Received: 16 June 2020 | Revised: 26 August 2020 | Accepted: 7 September 2020
DOI: 10.1111/sms.13827

ORIGINAL ARTICLE

WILEY

Associations of sedentary behavior bouts with community-dwelling older adults' physical function

Jason J. Wilson[1,2] | **Ilona McMullan**[1,2] | **Nicole E. Blackburn**[1] | **Mathias Skjødt**[3] | **Paolo Caserotti**[3] | **Maria Giné-Garriga**[4,5,6] | **Ana Farche**[4] | **Jochen Klenk**[7] | **Dhayana Dallmeier**[8,9] | **Manuela Deidda**[10] | **Marta Roqué i Figuls**[11,12] | **Mark A. Tully**[2]

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

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

[3]Department of Sports Science and Clinical Biomechanics, Center for Active and Healthy Ageing (CAHA), Syddansk Universitet, Odense, Denmark

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

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

[6]School of Health and Life Sciences, Glasgow Caledonian University, Glasgow, UK

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

[8]Agaplesion Bethesda Clinic, Geriatric Research Unit Ulm University and Geriatric Center Ulm Alb-Donau, Ulm, Germany

[9]Department of Epidemiology, Boston University School of Public Health, Boston, MA, USA

[10]Health Economics and Health Technology Assessment (HEHTA), Institute of Health and Wellbeing (IHW), University of Glasgow, Glasgow, UK

[11]Fundació Salut i Envelliment (Foundation on Health and Ageing), Universitat Autònoma de Barcelona, Barcelona, Spain

[12]Institute of Biomedical Research (IIB Sant Pau), Barcelona, Spain

Correspondence
Jason J. Wilson, School of Health Sciences, Centre for Health and Rehabilitation Technologies, Institute of Nursing and Health Research, Ulster University, Shore Road, Newtownabbey, Co Antrim, BT37 0QB, UK.
Email: jj.wilson@ulster.ac.uk

Funding information
The authors of this manuscript were supported and funded by the European Union program Horizon 2020 (H2020-Grant 634270) as part of the SITLESS consortium.

Abstract

The study aim was to explore associations between sedentary behavior (SB) bouts and physical function in 1360 community-dwelling older adults (≥65 years old). SB was measured using an ActiGraph wGT3X + accelerometer for seven consecutive days at the dominant hip and processed accordingly. Various SB bout lengths were assessed including: 1- to 9-minutes; 10- to 29-minutes; 30- to 59-minutes; and ≥60-minutes, as well as maximum time spent in a SB bout. Total SB time was adjusted for within the SB bout variables used (percentage SB time in the SB bout length and number of SB bouts per total SB hour). Physical function was assessed using the 2-minute walk test (2MWT), 5-times sit-to-stand (chair stand) test, and unipedal stance test (UST). Hierarchical linear regression models were utilized. Covariates such as moderate-vigorous physical activity (MVPA), demographic and health characteristics were controlled for. Lower percentage time spent in ≥60-minute SB bouts was significantly ($P < .05$) associated with longer 2MWT distance while lower numbers of ≥60-minute SB bouts were associated with longer 2MWT distance, shorter chair stand time and longer UST time. There were mixed associations with physical function for 10- to 29-minute SB bouts. In a large cohort of European older adults, prolonged SB bouts lasting ≥60-minutes appear to be associated with reduced physical function after controlling for MVPA and numerous other important covariates. Besides reducing SB levels, these findings suggest there is a need to regularly interrupt prolonged SB to improve physical function in older adults.

KEYWORDS
accelerometers, older adults, physical function, sedentary behavior

1 | INTRODUCTION

The recent Copenhagen Consensus statement focusing on physical activity (PA) and aging highlights the benefits of PA on physical function in older adults, such as increased cardiovascular and musculoskeletal capacity.[1] These benefits are evident in those achieving the PA guidelines but also in those completing lower levels of weekly PA.[1] Updated PA guidelines in countries such as the United States and the UK also recommend that older adults should not spend long periods in sedentary behavior (SB).[2,3] SB has been shown to be an independent risk factor of health such as increasing the risk of developing chronic diseases including diabetes, heart disease, and some cancers.[4] Longer time spent in SB also appears to reduce physical function which makes everyday tasks such as getting out of a chair, negotiating uneven surfaces and walking around shops more difficult.[5] Physical function has been defined as the ability to perform basic and instrumental activities of daily living.[6] Sufficient physical function is required by older adults to remain within the community, but physical function is complex and impacted by various physical and mental health-related elements.[6,7] For every 1-hour increase in older adults' daily time in SB, the risk of having sarcopenia has been shown to increase by 33%.[8] Therefore, reducing the time spent in SB could improve physical function in older adults.

It has been suggested that in addition to total SB time, it is important to determine how SB is accumulated throughout waking hours.[9] Greater total SB volume and higher duration of SB bouts >10 minutes have been associated with higher all-cause mortality risk in middle-to-old aged adults.[10] A recent meta-analysis focusing on SB and cardiometabolic health has also highlighted the importance of breaking up long periods of SB to improve glycemic control as well as reduce adiposity.[4] More breaks in SB may increase ability to undertake activities of daily living and reflect greater independence in older adults.[11] The mechanisms linking high levels of SB with reduced physical function, independent of moderate-vigorous PA (MVPA), are not well understood. However, suggestions have included suppressed lipoprotein lipase activity, less musculoskeletal contractions leading to lower energy expenditure, as well as increased pro-inflammatory cytokine activity leading to increased sarcopenia.[8,12]

Currently, there is ambiguity about whether changes in SB can have a clinically meaningful impact on physical function in older adults. A large study of 61 609 women has highlighted that higher subjectively measured sitting time is associated with reduced self-reported physical function.[13] However, subjective measures can be problematic due to self-reporting bias (ie, general trend of under-reporting of SB).[14] Recent research has begun exploring the relationship between device-measured SB bouts and physical function, with mixed findings. Liao et al[12] demonstrated in 281 Japanese older adults that prolonged SB bouts of >30 minutes was associated with reduced 5-m gait speed and slower timed up-and-go tests in women, but no significant association was shown in men. Using data from the Maastricht Study consisting of 1932 middle-to-older aged adults, Van der Velde et al[15] found that longer SB bout durations were associated with slower chair stand performances and lower 6-minute walk test distances in their initial regression model, although these associations attenuated after full adjustment for covariates including age, sex, educational level, smoking, alcohol consumption, cardiovascular disease history, self-reported physical functioning, and health status. Another smaller study found that the pattern of SB was more important than total SB time for predicting older adults' physical function, but this association was more pronounced in men compared to women, possibly due to less women meeting the PA guidelines.[16] A SB reducing pilot intervention which particularly focused on breaking up SB in older adults found that timed up-and-go performance and time to complete the 30-second chair stand test both significantly improved post-intervention.[17] However, these studies are not without limitations. Firstly, many have used small sample sizes (the Maastricht Study aside) which influences the robustness of current findings. Secondly, some have used mixed adult and older adult populations which effects the generalizability to older adults.[15] Thirdly, some studies have lacked using appropriate covariates such as MVPA and health status to properly examine the independent associations between SB bouts and physical function.

The full range of SB bouts that influences health in older adults is still to be determined. Research exploring the health implications of SB bouts in older adults has utilized bout lengths such as ≥10 minutes,[10] ≥30 minutes,[12,16] and ≥60 minutes.[16,18] SB bout lengths ≥30 minutes are likely to represent typical sedentary activities such as driving, watching a TV programme, or reading. Also, Byrom et al[19] recommend reporting the maximum sedentary bout length time, as it is an easy-to-understand measure and is likely to be sensitive to change in SB reducing interventions. However, there has been a lack of studies using this particular outcome. The aim of this study was to explore the associations between device-measured SB bouts and physical function in community-dwelling older adults.

2 | MATERIALS AND METHODS

2.1 | Study design and participants

This cross-sectional study included 1360 older adults (≥65 years old) assessed at baseline as part of the SITLESS study. The study protocol has been described elsewhere.[20] Briefly, the aim of this RCT is to enhance exercise referral schemes with self-management strategies to reduce SB, increase PA, and improve physical function in community-dwelling older adults from Denmark, Spain, Northern Ireland, and Germany. Inclusion criteria included being able to walk for ≥2 minutes without help from a person; scoring ≥4 on the Short Physical Performance Battery (SPPB)[21]; self-reported not meeting the PA guidelines (≥30 minutes on ≥5 d/wk); and/or spending prolonged time in SB (ie, 6-8 h/d). Exclusion criteria included ≥3 errors on a six-item cognitive impairment questionnaire; medical conditions likely to interfere with the study design, suffering from unstable medical conditions (eg, fluctuating blood pressure) or symptomatic cardiovascular diseases that prevented PA participation; unwilling to attend 75% of the intervention sessions; or had participated in an exercise referral scheme <6 months prior to their baseline assessment. Ethical approval was granted by the following Research and Ethics Committees of each country which recruited participants: 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). Participants provided informed written consent.

2.2 | SB assessment

Sedentary behavior was assessed using an ActiGraph wGT3X + accelerometer (ActiGraph, LLC). Participants wore the device for seven consecutive days on an elastic belt placed on the dominant hip during waking hours from the day after the baseline visit. It was removed during water-based activities (eg, washing or swimming), and during night-time sleeping with on and off times recorded in an activity monitor diary. The device was initialized to sample at 30Hz using the normal filter setting. The Choi 2011 algorithm[22] was used to calculate non-weartime. At least four valid days including one weekend day was required with ≥600 minutes needed for a valid day.[23,24] SB was classified as <100 CPM.[25] Maximum daily weartime was set at 19 hours using a pragmatic choice based on participants' diaries and sleep time recommendations for older adults.[26] For participants above this threshold, their activity monitor diary was compared with the software calculated weartime. For relevant participants, a log diary with on/off times from their own activity monitor diary was included. Raw data were analyzed using ActiLife 6.13.3 software (ActiGraph, LLC) and summarized into 10-second epochs. Accelerometer weartime was used to standardize total SB time to percentage time in total SB (ie, total SB volume). The following SB bout data was derived after being controlled for total SB time: percentage SB time in 1- to 9-minute, 10- to 29-minute, 30- to 59-minute, and ≥60-minute SB bouts; the number of 1- to 10-minute, 10- to 29-minute, 30- to 59-minute, and ≥60-minute SB bouts per total SB hour; and maximum time (minutes) in a SB bout (MaxSBB). Total SB time was used to standardize SB bouts because it was likely that time spent in SB bouts would be influenced by total SB volume (ie, more time taking part in a certain SB bout length due to more daily time spent being sedentary). Total SB time was highly correlated with weartime ($r = 0.62$; $P < .001$).

2.3 | Physical function

After the 7-day accelerometer assessment, three physical function tests were explained to participants with each performed once; the 2-minute walk test (2MWT) represented functional endurance, the 5-times sit-to-stand (chair stand) test represented lower-limb muscle power, and the unipedal stance test (UST) represented balance.

The 2MWT was completed over a 15.2-m out-and-back course. Participants walked as fast as they could until asked to stop at 2 minutes. If participants became fatigued, they could slow down but were encouraged to keep walking until the end. At halfway, participants were told the standardized line "You are doing well; you have 1-minute left." After the test had finished, the distance to the nearest 10 cm was recorded. Longer distances indicated better functional endurance. The 2MWT has good test-retest reliability with an intraclass correlation coefficient (ICC) of 0.82 (95% CI, 0.76-0.87).[27]

The chair stand test was completed on an unsupported, straight-backed chair without chair arms (standard 43.2 cm seat height). Participants were asked to stand up and sit down five times as fast as they could. Their arms were folded across their chests. Timing commenced on a "go" command and was stopped when the fifth stand was completed. Shorter times indicated better lower-limb muscle power.[28] The chair stand test has excellent test-retest reliability in community-dwelling adults and older adults with an ICC of 0.96.[29]

The UST required participants to stand on one leg for up to 30 seconds. Timing started when participants had their arms touching their waist and one leg raised above the ground. Timing stopped when both feet were touching the ground, a hand contacted a nearby chair/table placed close by for safety reasons, or 30 seconds had been reached. The right-side was used in the analysis as 93.7% of the sample indicated they were right-side dominant. Longer times indicated better balance. The UST has excellent test-retest reliability in community-dwelling adults and older adults with an ICC of 0.99.[30]

2.4 | Covariates

Several studies have highlighted confounders when exploring the associations between SB and physical function in older adults.[11,12,15] Therefore, the following demographic and health characteristics were controlled for: daily MVPA time using ≥2020 CPM at the vertical axis as used by Troiano and colleagues (2008)[31] (minutes); country (Denmark, Spain, Northern Ireland, and Germany); sex (male/female); age (years), marital status (single, married/stable relationship, widow/widower, divorced), education (cannot read or write, can read and write, primary, secondary, and tertiary levels); smoking (current smoker, used to smoke <1 year ago, used to smoke >1 year ago and never smoked); SF-12 self-rated physical health status (higher scores equals better physical health); SF-12 self-rated mental health status (higher scores equals better mental health); and body mass index (BMI—kg/m^2) were included in the analysis.

2.5 | Statistical analysis

Before analysis, multiple imputation of missing data using an Expectation Maximisation approach was utilized in SPSS (version 22; IBM) to maximize the sample size and reduce possible biases due to missing data. The assumptions of outliers, collinearity, independent errors, random normal distribution of errors, homoscedasticity and linearity, and non-zero variances were then tested. Assuming these conditions were met, linear regression was calculated to predict functional test measures including the 2MWT, chair stand test and UST based on SB variables using data from baseline. The covariates of MVPA, country, gender, age, marital status, education levels, smoking status, SF-12 (physical and mental components), and BMI were included in the models. These covariates have been chosen as they have previously been shown to be associated with SB in older adults. Hierarchical linear regression models with three steps were used to predict 2MWT distance, chair stand time, and UST time using: (a) SB variable; (b) SB variable + MVPA; and (c) SB variable + MVPA + demographic and health covariates. Regressions were run separately for each physical function test and SB variable. To understand whether prolonged SB bouts had an impact on the associations between physical function and smaller SB variables including 1- to 9-minute, 10- to 29-minute, and 30- to 59-minute SB bouts, the ≥60-minute SB bout variable was included as a covariate as part of a sensitivity analysis. However, the inclusion of ≥60-minute SB bouts in the models did not significantly impact the results meaning it was not included as a covariate in the final analyses.

3 | RESULTS

Baseline interviews, self-reported surveys, and functional tests were completed by 1360 participants. Table 1 contains demographic and health information without imputation. The main reason for missing data included participants not filling in or choosing not to complete a particular questionnaire or test. Participants were split relatively evenly between countries, mean age was 75.3 (6.29) years, there were more females than males, mean BMI suggested most participants were overweight, just over half of the sample were married or in a stable relationship, three quarters had at least secondary education and over half had never smoked.

Table 2 highlights information on the physical function tests and also the SB levels and patterns along with MVPA levels without imputation. Reasons for missing data included participants not meeting the valid weartime criteria (for SB and MVPA variables) and/or not being able to complete the particular physical function test (ie, the UST was only conducted in participants who were able to complete the full tandem stance for 10 seconds in the SPPB). On average, participants wore the accelerometer for 14.4 h/d. They spent >11 h/d being sedentary for any length of time (78.8% of waking hours) with just over 20 minutes per day in MVPA.

All assumptions were met, meaning separate hierarchical linear regressions, adjusted for MVPA and participant demographic and health characteristics, were developed to understand the associations between SB bouts and the physical function test. Tables 3a and 3b highlight the key information regarding the associations of different SB bout patterns with measures of physical function after adjusting for covariates and applying multiple imputation, leading to 1288 participants being included in the analyses. Full details for each model are given in the Tables S1-S30. Higher percentage

TABLE 1 Participant demographic and health characteristics (n = 1360)

	Number	Mean/%	Standard deviation
Country			
Denmark	338	24.9	
Spain	356	26.2	
Northern Ireland	321	23.6	
Germany	345	25.4	
Age	1359	75.3	6.3
Sex			
Male	520	38.2	
Female	840	61.8	
BMI	1352	28.9	5.2
SPPB score	1344	9.4	2.3
Physical SF-12 score	1305	44.8	9.2
Mental SF-12 score	1306	51.7	8.9
Marital status			
Single	117	8.9	
Married/stable relationship	690	52.9	
Widow/widower	354	27.0	
Divorced	147	11.2	
Unwilling to answer	5	0.4	
Education			
Cannot read or write	5	0.4	
Can read and write	36	2.7	
Primary education	279	20.8	
Secondary education	712	53.2	
Tertiary/university education	303	22.6	
Unwilling to answer	3	0.2	
Other	1	0.1	
Smoking status			
Current smoker	99	7.6	
No, but smoked <1 y ago	38	2.9	
No, but smoked >1 y ago	438	33.5	
Never smoked	731	56.0	

Abbreviations: BMI, body mass index; SPPB, Short Physical Performance Battery.

TABLE 2 Participants' physical function, SB and MVPA levels without imputation (n = 1360)

	Number	Mean	Standard deviation
Physical function			
2MWT distance (m)	1348	149.6	34.5
Chair stand test time (s)	1312	11.3	4.2
Unipedal stance test time (s)	1209	14.5	11.1
SB and MVPA variables			
Daily total SB time (min)	1266	678.7	75.9
Total SB volume (%)	1266	78.8	7.0
Daily total MVPA time (min)	1266	22.8	20.0
Total MVPA volume (%)	1266	2.6	2.3
Daily weartime (min)	1266	862.1	68.7
Percentage SB time in 1- to 9-min SB bouts (%)	1266	40.7	9.9
Number of 1- to 9-min SB bouts per total SB hour	1266	8.8	2.5
Percentage SB time in 10- to 29-min SB bouts (%)	1266	27.2	6.3
Number of 10- to 29-min SB bouts per total SB hour	1266	1.0	0.2
Percentage SB time in 30- to 59-min SB bouts (%)	1266	13.8	7.6
Number of 30- to 59-min SB bouts per total SB hour	1266	0.2	0.1
Percentage SB time in ≥60-min SB bouts (%)	1266	6.2	6.2
Number of ≥60-min SB bouts per total SB hour	1266	0.1	0.1
Maximum time in a sedentary bout (min)	1266	84.2	29.1

Abbreviations: 2MWT, 2-min walk test; MVPA, moderate-vigorous physical activity; SB, sedentary behavior.

time in total SB was associated with lower 2MWT distances and longer chair stand times while no significant associations were found using the UST. Higher percentage time, as well as the number of 10- to 29-minute SB bouts, was both associated with longer UST times. Higher percentage SB time in ≥60-minute SB bouts was associated with lower 2MWT distances although no significant associations were found using the chair stand test or UST. Significant associations were found for the number of ≥60-minute SB bouts per total SB hour regarding the 2MWT (less SB bouts = longer 2MWT distance), chair stand test (less SB bouts = shorter chair stand time), and UST (less SB bouts = longer UST time). No statistically significant associations ($P > .05$) for 1- to 9-minute SB bouts, 30- to 59-minute SB bouts, and MaxSBB with any of the physical function measures were found.

Perhaps unsurprisingly, being male, younger, more educated, having higher self-rated physical and mental function as well as having higher levels of MVPA were generally

TABLE 3A Associations of total SB volume and different sed patterns based on percentage SB time in bouts with measures of physical function after adjusting for covariates (Model 3)

Variables	Unstandardized β coefficients	95% Confidence intervals	P
2-min walk test (m; n = 1288)			
Total SB volume (% weartime)	**−0.35**	**−0.61 to −0.09**	**.009**
1- to 9-min SB bouts (% SB)	0.04	−0.11 to 0.19	.606
10- to 29-min SB bouts (% SB)	0.16	−0.07 to 0.38	.167
30- to 59-min SB bouts (% SB)	−0.03	−0.21 to 0.15	.729
≥60-min SB bouts (% SB)	**−0.34**	**−0.57 to −0.10**	**.005**
Maximum time in a SB bout (min)	−0.02	−0.07 to 0.03	.343
Chair stand test (s; n = 1288)			
Total SB volume (% weartime)	**0.06**	**0.01 to 0.10**	**.009**
1- to 9-min SB bouts (% SB)	−0.01	−0.04 to 0.01	.347
10- to 29-min SB bouts (% SB)	0.00	−0.03 to 0.04	.885
30- to 59-min SB bouts (% SB)	0.00	−0.03 to 0.02	.738
≥60-min SB bouts (% SB)	0.03	−0.01 to 0.07	.101
Maximum time in a SB bout (min)	0.00	−0.01 to 0.01	.736
Unipedal stance test (s; n = 1288)			
Total SB volume (% weartime)	0.03	−0.07 to 0.14	.508
1- to 9-min SB bouts (% SB)	−0.01	−0.06 to 0.05	.845
10- to 29-min SB bouts (% SB)	**0.17**	**0.08 to 0.26**	**.000**
30- to 59-min SB bouts (% SB)	−0.05	−0.11 to 0.02	.188
≥60-min SB bouts (% SB)	−0.08	−0.17 to 0.00	.063
Maximum time in a SB bout (min)	−0.01	−0.02 to 0.01	.446

Note: Abbreviations: SB, sedentary behavior.

Bold figures indicate statistical significance ($P < .05$).

found to be statistically significantly associated with better physical function (see Tables S1-S30). On average, Model 3 (ie, full adjustment for MVPA, demographic and health covariates) explained 54% of the variance in the 2MWT distance, 17% of the variance in the chair stand time and 33% of the variance in the UST time when using percentage time in total SB. When using any length of SB bout in Model 3 (ie, full adjustment for MVPA, demographic and health covariates), 54% of the variance in the 2MWT distance, 15% of the variance in the chair stand time, and 31% of the variance in the UST time were explained.

4 | DISCUSSION

This study highlights that device-measured total SB volume and ≥60-minute SB bouts were associated with physical function in a European sample of older adults. In essence, less time spent in total SB was associated with increased 2MWT distance and faster chair standing time while reduced numbers of prolonged SB bout lengths were associated with increased 2MWT distance, shorter chair standing time, and longer UST time. These associations remained after adjustment for MVPA as well as important demographic and health characteristics. SB bouts of 10- to 29-minutes had mixed-to-no significant associations with physical function. These findings suggest that accumulating SB in long uninterrupted bouts, in addition to total SB volume, had an important association with physical function. Potential mechanisms for the negative impact of high levels of SB on physical function are complex but some suggestions have included SB displacing time away from MVPA, increased levels of adiposity and reduced levels of anti-inflammatory markers in combination which could lead to increased muscle atrophy and may lead to increased risk of sarcopenia in older adults.[32]

Our findings for total SB volume are reflected within the relevant literature which generally has been mixed, with different physical function tests showing associations (eg, six-minute minute walk and elbow flexion test) while others have not (eg, grip strength, knee extension strength, and SPPB score).[13,15,16] No significant associations with physical function were found using lower SB bout lengths such as 1- to 9-minute and 10- to 29-minute SB bouts apart from higher percentage time and numbers of 10- to 29-minute SB bouts being associated with longer UST times. The latter finding was unexpected because more time being sedentary would seemingly reduce balance ability as has been previously shown.[33] One possible reason for this finding could be that the UST was not a strong

TABLE 3B Associations of different sedentary behavior patterns based on number of SB bouts per total SB hour with measures of physical function after adjusting for covariates (Model 3)

Variables	Unstandardized β coefficients	95% Confidence intervals	P
2-min walk test (meters; n = 1288)			
1- to 9-min SB bouts (n/SB hour)	0.29	−0.32 to 0.91	.351
10- to 29-min SB bouts (n/SB hour)	4.22	−2.17 to 10.61	.195
30- to 59-min SB bouts (n/SB hour)	−1.41	−13.87 to 11.05	.825
≥60-min SB bouts (n/SB hour)	**−50.35**	**−81.75 to −18.95**	**.002**
Chair stand test (s; n = 1288)			
1- to 9-min SB bouts (n/SB hour)	−0.05	−0.15 to 0.05	.327
10- to 29-min SB bouts (n/SB hour)	0.03	−0.99 to 1.05	.953
30- to 59-min SB bouts (n/SB hour)	−0.29	−2.28 to 1.71	.777
≥60-min SB bouts (n/SB hour)	**5.75**	**0.71 to 10.78**	**.025**
Unipedal stance test (s; n = 1288)			
1- to 9-min SB bouts (n/SB hour)	−0.19	−0.43 to 0.04	.106
10- to 29-min SB bouts (n/SB hour)	**5.19**	**2.77 to 7.61**	**.000**
30- to 59-min SB bouts (n/SB hour)	−3.01	−7.75 to 1.74	.214
≥60-min SB bouts (n/SB hour)	**−13.36**	**−25.34 to −1.37**	**.029**

Note: Abbreviations: n/SB hour, number per total sedentary behavior hour; SB, sedentary behavior.
Bold figures indicate statistical significance ($P < .05$)

indicator for physical function in the first instance. Liao et al[12] found that one leg standing test performance was not associated with total daily SB time in their overall older adult sample. The current study also found a lack of association for the UST with 30- to 59-minute SB bouts alongside MaxSBB. In all these instances, greater MVPA time was associated with longer UST times meaning higher intensities may be required to improve balance performance. Although light PA, which was not assessed in this paper, has also been shown to be associated with balance in older adults.[34]

A previous study has highlighted that older adult men can spend 43.2% of their sedentary time in ≥30-minute SB bouts, a large proportion of waking hours.[18] In our study, the 2MWT, chair stand test, and UST were not significantly associated with the percentage time and number of 30- to 59-minute SB bouts. Another study provides support for these findings despite utilizing different functional tests.[12] Liao et al[12] used 5-m gait speed, timed up-and-go and hand-grip tests which are quite different to those used in the current study. The 6-minute minute walk, a similar test to the 2MWT, has been found to not be associated with ≥30-minute SB bouts after full adjustment for covariates.[15] In fact, none of the functional test measures used by Van der Velde et al[15] were associated with time in ≥30-minute SB bouts after adjusting for covariates. This highlights the importance of using measures of physical function which are sensitive to change.

Longer percentage SB time in ≥60-minute SB bouts resulted in significantly lower 2MWT distance but not chair stand and UST times. However, higher numbers of ≥60-minute SB bouts per total SB hour negatively impacted all three physical function measures. These findings are supported by other research[16] which found that shorter time in ≥60-minute SB bouts was associated with higher SPPB scores and faster 400 m walk gait speeds in males. UK older adult men have been shown to spend 18.8% of their sedentary time in ≥60-minute SB bouts which is similar to the current study.[18] Despite this being a relatively low percentage of waking hours, our study appears to show that this prolonged pattern of SB plays an important role in physical function. In terms of interrupting prolonged SB bouts, research has suggested that 7 breaks from SB every hour would be a suitable approach to enhance older adults' ability to undertake activities of daily living.[11]

Using the MaxSBB length resulted in no significant associations with any physical function measure assessed in the present study. Although MaxSBB has been recommended as a measure to be used in SB reducing interventions, it has been acknowledged there could be high variability from day-to-day and may therefore be unable to detect changes.[19] This is likely to have occurred in our study.

4.1 | Strengths and limitations

Study strengths include having a larger sample size compared to similar research, exclusively focusing on older adults across several European countries, using an accelerometer, testing various SB bout lengths and controlling for a suitable number of covariates. The main limitation is the cross-sectional design, meaning it was impossible to establish whether spending more time in SB bouts causes reduced physical function or vice-versa. Future longitudinal research, such as the SITLESS study, could help to try and establish a causal relationship by determining how changes in SB influence physical function. This was also an exploratory analysis using 30 models with no correction for multiple testing. Using the ActiGraph to measure SB at the waist may have meant misclassification of standing into sitting.[35] Therefore, there is the possibility that activity <100 CPM is being classified as SB when in fact there could be a breaking of the SB bout due to standing. Future research using thigh-based accelerometry would allow more distinct capture of sitting and standing. The MVPA threshold of 2020 CPM could be deemed as being too high for many older adults but there is recognized ambiguity in the literature.[23] The ENGAGE project, currently being undertaken by some co-authors, is attempting to address these cut-point ambiguities. Using a UST selectively applied to participants able to complete the full tandem stance test and also being limited to 30 seconds may have been problematic. One hundred and fifty-one participants did not attempt the UST while almost a quarter (304) reached the 30-second limit, suggesting there was a ceiling effect. As SITLESS participants were required to have sufficient physical function to fully take part in the study, this may impact the generalizability of the findings as the cohort is not necessarily representative of very frail older adults. However, a mix of both high and low functioning participants were still part of this cohort. Excluding individuals who self-reported not meeting the PA guidelines or those not spending prolonged time in SB may have reduced the overall dispersion of SB, possibly leading to an under-estimation of the associations between SB and physical function. An important item not considered in the current analysis was the types of activities completed during non-sedentary bouts. This is likely to have varied by length and intensity. Recent research related to all-cause mortality risk has highlighted the likely interdependence between SB and PA.[36,37] Research using compositional modeling is helping to overcome this particular issue.[38]

5 | PERSPECTIVE

In a large cohort of community-dwelling European older adults, total SB volume and prolonged SB bouts of ≥60 minutes appear to be associated with reduced physical function after controlling for MVPA and numerous other important demographic and health covariates. Rather than simply reducing SB levels, these findings suggest that it might be beneficial to regularly interrupt SB every hour to improve physical function in older adults. These data are useful for two reasons; it supports the recommendation to break up long SB periods in the PA guidelines,[2,3] and it helps to inform the design of future SB reducing interventions by highlighting patterns of SB which researchers/clinicians should try to target.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation for all those that volunteered for this study and Mrs Nicky Laird for her administrative support. We also thank the Northern Ireland Clinical Research Facility and the Municipality of Odense for facilitating the assessments in the United Kingdom and Danish sites, respectively. The work described in this publication was part of the SITLESS project, supported and funded by the European Union program Horizon 2020 (H2020-Grant 634270). Consortium members of the participating organizations of the SITLESS project: Antoni Salvà Casanovas, Àlex Domingo, Marta Roqué and Laura Coll-Planas: Health and Ageing Foundation of the Autonomous University of Barcelona, Spain; Maria Giné-Garriga, Miriam Guerra-Balic, Carme Martin-Borràs, Javier Jerez-Roig, Guillermo R Oviedo, Marta Santiago-Carrés, Oriol Sansano and Guillermo Varela: Faculty of Psychology, Education and Sport Sciences Blanquerna, Ramon Llull University, Barcelona, Spain; Emma McIntosh and Manuela Deidda: Health Economics and Health Technology Assessment, University of Glasgow, UK; Dietrich Rothenbacher, Michael Denkinger, Katharina Wirth, Dhayana Dallmeier and Jochen Klenk: Institute of Epidemiology and Medical Biometry, Ulm University, Germany; Frank Kee: Centre for Public Health, School of Medicine, Dentistry and Biomedical Sciences, Queen's University Belfast, UK; Mark A Tully, Jason J Wilson, Nicole E Blackburn and Ilona McMullan: School of Health Sciences, Ulster University, UK; Paolo Caserotti and Mathias Skjødt: Department of Sport Science and Clinical Biomechanics, University of South Denmark, Denmark; Guillaume Lefebvre: SIEL, Sport initiative et Loisir Bleu association, Straßbourg, France; Denise González: SIEL, Sport initiative et Loisir Bleu association, Barcelona, Spain.

CONFLICT OF INTEREST

The authors report no potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Jason J. Wilson https://orcid.org/0000-0001-5558-8399
Nicole E. Blackburn https://orcid.org/0000-0003-4379-6312
Maria Giné-Garriga https://orcid.org/0000-0003-4449-3524
Jochen Klenk https://orcid.org/0000-0002-5987-447X
Manuela Deidda http://orcid.org/0000-0002-0921-6970
Marta Roqué i Figuls https://orcid.org/0000-0003-0043-1364
Mark A. Tully https://orcid.org/0000-0001-9710-4014

REFERENCES

1. Bangsbo J, Blackwell J, Boraxbekk C-J, et al. Copenhagen consensus statement 2019: physical activity and ageing. *Br J Sports Med*. 2019;53(14):856-858.
2. Piercy KL, Troiano RP, Ballard RM, et al. The physical activity guidelines for Americans. *JAMA*. 2018;320(19):2020-2028.
3. GOV.UK. UK Chief Medical Officers' physical activity guidelines. 2019.
4. Chastin SF, Egerton T, Leask C, Stamatakis E. Meta-analysis of the relationship between breaks in sedentary behavior and cardiometabolic health. *Obesity*. 2015;23(9):1800-1810.
5. Mañas A, Del Pozo-Cruz B, García-García FJ, Guadalupe-Grau A, Ara I. Role of objectively measured sedentary behaviour in physical performance, frailty and mortality among older adults: a short systematic review. *Eur J Sport Sci*. 2017;17(7):940-953.
6. Garber CE, Greaney ML, Riebe D, Nigg CR, Burbank PA, Clark PG. Physical and mental health-related correlates of physical function in community dwelling older adults: a cross sectional study. *BMC Geriatr*. 2010;10:6.
7. Painter P, Stewart AL, Carey S. Physical functioning: definitions, measurement, and expectations. *Adv Ren Replace Ther*. 1999;6(2):110-123.
8. Gianoudis J, Bailey CA, Daly RM. Associations between sedentary behaviour and body composition, muscle function and sarcopenia in community-dwelling older adults. *Osteoporos Int*. 2015;26(2):571-579.
9. Healy GN, Dunstan DW, Salmon J, et al. Breaks in sedentary time: beneficial associations with metabolic risk. *Diabetes Care*. 2008;31:661-666.
10. Diaz KM, Howard VJ, Hutto B, et al. Patterns of sedentary behavior and mortality in U.S. middle-aged and older adults: a national cohort study. *Ann Intern Med*. 2017;167(7):465-475.
11. Sardinha LB, Santos DA, Silva AM, Baptista F, Owen N. Breaking-up sedentary time is associated with physical function in older adults. *J Gerontol A Biol Sci Med Sci*. 2015;70(1):119-124.
12. Liao Y, Hsu HH, Shibata A, Ishii K, Koohsari MJ, Oka K. Associations of total amount and patterns of objectively measured sedentary behavior with performance-based physical function. *Prev Med Rep*. 2018;12:128-134.
13. Seguin R, LaMonte M, Tinker L, et al. Sedentary behavior and physical function decline in older women: Findings from the Women's Health Initiative. *J Aging Res*. 2012;271589.
14. 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(31).
15. van der Velde JHPM, Savelberg HHCM, van der Berg JD, et al. Sedentary behavior Is only marginally associated with physical function in adults aged 40–75 years—the Maastricht Study. *Front Physiol*. 2017;8:242.
16. Gennuso KP, Thraen-Borowski KM, Gangnon RE, Colbert LH. Patterns of sedentary behavior and physical function in older adults. *Aging Clin Exp Res*. 2016;28(5):943-950.
17. Harvey JA, Chastin SFM, Skelton D. Breaking sedentary behaviour has the potential to increase/maintain function in frail older adults. *JFSF*. 2018;3(1):26-34.
18. Jefferis BJ, Sartini C, Shiroma E, Whincup PH, Wannamethee SG, Lee IM. Duration and breaks in sedentary behaviour: accelerometer data from 1566 community-dwelling older men (British Regional Heart Study). *Br J Sports Med*. 2015;49(24):1591-1594.
19. Byrom B, Stratton G, McCarthy M, Muehlhausen W. Objective measurement of sedentary behaviour using accelerometers. *Int J Obes*. 2016;40(11):1809-1812.
20. Giné-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;18:21.
21. Guralnik JM, Ferrucci L, Simonsick EM, Salive ME, Wallace RB. Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *New Eng J Med*. 1995;332(9):556-562.
22. 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.
23. Gorman E, Hanson HM, Yang PH, Khan KM, Liu-Ambrose T, Ashe MC. Accelerometry analysis of physical activity and sedentary behavior in older adults: a systematic review and data analysis. *Eur Rev Aging Phys Act*. 2014;11(1):35-49.
24. Ricardo LIC, Wendt A, Galliano LM, et al. Number of days required to estimate objectively measured physical activity constructs in different age groups. *bioRxiv*. 2019.
25. Matthews CE, Chen KY, Freedson PS, et al. Amount of time spent in sedentary behaviors in the United States, 2003–2004. *Am J Epidemiol*. 2008;167(7):875-881.
26. Hirshkowitz M, Whiton K, Albert SM, et al. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. *Sleep Health*. 2015;1(1):40-43.
27. Bohannon RW, Wang YC, Gershon RC. Two-minute walk test performance by adults 18 to 85 years: normative values, reliability, and responsiveness. *Arch Phys Med Rehab*. 2015;96(3):472-477.
28. Reid KF, Fielding RA. Skeletal muscle power: a critical determinant of physical functioning in older adults. *Exerc Sport Sci Rev*. 2012;40(1):4-12.
29. Bohannon RW, Bubela DJ, Magasi SR, Wang Y-C, Gershon RC. Sit-to-stand test: Performance and determinants across the age-span. *Isokinet Exerc Sci*. 2010;18(4):235-240.
30. Springer BA, Marin R, Cyhan T, Roberts H, Gill NW. Normative values for the unipedal stance test with eyes open and closed. *J Geriatr Phys Ther*. 2007;30(1):8-15.
31. 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.
32. Smith L, Tully M, Jacob L, et al. The association between sedentary behavior and sarcopenia among adults aged ≥65 years in low- and middle-income countries. *Int J Environ Res Public Health*. 2020;17(5):E1708.
33. Santos DA, Silva AM, Baptista F, et al. Sedentary behavior and physical activity are independently related to functional fitness in older adults. *Exp Gerontol*. 2012;47(12):908-912.
34. McMullan II, Bunting BP, McDonough SM, Tully MA, Casson K. Changes in physical activity predict changes in a comprehensive model of balance in older community-dwelling adults. A longitudinal analysis of the TILDA study. *J Frailty Sarcopenia Falls*. 2019;4(4):102-110.
35. Steeves JA, Bowles HR, McClain JJ, et al. Ability of thigh-worn ActiGraph and activPAL monitors to classify posture and motion. *Med Sci Sports Exerc*. 2015;47(5):952-959.

36. Ekelund U, Steene-Johannessen J, Brown WJ, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *Lancet*. 2016;388(10051):1302-1310.
37. Ekelund U, Tarp J, Steene-Johannessen J, et al. Dose-response associations between accelerometry measured physical activity and sedentary time and all cause mortality: systematic review and harmonised meta-analysis. *BMJ*. 2019;366:l4570.
38. Chastin SF, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: A novel compositional data analysis approach. *PLoS One*. 2015;10(10):e0139984.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Wilson JJ, McMullan I, Blackburn NE, et al. Associations of sedentary behavior bouts with community-dwelling older adults' physical function. *Scand J Med Sci Sports*. 2020;00:1–10. https://doi.org/10.1111/sms.13827