ORIGINAL ARTICLE

WILEY

Sedentary behavior, physical activity, and mental health in older adults: An isotemporal substitution model

Mark A. Tully[1] | Ilona McMullan[2] | Nicole E. Blackburn[3] | Jason J. Wilson[2] | Brendan Bunting[4] | Lee Smith[5] | Frank Kee[6] | Manuela Deidda[7] | Maria Giné-Garriga[8,9] | Laura Coll-Planas[10] | Dhayana Dallmeier[11,12] | Michael Denkinger[11] | Dietrich Rothenbacher[13] | Paolo Caserotti[14]

[1]School of Health Sciences, Institute of Mental Health Sciences, Ulster University, Newtownabbey, UK

[2]School of Health Sciences, Ulster University, Newtownabbey, UK

[3]School of Health Sciences, Institute of Nursing and Health Research, Centre for Health and Rehabilitation Technologies, Ulster University, Newtownabbey, UK

[4]School of Psychology, Ulster University, Newtownabbey, UK

[5]The Cambridge Centre for Sport and Exercise Sciences, Anglia Ruskin University, Cambridge, UK

[6]Centre for Public Health, School of Medicine, Dentistry and Biomedical Science, Queen's University Belfast, Belfast, UK

[7]Health Economics & Health Technology Assessment, Institute of Health & Wellbeing, University of Glasgow, Glasgow, UK

[8]Department of Sport Sciences, Faculty of Psychology, Education and Sport Sciences Blanquerna, Universitat Ramon Llull, Barcelona, Spain

[9]Department of Physical Therapy, Faculty of Health Sciences Blanquerna, Universitat Ramon Llull, Barcelona, Spain

[10]Fundació Salut i Envelliment, Universitat Autònoma de Barcelona, Barcelona, Spain

[11]Geriatric Centre Ulm/Alb-Donau, AGAPLESION Bethesda Clinic Ulm, Geriatric Research Unit Ulm University, Ulm, Germany

[12]Dept. of Epidemiology, Boston University School of Public Health, Boston, MA, USA

[13]Institute of Epidemiology and Medical Biometry, Ulm University, Ulm, Germany

[14]Department of Sports Science and Clinical Biomechanics, Center for Active and Healthy Ageing (CAHA), University of Southern Denmark, Odense, Denmark

Correspondence
Mark A. Tully, School of Health Sciences, Institute of Mental Health Sciences, Ulster University, Shore Road, Newtownabbey, Co Antrim BT37 0QB, UK.
Email: m.tully@ulster.ac.uk

Introduction: Regular moderate-to-vigorous physical activity (MVPA) is associated with improved mental health, but the evidence for the effect of reducing sedentary behavior (SB) or increasing light PA (LPA) in older adults is lacking. Using isotemporal substitution (IS) models, the aim of this paper was to investigate the effect of substituting SB with LPA or MVPA on associations with mental health in older adults.

Methods: Data from 1360 older adults (mean age 75.18 years) in four countries were utilized. PA and SB was measured using ActiGraph wGT3X-BT + accelerometers worn for 7 days. Self-rated mental health was measured using the Hospital and Anxiety Depression Scale (HADS). IS models estimated cross-sectional associations when 30 minutes of one behavior was substituted with another. Models were adjusted for age, sex, marital status, and educational attainment.

Results: Substituting 30 minutes of SB with LPA (β −.37; 95% CI −0.42, −0.32) or MVPA (β −.14; 95% CI −0.21, −0.07) and substituting LPA with MVPA (β −.11; 95% CI −0.18, −0.04) were associated with improvements in anxiety. However, substituting 30 minutes of SB with LPA (β .55; 95% CI 0.49, 0.62) was associated with increased depression.

Conclusion: Replacing 30 minutes of SB with LPA or MVPA was associated with improved anxiety symptoms in older adults. Greater benefits were observed when shifting SB and LPA to MVPA.

KEYWORDS

isotemporal, light physical activity, mental health, moderate-vigorous physical activity, older adults

1 | INTRODUCTION

Regular physical activity is associated with a wide range of health benefits for older adults.[1,2] There is considerable previous evidence demonstrating an association between moderate-to-vigorous intensity physical activity (MVPA) and mental health, including reduced levels of anxiety and depression.[3,4] A systematic review of 12 prospective studies including 128,553 participants reported a significant positive association between SB and the risk of depression.[5] Evidence is accumulating that demonstrates an association between both sedentary behavior (SB) and light-intensity physical activity (LPA) with mental health,[6,7] though the evidence is inconsistent.[8] In addition, there is a lack of research on the relationship between physical activity and mental health in older adults.[1]

Levels of physical activity decline with age,[9,10] meaning that older adults spend 79% of their waking day in SB,[9,10] defined as any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents (METs), while in a sitting, reclining, or lying posture.[11] The rest of their day is spent either in LPA, MVPA, or sleeping. With current evidence supporting a dose response relationship between physical activity and health, current public health recommendations encourage people to "sit less and move more."[12,13] However, less evidence exists as to the specific benefits of substituting SB with either LPA or MVPA on mental health, or indeed the volume of substituted activity that may be confer these benefits.[14] This may be in part due to the financial and time costs of conducting randomized controlled trials. Previous studies of the association between health outcomes and SB have generally adjusted for minutes of MVPA of participants, without consideration LPA or of the how changes in MVPA impact on the time spent in other behaviors.[15]

The isotemporal substitution (IS) approach as suggested by Mekary et al's[16] simultaneously model the replacement of one activity for another and so has the potential to show the effects of substituting SB for physical activity such as LPA or MVPA and therefore are useful for modeling this.[17] A recent review of IS studies has demonstrated that the majority of evidence relates to substituting SB with MVPA, resulting in potential benefits to mortality, general health, mental health, adiposity, fitness, and cardiometabolic biomarkers.[18] In a study of 32 900 US women from the Nurses' Health Study, Mekary et al[16] concluded that reallocating time spent watching TV to brisk walking was associated with a significantly lower risk of depression. However, this was not shown for the reallocation of time spent watching TV to slow walking. Rethorst et al[19] demonstrated that replacing SB with vigorous intensity activity, but not LPA or moderate intensity activity, was significantly associated with a decrease in depressive symptoms in a cohort of 16 415 Hispanic/Latino men and women, aged 18-74 years. In contrast, Curtis et al did not find an association between substituting SB with either LPA or MVPA and symptoms of depression, anxiety, or stress.[20]

There has been a lot less research investigating the association between reallocating SB time with physical activity on depression and anxiety in older adults. Del Pozo Cruz et al[21] have demonstrated that reallocating 60 minutes from SB to MVPA was associated with small reductions in depressive symptoms in a sample of 3233 adults and older adults from the USA. Similarly, Dillon et al observed and an association between a reallocation of 30 minutes of SB to LPA and decreased anxiety symptoms but not depression in 396 adults aged 50-69.[22] No statistically significant associations with depressive symptoms were observed when sedentary behavior was substituted with either LPA or MVPA. In a study of 276 older adults, Yasunaga et al[23] concluded that replacing 30 minutes of SB with the same amount of LPA is statistically negatively associated with depression measured using the geriatric depression scale in a study of 276 Japanese older adults aged 65-85 years. However, data from European countries are lacking.

On average, older adults only spend 3% of their waking day in MVPA.[9,10] Health-related barriers, such as frailty, are the main reasons given by older adults for not undertaking

MVPA, but they also report other barriers such as habits, caring duties, low motivation, and misperceptions of physical activity and ageing.[24] Therefore, for inactive older adults, targeting substituting SB with LPA may be a more feasible, attractive, or realistic behavior change to target in the first instance. However, a lack of studies using IS models to explore the benefits of substituting SB with LPA on mental health in older adults has been identified.[18]

Given both the lack of research investigating the relationship between substituting SB for LPA and mental health in older adults, and the potential attractiveness of LPA for older adults, there is a need for research to examine these areas.

Using a larger sample of older adults than in the previous study of older adults, drawn from four different countries, the aim of this paper was to investigate the associations between Actigraph measured SB, LPA, and MVPA with mental health, anxiety, and depression. This was done by exploring the effect of substituting SB with LPA or MVPA on associations with mental health in older adults using an isotemporal approach.

2 | MATERIALS AND METHODS

2.1 | Participants

This cross-sectional analysis is based on baseline data available from the SITLESS study, which is a prospective trial of community-dwelling men and women aged ≥65 years from Denmark, Spain, Germany, and Northern Ireland.[25] Participants were eligible if they were able to walk for ≥2 minutes (with or without a walking aid), scored four or above on the Short Physical Performance Battery (SPPB), reported undertaking regular MVPA ≤30 minutes on 5 days per week, and/or spend 6-8 hours per day sitting (eg, watching TV or working at the computer). Participants were excluded if they had three or more errors on a six-item cognitive impairment questionnaire to identify moderate or severe dementia, had a medical condition that contraindicated to undertaking an exercise intervention such as unstable medical conditions (eg, uncontrolled hypertension), could not commit to attend 75% of the intervention exercise sessions, and/or had participated in an exercise program in the six months prior to their entry into the study. A total of 2660 older adults were recruited across the four countries via media (letters and social media), general practitioners, and other health professionals from primary care, and senior center community groups. Of those, 45.15% did not participate in the study (27.3% of those were excluded based on eligibility assessment). A total of 1360 older adults provided baseline data. Further details can be found in the study protocol.[25] SITLESS has been approved by the Ethics and Research Committee of each intervention site: The Ethics and Research Committee of Ramon Llull

University (Spain), The Regional Committees on Health Research Ethics for Southern Denmark (Denmark), Office for Research Ethics Committees in Northern Ireland (Northern Ireland), and the Ethical Review Board of Ulm University (Germany). Participation was voluntary, and all participants provided informed consent before the start of the study.

2.2 | Outcome measures

2.2.1 | Physical activity and sedentary behavior

At baseline, all participants were asked to wear an accelerometer (ActiGraph wGT3X-BT+; ActiGraph, LLC, Pensacola, FL) on their dominant hip during waking hours for seven consecutive days and were told to remove them during any water-based activities such as bathing or swimming, and during sleep time. The devices were initialized to collect data at 30 hz, analyzed using ActiLife v6.13.3 software with normal filter, and summarized using 10-second epochs. Non-wear time was defined using the Choi algorithm[26] which uses a 2-window system, a 90-minute window for checking for consecutive zero counts, and another 30-minute up- and down-stream window for checking for more than 2 minutes of non-zero counts.[26] The study included the results from participants with at least four valid days including at least one weekend day.[27] Furthermore, to be included, each day had to include at least 600 minutes (10 h/d) of wear time as in previous studies.[27] Activity counts, accelerations due to body movement, were classified using set of cutpoints to calculate the amount and intensity of SB and physical activity.[27] SB was classified as <100 counts per minute (CPM), daily LPA was 100-2019 CPM, and daily MVPA was >2020 CPM. Values are the average daily time spent in SB, LPA, and MVPA.[28]

2.2.2 | Mental health

Self-rated mental health was measured using the Hospital and Anxiety Depression Scale (HADS)[29] is a self-reported questionnaire consisting of 14 items split across anxiety and depression. A high score indicates high psychological distress.

2.3 | Statistical analysis

We investigated the hypothesis that replacing SB with physical activity (LPA or MVPA) results in improvements in HADS anxiety and HADS depression scores. All analyses were carried out in Mplus (version 7.4; Muthen & Muthen, Los Angeles, CA). A robust form of weighted least

squares (WLSMV) was used to correct for non-normaility. WLSMV was used to optimize the relationship between the dichotomous variable and the latent construct as this makes the relationship between the factor(s) and the observed variable non-linear, with a Probit link function. A model-based estimation strategy involves using the fit indices to understand how well the model describes the data and missing data is based on the entire data set including observations with missing data. Missing data were assumed to be missing at[30] random and a robust WLSMV approach uses a model-based estimation strategy to address missing data.[31]

To address the inconsistency between studies regarding the dimensionality of the HADS depression and HADS anxiety subscales,[32] a bifactor model including all items loaded onto a general distress factor (GD), an anxiety (HA), and a depression (HD) factor as outlined by Norton et al[33] was used (Figure 1). Model fit was evaluated using a root mean square error of approximation (RMSEA) ≤ 0.05 with an upper limit (90% CI) ≤ 0.08; a comparative fit index (CFI) ≥ 0.95; a Tucker Lewis index (TLI) ≥ 0.95; and a standardized root mean square residual (SRMR) ≤ 0.05.[34,35] Where the levels of fit indices were not achieved, the modification indices were examined, and where appropriate, the necessary adjustments were made.

Following this, three multiple linear regression models comprising single-activity, partition, and IS models were conducted to examine the association between SB, LPA, and MVPA with both HADS anxiety and HADS depression. SB and physical activity (LPA and MVPA) were standardized using 30 minutes as a unit for activity in analyses. Research suggests that 30 minutes rather than 60 minutes of LPA or MVPA is more feasible for older adults,[36,37] so IS models assessed the effect of replacing 30 minutes of one form of activity with the equal time of another.

Since the total hours in a day are fixed, SB, LPA, and MVPA are inter-related where increasing one results in the reduction in another. These substitutional relationships need to be considered when considering how a particular activity is associated with health outcomes. The IS approach enables researchers to simultaneously model a specific activity being performed and an activity being displaced in an equal time-exchange manner. The single-activity model analyzes SB, LPA, and MVPA separately without considering the other activity types, adjusting for total wear time and covariates. The partition model analyzes SB, LPA, and MVPA simultaneously, without adjusting for total wear time. The coefficient for one type of activity represents the effect of increasing this type of activity while holding the other activities constant in this model. The model represents the effects of adding rather than substituting an activity type, because the total wear time is not included in the model (thus is not held constant). The IS model assesses the effect of substituting one activity with another for the equal amount of time (eg, replacing LPA with SB, by removing SB from the model). It should be noted that as this data are cross-sectional, the observed effects of substitution are not temporal.

The *single-activity model* assessed the association between SB, LPA, or MVPA and mental health separately, adjusting for accelerometer wear time and other covariates that are known to be associated with both activity and mental health (age, sex, marital status, educational attainment, physical health component of the 12-item Short Form Health (SF-12) questionnaire[38]).

Following this, *partition models* were prepared, whereby the coefficient for one activity type is the effect of increasing that activity type while holding all others constant. The model represents the effects of adding, not substituting a
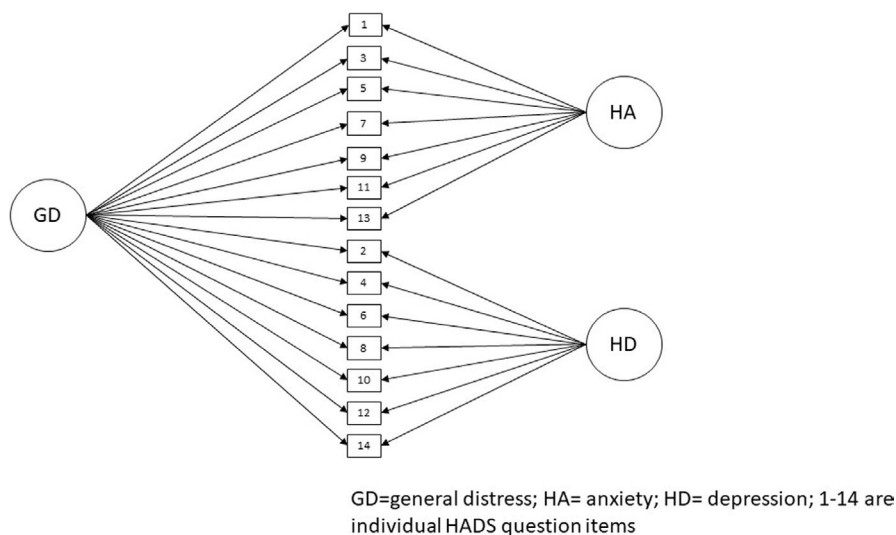

GD=general distress; HA= anxiety; HD= depression; 1-14 are individual HADS question items

FIGURE 1 HADS bifactor model.[33] GD, general distress; HA, anxiety; HD, depression; HADS, Hospital and Anxiety Depression Scale; 1-14 are individual HADS question items

particular activity type because total wear time is excluded in this model and so is not held constant.

Finally, in *IS models* with total wear time included, one of the activities is eliminated from the model to ascertain the effect of replacing 30 minutes of one activity with 30 minutes of another activity.

3 | RESULTS

As displayed in Table 1, of the included participants (n = 1360), 62% were female and the mean age was 75 (6.3) years. Participants showed on average low levels of anxiety and depression and good mental and physical health compared to normative values.[38,39]

TABLE 1 Characteristics of study participants

	n or Mean (SD), %	
Sex		
Male	520	38.2%
Female	840	61.8%
Age (y)	75.18 (6.17)	
Marital status		
Married	690	50.6%
Single (including widowed, divorced, separated)	618	45.4%
Education attainment		
Primary education	320	24.0%
Secondary education	712	53.3%
University	303	22.7%
Country of residence		
Denmark	338	24.9%
Germany	345	25.4%
Spain	356	26.2%
Northern Ireland	321	23.6%
Total accelerometer wear time per day (30 min/d)	28.74 (2.33)	
SB per day (30 min/d)	22.62 (2.52)	
LPA per day (30 min/d)	5.36 (1.76)	
MVPA per day (30 min/d)	0.76 (0.66)	
SF12-physical score	44.96 (9.10)	
HADS anxiety score	4.96 (3.65)	
HADS depression score	4.05 (3.29)	

Note: In this table, a high score on HADS indicates good mental health, and a high score on SF-12 indicates good physical health. Columns may not sum up to total of 1,360 participants because of missing data in some variables.

Abbreviations: HADS Anxiety, Depression, 19 items; LPA, light-intensity physical activity; MVPA, moderate-vigorous intensity behavior; SB, sedentary behavior; SF12-Physical health component, 12 items.

For HADS anxiety, in both single and partition models, higher SB, LPA, and MVPA levels were associated with lower scores on HADS anxiety scale which in this model indicates lower symptoms of anxiety (Table 2). Replacing 30 minutes of SB with LPA or MVPA in the IS model was associated with significant improvements in anxiety, with apparently greater dividends from replacing SB with LPA (−0.37) than MVPA (−0.14). In addition, replacing 30 minutes of LPA with MVPA results in significant improvements in anxiety symptoms (Table 2).

The single model analyses showed that higher levels of both SB and MVPA were associated with higher scores on HADS depression scale which in this model indicates higher symptoms of depression (Table 3). In contrast, a higher level of LPA was associated with a lower depression score. In the partition model, higher levels of SB and LPA were associated with higher levels of symptoms of depression (Table 3). In the IS model, replacing 30 minutes of SB with LPA (0.55), replacing 30 minutes of LPA with SB (0.58), or replacing 30 minutes of MVPA with either SB (0.38) or LPA (0.28) was associated with increased depression (Table 3).

4 | DISCUSSION

This study including 1360 older adults from four European countries aimed to investigate the effect of substituting SB with LPA or MVPA on associations with mental health in older adults using an IS approach. Our results demonstrate that in this cross-European cohort of older adults, substituting 30 minutes of either SB or LPA with MVPA was associated with improved symptoms of anxiety. In addition, replacing 30 minutes of SB with LPA was associated with improved anxiety scores. The findings for symptoms of depression were inconsistent across the single, partition and IS modeled. For example, the single model demonstrated that a more time spent in SB was associated with higher depression scores, but replacing SB with LPA was also associated with a significantly higher depression score.

For anxiety, the largest effect size was seen when substituting 30 minutes of SB with LPA (β −.37), which was over two and a half times that of substituting 30 minutes of SB with MVPA (β −.14) and over three times that of substituting 30 minutes of LPA with MVPA (β −.11). To achieve the same effect size as substituting 30 minutes of SB with LPA would require substituting 79 minutes of SB or 101 minutes of LPA, respectively. The β value represents the effect of substituting 30 minutes of one type of PA for another on the latent construct of HADS, which in our model is scored from 1 to 4. So for example, by reducing SB by 30 minutes and replacing it with LPA, the effect on HADS anxiety will be a decrease of 0.37, indicating better mental health. Consequently,

TABLE 2 The associations of SB, LPA, and MVPA with HADS anxiety score

	SB		LPA		MVPA	
	β	95% CI	β	95% CI	β	95% CI
Single-activity model	*−.44	(−0.48, −0.39)	*−.39	(−0.44, −0.34)	*−.27	(−0.34, −0.19)
Partition model	*−.33	(−0.39, −0.26)	*−.16	(−0.22, −0.09)	*−.23	(−0.29, −0.17)
Isotemporal model						
Replace SB with	Dropped		*−.37	(−0.42, −0.32)	*−.14	(−0.21, −0.07)
Replace LPA with	*−.42	(−0.47, −0.37)	Dropped		*−.11	(−0.18, −0.04)
Replace MVPA with	*−.33	(−0.39, −0.26)	*−.16	(−0.22, −0.09)	Dropped	

Note: All models adjusted for covariates of age, sex, marital status, educational attainment, SF-12 physical health component. Single and substitution models adjusted for all covariates including total accelerometer wear time. β = Regression coefficients correspond to a 30 min increment of each activity. A high score on HADS Anxiety indicates high anxiety in this model.

Abbreviations: LPA, light-intensity physical activity; MVPA, moderate-to-vigorous physical activity; SB, sedentary behavior.

*P < .05.

TABLE 3 The associations of SB, LPA, and MVPA with HADS depression score

	SB		LPA		MVPA	
	β	95% CI	β	95% CI	β	95% CI
Single-activity model	*.59	(0.52, 0.65)	*−.30	(−0.51, −0.43)	*.21	(0.10, 0.32)
Partition model	*.38	(0.29, 0.47)	*.28	(0.19, 0.37)	−.02	(−0.09, 0.06)
Isotemporal model						
Replace SB with	Dropped		*.55	(0.49, 0.62)	.06	(−0.04, 0.16)
Replace LPA with	*.58	(0.51, 0.65)	Dropped		.04	(−0.06, 0.14)
Replace MVPA with	*.38	(0.30, 0.47)	*.28	(0.19, 0.37)	Dropped	

Note: All models adjusted for covariates of age, sex, marital status, educational attainment, SF-12 physical health component. Single and substitution models adjusted for all covariates including total accelerometer wear time. β = Regression coefficients correspond to a 30 min increment of each activity. A high score on HADS Depression indicates high anxiety in this model.

Abbreviations: LPA, light-intensity physical activity; MVPA, moderate-to-vigorous physical activity; SB, sedentary behavior.

*P < .05.

a decrease of 0.37 within a range of 1 to 4 would be relatively meaningful in terms of better mental health.

On the other hand, the results for depression did not follow this pattern. Substituting 30 minutes of SB with LPA or LPA with MVPA led to similar increases in the effect size for depressive symptoms. However, no effect was observed for substituting 30 minutes of SB with MVPA. This adds to our knowledge of the range of benefits for older adults if they replace SB with LPA in terms of anxiety. This effect was considerably larger than effects sizes for replacing SB with MVPA. However, for depression, MVPA appears to still be important.

Taken together, these findings support current health recommendations that inactive adults should be to initially encouraged to increase their LPA, which may be a more realistic and sustainable change. There has been a shift in the emphasis of national physical activity guidelines toward encouraging people to "sit less and move more" for a number of health benefits, including mental health.[12,13] These recommendations have been based largely on epidemiological evidence.[5] However, the evidence from IS analyses has shown inconsistent findings. Yasunaga et al[23] have shown that substituting SB with either LPA or MVPA is associated with improvements in depression, but Curtis et al did not find this relationship for depression, anxiety, or stress.[20] Dillon et al[22] observed that reallocating 30 minutes of SB to LPA was associated with a decrease in anxiety symptoms but not depression in 396 adults aged 50-69.

We have demonstrated that the message to sit less and move more for older adults would result in significant benefit to mental health and symptoms of anxiety, but not symptoms of depression. Hallgren et al[40] have posited that there may be different associations with depression between different types of SB, based on the mental stimulation they offer. They have proposed that mentally passive SB (eg, TV viewing) may be associated with depression whereas as mentally active SB (eg, reading) may be beneficial. This

may explain why we have shown mixed findings for symptoms of depression.

Additionally, in a study of 3233 US adults and older adults, Del Pozo Cruz et al[21] used compositional analysis to show that reallocating 60 minutes of SB to MVPA was associated with small reductions in depression symptoms, but reallocating SP to LPA was not associated with changes in depressive symptoms. The small effect sizes Del Pozo Cruz identified suggest that one reason we did not see an effect was that the time period of 30 minutes in the current study may be too small to detect a change.

Although the recognized definition of SB is that it includes all time spent sitting during waking hours,[11] it is comprised of a range of behaviors, undertaken for varying different reasons. A systematic review of qualitative studies indicated that although older adults understand the health consequences of prolonged SB, they also recognized that some SBs may confer cognitive or social benefits.[41] A systematic review of 18 studies (n = 40 228) concluded that there is still some uncertainty about the relationship between sedentary behavior and cognition in older adults but posited that the underlying mechanisms are likely to be similar to physical activity.[42] There is a need for further research to examine the relationship between different domains of SB and cognitive and mental health in older adults. The increasing use of accelerometers to measure SB is improving the quality of the data,[43] but questionnaire data have a role in complementing Actigraph measured data to allow an understanding of the contribution of different types of SB. Furthermore, Actigraph measured physical activity, while providing a measure of overall activity, do not allow for the comparison of different types of physical activity (group exercise, active travel, domestic physical activity, outdoor recreation) which conceivably could also differentially impact on depression through the associated social benefits.[44]

A key strength of this study was the use of confirmatory factor analysis (CFA) (configural, metric, and scalar invariance) to assess the reliability and the variance of each observed measure within the composite measures of HADS. This approach addresses unreliability and consequently measurement error and so increases the robustness of the findings.[45,46]

Also, this study measured physical activity using an accelerometer-based measure of activity rather than self-report in order to provide objective evidence of links with depression, anxiety, and mental health. Self-report measures are more commonly used in observational epidemiology studies exploring physical activity and health outcomes. Consequently, bias caused by using self-reported physical activity measures such as social desirability or problems in recall which limit the accuracy of self-reports in older adults are removed. Therefore, the results from this study provide a more accurate reflection of the actual physical activity carried out by older adults in a community setting.

Multicollinearity is a disadvantage of this approach. Although some researchers have suggested that a correlation coefficient of >.6 should be carefully considered when included in a model,[47] others view the removal of confounding as more important and think that collinear variables of up to .90 can still be reasonably controlled in various models.[48] Regardless, the goodness-of-fit tests for our models were adequate, and results were still able to distinguish important differences in change in different substitution models.

The use of IS in SB research is becoming increasingly popular as it offers novel insights into the potential benefits from changing behaviors with the cost or duration of an intervention. There is some debate in the literature as to the most appropriate way to approach developing IS models.[18] We have not accounted for sleep time in our analysis. Compositional data analysis seeks to address this by modeling substitutions to and from sleep as well as the other behaviors, which has been proposed to be a more robust method.[49] In response, Mekary et al[50] have highlighted that the statistical properties of IS models encompass those of models that have been derived from the approach, such as compositional data analysis and that IS models convey their findings in absolute terms which make them easier to communicate and inform physical activity guidelines. Irrespective of which statistical model is used, there is a need to test the assumptions in the model on prospective longitudinal data. The data included in this study were cross-sectional; therefore, causal inferences about the associations that were observed cannot be made. It is not possible to rule out reverse causality, or the possibility that an unmeasured confounding factor may explain the associations observed.

5 | PERSPECTIVE

Regular physical activity in older adults is associated with a wide range of health benefits.[1,2] Current public health recommendations encourage older adults to "sit less and move more."[12,13] Using IS, we have demonstrated that replacing 30 minutes of SB with LPA or MVPA was associated with improved mental health in older adults. Greater benefits were observed when shifting SB and LPA to MVPA. These results should be used to encourage older adults for a more physical active lifestyle.

ORCID

Mark A. Tully [ID] https://orcid.org/0000-0001-9710-4014
Nicole E. Blackburn [ID] https://orcid.org/0000-0003-4379-6312
Jason J. Wilson [ID] https://orcid.org/0000-0001-5558-8399
Lee Smith [ID] https://orcid.org/0000-0002-5340-9833
Frank Kee [ID] https://orcid.org/0000-0002-0606-8167
Maria Giné-Garriga [ID] https://orcid.org/0000-0003-4449-3524
Laura Coll-Planas [ID] https://orcid.org/0000-0001-5204-8717
Dhayana Dallmeier [ID] https://orcid.org/0000-0003-3665-7023
Michael Denkinger [ID] https://orcid.org/0000-0002-8097-060X
Dietrich Rothenbacher [ID] https://orcid.org/0000-0002-3563-2791

REFERENCES

1. Bangsbo J, Blackwell J, Boraxbekk CJ, et al. Copenhagen Consensus statement 2019: physical activity and ageing. *Br J Sports Med*. 2019;53(14):856-858.

2. Cunningham C, O' Sullivan R, Caserotti P, Tully MA. Consequences of physical inactivity in older adults: a systematic review of reviews and meta-analyses. *Scand J Med Sci Sports*. 2020;30(5):816-827.

3. Schuch FB, Stubbs B, Meyer J, et al. Physical activity protects from incident anxiety: a meta-analysis of prospective cohort studies. *Depress Anxiety*. 2019;36(9):846-858.

4. Schuch FB, Vancampfort D, Firth J, et al. Physical activity and incident depression: a meta-analysis of prospective cohort studies. *Am J Psychiatry*. 2018;175(7):631-648.

5. Huang Y, Li L, Gan Y, et al. Sedentary behaviors and risk of depression: a meta-analysis of prospective studies. *Transl Psychiatry*. 2020;10(1):26.

6. Hoare E, Milton K, Foster C, Allender S. The associations between sedentary behaviour and mental health among adolescents: a systematic review. *Int J Behav Nutr Phys Act*. 2016;13(1):108.

7. Hallgren M, Nguyen TT, Owen N, et al. Associations of sedentary behavior in leisure and occupational contexts with symptoms of depression and anxiety. *Prev Med*. 2020;133:e106021.

8. de Rezende LF, Rey-Lopez JP, Matsudo VK, Luiz OC. Sedentary behavior and health outcomes among older adults: a systematic review. *BMC Public Health*. 2014;14:333.

9. Giné-Garriga M, Sansano-Nadal O, Tully MA, et al. Accelerometer-measured sedentary and physical activity time and their correlates in european older adults: the SITLESS study. *J Gerontol Series A*. 2020.

10. Smith L, Gardner B, Fisher A, Hamer M. Patterns and correlates of physical activity behaviour over 10 years in older adults: prospective analyses from the English Longitudinal Study of Ageing. *BMJ Open*. 2015;5(4):e007423.

11. Tremblay MS, Aubert S, Barnes JD, et al. Sedentary Behavior Research Network (SBRN) – terminology consensus project process and outcome. *Int J Behav Nutr Phys Act*. 2017;14(1):75.

12. Piercy KL, Troiano RP, Ballard RM, et al. The physical activity guidelines for Americans. *JAMA*. 2018;320(19):2020-2028.

13. Department of Health and Social Care. *UK Chief Medical Officers' Physical Activity Guidelines*. London, UK: Department of Health and Social Care; 2019.

14. Smith L, Ekelund U, Hamer M. The potential yield of non-exercise physical activity energy expenditure in public health. *Sports Med*. 2015;45(4):449-452.

15. Gupta N, Mathiassen SE, Mateu-Figueras G, et al. A comparison of standard and compositional data analysis in studies addressing group differences in sedentary behavior and physical activity. *Int J Behav Nutr Phys Act*. 2018;15(1):53.

16. Mekary RA, Lucas M, Pan A, et al. Isotemporal substitution analysis for physical activity, television watching, and risk of depression. *Am J Epidemiol*. 2013;178(3):474-483.

17. Mekary RA, Willett WC, Hu FB, Ding EL. Isotemporal substitution paradigm for physical activity epidemiology and weight change. *Am J Epidemiol*. 2009;170(4):519-527.

18. Grgic J, Dumuid D, Bengoechea EG, et al. Health outcomes associated with reallocations of time between sleep, sedentary behaviour, and physical activity: a systematic scoping review of isotemporal substitution studies. *Int J Behav Nutr Phys Act*. 2018;15(1):69.

19. Rethorst CD, Moncrieft AE, Gellman MD, et al. Isotemporal analysis of the association of objectively measured physical activity with depressive symptoms: results from Hispanic Community Health Study/Study of Latinos (HCHS/SOL). *J Phys Act Health*. 2017;14(9):733-739.

20. Curtis RG, Dumuid D, Olds T, et al. The association between time-use behaviors and physical and mental well-being in adults: a compositional isotemporal substitution analysis. *J Phys Act Health*. 2020;17(2):197-203.

21. Del Pozo CB, Alfonso-Rosa RM, McGregor D, Chastin SF, Palarea-Albaladejo J, Del Pozo CJ. 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.

22. Dillon CB, McMahon E, O'Regan G, Perry IJ. Associations between physical behaviour patterns and levels of depressive symptoms, anxiety and well-being in middle-aged adults: a cross-sectional study using isotemporal substitution models. *BMJ Open*. 2018;8(1):e018978.

23. Yasunaga A, Shibata A, Ishii K, Koohsari MJ, Oka K. Cross-sectional associations of sedentary behaviour and physical activity on depression in Japanese older adults: an isotemporal substitution approach. *BMJ Open*. 2018;8(9):e022282.

24. Park CH, Elavsky S, Koo KM. Factors influencing physical activity in older adults. *J Exerc Rehabil*. 2014;10(1):45-52.

25. Gine-Garriga M, Coll-Planas L, Guerra M, et al. The SITLESS project: exercise referral schemes enhanced by self-management strategies to battle sedentary behaviour in older adults: study protocol for a randomised controlled trial. *Trials*. 2017;18(1):221.

26. Choi L, Liu Z, Matthews CE, Buchowski MS. Validation of accelerometer wear and nonwear time classification algorithm. *Med Sci Sports Exerc*. 2011;43(2):357-364.

27. Migueles JH, Cadenas-Sanchez C, Ekelund U, et al. Accelerometer data collection and processing criteria to assess physical activity and other outcomes: a systematic review and practical considerations. *Sports Med*. 2017;47(9):1821-1845.

28. Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008;40(1):181-188.

29. Zigmond AS, Snaith RP. The hospital anxiety and depression scale. *Acta Psychiatr Scand*. 1983;67(6):361-370.

30. Finney S, DiStefano C. Non-normal and categorical data in Structural equation modeling: A second courseNonnormal and categorical data in structural equation modeling. In: Hancock GR, Mueller RO (eds.), *Quantitative Methods In Education and the Behavioral Sciences: Issues, Research, And Teaching. Structural Equation Modeling: A Second Course*. Charlotte, NC: IAP Information Age Publishing; 2013: 439-492.

31. Brown TA. *Confirmatory Factor Analysis for Applied Research*. New York; NY: Guilford Press; 2006.

32. Coyne JC, van Sonderen E. No further research needed: abandoning the Hospital and Anxiety Depression Scale (HADS). *J Psychosom Res*. 2012;72(3):173-174.

33. Norton S, Cosco T, Doyle F, Done J, Sacker A. The Hospital Anxiety and Depression Scale: a meta confirmatory factor analysis. *J Psychosom Res*. 2013;74(1):74-81.

34. Hoyle RH. *Structural Equation Modeling: Concepts, Issues, and Applications*. Thousand Oaks, CA: Sage; 1995.

35. Kline RB. *Principles and Practice of Structural Equation Modeling*. New York, NY: Guilford Press; 2015.

36. Fitzsimons CF, Kirk A, Baker G, Michie F, Kane C, Mutrie N. Using an individualised consultation and activPAL feedback to reduce sedentary time in older Scottish adults: results of a feasibility and pilot study. *Prev Med*. 2013;57(5):718-720.

37. Gardiner PA, Eakin EG, Healy GN, Owen N. Feasibility of reducing older adults' sedentary time. *Am J Prev Med*. 2011;41(2):174-177.

38. Ware JE, Kosinski M, Keller SD. A 12-item short-form health survey: construction of scales and preliminary tests of reliability and validity. *Med Care*. 1996;34(3):220-233.

39. Bjelland I, Dahl AA, Haug TT, Neckelmann D. The validity of the Hospital Anxiety and Depression Scale. An updated literature review. *J Psychosom Res*. 2002;52(2):69-77.

40. Hallgren M, Dunstan DW, Owen N. Passive versus mentally active sedentary behaviors and depression. *Exerc Sport Sci Rev*. 2020;48(1):20-27.

41. Rawlings GH, Williams RK, Clarke DJ, et al. Exploring adults' experiences of sedentary behaviour and participation in non-workplace interventions designed to reduce sedentary behaviour: a thematic synthesis of qualitative studies. *BMC Public Health*. 2019;19(1):1099.

42. Olanrewaju O, Stockwell S, Stubbs B, Smith L. Sedentary behaviours, cognitive function, and possible mechanisms in older adults: a systematic review. *Aging Clin Exp Res*. 2020;32(6):969-984.

43. Prince SA, Cardilli L, Reed JL, et al. A comparison of self-reported and device measured sedentary behaviour in adults: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act*. 2020;17(1):31.

44. Rapp K, Mikolaizak S, Rothenbacher D, Denkinger MD, Klenk J. Prospective analysis of time out-of-home and objectively measured walking duration during a week in a large cohort of older adults. *Eur Rev Aging Phys Act*. 2018;15:8.

45. Bollen KA. *Structural Equations with Latent Variables*. New York, NY, Chichester, UK: Wiley; 1989.

46. McCoach DB, Black AC, O'Connell AA. Errors of inference in structural equation modeling. *Psychol Sch*. 2007;44(5):461-470.

47. McGee D, Reed D, Yano K. The results of logistic analyses when the variables are highly correlated: an empirical example using diet and CHD incidence. *J Chronic Dis*. 1984;37(9–10):713-719.

48. Pischon T, Girman CJ, Rifai N, Hotamisligil GS, Rimm EB. Association between dietary factors and plasma adiponectin concentrations in men. *Am J Clin Nutr*. 2005;81(4):780-786.

49. Biddle GJH, Edwardson CL, Henson J, et al. Associations of physical behaviours and behavioural reallocations with markers of metabolic health: a compositional data analysis. *Int J Environ Res Public Health*. 2018;15(10):2280.

50. Mekary RA, Ding EL. Isotemporal substitution as the gold standard model for physical activity epidemiology: why it is the most appropriate for activity time research. *Int J Environ Res Public Health*. 2019;16(5):797.