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Original Study

Reallocating Accelerometer-Assessed Sedentary Time to Light or Moderate- to Vigorous-Intensity Physical Activity Reduces Frailty Levels in Older Adults: An Isotemporal Substitution Approach in the TSHA Study

Asier Mañas MSc [a,b], Borja del Pozo-Cruz PhD [c], Amelia Guadalupe-Grau PhD [b,d], Jorge Marín-Puyalto MSc [e], Ana Alfaro-Acha PhD, MD [b,f], Leocadio Rodríguez-Mañas PhD, MD [b,g], Francisco J. García-García PhD, MD [b,f], Ignacio Ara PhD [a,b,*]

[a] GENUD Toledo Research Group, University of Castilla-La Mancha, Toledo, Castilla-La Mancha, Spain
[b] CIBER of Frailty and Healthy Aging (CIBERFES), Madrid, Comunidad de Madrid, Spain
[c] Department of Exercise Sciences, University of Auckland, Auckland, New Zealand
[d] ImFINE Research Group, Department of Health and Human Performance, Technical University of Madrid, Madrid, Spain
[e] GENUD Research Group, Faculty of Health and Sport Sciences, University of Zaragoza, Huesca, Aragón, Spain
[f] Geriatric Department, Hospital Virgen del Valle, Toledo, Castilla-La Mancha, Spain
[g] Geriatric Department, Hospital Universitario de Getafe, Getafe, Comunidad de Madrid, Spain

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A B S T R A C T

Introduction: The effects of replacing sedentary time with light or moderate- to vigorous-intensity physical activity on frailty are not well known.
Aim: To examine the mutually independent associations of sedentary time (ST), light-intensity physical activity (LPA), and moderate- to vigorous-intensity physical activity (MVPA) with frailty status in older adults.
Methods: A total of 628 people aged ≥65 years from the Toledo Study of Healthy Aging (TSHA) participated in this cross-sectional study. Frailty was measured using the Frailty Trait Scale. Hip-worn accelerometers were used to capture objective measurements of ST, LPA, and MVPA. Linear regression and isotemporal substitution analyses were used to examine associations of ST, LPA, and MVPA with frailty status. Analyses were also stratified by comorbidity.
Results: In single and partition models, LPA and MVPA were negatively associated with frailty. Time in sedentary behavior was not associated with frailty in these models. In the isotemporal substitution models, replacing 30 minutes/d of ST with MVPA was associated with a decrease in frailty [β −2.460; 95% confidence interval (CI): −3.782, −1.139]. In contrast, replacing ST with LPA was not associated with favorable effects on this outcome. However, when the models were stratified by comorbidity, replacing ST with MVPA had the greatest effect on frailty in both the comorbidity (β −2.556; 95% CI: −4.451, −0.661) and the no comorbidity group (β −2.535; 95% CI: −4.343, −0.726). Moreover, the favorable effects of LPA in people with comorbidities was found when replacing 30 minutes/d of ST with LPA (β −0.568; 95% CI: −1.050, −0.086).
Conclusions: Substituting ST with MVPA is associated with theoretical positive effects on frailty. People with comorbidity may also benefit from replacing ST with LPA, which may have important clinical implications in order to decrease the levels of physical frailty.

The authors declare no conflicts of interest.

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* Address correspondence to Ignacio Ara, PhD, GENUD Toledo Research Group, University of Castilla-La Mancha, Avda. Carlos III s/n, Toledo 45071, Spain.
E-mail address: ignacio.ara@uclm.es (I. Ara).

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According to Clegg et al,[1] one of the most problematic manifestations of population ageing is the clinical condition of frailty. In Spain, 1 in 2 people over 65 years are prefrail, and there is a frailty prevalence of 27.3%, the highest of the 10 European countries tested in the study of Santos-Eggimann et al.[2] Frailty is a multifaceted condition that coincides with a decreased functional reserve capacity in different organ systems. Frailty leads to a number of adverse health outcomes, including disability, falls, hospitalization, and death.[1] Frailty syndrome increases the need of medical and social care of patients and, therefore, increases health care–derived costs. Consequently, the prevention and reduction of frailty is one of the most important challenges that public health authorities face in ageing societies.[3]

Lifestyle is considered one of the keystones in the development of frailty,[4] and increasing physical activity (PA) has been suggested as a fundamental strategy to prevent the onset, perpetuation, and progression of this syndrome.[5] According to the World Health Organization,[6] all older adults over 65 years should accumulate at least 150 minutes of moderate-intensity aerobic PA, or at least 75 minutes of vigorous-intensity aerobic PA, or an equivalent combination of both intensities in 10-minute bouts in order to achieve the health-enhancing benefits of physical activity. However, relatively few adults meet the physical activity guidelines, and the odds of doing so drop as a person ages. Older adults are the most inactive age group, spending 8.7 minutes/d for males and 5.4 minutes/d for females in objectively measured moderate- to vigorous-intensity physical activity (MVPA).[7]

The negative consequences of sedentary behavior, characterized by very low energy expenditure (eg, sitting or reclining posture),[8] on health have been recently acknowledged.[9,10] Studies in the United States and Europe report that older adults spend between 60% and 80% of their awake time in sedentary behavior, which represents 8 to 12 hours per day.[11,12] It has been previously suggested that sedentary time (ST) is associated with frailty in the elderly[13–15] independent of MVPA,[16,17] but in recent international research concerning sedentary time it is necessary to include health results relevant to the geriatric population with the quantification of the dose-response relationship.[18]

Recently, light-intensity PA (LPA) has been suggested to improve various health outcomes.[19] LPA may be more appealing and feasible for currently inactive populations. This is relevant among older adults, where MVPA guidelines are generally not met. Previous research has demonstrated that in inactive older adults and older adults with comorbidities (which tend to be less active and more frail), LPA is associated with better cardiometabolic[19,20] and mortality outcomes.[21] Whether LPA may reduce the frailty level among older adults with comorbidities is still unknown.

In addition, the isotemporal substitution approach,[22] which has been recently developed, assumes that activity time in a day is finite and that performing one activity involves substitution for another. Depending on the kind of activity that is replaced, the effects on health may be varied. Despite the recently acknowledged impact of sedentary behaviors,[13,15] the potential benefits of replacing sedentary behaviors with LPA or MVPA on frailty among older adults are largely unknown. A deeper understanding on how ST and PA interact with frailty in older adults is highly relevant to public health professionals for identifying research-informed strategies for prevention and management of frailty in this population group.

Therefore, the aim of this study was to use the isotemporal substitution technique to investigate the displacement effect of replacing ST with LPA and MVPA on frailty status among older adults in the Toledo Study for Healthy Aging (TSHA). We hypothesized that replacing ST with MVPA will produce reductions in frailty in both older adults with and without comorbidities and that LPA will only be beneficial in older adults with comorbidities.

Methods

Study Design and Participants

This cross-sectional investigation used baseline data from the TSHA. The complete methodology of the TSHA has been reported elsewhere.[23,24] Briefly, the TSHA is a population prospective cohort study aimed at studying the determinants and consequences of frailty in institutionalized and community-dwelling individuals older than 65 years living in the province of Toledo, Spain. Data were collected in 3 stages. In the first stage, 6 psychologists conducted computer-assisted interviews face-to-face with potential subjects. In the second stage, 3 nurses performed a physical examination followed by clinical and performance tests at the subject's home. In the third stage, the participants went to their health center to provide a blood sample while fasting. At this stage, participants were invited to wear an accelerometer for a week. Only those who agreed to and wore the accelerometer were included in the study (n = 628). Data were collected from July 2012 until June 2014. Signed informed consent was obtained from all participants. The study was approved by the Clinical Research Ethics Committee of the Toledo Hospital.

Measurements

Frailty status

The Frailty Trait Scale (FTS)[25] was used to assess frailty in this study. The FTS includes 7 aspects: energy balance and nutrition, activity, nervous system, vascular system, weakness, endurance, and slowness. These domains become operational through 12 items. Each item score represents a biological trait. Each item ranges from 0 (the best) to 4 (the worst) except in the "chair test" where the range is from 0 to 5 points because of the necessity of scoring those unable to stand a single time. When appropriate, items are analyzed according to the item's quintile distribution in the population.

To be included in the study, the participants had to overcome at least 75% (9 of the 12) of the items included in the FTS. The total score was calculated by adding all the scores in each item divided by total score for each individual and multiplying by 100, standardizing the measure to a range from 0 (best score) to 100 (worst score), according to the formula Total score = (Σ items score/total score possible by individual) × 100.

Physical activity and sedentary behavior assessment

Physical activity and sedentary behavior were objectively assessed by accelerometry (ActiTrainer; ActiGraph, LLC, Fort Walton Beach, FL). All participants were instructed how to wear an accelerometer on the left hip during waking hours. Participants wore the accelerometer for 7 consecutive days and removed it during any bathing or swimming activities. The ActiTrainer device was initialized to collect data using 1-minute epochs. Nonwear time was defined as periods of at least 60 consecutive minutes of zero counts, with allowance for 2 minutes of counts between zero and 100.[26] The study included the results from participants with at least 4 valid days with at least 480 minutes (8 hours) of wear time without excessive counts (ie, >20,000 counts). Accelerometer counts were used to derive the time spent in each intensity band: sedentary behavior (<100 counts/min), light-intensity physical activity (100-1951 counts/min), and moderate- to vigorous-intensity physical activity (≥1952 counts/min).[27] Although there is a lack of consensus on the use of cut-off points to classify the intensity of the activity, the cut-off points used in this study are the most commonly reported in this population group[28]; this makes our results comparable to other studies. Minutes spent in each of these 3 behaviors were tallied per day and averaged over all available valid days, expressed as proportions of 24 hours.

Table 1
Comparison of Characteristics in Those Included and Excluded by Accelerometry From the Study

	Included Sample (n = 519)	Excluded Sample (n = 65)	*P* Value
Age, y	78.8 (4.6)	79.0 (4.7)	.847
Sex, n (%)			.311
Male	234 (45.1)	27 (41.5)	
Female	285 (54.9)	38 (58.5)	
BMI	30.5 (4.7)	31.1 (5.1)	.419
WHR	0.90 (0.11)	0.90 (0.08)	.991
Whole body fat mass (%)	36.7 (7.5)	38.0 (6.6)	.216
Whole body lean mass (kg)	43.79 (8.23)	43.17 (7.68)	.560
Education, n (%)			.379
None	213 (41.0)	31 (47.7)	
Lower than primary	215 (41.4)	26 (40.0)	
Completed primary or more	90 (17.3)	8 (12.3)	
Number of drugs	5.1 (2.9)	4.8 (2.6)	.481
FTS (0-100)	37.81 (14.17)	41.45 (14.10)	.438
SPPB score	8.44 (2.26)	8.40 (2.47)	.640
MMSE score	23.02 (4.40)	22.83 (3.98)	.756
Charlson Index	1.13 (1.56)	0.80 (1.25)	.118
Comorbidity status, n (%)			.217
With comorbidity	272 (52.6)	36 (55.4)	
Without comorbidity	245 (47.4)	29 (44.6)	
Accelerometry			
Valid minutes per valid day of wear time, min	780.71 (84.68)	—	
SB, %	69.48 (11.52)	—	
LPA, %	28.30 (10.66)	—	
MVPA, %	2.21 (2.68)	—	
Meet WHO Guidelines, n (%)			
No	362 (70.4)	—	
Yes	152 (29.6)	—	

BMI, body mass index; MMSE, Mini-Mental State Examination; WHO, World Health Organization; WHR, waist-to-hip ratio.
Values are means (SD), unless otherwise indicated.

Anthropometrics and confounding variables

Participants self-reported their age, sex, ethnicity, and educational status. Height and weight were measured using standard procedures. Body mass index was then calculated as weight (in kilograms) divided by height-squared (in meters). Waist and hip circumference were measured using standard procedures.[29] Waist-to-hip ratio was then calculated by dividing waist circumference (cm) by hip circumference (cm).

The Charlson Comorbidity Index was used to account for comorbidity status of participants in the study.[30] Diseases included in this Index and their weighting are myocardial infarction, congestive heart failure, peripheral vascular disease, dementia, cerebrovascular disease, chronic lung disease, connective tissue disease, ulcer, chronic liver disease, diabetes (weight 1); hemiplegia, moderate or severe kidney disease, diabetes with complication, tumor, leukemia, lymphoma (weight 2); moderate or severe liver disease (weight 3); metastatic solid tumor, and AIDS (weight 6). We also assessed objective cognitive function using the Mini-Mental State Examination.[31] Finally, the number of prescription and nonprescription drugs within the Anatomical Therapeutic Chemical (ATC) Classification System taken by the participant was calculated.[32]

The Short Physical Performance Battery (SPPB) was used to assess physical function in this study.[33] The SPPB measures gait speed (8-foot walk), standing balance, and lower extremity strength and endurance (chair rise task). The tests were performed and scored as described in the original protocol.[33]

Statistical Analysis

All analyses were performed using the statistical software SPSS, version 24.0 (IBM Corp, Armonk, NY). Mean (standard deviation) and frequency (percentage) were provided for continuous and categorical variables, respectively. Descriptive variables were compared between included and excluded participants with an independent *t* test or chi-square test for continuous and categorical variables, respectively. Linear regression models were used to examine associations between time spent (minutes/d) in sedentary behavior, LPA, and MVPA with the score in the FTS. Models were adjusted for prespecified covariates hypothesized to be independently associated with both exposure and outcome variables, including sex, age, educational status, polypharmacy status, functional fitness (SPPB), waist-to-hip ratio, comorbidity status (Charlson Index), and cognitive function (Mini-Mental State Examination). Variance inflation factor was calculated to quantify the severity of multicollinearity in the regression analyses. All variance inflation factors were below 10. The Condition Number and Durbin-Watson statistic were also analyzed. When performing subgroup analysis by comorbidity status, the Charlson Index was removed from the covariates. Subjects without comorbidity were those who scored 0 and subjects with comorbidity scored 1 or higher on the Charlson Index. Three different linear regression models were used.[34] The first set of models are single-factor, examining the association of each intensity category (ST, LPA, and MVPA) with frailty status without mutual adjustment for other activity categories. The second are partition models examining the association of each intensity category while controlling for each of the other categories of activity. The third are isotemporal substitution models that represent the estimated effects of substituting ST with an equal amount of time spent in LPA or in MVPA. In this model, ST was excluded whereas total wear time was kept constant in the equation.[22] For ease of interpretation, 30-minute

Table 2
Single Behavior, Partition, and Isotemporal Substitution Models for Frailty (FTS) in Elderly People (n = 519)

Model	Regression Coefficient (95% CI), R^2		
	SB	LPA	MVPA
Single behaviors (models 1-3)	0.006 (−0.004, 0.016), *0.461*	**−0.014 (−0.024, −0.004)**, *0.468***	**−0.094 (−0.136, −0.052)**, *0.481***
Partition behaviors (models 4-6)	−0.004 (−0.017, 0.08), *0.486*	**−0.012 (−0.025, 0.000)*, *0.486***	**−0.086 (−0.129, −0.043)**, *0.486***
Isotemporal substitution[a]			
Replace SB (models 7 and 8)	Dropped	−0.237 (−0.573, 0.099), *0.486*	**−2.460 (−3.782, −1.139)**, *0.486***

Bold indicates statistical significance (*$P < .05$, **$P < .01$). Italics indicates R^2 of the model.
Covariates for models included sex, age, educational status, number of drugs, functional fitness (SPPB), waist-to-hip ratio, comorbidity status (Charlson Index), and cognitive function (Mini-Mental State Examination).
For model 1, SB and covariates were entered in the model.
For model 2, LPA and covariates were entered in the model.
For model 3, MVPA and covariates were entered in the model.
For models 4, 5, and 6, SB, LPA, MVPA, and covariates were entered in the model.
For models 7 and 8, LPA, MVPA, and covariates (plus total behavior time) were entered in the model (sedentary behavior dropped).
[a]Prior to the regression models, all behavior variables were divided by a constant of 30 so that unit increase in the behavior represented an increase of 30 minutes/d within the given behavior.

units were chosen as time units for each behavior. These models assume linear relationships between dependent and independent variables, which were determined prior to performing these analyses.

Results

From the initial sample (n = 628), data from 519 participants (male, 45.1%; mean age 78.8 ± 4.6 years) were included in the analysis. Exclusion criteria were missing frailty data (n = 27) or covariates (n = 17), and insufficient accelerometer wear time data (n = 65). Descriptive variables between those who were included in the analyses versus those who were excluded because of insufficient accelerometer wear time are presented in Table 1. Compared with the included sample, excluded participants were not different in any outcome. For the included sample, participants spent 17.6 minutes per day of the wear time in MVPA and 224 minutes in LPA on average. Sedentary time accounted for 69.5% of the wear time (ie, 540.0 ± 93.9 minutes).

Table 2 presents single, partition, and isotemporal substitution models for the associations between specific activity categories and frailty status after the adjustment for potential confounders.

In single and partition models, LPA and MVPA showed an inverse relationship with the frailty score, but no association was found between ST and frailty. In isotemporal substitution models, replacing 30 minutes/d of ST with 30 minutes of MVPA was associated with a decrease in the frailty score [β −2.460; 95% confidence interval (CI): −3.782, −1.139]. However, replacing ST with LPA was not associated with changes in the frailty score.

Table 3 displays the results of the single, partition, and isotemporal substitution models for ST, LPA, and MVPA on frailty status divided by comorbidity status. In people without comorbidity, only MVPA was associated with a decrease in the frailty score, as shown by the single and partition models. However, for people with comorbidity LPA showed an inverse relationship with the frailty score, in addition to MVPA. Associations were also observed between increased sedentary time and increased frailty status in the single model in people with comorbidity.

Reallocating 30 minutes/d of ST to 30 minutes of LPA or MVPA in people with comorbidity resulted in an estimated reduction in the FTS (adjusted β −0.568; 95% CI: −1.050, −0.086; adjusted β −2.556; 95% CI: −4.451, −0.661, respectively). Similarly, replacing 30 minutes/d of ST with 30 minutes of MVPA showed a decrease in the frailty score (adjusted β −2.535; 95% CI: −4.343, −0.726) in people without comorbidity. However, in people categorized as being without comorbidities, the reallocation of 30 minutes/d of ST to 30 minutes of LPA was not associated with significant changes in the frailty score.

Discussion

This study aimed to investigate the relationship between physical activity, sedentary behavior, and frailty. We first assessed the association between these factors using a classical approach, then using a theoretical model, to examine how the displacement of activity of different intensities is associated with changes in the frailty score using isotemporal substitution modeling. Our results estimate that replacing 30 minutes of ST with an equivalent amount of MVPA is associated with a more theoretically favorable frailty status in older adults, regardless of comorbidity or physical function status. Equal time-exchange of ST with LPA is predicted to reduce frailty but only in older adults with comorbidity (52.6% in our subsample). In addition, the modeled relationships also suggest potential benefits of LPA in those with comorbid conditions, which may be a more feasible and less challenging approach than more strenuous activity.

In our study, we found that replacing sitting time with MVPA resulted in reductions in the Frailty Trait Scale. This is consistent with

Table 3
Single Behavior, Partition, and Isotemporal Substitution Models for Frailty (FTS) Subdivided by Comorbidity (Charlson Index) in Elderly People (n = 519)

Model	Regression Coefficient (95% CI), R^2					
	SB		LPA		MVPA	
Comorbidity Level	Without Comorbidity	With Comorbidity	Without Comorbidity	With Comorbidity	Without Comorbidity	With Comorbidity
Single Behaviors (Models 1-3)	−0.003 (−0.016 to 0.010), *0.484*	**0.017 (0.002 to 0.031)*, *0.442***	−0.003 (−0.018 to 0.011), *0.484*	**−0.023 (−0.037 to −0.009)**, *0.455***	**−0.091 (−0.148 to −0.034)**, *0.507***	**−0.103 (−0.165 to −0.042)**, *0.456***
Partition Behaviors (Models 4-6)	−0.007 (−0.023 to 0.009), *0.509*	0.000 (−0.018 to 0.019), *0.472*	−0.004 (−0.021 to 0.014), *0.509*	**−0.019 (−0.036 to −0.001)*, *0.472***	**−0.092 (−0.150 to −0.034)**, *0.509***	**−0.085 (−0.148 to −0.022)**, *0.472***
Isotemporal substitution[a]						
Replace SB (models 7 and 8)	Dropped	Dropped	0.105 (−0.361 to 0.570), *0.509*	**−0.568 (−1.050 to −0.086)*, *0.472***	**−2.535 (−4.343 to −0.726)**, *0.509***	**−2.556 (−4.451 to −0.661)**, *0.472***

Bold indicates statistically significant (*$P < .05$, **$P < .01$). Italics indicates R^2 of the model.
Covariates for models included sex, age, educational status, number of drugs, waist-to-hip ratio, functional fitness (SPPB), and cognitive function (MMSE).
For model 1, SB and covariates were entered in the model.
For model 2, LPA and covariates were entered in the model.
For model 3, MVPA and covariates were entered in the model.
For models 4, 5, and 6, SB, LPA, MVPA, and covariates were entered in the model.
For models 7 and 8, LPA, MVPA, and covariates (plus total behavior time) were entered in the model (sedentary behavior dropped).
[a]Prior to the regression models, all behavior variables were divided by a constant of 30 so that unit increase in the behavior represented an increase of 30 minutes/d within the given behavior.

previous findings where MVPA was associated with frailty even after controlling for ST.[16] MVPA is well known to affect cognitive and physical outcomes, all known to impact frailty. Supporting our results are the findings of Song et al[17] and Peterson et al,[35] which show evidence that ST negatively impacts frailty in older adults. Likewise, Fanning et al[36] only found an improvement in self-regulatory behavior and executive functioning when 30 minutes of ST was replaced by 30 minutes of MVPA time.

We have found in single and partition models that LPA has a role on frailty. Some authors have found a positive relationship between LPA and different outcomes regarding frailty, whereas others have not. Elkins[37] showed that daily time spent in LPA is associated with lower risk of onset and progression of disability whereas Lee et al[38] found a positive effect of LPA in cognitive status. Jantunen et al[39] also showed that LPA was positively associated with better physical performance. However, Pau et al[40] found that LPA is not the most adequate intensity to improve daily static and dynamic motor tasks.

As a novelty, our grouping analysis shows that only in people reporting comorbidities did LPA bring benefits in terms of frailty. Other studies have shown the beneficial effects of LPA in the isotemporal substitution analyses. Ekblom-Bak et al[41] showed significant lower metabolic syndrome prevalence by replacing 10 minutes of ST with the same amount of LPA. Similarly, Fishman et al[42] and Schmid et al[43] found that replacing 30 minutes of ST with LPA was associated with significant reduction in mortality risk. Our findings show that in frail individuals, with low fitness even minimal movement can positively impact health.[44] But when a certain fitness level is reached, more strenuous activity is needed to elicit more beneficial results.

Despite requiring between 4 to 5 times more LPA to elicit the same changes in frailty compared with MVPA, according to our estimates, the benefits of LPA for improving frailty status in those with comorbidities is of relevance from a public health perspective as might be a population, of those with comorbidities, that cannot or do not find opportunities to (frail older adults spend 84.9% of their daily time in sedentary behaviors[45]) become engaged in MVPA successfully. Thus, replacing ST (eg, television viewing, sitting) with LPA (eg, leisure walking, active transport) may be a more feasible strategy to reduce the risk of frailty in older adults with additional disease. Future longitudinal experimental studies should confirm these results.

This study has several strengths and limitations. The sample includes a relatively large number of community-dwelling older adults with objectively assessed frailty and physical activity. However, when comparing the full cohort with the included sample, there were differences in most outcomes used in this study, so caution should be exercised when interpreting the results. Although there is no established gold standard to identify frailty, the Frailty Trait Scale, derived from the classical model proposed by Fried et al[46] in combination with the positive aspects of the Frailty Index of Rockwood et al,[47] has been suggested as a more sensitive scale for detecting changes in the individual's biological status.[25] The validity of this scale was evaluated by assessing its association with comorbidities, biomarkers associated with frailty status, and by comparing its predictive value for adverse events with the 2 most frequently used frailty scales: Frailty Phenotype[46] and the Frailty Index.[47] Although accelerometry has some advantages over questionnaires and other self-report methods,[48] it is not exempt from error. Waist-worn accelerometers are not able to detect differences between sitting and standing positions, and therefore the measurement of ST can be overestimated. In addition, the cut-off points used in this study and the algorithm chosen to discard zero-value periods can affect the amount of different physical activity intensity ranges and sedentary behavior.

Causal inferences are limited towing to the cross-sectional nature of the study. Moreover, isotemporal substitution models represent a mathematical way of replacing one behavior with another, so the results should be interpreted with caution. There is therefore a need for more experimental research in this area, especially in the clinical setting, in order to better understand the impact of replacing ST with activity of different intensities on frailty status among older adults. Another limitation of the study may be the nonmeasurement of sleep, an important behavior that may affect the associations found in this study.

Conclusions

In conclusion, this study demonstrates that replacing 30 minutes/d of sedentary behavior with the same amount of MVPA could bring benefits in terms of frailty status among older adults. Participants with comorbidities may also benefit from the substitution of ST by LPA. From a public health perspective, this is an important message in order to improve frailty status through increasing LPA, which a priori seems to be a more feasible approach as opposed to increasing MVPA in this population group. Future research should move beyond this hypothetical, observational evidence and identify more-robust indication of the frailty outcomes of experimentally reallocating time spent in sedentary behaviors with physical activities of different intensities.[49]

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