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The interplay between lying, sitting, standing, moving, and walking on obesity risk in older adults: a compositional and isotemporal substitution analysis

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Abstract

Introduction Obesity in older adults is linked to various chronic conditions and decreased quality of life. Traditional physical activity guidelines often overlook the specific postures and movements that older adults engage in daily. This study aims to explore the compositional associations between posture-specific behaviours and obesity risk in younger (M = 67.35 ± 2.03 years) and older (M = 75.73 ± 4.17 years) groups of older adults and investigate the differences in body mass index (BMI) associated with replacing time spent in lying, sitting and standing with moving or walking.

Methods This cross-sectional study involved 309 older adults aged 65 and above from Czech Republic. Participants' movement behaviours, including lying, sitting, standing, moving, and walking, were measured using accelerometers. The data were analysed using compositional data analysis (CoDA) and isotemporal substitution models to assess the impact of reallocating time between different activities on self-reported (BMI).

Results The younger group engaged in more overall movement (193.84 min/day vs. 172.41 min/day) and walking (92.15 min/day vs. 76.62 min/day) than the older group. Significant estimated increases in BMI were associated with reallocating 30 min from movement to lying, sitting, or standing (up to + 3.31 kg/m^2), while reallocating the same amount of time from lying, sitting, or standing to movement was associated with estimated reductions in BMI (up to − 2.54 kg/m^2). In the older group, reallocating time from slow walking to lying or sitting was associated with estimated increases in BMI (up to + 1.86 kg/m^2), while increasing time spent slow walking at the expense of lying or sitting theoretically reduced BMI (up to − 0.95 kg/m^2).

Conclusions The findings suggest that promoting movement and walking, including both slow and fast walking, may play a role in managing obesity risk in older adults. This study highlights the potential benefits of reducing sedentary time and encouraging low-intensity physical activity tailored to the capabilities of seniors, especially those aged 70+, as a possible strategy to mitigate obesity risk. However, further longitudinal studies are needed to confirm these associations and explore causal relationships.

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Keywords backwards pivot coordinates, slow walking, standing, sitting, body mass index

Introduction

Obesity is a pervasive public health issue that affects individuals of all ages, including older adults [1]. In older adults, obesity is associated with a higher risk of chronic diseases [2], multimorbidity, functional decline [3], increased risk and severity of falls [4], and diminished quality of life [5]. To effectively prevent and manage obesity in older adults, it is crucial to adopt a physically active lifestyle that helps maintain muscle mass and increase energy expenditure.

During the past decade, a more comprehensive approach for describing a physically active lifestyle has been advocated, addressing various movement behaviours throughout the day, including physical activity, sedentary time, and sleep [6]. These behaviours are naturally interrelated and optimising the balance between them in 24-hour cycles is essential for health and well-being [7].

Prior articles focused on 24-hour behaviour primarily from the perspective of intensity, distinguishing between Sedentary Behaviour (SB), Light Physical Activity (LPA), and Moderate-to-Vigorous Physical Activity (MVPA), and sleep. This intensity-based classification provides valuable insights into variations in energy expenditure and is particularly beneficial for understanding health impacts of different activity levels, especially in older adults. However, these classifications fail to account for the postures in which these behaviours are performed. For instance, assessing SB based solely on intensity might misclassify postures like quiet standing as SB, despite differences in muscle activation and energy expenditure compared to actual sedentary postures like sitting or reclining. Yet, specific postures significantly influence energy expenditure, muscle function, and metabolic responses.

In contrast to the traditional intensity-based approach, posture-specific analyses offer an adaptable strategy that better accommodates the unique abilities and limitations of older populations. This posture-based methods are particularly valuable when designing interventions for older adults, as it addresses the challenge of incorporating physical activity within their capabilities. By reducing the bias inherent in intensity-based measures, posture-specific classifications provide an alternative view.

For instance, accelerometers commonly used in intensity-based studies do not distinguish between sitting and standing still, leading to measurement bias for SB and LPA [8]. Such biases may overestimate the relative contribution of MVPA over other movement behaviours. Using posture-specific measurements, future studies can provide a more accurate and balanced representation of all movement behaviours, improving the overall quality of evidence [9].

As the global population continues to age, with the number of individuals aged 60 and over projected to double by 2050 [10], this approach becomes increasingly justified. Older individuals often have varying degrees of mobility and different physical limitations compared to younger or more active populations [11]. Additionally in older populations, it is crucial to monitor walking, alongside other activities as it is a fundamental activity that significantly impacts overall health, mobility, and independence in seniors [12]. By focusing on posture and ensuring that walking is adequately incorporated and monitored, healthcare providers can tailor physical activity recommendations and interventions that are both safe and effective for older adults.

This paper seeks to delve into the interplay among lying down, sitting, standing, moving, and walking. Specifically, we will analyse posture-specific behaviours and their connection to obesity risk in younger and older groups of elderly. Through three compositions with 4, 5, and 6 components, each progressively detailing specific activities, we can comprehensively assess variations in daily activities and their health implications. The first composition includes lying, sitting, standing, and any form of movement. The second composition further breaks down movement into non-walking movement and walking. The third composition then differentiates walking into slow and fast walking. This approach allows for a nuanced understanding of how is each specific activity associated with BMI and obesity risk.

Through compositional and isotemporal substitution analyses, we intend to provide insightful perspectives for crafting targeted interventions tailored to the distinct needs of older adults. Therefore, the aims of this study are to:

A) describe posture-specific behaviours (lying, sitting, standing, moving and slow and fast walking) in younger and older groups of older adults;
B) examine the compositional associations between the 24-hour posture-specific behaviours and BMI; and
C) investigate the differences in BMI associated with replacing time spent in lying, sitting and standing with moving or walking.

Methods

Design and participants

The research protocol received ethical clearance from the Institutional Research Ethics Committee at the Faculty of Physical Culture, Palacký University Olomouc, under protocol number 08/2020 and 10/2021. Participants were engaged through telephonic communication, wherein they were comprehensively briefed about all facets of the study protocol. A pivotal aspect of the study's participation procedure involved procuring written informed consent from each participant. The cohort under investigation comprised senior citizens, aged 65 years and above, approached for participation between November 2020 and December 2023. Part of the data collection transpired during the period of enforced social distancing measures instated by the Czech Republic's government in response to the COVID-19 pandemic. Specifically, between November 2020 and December 2021, measurements were conducted only during intervals when gatherings (in small groups) were permitted.

A preliminary power analysis indicated that an alpha error of <0.001 and a statistical power of 95% required at least 250 participants in the final dataset to detect a medium effect ($f^2 = 0.15$) [13]. Based on our previous experience, we anticipated a ~ 25% loss of participants due to missing data; thus, we aimed to recruit at least 340 participants to ensure a sufficient sample size. A total of 416 older adults were involved in the study; however, only 382 completed the measurements. Notably, 73 participants did not adhere to the requisite criteria for a wear time of accelerometers (minimum 3 weekdays and 1 weekend day, with at least 16 h per day), thereby resulting in a final sample of 309 older adults. Participants for this study were recruited through several channels. We reached out to university students of the third age, members of senior clubs located in the Olomouc, Moravian-Silesian, and Zlín regions of the Czech Republic, and clients from the geriatric outpatient department at the Olomouc University Hospital, specifically as part of the prevention program "Nestárneme."

Measurements

Quantification of movement behaviours

In quantifying 24-hour movement behaviour, three accelerometers of distinct types were employed. All sensors were initialised on the same computer with the same time setting calibration. The different sampling rates were chosen according to the Acti4 manual and the authors' recommendations. The initial accelerometer, the ActiGraph wGT3X-BT (manufactured by ActiGraph Ltd., Pensacola, Florida, US), was affixed to the participants' right hip and functioned at a data collection frequency of 30 Hz, with a dynamic range spanning ± 8 g. Initialisation of the ActiGraph device was executed, and data retrieval was facilitated utilising ActiLife version 6.13.4 software. The unprocessed data was archived in the raw .gt3x format. This particular accelerometer furnished data pertaining to both the acceleration and movement of the torso. Participants were instructed to wear sensor for 7 days and remove it only during sleep and water activities to ensure comprehensive data collection throughout the study.

Two additional accelerometers, the Axivity AX3 devices (developed by Axivity Ltd., Newcastle, UK), were secured to the right thigh and non-dominant wrist. These devices operated at a data sampling frequency of 25 Hz and boasted a dynamic range spanning ± 8 g. Setup and data acquisition for the Axivity devices were accomplished via the utilisation of OmGui open-source software (OmGui Version 1.0.0.37, Open Movement, Newcastle, UK), and the stored data was saved in the.cwa format. These accelerometers facilitated the collection of data pertaining to the movement of the lower and upper limbs. Participants were instructed to wear the sensors continuously for 7 days and 7 nights, excluding water activities.

The accelerometers were fitted during personal meetings at the university faculty or university hospital, arranged by telephone based on participants' confirmation. The devices were returned either in person or anonymously in an envelope to the nursing staff or reception.

The software employed, Acti4 (developed by The National Research Center for the Working Environment in Copenhagen, Denmark, and BAuA in Berlin, Germany), facilitated the concurrent processing of data from all employed accelerometers. This software facilitated the derivation of comprehensive descriptions concerning the nature and positioning of physical activities. The initial step entailed the conversion of raw data to the .acti4 format, which was then subjected to analytical scrutiny based on accelerometer inclinations and accelerations.

Since activities such as running, cycling, and "other activity" were rarely observed in this older population sample, resulting in frequent zero values, we combined them into a "move" category. This approach enhanced the robustness of the analysis, allowing us to focus on the most consistently observed movement behaviours within this demographic. Sleep and awake lying were combined into a single 'lying' category in our analysis. Definitions of posture-specific movement behaviours are in Table 1.

Obesity indicator

Body Mass Index (BMI) was calculated from self-reported body weight in kilograms divided by self-reported body height in meters squared. For sample description, BMI was categorised as 'normal' weight (18.5–24.9 kg/m2), overweight (25–29.9 kg/m^2) and obesity (≥30 kg/m^2) [15].

Statistical analysis

Statistical analysis was performed using the R Statistical Software, version 4.4.0 (The R Foundation for Statistical Computing) using the robCompositions [16] package, and the IBM Statistical Package for the Social Sciences software, version 23 (SPSS Inc., an IBM Company,

Table 1 Definition of movement behaviour types [14]

Type:	Definition:
LIE	Length of periods lying. Lying is detected if the thigh inclination is above 45°and also the hip inclination is above 65°.
SIT	Length of sitting periods. Sitting is detected if the inclination of the thigh is above 45 and lying is not detected.
STAND	Length of periods standing still. Still standing is detected if the inclination of the thigh is less than 45 and no movement of the thigh is detected.
MOVE	Length of periods moving. This is an activity used if none of the non-moving activities lying, sitting, or standing is detected. It will normally correspond to every move, including walking, running, cycling, or sports activities.
MOVE-WW	Length of periods moving. This is an activity used if none of the non-moving activities lying, sitting, or standing is detected. It will normally correspond to every move, including running, cycling, or sports activities, without walking (WW).
WALK	Length of periods walking. Walking is detected if the standard deviation on the longitudinal axis of the thigh is between 0.1G and 0.72G.
SLOW WALK	Length of periods with walking speed less than 100 steps pr. minute.
FAST WALK	Length of periods with walking above (or equal) 100 steps pr. minute (only the activity walk is used for this calculation, periods with run is not included).

Armonk, NY, USA). To examine the association between BMI and the posture-specific 24-hour movement behaviour compositions, the approach of compositional data analysis (CoDA) [17] was employed. Movement compositions were mapped into real Euclidean space using specific isometric log-ratio coordinates known as backwards pivot coordinates (BPC) [18], which enable the use of simpler pairwise logratios. We conducted multivariate robust compositional regression analyses with posture-specific movement behaviours as explanatory variables and BMI as a dependent variable. The construction of BPCs and interpretation of regression analysis can be found in Nesrstová et al. [19].

The regression models were applied for two age groups of older adults: "younger" (65–69.99 years, $n=147$) and "older" (70+years, $n=162$). The age of 70 was selected as the cut-off based on previous research indicating significant changes in movement behaviours and functional fitness occurring around this age [20, 21].

They were adjusted for sex, age, season and periods (Covid and after Covid) categories of data collection and applied for three different 24-hour compositions with 4, 5, and 6 components, each progressively detailing specific activities:

Composition 1: This composition includes all basic activities, encompassing lying, sitting, standing, and general movement.

Composition 2: This composition covers the basic activities of lying, sitting, and standing, but excludes walking from the movement category. Instead, it focuses specifically on non-walking movement activities, distinguishing between non-walking movement and walking.

Composition 3: In this composition, the basic activities (lying, sitting, standing) are considered along with more detailed distinctions within movement activities. It differentiates between slow walking, fast walking, and movement without walking.

To determine how reallocations of time affect changes in BMI, a compositional isotemporal substitution analysis based on BPCs was used. One-for-one reallocations were utilised to evaluate the theoretical impact on BMI – the time was reallocated between two components of the time-use composition (e.g., from SIT to LIE and vice versa), using the mean baseline composition as a starting point. Hereby the usual additive reallocation [22] was conducted, but the effect of this reallocation can now be potentially assessed in terms of pairwise logratios, i.e. elemental information in compositional data [22]. A 10-minute reallocation was initially chosen as a baseline, as this is a common standard in similar studies and provides a practical starting point. To maintain realistic and manageable reallocations, the duration was then increased up to a maximum of 30 min, but only for specific categories. This approach was chosen to avoid potential extrapolation and to ensure that the reallocations remain within a plausible range. The significance level for the predicted changes was set at $p<0.05$.

Results

Sample characteristics

The main characteristics for younger (years M=67.35±2.03) and older (years M=75.73±4.17) groups are shown in Table 2. There are comparable body weights, body heights and BMI across the age groups. Looking at the 24-hour composition, the younger group generally engages in more physical activity, particularly in general movement and walking, compared to the older group. This reduction in physical activity with age is significant in overall movement and particularly in fast walking.

Association between BMI and posture-specific movement-behaviour compositions

Table 3 summarises the regression results for the younger and older groups of older adults across all three compositions. In this table, there are shown the associations for pairwise logratios, which include all possible combinations within the given composition. The regression results for such as pairwise logratio SIT/LIE are interpreted such that an increase in sitting at the expense of an equivalent decrease in lying, leads to a positive or negative change in BMI.

Table 2 Sample characteristics

	Younger group $n = 147$		Older group $n = 162$		
	MEAN	*SD*	*MEAN*	*SD*	*p*
Age [years]	67.35	2.03	75.73	4.17	< 0.001
Body weight [kg]	77.67	14.84	77.36	13.62	0.852
Body height [cm]	167.84	9.06	166.73	7.74	0.25
Body mass index [kg/m^2]	27.52	4.48	27.8	4.43	0.576
BMI CATEGORIES ((N (%))					
Normal weight	43 (29.2)		46 (28.4)		
Overweight	68 (46.3)		71 (43.8)		
Obese	36 (24.5)		45 (27.8)		
Movement behaviour (24 h)[a]					
Lie [min/day]	616.77	100.88	620.10	104.15	0.776
Sit [min/day]	423.50	107.82	439.04	124.62	0.245
Stand [min/day]	205.88	62.39	208.45	71.28	0.738
Move [min/day]	193.84	63.75	172.41	58.55	0.002
• Move-WW [min/day]	101.69	36.38	95.79	35.03	0.149
• Walk [min/day]	92.15	37.13	76.62	34.77	< 0.001
o **Slow Walk [min/day]**	25.68	13.51	25.24	15.85	0.809
o **Fast Walk [min/day]**	66.47	30.11	51.38	28.45	< 0.001

SD – standard deviation, BMI – body mass index, $p < 0.05$, MOVE-WW – move without walk

a Values are presented as robust compositional mean and variance expressing the total variance related to a given time-use component

In younger group, we found significant associations in logratio MOVE/LIE (−7.85, $p < 0.001$) and MOVE/SIT (−7.17, $p < 0.001$). Moreover, significant negative associations with BMI were found in logratio STAND/SIT (Estimate: -2.92, p-value: 0.021) and surprisingly with logratio MOVE/STAND (Estimate: −4.25, p-value: 0.028). In second composition distinguishing between non-walking and walking movement, significant negative associations with BMI were seen in logratios such as WALK/LIE (−3.06, $p = 0.038$), MOVE-WW/LIE (−8.01, $p = 0.002$), MOVE-WW/SIT (Estimate: −7.27, p-value: <0.001), WALK/SIT (Estimate: −2.31, p-value: 0.025) and MOVE-WW/STAND (Estimate: −4.99, p-value: 0.032). Positive associations with BMI are observed in logratio WALK/MOVE-WW (4.96, $p = 0.007$). Based on third composition showing detailed differentiation including walking intensity, both logratios SLOW WALK/LIE (−2.85, $p = 0.030$) and FAST WALK/SIT (Estimate: −2.46, p-value: 0.041) are negatively associated with BMI. Surprisingly, positive associations with BMI were found in logratios SLOW WALK/MOVE-WW (Estimate: 5.22, p-value: 0.008) and FAST WALK/MOVE-WW (Estimate: 4.85, p-value: 0.004).

In older group, the significant negative association with BMI was found in the logratio MOVE/SITTING (−4.86, $p = 0.001$) in first composition. Significant negative association with BMI was confirmed in second composition in WALK/SIT (−3.38, $p = 0.008$) and MOVE-WW/SIT (Estimate: −2.89, p-value: 0.093) logratios. In composition three, the increase of SLOW WALK at the expense of SIT shows a significant negative association with BMI (−2.68, $p = 0.026$) and similar negative association is noted for logratio FAST WALK/SIT (−2.76, $p = 0.027$).

Reallocations across various movement behaviours with the effects on BMI

Figures 1 and 2 show the results of the analysis of 10, 20, and 30-minute reallocations across various movement behaviours and the associated BMI measurements in both younger and older groups, respectively. The underlying values from which the figures were obtained can be found in the Appendix 1, 2 and 3. In younger group, significant increases in BMI were found in increasing LIE, SIT and STAND at the expense of MOVE-WW, particularly at 30 min, with values reaching 3.29, 3.31 and 3.05 kg/m^2, respectively. Conversely, significant decreases in BMI were found when reallocating time to MOVE-WW instead of LIE, SIT, and STAND, with the largest reductions observed at 30 min (−2.51, −2.54 and −2.26 kg/m^2, respectively). Furthermore, significant increases in BMI were noted when reallocating from MOVE-WW to SLOW WALK and FAST WALK, particularly in 30 min, with values 3.26 and 2.89 kg/m^2, respectively. In contrast, a 20-minute reallocation from SLOW WALK to MOVE-WW was associated with a −2.0655 kg/m^2 reduction in BMI, and a 30-minute reallocation from FAST WALK to MOVE-WW was linked to a BMI decrease of −2.00 kg/m^2.

The older group exhibited similar trends but with generally smaller changes in BMI. For example, reallocating time to LIE and SIT at the expense of SLOW WALK showed an increase in BMI, particularly at 20 min (1.74, 1.86 kg/m^2, respectively), while reallocating time to SLOW WALK at the expense of LIE and SIT was associated with BMI reductions, particularly in 30 min (−0.77 and −0.95 kg/m^2, respectively). Consistent with the younger group, transitions from more active to less active states (e.g., from MOVE-WW to SIT, from FAST WALK to LIE) showed an increase in BMI, while transitions from sedentary to more active states (e.g., from SIT to MOVE-WW, from SIT to FAST WALK) were associated with BMI reductions. In opposite to younger group, there were found significant decreases of BMI in 20 min transitions from SLOW WALK to STAND and SLOW WALK to MOVE-WW (−1.51, −1.48, respectively).

Discussion

This study examined the associations of different compositions of 24-hour movement and non-movement behaviours with BMI across two age groups: the younger and older groups of older adults. The findings suggested that

Table 3 Association between BMI and posture-specific movement behaviour compositions

	Younger group			Older group		
	Estimate	*Std. Error*	*p-value*	*Estimate*	*Std. Error*	*p-value*
Composition 1						
SIT/LIE	-0.68	2.13	0.749	1.22	2.18	0.576
STAND/LIE	-3.60	2.21	0.106	-1.94	2.02	0.339
MOVE/LIE	-7.85	2.08	< 0.001	-3.64	1.86	0.052
STAND/SIT	-2.92	1.25	0.021	-3.16	1.81	0.083
MOVE/SIT	-7.17	1.28	< 0.001	-4.86	1.48	0.001
MOVE/STAND	-4.25	1.91	0.028	-1.71	2.24	0.448
Composition 2						
SIT/LIE	-0.74	2.14	0.728	1.61	2.16	0.458
STAND/LIE	-3.03	2.15	0.160	-1.94	2.09	0.354
MOVE-WW/LIE	-8.02	2.56	0.002	-1.28	2.05	0.532
WALK/LIE	-3.06	1.46	0.038	-1.77	1.50	0.239
STAND/SIT	-2.29	1.40	0.105	-3.55	1.93	0.068
MOVE-WW/SIT	-7.27	1.48	< 0.001	-2.89	1.71	0.093
WALK/SIT	-2.32	1.02	0.025	-3.38	1.26	0.008
MOVE-WW/STAND	-4.99	2.30	0.032	0.66	2.37	0.781
WALK/STAND	-0.03	1.22	0.980	0.17	1.74	0.923
WALK/MOVE-WW	4.96	1.81	0.007	-0.49	1.82	0.787
Composition 3						
SIT/LIE	-0.76	2.14	0.723	1.44	2.22	0.517
STAND/LIE	-3.08	2.28	0.179	-2.04	2.12	0.338
MOVE-WW/LIE	-8.07	2.52	0.002	-1.43	2.05	0.486
SLOW WALK/LIE	-2.85	1.30	0.030	-1.23	1.54	0.426
FAST WALK/LIE	-3.22	2.23	0.150	-1.32	1.46	0.369
STAND/SIT	-2.32	1.40	0.100	-3.48	2.01	0.085
MOVE-WW/SIT	-7.31	1.45	< 0.001	-2.87	1.75	0.102
SLOW WALK/SIT	-2.09	1.33	0.119	-2.68	1.19	0.026
FAST WALK/SIT	-2.46	1.19	0.041	-2.76	1.23	0.027
MOVE-WW/STAND	-4.99	2.24	0.027	0.61	2.35	0.795
SLOW WALK/STAND	0.23	1.65	0.889	0.81	1.60	0.616
FAST WALK/STAND	-0.14	1.37	0.917	0.72	1.82	0.692
SLOW WALK/MOVE-WW	5.22	1.93	0.008	0.20	1.57	0.900
FAST WALK/MOVE-WW	4.85	1.65	0.004	0.11	1.73	0.948
FAST WALK/SLOW WALK	-0.37	1.92	0.846	-0.09	1.09	0.938

The significance level for the predicted changes was set at $p < 0.05$. In this table, there are shown the associations for pairwise logratios, which include all possible combinations within the given composition. The regression results for such as pairwise logratio SIT/LIE are interpreted such that an increase in sitting at the expense of an equivalent decrease in lying, leads to a positive or negative change in BMI

an increase in any kind of moving or walking, regardless of intensity, at the expense of low-energy activities such as lying down, sitting, and standing, was associated with a significant reduction in BMI in older adults. Our results are consistent with previous studies that examined the association between intensity-based movement behaviour composition and adiposity measures such as BMI, waist circumference, waist-to-hip ratio, and body fat [23–25]. These studies indicated that obesity-related outcomes improved as the relative contribution of MVPA to the 24-hour movement behaviour composition increased. Conversely, reallocating sedentary time to physical activity may be associated with reduced BMI, body fat percentage, and waist circumference in all age groups, with the magnitude of associations being greater for higher intensities of physical activity.

The study reveals several critical differences between the younger (65–69.99 years) and older (70+years) age groups in terms of movement patterns and their associations with BMI. Notably, an increase in any kind of movement or walking, regardless of intensity, at the expense of low-energy activities such as lying down, sitting, and standing was associated with a significant reduction in BMI in the younger group. In contrast, for the older group, significant results were fewer and primarily involved transitions such as moving to sitting and walking (both fast and slow) to sitting. This suggests that older adults show stronger associations between changes in sedentary behaviour and walking, which aligns with their

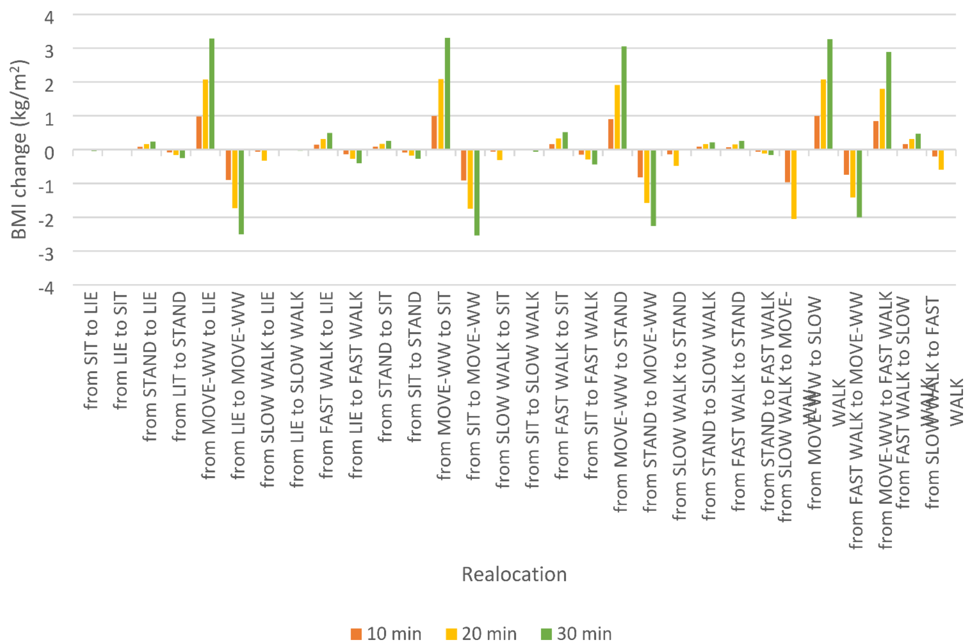

Fig. 1 10, 20, and 30 min reallocations across various movement behaviours and the associated BMI changes in younger group

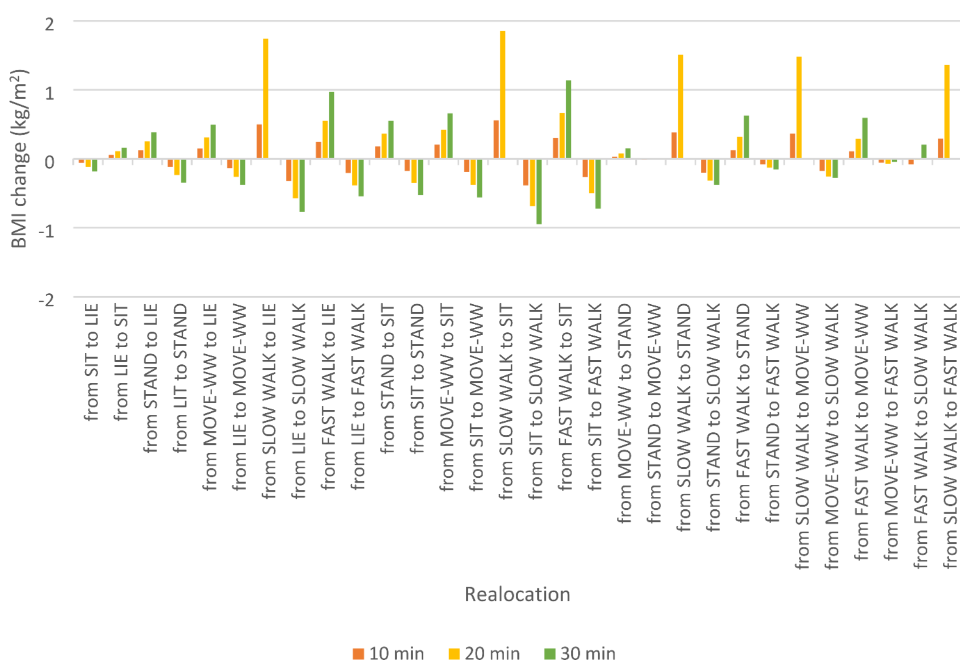

Fig. 2 10, 20, and 30 min reallocations across various movement behaviours and the associated BMI changes in older group

physical capabilities. This clearly indicates that while younger individuals experience a wider range of transitions across 24 h, older individuals' 24-hour patterns are more concentrated in specific activities like sitting and walking. This highlights the importance of focusing on reducing sedentary behaviour and promoting walking as key areas for intervention in older adults.

Moreover, the younger group exhibited stronger BMI responses to changes in movement patterns, suggesting a higher metabolic responsiveness compared to the older group. The observed differences between the younger and older groups can be partly attributed to age-related metabolic changes. As individuals age, basal metabolic rate tends to decline, primarily due to a reduction in lean muscle mass [26]. This decrease in metabolic rate, coupled with changes in hormone levels and an increased propensity for fat accumulation, particularly visceral fat, likely contributes to the less pronounced BMI changes in response to movement observed in the older group [27].

In the younger group, we found interesting results related to standing within a 24-hour period. Based on Composition 1, time spent standing at the expense of sitting was associated with a decrease in BMI. Additionally, an increase in time spent moving at the expense of standing was also associated with a decrease in BMI. This suggests that even minor increases in energy expenditure (for instance, standing instead of sitting) or activity intensity can lead to increased calorie expenditure and potential weight loss, highlighting the importance of maintaining consistent activity levels. A positive association between BMI and standing time was confirmed in other studies in older adult populations, corresponding to our younger group [28].

In older group, transitions from slow walk to lie, sit or stand were associated with the highest increases of BMI and underscore the importance of specifically slow walking for this 70+aged group. Therefore, strategies should focus on encouraging sustained physical activity and preventing reductions in activity intensity, even from moderate activities like slow walking.

The study revealed some unexpected results, particularly in the younger group, concerning the transitions between different posture-specific 24-hour behaviours and their effects on BMI. The unexpected finding that increasing time spent in slow or fast walking at the expense of non-walking movement is associated with an increase in BMI suggests that not all types of movement are equally beneficial. This result is counterintuitive as it implies that some activities categorised under "moving" may be more vigorous than walking, leading to increased calorie expenditure and potential weight reduction. This emphasises the need for precise categorisation and communication of activity type and intensity in health recommendations, as not all physical activities contribute equally to energy expenditure and effective weight management.

Additionally, reductions in slow walking may have a greater impact on BMI than reductions in fast walking, likely because slow walking is a more consistently practiced baseline activity among seniors. Although fast walking has a higher intensity, it is performed less consistently across participants and thus could have a smaller impact on BMI. Moreover, the moving category includes higher-intensity activities, such as cycling, which may contribute to greater energy expenditures. Reallocating time from these high-intensity activities to walking could decrease overall energy expenditure, potentially increasing BMI. These observations underscore the nuanced role that different activity types play in managing BMI and reinforce the importance of maintaining consistent physical activity for seniors.

Strengths and limitations

This study offers several key strengths. The first one is the detailed analysis of specific types of posture-specific movements, including different walking intensities, adds valuable and new insights. Secondly, the use of multiple accelerometer-based assessments provided precise, objective data on 24-hour posture-specific behaviours, surpassing the reliability of self-reported data. Thirdly, by including both younger and older groups, the study effectively highlights age-related differences in metabolic responses to physical activity. Additional strength is related to statistical approach. The backwards pivot coordinates approach used in this paper provides an orthonormal alternative to the classic additive log-ratio coordinates, making the interpretation of results straightforward for all practitioners. Due to orthonormality of bpc, the results are consistent and reliable [18, 29].

Despite its strengths, the study has several limitations. The cross-sectional design limits the ability to establish causal relationships between posture-specific behaviours and BMI changes, as it captures only a snapshot in time rather than long-term effects and introduces the possibility of reverse causality. In this age group, healthier older adults with lower BMI may be more capable of engaging in higher levels of physical activity, particularly walking, rather than increased physical activity leading to lower BMI. Additionally, part of the data collection occurred during the COVID-19 pandemic, which may have influenced participants' movement behaviours and BMI due to enforced social distancing measures and restrictions on gatherings. Moreover, the categorisation of activities used in our compositions might not fully capture the complexity and variability of real-life movement behaviours, particularly strength training activities, which can significantly affect body composition and BMI but are not well represented in posture-based classifications. Another limitation is the reliance on self-reported BMI, which may introduce bias due to inaccuracies in self-reporting or misreporting of height and weight. Moreover, while we controlled for key demographic and seasonal covariates, the absence of data on socioeconomic status (SES) and dietary factors may limit our ability to account for all potential influences on movement behaviours and BMI. The absence of detailed adiposity measures beyond BMI, such as body fat percentage, limits our understanding of participants' body composition. Moreover, BMI is a complex health indicator in older adults. Research indicates that higher BMI can sometimes be associated with decreased all-cause mortality, known as the "obesity paradox" [30, 31]. This suggests that BMI alone may not fully capture health risks or benefits related to body composition in this population. Therefore, our reliance on BMI without additional measures of body composition or functional health status may limit the interpretation of our findings. Future studies should consider incorporating comprehensive assessments of adiposity and health indicators specific to older adults. The study's sample size, though adequate, may limit the generalisability of the findings to broader populations. Future research with larger, more diverse samples and longitudinal designs would help to confirm these findings, address the issue of reverse causality, and further explore the nuances of posture-specific behaviour's impact on BMI.

Conclusion

The study found that higher levels of movement or walking, regardless of intensity, are significantly associated with lower BMI in older adults, with a stronger association observed in younger older adults. Our findings indicate that adults aged 70 and above show stronger associations between changes in sedentary behaviour, walking, and BMI compared to younger elderly adults, highlighting the importance of reducing sedentary time and promoting even slow walking. The findings emphasize the need for precise categorization and communication of activity type and intensity in health recommendations, as not all physical activities contribute equally to energy expenditure and weight management.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Author contributions

J.P. conceived the idea for this study, contributed to acquisition, analysis and interpretation of data, and wrote the main manuscript text. J.V. was mainly involved in data collection and data procession, prepared the Tables 1, 2 and 3; Figs. 1 and 2, and critically revised the manuscript. P.J. analyzed data, contributed to the interpretation of data and critically revised the manuscript. K.H. helped conceptualize the study idea, contributed to methodology of data analyses, and critically revised the manuscript.

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Data availability

The dataset generated during and analyzed during the current study is available in the Figshare repository, https://doi.org/10.6084/m9.figshare.26562718.

Declarations

Ethics approval and consent to participate

All participants were informed that their participation was voluntary and that they could withdraw from the study at any time. They provided their written informed consent before participating in measurements. All methods were carried out in accordance with relevant guidelines and regulations. The study was approved by the Institutional Research Ethics Committee, Faculty of Physical Culture, Palacký University Olomouc (Ref. No. 08/2020 and 10/2021).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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