using a multi-sensor pattern-recognition monitor considered a gold standard instrument in health-related research (16). This study also had some limitations. First, in our cross-sectional design, a potential reverse causality in the direction of associations between PA and frailty or physical functioning should not be ignored but our high-functioning sample potentially reduces the possibility of reverse causation. Second, our study was carried out with a convenience sample, which limits the generalization of our results to the rest of the elderly population. Third, the short data collection period for 48 hours due to storage restrictions and battery life from the IDEEA. However, in a previous study, we observed a low percentage of variation and a high reliability for most of the activities analyzed during two monitoring days (43). Fourth, data of some components of frailty and physical performance were self-reported; these measures might be less reliable than objective measures, mainly affected by recall bias; nevertheless a previous research has shown that different definitions of frailty, based on self-reported measures and anamnestic information, have accurately classified people with and without adverse physical health outcomes (44).

## 1   **Conclusion**

2           In conclusion, to the best of our knowledge, this is the first study examining the  
3   activity-specific and isothermal association of daily activities with frailty and physical  
4   functioning in older adults. MVPA was associated with an improvement of the frailty  
5   and physical functioning, whereas light PA also has certain benefits in physical  
6   functioning. In contrast, lying was related to a decrease in physical function.  
7   Isothermal substitution analyses showed that replacing sedentary behaviors (lie,  
8   recline, passive sit) by light-intensity activities (active sit, stand and walk at slow pace),  
9   as well as light-intensity activities by activities at MVPA such as walk at brisk pace,  
10   may produce theoretical improvements in frailty and physical function. These findings  
11   are important for the development of effective interventions focused on reducing age-  
12   related frailty and declines in physical functioning.

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**Conflict of interest**

The authors declare that they have no conflict of interest.

1

1    **Ethical standards**

2            All procedures were performed in accordance with the principles of the  
3    Declaration of Helsinki and approved by the appropriate institutional review committee.  
4    In addition, all participants gave their informed consent to participate in the study.  
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## REFERENCES

1. World Health Organization. World Report on Ageing and Health. *World Heal. Organ.* 1–246 (2015). doi:10.1007/s13398-014-0173-7.2
2. Cosco, T. D., Prina, A. M., Perales, J., Stephan, B. C. M. & Brayne, C. Operational definitions of successful aging: a systematic review. *Int. Psychogeriatrics* **26**, 373–381 (2014).
3. Blodgett, J., Theou, O., Kirkland, S., Andreou, P. & Rockwood, K. The association between sedentary behaviour, moderate–vigorous physical activity and frailty in NHANES cohorts. *Maturitas* **80**, 187–191 (2015).
4. Dunlop, D. D. *et al.* Sedentary Time in US Older Adults Associated with Disability in Activities of Daily Living Independent of Physical Activity. *J. Phys. Act. Heal.* **12**, 93–101 (2015).
5. Hamer, M. & Stamatakis, E. Screen-Based Sedentary Behavior, Physical Activity, and Muscle Strength in the English Longitudinal Study of Ageing. *PLoS One* **8**, e66222 (2013).
6. Keevil, V. L. *et al.* Television Viewing, Walking Speed, and Grip Strength in a Prospective Cohort Study. *Med. Sci. Sport. Exerc.* **47**, 735–742 (2015).
7. Semanik, P. A. *et al.* Accelerometer-Monitored Sedentary Behavior and Observed Physical Function Loss. *Am. J. Public Health* **105**, 560–566 (2015).
8. Peterson, M. J. *et al.* Physical Activity as a Preventative Factor for Frailty: The Health, Aging, and Body Composition Study. *Journals Gerontol. Ser. A Biol. Sci. Med. Sci.* **64A**, 61–68 (2009).
9. Binder, E. F. *et al.* Effects of exercise training on frailty in community-dwelling

- 1 older adults: results of a randomized, controlled trial. *J. Am. Geriatr. Soc.* **50**,  
2 1921–8 (2002).
- 3 10. Paterson, D. H. & Warburton, D. E. Physical activity and functional limitations  
4 in older adults: a systematic review related to Canada’s Physical Activity  
5 Guidelines. *Int. J. Behav. Nutr. Phys. Act.* **7**, 38 (2010).
- 6 11. Mañas, A. *et al.* Reallocating Accelerometer-Assessed Sedentary Time to Light  
7 or Moderate- to Vigorous-Intensity Physical Activity Reduces Frailty Levels in  
8 Older Adults: An Isotemporal Substitution Approach in the TSHA Study. *J. Am.*  
9 *Med. Dir. Assoc.* **19**, 185.e1-185.e6 (2018).
- 10 12. Amireault, S., Baier, J. M. & Spencer, J. R. Physical Activity Preferences Among  
11 Older Adults: A Systematic Review. *J. Aging Phys. Act.* **27**, 128–139 (2019).
- 12 13. Aguilar-Farías, N., Brown, W. J. & Peeters, G. M. E. E. (Geeske). ActiGraph  
13 GT3X+ cut-points for identifying sedentary behaviour in older adults in free-  
14 living environments. *J. Sci. Med. Sport* **17**, 293–299 (2014).
- 15 14. Mekary, R. A., Willett, W. C., Hu, F. B. & Ding, E. L. Isotemporal substitution  
16 paradigm for physical activity epidemiology and weight change. *Am. J.*  
17 *Epidemiol.* **170**, 519–27 (2009).
- 18 15. Cabanas-Sánchez, V., Higuera-Fresnillo, S., DE LA Cámara, M. Á., Esteban-  
19 Cornejo, I. & Martínez-Gómez, D. 24-h Movement and Nonmovement  
20 Behaviors in Older Adults. The IMPACT65+ Study. *Med. Sci. Sports Exerc.* **51**,  
21 671–680 (2019).
- 22 16. Zhang, K., Werner, P., Sun, M., Pi-Sunyer, F. X. & Boozer, C. N. Measurement  
23 of human daily physical activity. *Obes. Res.* **11**, 33–40 (2003).

- 1 17. Arvidsson, D., Fitch, M., Hudes, M. L. & Fleming, S. E. Accuracy of multisensor  
2 activity monitors in normal versus high BMI African American children. *J. Phys.*  
3 *Act. Health* **8**, 1124–1134 (2011).
- 4 18. Cabanas-Sánchez, V., Higuera-Fresnillo, S., De la Cámara, M. Á., Veiga, O. L.  
5 & Martínez-Gómez, D. Automated algorithms for detecting sleep period time  
6 using a multi-sensor pattern-recognition activity monitor from 24 h free-living  
7 data in older adults. *Physiol. Meas.* **39**, 055002 (2018).
- 8 19. Buchman, A. S., Wilson, R. S., Bienias, J. L. & Bennett, D. A. Change in Frailty  
9 and Risk of Death in Older Persons. *Exp. Aging Res.* **35**, 61–82 (2009).
- 10 20. Wu, C. *et al.* Development, Construct Validity, and Predictive Validity of a  
11 Continuous Frailty Scale: Results From 2 Large US Cohorts. *Am. J. Epidemiol.*  
12 **187**, 1752–1762 (2018).
- 13 21. Fried, L. P. *et al.* Frailty in older adults: evidence for a phenotype. *J. Gerontol. A.*  
14 *Biol. Sci. Med. Sci.* **56**, M146-156 (2001).
- 15 22. Orme, J. G., Reis, J. & Herz, E. J. Factorial and discriminant validity of the  
16 Center for Epidemiological Studies Depression (CES-D) scale. *J. Clin. Psychol.*  
17 **42**, 28–33 (1986).
- 18 23. Cust, A. E. *et al.* Validity and repeatability of the EPIC physical activity  
19 questionnaire: a validation study using accelerometers as an objective measure.  
20 *Int. J. Behav. Nutr. Phys. Act.* **5**, 33 (2008).
- 21 24. Cadore, E. L., Rodríguez-Manas, L., Sinclair, A. & Izquierdo, M. Effects of  
22 different exercise interventions on risk of falls, gait ability, and balance in  
23 physically frail older adults: a systematic review. *Rejuvenation Res.* **16**, 105–114



(2013).

25. Vilagut, G. *et al.* [Interpretation of SF-36 and SF-12 questionnaires in Spain: physical and mental components]. *Med. Clin. (Barc)*. **130**, 726–735 (2008).
26. Gutiérrez-Fisac, J. L., López, E., Banegas, J. R., Graciani, A. & Rodríguez-Artalejo, F. Prevalence of overweight and obesity in elderly people in Spain. *Obes. Res.* **12**, 710–715 (2004).
27. Cesari, M. *et al.* A Physical Activity Intervention to Treat the Frailty Syndrome in Older Persons--Results From the LIFE-P Study. *Journals Gerontol. Ser. A Biol. Sci. Med. Sci.* **70**, 216–222 (2015).
28. Garatachea, N. *et al.* Exercise attenuates the major hallmarks of aging. *Rejuvenation Res.* **18**, 57–89 (2015).
29. Higuera-Fresnillo, S. *et al.* Physical Activity and Association Between Frailty and All-Cause and Cardiovascular Mortality in Older Adults: Population-Based Prospective Cohort Study. *J. Am. Geriatr. Soc.* **66**, 2097–2103 (2018).
30. Giné-Garriga, M., Roqué-Fíguls, M., Coll-Planas, L., Sitjà-Rabert, M. & Salvà, A. Physical Exercise Interventions for Improving Performance-Based Measures of Physical Function in Community-Dwelling, Frail Older Adults: A Systematic Review and Meta-Analysis. *Arch. Phys. Med. Rehabil.* **95**, 753–769.e3 (2014).
31. Pahor, M. *et al.* Effect of Structured Physical Activity on Prevention of Major Mobility Disability in Older Adults. *JAMA* **311**, 2387 (2014).
32. Lopez, P. *et al.* Effectiveness of Multimodal Training on Functional Capacity in Frail Older People: A Meta-Analysis of Randomized Controls Trials. *J. Aging Phys. Act.* 1–36 (2017). doi:10.1123/japa.2017-0188

- 1 33. Chou, C.-H., Hwang, C.-L. & Wu, Y.-T. Effect of Exercise on Physical Function,  
2 Daily Living Activities, and Quality of Life in the Frail Older Adults: A Meta-  
3 Analysis. *Arch. Phys. Med. Rehabil.* **93**, 237–244 (2012).
- 4 34. Physical Activity Guidelines Advisory Committee. Physical Activity Guidelines  
5 Advisory Committee Report. *Washingt. DC US* **67**, 683 (2008).
- 6 35. Nagai, K. *et al.* Isotemporal substitution of sedentary time with physical activity  
7 and its associations with frailty status. *Clin. Interv. Aging* **Volume 13**, 1831–  
8 1836 (2018).
- 9 36. Tse, A. C. Y., Wong, T. W. L. & Lee, P. H. Effect of Low-intensity Exercise on  
10 Physical and Cognitive Health in Older Adults: a Systematic Review. *Sport.*  
11 *Med. - Open* **1**, 37 (2015).
- 12 37. Jantunen, H. *et al.* Objectively measured physical activity and physical  
13 performance in old age. *Age Ageing* **46**, 232–237 (2016).
- 14 38. Lerma, N. L. *et al.* Isotemporal Substitution of Sedentary Behavior and Physical  
15 Activity on Function. *Med. Sci. Sport. Exerc.* **50**, 792–800 (2018).
- 16 39. Powell, K. E., Paluch, A. E. & Blair, S. N. Physical Activity for Health: What  
17 Kind? How Much? How Intense? On Top of What? *Annu. Rev. Public Health* **32**,  
18 349–365 (2011).
- 19 40. del Pozo-Cruz, B. *et al.* Frailty is associated with objectively assessed sedentary  
20 behaviour patterns in older adults: Evidence from the Toledo Study for Healthy  
21 Aging (TSHA). *PLoS One* **12**, e0183911 (2017).
- 22 41. Mañas, A., del Pozo-Cruz, B., García-García, F. J., Guadalupe-Grau, A. & Ara, I.  
23 Role of objectively measured sedentary behaviour in physical performance,

1 frailty and mortality among older adults: A short systematic review. *Eur. J. Sport*  
2 *Sci.* **17**, 940–953 (2017).

3 42. da Silva Coqueiro, R. *et al.* Cross-sectional relationships between sedentary  
4 behavior and frailty in older adults. *J. Sports Med. Phys. Fitness* **57**, 825–830  
5 (2017).

6 43. de la Cámara, M. Á., Higuera-Fresnillo, S., Martínez-Gómez, D. & Veiga, Ó. L.  
7 Interday Reliability of the IDEEA Activity Monitor for Measuring Movement  
8 and Nonmovement Behaviors in Older Adults. *J. Aging Phys. Act.* **27**, 141–154  
9 (2019).

10 44. Pedone, C. *et al.* Are Performance Measures Necessary to Predict Loss of  
11 Independence in Elderly People? *Journals Gerontol. Ser. A Biol. Sci. Med. Sci.*  
12 **71**, 84–89 (2016).

1 **Table 1** Descriptive characteristics of study sample

	All
<i>n</i>	436
Women (%)	65.83
Age (years)	71.65±5.28
Education level	
Primary studies or lower (%)	57.34
Secondary studies or higher (%)	42.67
Weight (kg)	71.07±12.79
Height (cm)	157.29±8.85
Body mass index (kg/m <sup>2</sup> )	28.69±4.48
Overweight (%)	51.61
Obesity (%)	31.19
≥1 Chronic conditions (%)	45.18
Smoking (%)	
Currently	6.42
Former	37.16
Never	56.42
Alcohol drinking (%)	
Currently	62.61
Former	6.19
Never	31.19
IDEEA wake time (h/day)	14.90±1.80
Sedentary behaviors (h/day)	7.13±1.72
Lie	0.82±0.92
Recline	1.19±1.23
Passive sit	5.12±1.93
Light PA (h/day)	7.32±2.00
Active sit	0.60±0.40
Stand	5.08±1.66
Walk at slow pace	1.23±0.46
Walk at average pace	0.41±0.28
MVPA (h/day)	0.46±0.50
Walk at brisk pace	0.38±0.46
Other activities	0.08±0.13

2 Values are mean ± standard deviation or percentage. PA= Physical Activity; MVPA= Moderate to Vigorous  
3 Physical Activity.

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**Table 2.** Independent associations of daily activities with the frailty score and physical functioning

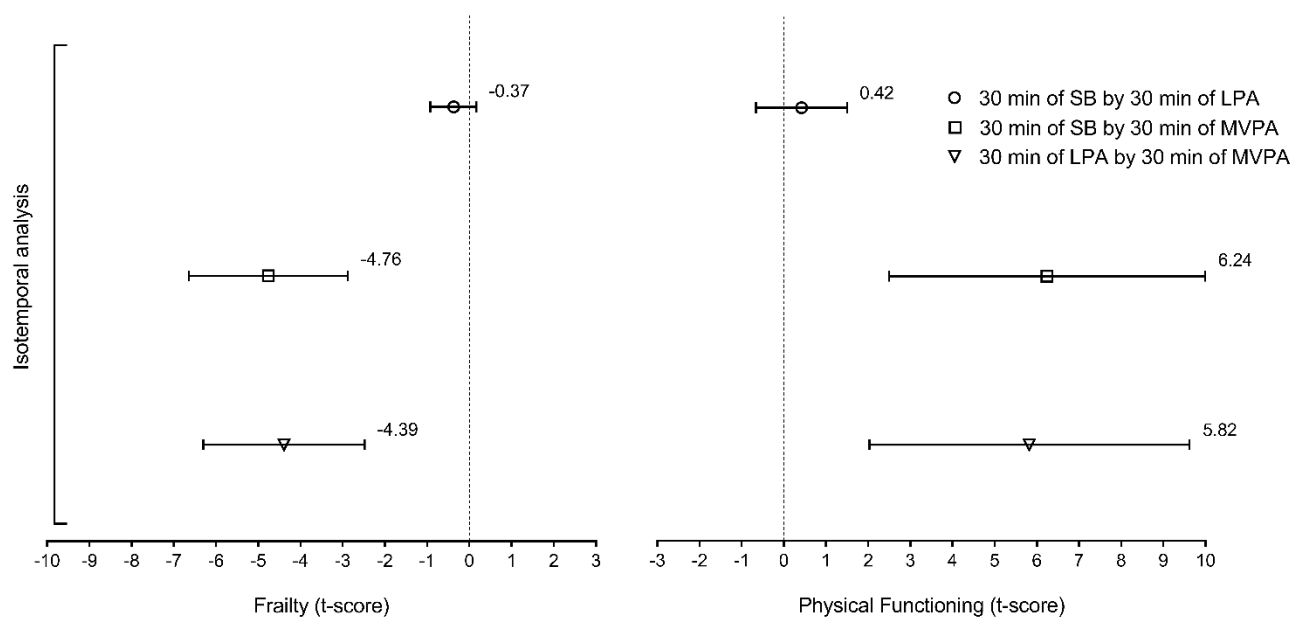
	Model 1 (95% CI)	Model 2 (95% CI)	Model 3 (95% CI)	Model 4 (95% CI)
<b>Frailty score</b>				
Sedentary behavior (30min/day)				
Lie	1.44 (0.52, 2.36)**	0.98 (0.06, 1.90)*	1.16 (0.21, 2.10)**	0.82 (-0.12, 1.76)
Recline	0.85 (0.12, 1.57)*	0.41 (-0.34, 1.16)	0.80 (-0.10, 1.71)	0.55 (-0.34, 1.45)
Passive sit	-0.17 (-0.66, 0.31)	0.03 (-0.45, 0.51)	0.43 (-0.16, 1.02)	0.23 (-0.35, 0.82)
Light PA (30min/day)				
Active sit	-0.51 (-2.74, 1.72)	0.24 (-1.94, 2.41)	-0.10 (-2.28, 2.08)	-0.59 (-2.73, 1.55)
Stand	-0.17 (-0.86, 0.51)	-0.18 (-0.85, 0.49)	-0.27 (-0.96, 0.42)	-0.35 (-1.03, 0.32)
Walk at slow pace <sup>a</sup>	-0.02 (-1.98, 2.01)	0.00 (-1.94, 1.94)	0.99 (-1.09, 3.08)	0.38 (-1.68, 2.44)
Walk at average pace <sup>b</sup>	-4.93 (-8.03, -1.83)**	-3.84 (-6.92, -0.76)*	-4.34 (-7.61, -1.08)**	-2.95 (-6.20, 0.30)
MVPA (30min/day)				
Walk at brisk pace <sup>c</sup>	-5.73 (-7.70,-3.75)***	-4.70 (-6.71,-2.69)***	-4.59 (-6.61,-2.58)***	-4.72 (-6.75,-2.71)***
Other activities <sup>d</sup>	-7.41 (-14.04, -0.79)*	-6.00 (-12.49, 0.48)	-4.99 (-11.34, 1.37)	-5.06 (-11.41, 1.30)
<b>Physical functioning</b>				
Sedentary behavior (30min/day)				
Lie	-3.01 (-4.80, -1.22)**	-2.25 (-4.04, -0.45)*	-2.36 (-4.21, -0.51)*	-1.92 (-3.78, -0.06)*
Recline	-1.99 (-3.40, -0.59)**	-1.20 (-2.67, 0.27)	-1.41 (-3.19, 0.36)	-1.09 (-2.86, 0.68)
Passive sit	0.89 (-0.05, 1.82)	0.53 (-0.40, 1.47)	-0.20 (-1.35, 0.95)	0.05 (-1.10, 1.20)
Light PA (30min/day)				
Active sit	-1.49 (-5.81, 2.83)	-2.83 (-7.07, 1.42)	-2.03 (-6.26, 2.21)	-1.48 (-5.71, 2.75)
Stand	0.36 (-0.97, 1.68)	0.25 (-1.06, 1.56)	0.52 (-0.82, 1.86)	0.61 (-0.73, 1.94)
Walk at slow pace <sup>a</sup>	-0.58 (-4.46, 3.29)	-0.59 (-4.38, 3.21)	-2.92 (-6.98, 1.13)	-2.24 (-6.03, 1.82)
Walk at average pace <sup>b</sup>	10.73 (4.74,16.73)***	9.45 (3.45, 15.45)**	10.52 (4.16, 16.87)**	8.95 (2.53, 15.38)**
MVPA (30min/day)				
Walk at brisk pace <sup>c</sup>	7.45 (3.58, 11.40)***	6.20 (2.21, 10.19)**	6.05 (2.05, 10.05)**	6.20 (2.18, 10.23)**
Other activities <sup>d</sup>	10.05 (-2.83, 22.94)	7.83 (-4.88, 20.54)	6.48 (-6.14, 19.11)	6.56 (-6.07, 19.20)

Values are unstandardized regression coefficients (95% Confidence Interval). PA= Physical Activity; MVPA= Moderate to Vigorous Physical Activity. Model 1 was adjusted for age, sex and wake time. Model 2 was adjusted as model 1, plus educational level, BMI, smoking, alcohol drinking and chronic conditions. Model 3 was adjusted as model 2, plus time in other activities within category. Model 4 was adjusted as model 3, plus time in MVPA for sedentary behaviors and light PA, and plus time in light PA for MVPA activities. <sup>a</sup>Walk at <2 miles per hour. <sup>b</sup>Walk at 2-2.49 miles per hour. <sup>c</sup>Walk at ≥2.5 miles per hour. <sup>d</sup>Other activities include step up, step down, run and jump. \*p<0.05; \*\*p<0.01; \*\*\*p<0.001

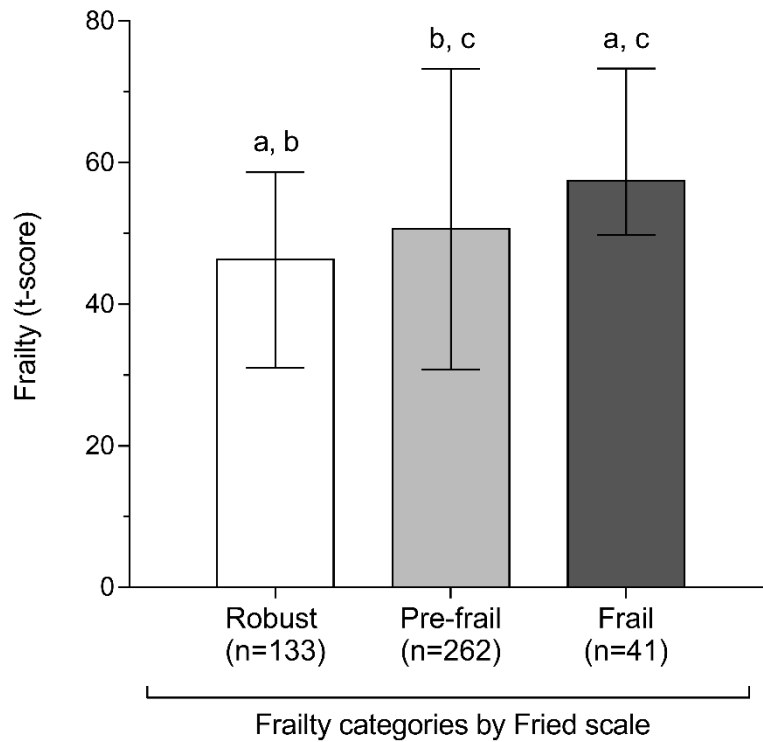
**Table 3.** Associations between daily activities and frailty (above the diagonal) and physical functioning (below the diagonal) when reallocating 30 minutes of one activity to 30 minutes of another activity

Reallocate 30 min of...	...to 30 min of...								
	Lie	Recline	Passive sit	Active sit	Stand	Walk at slow pace	Walk at average pace	Walk at brisk pace	Other activities
Lie	Dropped	-0.24 (-1.43, 0.95)	-0.52 (-1.49, 0.46)	-0.88 (3.11, 1.35)	-0.75 (-1.77, 0.28)	-0.13 (-2.40, 2.14)	-3.15 (-6.48, 0.17)	-4.68 (-6.89, -2.48)***	-5.49 (-11.89, 0.91)
Recline	-0.88 (-3.21, 1.46)	Dropped	-0.27 (-1.01, 0.47)	-0.64 (-2.93, 1.66)	-0.50 (-1.48, 0.48)	0.12 (-2.10, 2.33)	-2.91 (-6.25, 0.42)	-4.44 (-6.66, -2.22)***	-5.25 (-11.65, 1.15)
Passive sit	-1.85 (-3.77, 0.07)	-0.97 (-2.43, 0.48)	Dropped	-0.37 (-2.55, 1.82)	-0.23 (-0.94, 0.48)	0.39 (-1.67, 2.46)	-2.64 (-5.96, 0.69)	-4.17 (-6.28, -2.05)***	-4.97 (-11.34, 1.42)
Active sit	0.43 (-3.96, 4.81)	1.30 (-3.21, 5.82)	2.27 (-2.02, 6.59)	Dropped	0.14 (-2.12, 2.40)	0.76 (-2.24, 3.76)	-2.27 (-6.04, 1.50)	-3.80 (-6.62, 0.98)**	-4.61 (-11.40, 2.18)
Stand	-2.01 (-4.02, 0.01)	-1.13 (-3.06, 0.80)	-0.16 (-1.55, 1.24)	-2.43 (-6.88, 2.01)	Dropped	0.62 (-1.71, 2.95)	-2.41 (-5.72, 0.91)	-3.94 (-6.11, -1.76)***	-4.74 (-11.14, 1.65)
Walk at slow pace <sup>a</sup>	0.43 (-4.03, 4.90)	1.31 (-3.05, 5.67)	2.28 (-1.78, 6.34)	0.01 (-5.90, 5.91)	2.44 (-2.15, 7.03)	Dropped	-3.03 (-7.47, 1.42)	-4.56 (-7.30, 1.82)**	-5.36 (-12.11, 1.38)
Walk at average pace <sup>b</sup>	-9.68 (-16.22, -3.14)**	-8.80 (-15.36, -2.24)**	-7.83 (-14.37, -1.29)*	-10.11 (-17.52, -2.70)**	-7.67 (-14.20, -1.15)*	-10.11 (-18.86, -1.37)*	Dropped	-1.53 (-5.79, 2.73)	-2.34 (-9.36, 4.69)
Walk at brisk pace <sup>c</sup>	-5.86 (-10.19, -1.52)**	-4.98 (-9.35, -0.61)*	-4.01 (-8.17, 0.15)	-6.28 (-11.83, -0.73)*	-3.85 (-8.13, 0.43)	-6.29 (-11.68, -0.90)*	3.82 (-4.56, 12.20)	Dropped	-0.81 (-7.67, 6.06)
Other activities <sup>d</sup>	-8.38 (-20.97, 4.21)	-7.51 (-20.09, 5.08)	-6.53 (-19.10, 6.03)	-8.81 (-22.17, 4.55)	-6.38 (-18.96, 6.21)	-8.81 (-22.08, 4.45)	1.30 (-12.53, 15.12)	-2.52 (-16.03, 10.99)	Dropped

Values are unstandardized regression coefficients (95% Confidence Interval). Analyses were adjusted for age, sex, weak time, educational level, BMI, smoking, alcohol drinking and chronic conditions. <sup>a</sup>Walk at <2 miles per hour. <sup>b</sup>Walk at 2-2.49 miles per hour. <sup>c</sup>Walk at ≥2.5 miles per hour. <sup>d</sup>Other activities include step up, step down, run and jump. \*p<0.05; \*\*p<0.01; \*\*\*p<0.001.



**Figure 1.** Hypothetical changes in frailty and physical functioning associated with 30 minutes time reallocation between daily activities (isotemporal substitution analyses). Values are standardized regression coefficients (95% Confidence Interval). SB: Sedentary Behaviors; LPA: Light Physical Activity; MVPA: Moderate to Vigorous Physical Activity.



**Supplementary figure 1.** Differences between frailty assessed with Fried scale and score of frailty. Values are mean  $\pm$  standard deviation. <sup>a</sup> denote statistically significant differences with pre-frail group; <sup>b</sup> denote statistically significant differences with frail group; <sup>c</sup> denote statistically significant differences with robust group. All  $p < 0.001$



**Supplementary Table 1.** Independent associations of daily activities with the frailty score excluded the physical activity component.

	Model 1 (95% CI)	Model 2 (95% CI)	Model 3 (95% CI)	Model 4 (95% CI)
<b>Sedentary behavior (30min/day)</b>	0.87 (0.25, 1.48)**	0.79 (0.17, 1.40)*	NA	0.59 (-0.02, 1.21)
Lie	1.53 (0.50, 2.57)**	1.06 (0.03, 2.09)*	1.32 (0.26, 2.38)*	1.04 (-0.02, 2.10)
Recline	0.71 (-0.11, 1.52)	0.33 (-0.51, 1.17)	0.89 (-0.12, 1.91)	0.69 (-0.32, 1.70)
Passive sit	-0.06 (-0.61, 0.48)	0.17 (-0.36, 0.71)	0.62 (-0.04, 1.28)	0.46 (-0.20, 1.12)
<b>Light PA (30min/day)</b>	-0.50 (-1.13, 0.14)	-0.47 (-1.09, 0.15)	NA	-0.59 (-1.21, 0.02)
Active sit	-1.33 (-3.83, 1.17)	-0.32 (-2.75, 2.11)	-0.58 (-3.02, 1.85)	-1.01 (-3.43, 1.40)
Stand	-0.52 (-1.29, 0.25)	-0.60 (-1.35, 0.15)	-0.75 (-1.52, 0.02)	-0.82 (-1.59, -0.06)*
Walk at slow pace <sup>a</sup>	0.75 (-1.50, 2.99)	0.61 (-1.56, 2.77)	1.82 (-0.51, 4.15)	1.28 (-1.04, 3.06)
Walk at average pace <sup>b</sup>	-3.49 (6.99, 0.2)	-2.83 (-6.29, 0.63)	-3.83 (-7.48, -0.18)*	-2.60 (-6.27, 1.07)
<b>MVPA (30min/day)</b>	-4.65 (-6.75, -2.56)***	-3.98 (-6.10, -1.86)***	NA	-3.59 (-5.74, 1.44)**
Walk at brisk pace <sup>c</sup>	-4.72 (-6.97, -2.46)***	-3.95 (-6.22, -1.67)**	-3.83 (-6.10, -1.55)**	-4.04 (-6.32, -1.76)**
Other activities <sup>d</sup>	-7.03 (-14.49, 0.42)	-3.08 (-13.34, 1.17)	-5.23 (-12.42, 1.96)	-5.35 (-12.51, 1.82)

Values are unstandardized regression coefficients (95% Confidence Interval). PA= Physical Activity; MVPA= Moderate to Vigorous Physical Activity; NA: not applicable. Model 1 was adjusted for age, sex and wake time./ Model 2 was adjusted as model 1, plus educational level, BMI, smoking, alcohol drinking and chronic conditions. Model 3 was adjusted as model 2, plus time in other activities within category. Model 4 was adjusted as model 3, plus time in MVPA for sedentary behaviors and light PA, and plus time in light PA for MVPA activities. <sup>a</sup>Walk at <2 miles per hour. <sup>b</sup>Walk at 2-2.49 miles per hour. <sup>c</sup>Walk at ≥2.5 miles per hour. <sup>d</sup>Other activities include step up, step down, run and jump. \*p<0.05; \*\*p<0.01; \*\*\*p<0.001

**Supplementary Table 2.** Associations between daily activities and frailty when reallocating 30 minutes of one activity to 30 minutes of another activity

Reallocate 30 min of...	...to 30 min of...								
	Lie	Recline	Passive sit	Active sit	Stand	Walk at slow pace	Walk at average pace	Walk at brisk pace	Other activities
Lie	Dropped	-0.24 (-1.43, 0.95)	-0.52 (-1.49, 0.46)	-0.88 (3.11, 1.35)	-0.75 (-1.77, 0.28)	-0.13 (-2.40, 2.14)	-3.15 (-6.48, 0.17)	-4.68 (-6.89, -2.48)***	-5.49 (-11.89, 0.91)
Recline	0.24 (-0.95, 1.43)	Dropped	-0.27 (-1.01, 0.47)	-0.64 (-2.93, 1.66)	-0.50 (-1.48, 0.48)	0.12 (-2.10, 2.33)	-2.91 (-6.25, 0.42)	-4.44 (-6.66, -2.22)***	-5.25 (-11.65, 1.15)
Passive sit	0.52 (-0.46, 1.50)	0.27 (-0.47, 1.01)	Dropped	-0.37 (-2.55, 1.82)	-0.23 (-0.94, 0.48)	0.39 (-1.67, 2.46)	-2.64 (-5.96, 0.69)	-4.17 (-6.28, -2.05)***	-4.97 (-11.34, 1.42)
Active sit	0.88 (-1.35, 3.11)	0.64 (-1.66, 2.93)	0.37 (-1.82, 2.55)	Dropped	0.14 (-2.12, 2.40)	0.76 (-2.24, 3.76)	-2.27 (-6.04, 1.50)	-3.80 (-6.62, 0.98)**	-4.61 (-11.40, 2.18)
Stand	0.75 (-0.28, 1.77)	0.50 (-0.48, 1.48)	0.23 (-0.48, 0.94)	-0.14 (-2.40, 2.12)	Dropped	0.62 (-1.71, 2.95)	-2.41 (-5.72, 0.91)	-3.94 (-6.11, -1.76)***	-4.74 (-11.14, 1.65)
Walk at slow pace <sup>a</sup>	0.13 (-2.14, 2.40)	-0.12 (-2.33, 2.10)	-0.39 (-2.46, 1.67)	-0.76 (-3.76, 2.24)	-0.62 (-2.95, 1.71)	Dropped	-3.03 (-7.47, 1.42)	-4.56 (-7.30, 1.82)**	-5.36 (-12.11, 1.38)
Walk at average pace <sup>b</sup>	3.15 (-0.17, 6.48)	2.91 (-0.42, 6.25)	2.64 (-0.69, 5.96)	2.27 (-1.50, 6.04)	2.41 (-0.91, 5.72)	3.03 (-1.42, 7.47)	Dropped	-1.53 (-5.79, 2.73)	-2.34 (-9.36, 4.69)
Walk at brisk pace <sup>c</sup>	4.68 (2.48, 6.89)***	4.44 (2.22, 6.66)***	4.17 (2.05, 6.28)***	3.80 (0.98, 6.62)**	3.94 (1.76, 6.11)***	4.56 (1.82, 7.30)**	1.53 (-2.73, 5.79)	Dropped	-0.81 (-7.67, 6.06)
Other activities <sup>d</sup>	5.49 (-0.91, 11.89)	5.25 (-1.15, 11.65)	4.97 (-1.42, 11.36)	4.61 (-2.18, 11.40)	4.74 (-1.65, 11.14)	5.36 (-1.38, 12.10)	2.34 (-4.69, 9.36)	0.81 (-6.06, 7.67)	Dropped

Values are unstandardized regression coefficients (95% Confidence Interval). Analyses were adjusted for age, sex, weak time, educational level, BMI, smoking, alcohol drinking and chronic conditions. <sup>a</sup>Walk at <2 miles per hour. <sup>b</sup>Walk at 2-2.49 miles per hour. <sup>c</sup>Walk at ≥2.5 miles per hour. <sup>d</sup>Other activities include step up, step down, run and jump. \*p<0.05;

\*\*p<0.01; \*\*\*p<0.001.

**Supplementary Table 3.** Associations between daily activities and physical functioning when reallocating 30 minutes of one activity to 30 minutes of another activity

Reallocate 30 min of...	...to 30 min of...								
	Lie	Recline	Passive sit	Active sit	Stand	Walk at slow pace	Walk at average pace	Walk at brisk pace	Other activities
Lie	Dropped	0.88 (-1.46, 3.21)	1.85 (-0.07, 3.77)	-0.43 (-4.81, 3.96)	2.01 (-0.01, 4.02)	-0.43 (-4.90, 4.03)	9.68 (3.14, 16.22)**	5.86 (1.52, 10.19)**	8.38 (-4.21, 20.97)
Recline	-0.88 (-3.21, 1.46)	Dropped	0.97 (-0.48, 2.43)	-1.30 (-5.82, 3.21)	1.13 (-0.80, 3.06)	-1.31 (-5.67, 3.05)	8.80 (-2.24, 15.36)**	4.98 (0.61, 9.35)*	7.51 (-5.08, 20.09)
Passive sit	-1.85 (-3.77, 0.07)	-0.97 (-2.43, 0.48)	Dropped	-2.27 (-6.57, 2.02)	0.16 (-1.24, 1.55)	-2.28 (-6.34, 1.78)	7.83 (1.29, 14.37)*	4.01 (-0.15, 8.17)	6.53 (-6.03, 19.10)
Active sit	0.43 (-3.96, 4.81)	1.30 (-3.21, 5.82)	2.27 (-2.02, 6.59)	Dropped	2.43 (-2.01, 6.88)	-0.01 (-5.91, 5.89)	10.11 (2.70, 17.52)**	6.28 (0.73, 11.83)*	8.81 (-4.55, 22.17)
Stand	-2.01 (-4.02, 0.01)	-1.13 (-3.06, 0.80)	-0.16 (-1.55, 1.24)	-2.43 (-6.88, 2.01)	Dropped	-2.44 (-7.03, 2.15)	7.67 (1.15, 14.20)*	3.85 (-0.43, 8.13)***	6.38 (-6.21, 18.96)
Walk at slow pace <sup>a</sup>	0.43 (-4.03, 4.90)	1.31 (-3.05, 5.67)	2.28 (-1.78, 6.34)	0.01 (-5.90, 5.91)	2.44 (-2.15, 7.03)	Dropped	10.11 (1.37, 18.86)*	6.29 (0.90, 11.68)*	8.81 (-4.45, 22.08)
Walk at average pace <sup>b</sup>	-9.68 (-16.22, -3.14)**	-8.80 (-15.36, -2.24)**	-7.83 (-14.37, -1.29)*	-10.11 (-17.52, -2.70)**	-7.67 (-14.20, -1.15)*	-10.11 (-18.86, -1.37)*	Dropped	-3.82 (-12.20, 4.56)	-1.30 (-15.12, 12.53)
Walk at brisk pace <sup>c</sup>	-5.86 (-10.19, -1.52)**	-4.98 (-9.35, -0.61)*	-4.01 (-8.17, 0.15)	-6.28 (-11.83, -0.73)*	-3.85 (-8.13, 0.43)	-6.29 (-11.68, -0.90)*	3.82 (-4.56, 12.20)	Dropped	2.52 (-10.99, 16.03)
Other activities <sup>d</sup>	-8.38 (-20.97, 4.21)	-7.51 (-20.09, 5.08)	-6.53 (-19.10, 6.03)	-8.81 (-22.17, 4.55)	-6.38 (-18.96, 6.21)	-8.81 (-22.08, 4.45)	1.30 (-12.53, 15.12)	-2.52 (-16.03, 10.99)	Dropped

Values are unstandardized regression coefficients (95% Confidence Interval). Analyses were adjusted for age, sex, weak time, educational level, BMI, smoking, alcohol drinking and chronic conditions. <sup>a</sup>Walk at <2 miles per hour. <sup>b</sup>Walk at 2-2.49 miles per hour. <sup>c</sup>Walk at ≥2.5 miles per hour. <sup>d</sup>Other activities include step up, step down, run and jump. \*p<0.05; \*\*p<0.01; \*\*\*p<0.001.