The Associations of Activity Fragmentation with Physical and Mental Fatigability among Community-Dwelling 75-, 80- and 85-Year-Old People

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Abstract

Background

Fatigue related to task standardized by duration and intensity, termed fatigability, could manifest as shortening of activity bouts throughout the day causing daily activity to accumulate in a more fragmented pattern. Our purpose was to study the association of activity fragmentation with physical and mental dimensions of fatigability.

Methods

A cross-sectional study of 485 community-dwelling 75-,80- and 85-year-old people using a thigh-worn accelerometer for 3 to 7 days. Activity fragmentation was studied as Active-to-Sedentary Transition Probability (ASTP) for two operational definitions of physical activity: accelerations equivalent to at least light physical activity, and for upright posture. Physical fatigability was assessed as perceived exertion fatigability, performance fatigability severity, and with the Physical Fatigue Subscale of the Situational Fatigue Scale (SFS). Mental fatigability was assessed with the Mental Fatigue Subscale of the SFS and as a decrease in perceived mental alertness after a six-minute walk test (6MWT).

Results

Higher activity fragmentation was associated with higher self-reported physical fatigability, perceived exertion fatigability and performance fatigability severity, independent of total activity minutes (β 0.13-0.33, $p<0.05$ for all). Higher activity fragmentation was not associated with mental fatigability in the fully adjusted models. The associations with fatigability indices were similar for both activity fragmentation indicators. Associations of activity fragmentation and performance fatigability severity were similar also among those with the highest intensity-based physical activity volume.

Conclusions

The findings provide support that studying fragmented activity patterns can be useful in identifying those at risk for high fatigability, even among those with relatively high physical activity level.

Keywords: Activity patterns, adaptive strategies, fatigue, physical activity

Introduction

Fatigue is a common symptom among older people. It may be described as a subjective and unpleasant symptom which interferes with an individual's ability to function at their normal level and manifests as feelings ranging from tiredness to exhaustion (1). Fatigue is a commonly reported barrier to physical activity and a reason for restricted activity (2,3). With advancing age and decline in health, different daily activities may become increasingly fatiguing (4,5). Fatigability refers to fatigue related to a specific task, which is standardized by duration and intensity (6). Assessments of fatigability can be divided into perceived fatigue and performance fatigability, the latter referring to the magnitude of decrease in task performance (7). These assessment methods can be applied to different domains of fatigability, including physical and mental fatigability (7). People with higher fatigability may start modifying their physical activity behavior by pacing, resting, conserving energy and avoiding fatigue-inducing activities in an attempt to remain below their fatigue threshold (5,6,8) while continuing their participation in specific activities (9). Adaptive behaviors occurring in the early phase of fatigability could potentially manifest as shortening of activity bouts throughout the day (10).

In old age, when functional capacity declines, activity patterns often become more fragmented, as maintaining longer bouts of physically demanding activities gets progressively harder (10,11). More fragmented patterns of physical activity are associated with lower functional ability (10), higher mortality risk, (12) and higher physical fatigability

(10). People perceiving higher physical fatigability are less physically active (13) and at an increased risk of decline in physical function (14). However, studies on the associations of activity fragmentation with a more comprehensive range of fatigability measures, including performance fatigability severity, are lacking.

Fatigability has also mental and emotional dimensions (5). Perception of physical fatigue can be described as perceived lack of physical energy, whereas mental fatigue can be characterized as perceptions of ie. mental tiredness or lack of energy to think (5). However, previous studies among older people have thus far mainly focused on physical fatigability (10,13,14). Thus, less is known about the relationship between physical activity and mental fatigability. A recent concept analysis of fatigability suggested that the perception of fatigue is not domain-specific, i.e., mental fatigue could also be induced by physical activity, and vice versa (5). This concept is supported by an earlier finding showing that higher mental fatigability was associated with a steeper decline in physical function (15). Higher mental fatigue may also lead to increased perceived effort in performing physical activity (16), and may therefore concur with more fragmented patterns of physical activity.

Accelerometers are commonly used in measuring bouts of movement and non-movement in free-living conditions. However, the usefulness of categorizing accelerometer-data based on intensity-levels among older people has been contested in recent years (17). While the absolute intensity of physical activity often declines with age, for those with reduced physical capacity the relative intensity (i.e. effort with respect to capacity) of daily activities may become higher (18,19). Similarly, for those with slower walking speed, the energetic cost of walking is often higher (20) and therefore they may not be capable of performing activities classified as vigorous based on absolute intensity. Furthermore, accelerometers may be limited in their ability to detect light intensity activities (17,21). Possible solutions to these issues could be to study activity fragmentation based on movement of at least low absolute intensity (10,22) or solely on posture estimation. Posture estimation can be useful in evaluating physical behavior among older adults and can be accurately measured even among frail older people (23). Sedentary behavior can be defined as activities that are ≤1.5 MET and performed in a sitting, reclining or lying posture (24). On these premises, any activity performed in an upright posture, including standing, that has an energy consumption of >1.5 MET will be categorized as active behavior (24). Most standing activities have been shown to have an energy consumption of >1.5 MET (25), and therefore activity could be categorized into sedentary and non-sedentary based solely on posture. However, this has not been systematically studied in population-based samples of older people.

In the present study, we explored whether higher activity fragmentation is associated with physical and mental dimensions of fatigability among community-dwelling 75-, 80-, and 85-year-old people. We hypothesized that higher activity fragmentation is associated with more pronounced mental and physical fatigability. We measured activity fragmentation in two ways. First, it was assessed as Active-to-Sedentary Transition Probability (ASTP) based on acceleration bouts equivalent to at least light physical activity. Second, to introduce a possible alternative for intensity-based assessments, we assessed it based on ASTP based on upright posture.

Methods

Study design and participants

The present study is a part of the “Active Aging – resilience and external support as modifiers of the disablement outcome” (AGNES) project. The study protocol has been reported in detail elsewhere (26). Briefly, participants were 75-, 80- and 85-year-old people residing in the Jyväskylä area in Central Finland and were recruited from the Finnish Population Register Centre. A total of 1 021 people took part, of whom 495 wore a tri-axial accelerometer (range ±16 g, 13-bit analog-to-digital conversion, sampled at 100 Hz, UKK RM42, UKK Terveyspalvelut Oy, Tampere, Finland) for 7 to 10 consecutive days following a home interview (27). In addition, participants completed a postal questionnaire and participated in assessments at the research center. In the current analyses, we included participants with at least three days of valid accelerometer data (n=485). The study protocol followed the principles of the Declaration of Helsinki. The AGNES study has been approved by the Ethical Committee of the Central Finland Health Care District. All participants signed a written informed consent.

Self-reported physical and mental fatigability in daily life

We measured fatigability in daily life with a Finnish version of the Situational Fatigue Scale (SFS) (28) during a face-to-face interview. The scale was translated into Finnish and the translation was carefully evaluated by the research group. Participants were asked to report on a 6-point scale (0=not fatigued at all, 5=extremely fatigued) how fatigued they get after performing different specific activities (e.g., taking a walk for 1 hour, jogging for 20 minutes, hosting a social event for 30 minutes, watching TV for 2 hours). The physical activity items were used to form a Physical Fatigue Subscale (PFS, 4 items, range 0-20) and the mental activities to form a Mental Fatigue Subscale (MFS, 9 items, range 0-45) (28).

Non-drivers were not asked the question about fatigability after driving for an hour (n=128). Furthermore, 114 participants (23%) had at least one missing item on the PFS and 28 (6%) at least one other missing item on the MFS. Items with the most missing data were self-reported fatigue after jogging for 20 minutes (n=107) or playing a ball game for 30 minutes (n=89). We imputed missing data with the multiple imputation (MI) procedure in SPSS. Imputation was done based on responses to other items on the SFS, self-reported walking ability and modifications in climbing a flight of stairs and walking distances of 2km and 500m, self-rated health, three IADL functions, three items from the Center for Epidemiologic Studies Depression Scale (CES-D) scale and perception of sufficient health to go out and about (eTable1 in the Supplement). Activity fragmentation was also added to the imputation model, as the inclusion of predictors in imputation models has been shown to lead to less biased estimates (29). We created 20 datasets of imputed values, and pooled results were reported for the corresponding analyses.

Perceived exertion fatigability and mental fatigability after a 6MWT

Participants completed a modified 6MWT at the research center. They walked 40-m laps for six minutes in an indoor corridor at their usual walking pace. Participants were allowed to use a walking aid, if necessary. Perceived exertion fatigability was assessed using a modified version of a method validated by Murphy and colleagues (30). Perceived exertion was assessed using the Borg scale (RPE, range 6-20, 6=no exertion, 20=completely exhausted) before and after completing the 6MWT (31). *Perceived exertion fatigability* was then calculated by dividing RPE at the end of the 6MWT by RPE at the beginning of the walk, and further dividing the result by meters walked during the 6MWT. The result was then multiplied by 1000, for reporting purposes. *Perceived mental fatigability* was assessed as perceived mental alertness both prior to and after the 6MWT using a modified version of a seven-point Likert scale (1=mentally exhausted, 7=very alert and energetic) introduced by Schnelle and colleagues (32). Participants were dichotomized into those who felt mentally less alert after the 6MWT than before performing the test, and those who felt more energetic or reported no change.

Performance Fatigability Severity

Performance fatigability severity was assessed during the 6MWT. We assessed the proportion of change in lap times between the second and the second-to-last 40-m lap, relative to walking speed during the entire 6MWT. This was done to account for potential faster-than-average starting during the first lap and anticipation of the finish during the last lap (33). Performance fatigability severity was then calculated by using a modified version of method introduced by Schnelle and colleagues (32) and has been further validated for the 6MWT (30). We modified the method to better incorporate slowing down of performance into the formula. Our calculation was done by dividing the second-to-last lap time (s) by the second lap time (s). The result was further divided by the total distance walked (m) during the 6MWT to account for walking speed, and multiplied by 1000 for reporting purposes. Higher performance fatigability severity scores indicate more slowing down of performance relative to walking speed.

Activity fragmentation

Activity fragmentation data were derived from the accelerometer recordings. Accelerometers were attached to the participants´ dominant thigh with self-adhesive film. Although the film was waterproof, longer water-related activities such as swimming or taking a bath or sauna were not recommended while wearing the monitor. Participants completed an activity diary in which they reported any potential breaks in wearing the accelerometer and engaging in physical activities other than walking (26).

The method for physical activity quantification and posture estimation based on accelerometer recordings have been reported elsewhere (27). Briefly, the resultant accelerations were calculated for sampling instants and mean amplitude deviation (MAD) for non-overlapping 5-s epochs. Mean daily minutes spent in at least light activity was based on a MAD value of at least 16.7 mg which has been shown to differentiate typical sedentary tasks from slow walking (34). Posture estimation was done following the approach by Vähä-Ypyä and colleagues (35). Postures were categorized into two categories: either sitting or lying down, and upright. Posture categories for each 5-s epoch were then identified. The median posture category for each minute of recording was then used to calculate mean daily minutes spent in an upright posture (27). Accelerometer recordings were then used to determine active time based on intensity (at least light activity) and posture (standing still or moving in an upright posture). Based on the recordings, mean minutes of daily active time, mean number of active daily bouts and mean bout duration in minutes based on both intensity (MAD-activity) and posture criteria (Posture-activity) were recorded.

Activity fragmentation was assessed as ASTP (10,22). ASTP was calculated separately for mean daily minutes based on MAD values classified as at least light activity (MAD-ASTP) and mean daily minutes spent in an upright posture (Posture-ASTP). This was done by dividing mean active daily bouts by the mean sum of active daily minutes (22). MAD-ASTP and Posture-ASTP were categorized into tertiles for group comparisons. In all other analyses, MAD-ASTP and Posture-ASTP were used as continuous variables. Higher values in MAD-ASTP and Posture-ASTP indicate higher activity fragmentation. Results are reported per 0.1-point increase in the ASTP measures.

Covariates

Covariates were selected based on existing literature and their association with at least one of the predictors and the outcome variables. Age and sex were derived from the population register. Total years of full-time education were self-reported. Lower extremity function was measured with the Short Physical Performance Battery (SPPB, range 0-12; higher scores indicate better lower extremity function). The test includes balance, walking speed and chair stands (36). Global cognitive function was assessed with the Mini Mental State Examination (MMSE, range 0-30; higher scores indicate better cognitive function) (37). Depressive symptoms were measured with the CES-D Scale (range 0-60; higher scores indicate more depressive symptoms) (38). Self-reported physician-diagnosed chronic conditions were ascertained with a help of a list of common chronic conditions. For each condition, participants were asked whether a doctor has told them that they have that condition. Physician-diagnosed chronic conditions that were not included in the list were asked with additional open-ended questions (26). Number of chronic conditions was then calculated as the sum of individual chronic conditions. In addition, accelerometer-based mean Posture-activity and MAD-activity minutes were used as covariates.

Statistical methods

Descriptive statistics by tertiles of ASTP included percentages for categorized variables and means with standard deviations for continuous variables. Group differences were analyzed with chi-square test for categorical variables, one-way ANOVA for normally distributed continuous variables and Kruskal-Wallis test for non-normally distributed continuous variables. We used linear regression analysis to study associations of activity fragmentation and the continuous fatigability measures. Preliminary analyses suggested that the distribution of the MFS was skewed towards the lower end of scores and therefore we categorized the scale into quartiles of mental fatigability for further analyses. Ordinal regression analyses were performed to study the association of activity fragmentation with the quartiles of MFS. Binary logistic regression analyses were performed to study the association of activity fragmentation and perceived mental fatigability after the 6MWT. Models were first adjusted for age and sex and further for education, number of chronic conditions, lower extremity function, cognition and depressive symptoms. Finally, to assess whether the amount of physical activity explained the association of activity fragmentation and fatigability, we added mean Posture-activity minutes into the models that included Posture-ASTP and mean MAD-activity minutes into the models that included MAD-ASTP.

Furthermore, we performed additional sensitivity analyses. First, we re-ran our analyses using the non-imputed data to see whether MI affected our findings. Second, we performed activity-stratified analyses on the association of activity fragmentation with mental and physical activity to see whether similar associations can be found among participants in all activity levels. Stratifying was performed according to tertiles of mean activity minutes (high activity, moderate activity, low activity) separately for posture- and MAD-based activity.

IBM SPSS Statistics 24 for Windows was used for all analyses. Results were considered statistically significant when p-value was less than 0.05 or when confidence intervals for odds ratios did not include one.

Results

Descriptive information on the participants is presented in Table 1, and fatigability and physical activity characteristics, according to the Posture-ASTP tertiles, in Table 2. These results largely resembled those found for the tertiles of MAD-ASTP, and hence, only group differences based on Posture-ASTP are reported. Those in the highest fragmentation tertile had higher self-reported physical fatigability scores ($p<0.001$), perceived exertion fatigability ($p<0.001$) and performance fatigability severity ($p<0.001$) than those in the lowest fragmentation tertiles. In addition, they were more likely to experience higher perceived mental fatigability after the 6MWT ($p=0.013$), but did not differ in self-reported mental fatigability ($p=0.103$). Furthermore, those in the highest fragmentation tertile were more likely to be female ($p=0.004$), have slightly lower physical function ($p=0.032$), more chronic conditions (p=0.002), fewer mean daily active minutes based on both MAD values and posture (p<0.001) and more but shorter active bouts based on posture (p<0.001 for both) and less and shorter active bouts based on MAD values (p<0.01 for both). In addition, those in the highest fragmentation tertile had slightly lower cognitive function (p=0.020). The groups did not differ in age, education or depressive symptoms.

Posture-ASTP and MAD-ASTP correlated moderately with each other (Spearman's rho=.39, p<0.001) and both were associated with higher performance fatigability severity (*Posture-ASTP* B 0.44, SE 0.05; *MAD-ASTP* B 0.35, SE 0.04, p<0.001 for both; reported per 0.1 unit increase), higher perceived exertion fatigability after the 6MWT (*Posture-ASTP* B 0.70, SE 0.09; *MAD-ASPP* B 0.62, SE 0.08; p<0.001 for both) and higher self-reported physical fatigability (PFS) in daily activities (*Posture-ASTP* B 2.89, SE 0.34; *MAD-ASTP* B 2.65, SE 0.32; p<0.001 for both). The associations attenuated but remained statistically significant after controlling for covariates and after adding mean Posture- or MAD-activity minutes into the models (Table 3).

Among our study group, 33% perceived more mental fatigue after the 6MWT than before the test. Posture-ASTP, but not MAD-ASTP, was associated with higher perceived mental fatigability after the 6MWT (*Posture-ASTP* OR 1.78, 95% CI 1.23-2.59) when adjusted only for age and sex. However, the association was attenuated and no longer statistically significant after adjusting for education, depressive symptoms, cognition, physical performance and number of chronic conditions. Both Posture-ASTP and MAD-ASTP were associated with increased odds for higher self-reported mental fatigability (*Posture-ASTP* OR 1.67, 95% CI 1.23-2.28; *MAD-ASTP* OR 1.63, CI 1.24-2.15); however, the associations were attenuated after adjusting for education, depressive symptoms, cognition, physical performance and number of chronic conditions (Table 4).

Sensitivity analyses showed that imputation did not materially affect our findings. In the activity-stratified analyses, the association of Posture-ASTP and MAD-ASTP with performance fatigability severity was similar even in the most active group according to MAD-Activity. In addition, similar associations were found between Posture-ASTP and performance fatigability severity and self-reported physical fatigability in the highest Posture-activity group, although these associations did not reach statistical significance plausibly due to the small group size. The association of Posture-ASTP with mental fatigability was observed only in the lowest activity groups.

Discussion

In the present study, we found associations between more fragmented activity patterns and higher self-reported physical fatigability, perceived exertion fatigability and performance fatigability severity, independent of total activity minutes. Furthermore, we found associations between more fragmented patterns of activity and higher mental fatigability, but these associations were attenuated in the fully adjusted models. Activity fragmentation among older people is a recent research interest, and, to the authors' best knowledge, only one previous study thus far has reported on the associations between activity fragmentation and perceived physical fatigability (10). This study expands previous findings by showing that, in addition to perceived exertion fatigability, more fragmented patterns of activity are associated with higher self-reported physical fatigability and higher performance fatigability severity.

Activities approaching the maximum energetic limit, irrespective of the maximum, will likely lead to fatigue. To avoid fatigue older people may modify their way of doing different tasks to conserve energy and reduce task demand (4-6,8). This may allow them to aggregate a relatively high volume of total physical activity in the course of the day by pacing the activities into shorter periods and avoiding longer bouts of continuous activity. The present findings are line with earlier findings (10) suggesting that more fragmented physical activity patterns may be more important in identifying older individuals with increasing physical fatigability than total activity minutes. We found that among those with rather high total physical activity, fragmented patterns of physical activity could be an early sign of increasing physical fatigability also and thus could have the potential to serve as a more sensitive indicator of impending high fatigability compared to total minutes spent in physical activity. With increasing fatigability older people may reduce or avoid fatigue-inducing activities (5,6). Reducing physical activities, in turn, may lead to a reduced level of fitness, less energy available for physical activities and consequently even higher fatigability related to specific physical activities (8). Identifying individuals at risk for high fatigability is thus important for preventing further increase in fatigability.

Our finding concerning mental fatigability can lay grounds for future studies on the topic, but need to be interpreted with some caution. The associations between activity fragmentation and mental fatigability were attenuated in our models after controlling for demographic and health factors as well as the activity levels of the participants. This suggests that poorer health and concurring low physical activity may underlie the association of activity fragmentation and mental fatigability, a potentially interesting future research topic. However, another interesting observation may stem from methodological challenges. Our participants aged 75, 80 or 85 years reported lower mental fatigability than the 18-60-year-old people participating in the SFS validation study (28). This was unexpected, because one might expect that fatigability in the context of demanding mental and social activities will increase with age. It is possible that people of different ages evaluate their fatigue level in relation to some MFS subscale items based on different grounds. Some items may be more relevant for working age people. However, it is also possible that with increasing age people gain experience e.g. about hosting social events which reduces accompanying mental fatigability. It has also been reported that after retirement there will be less of a burden of mental tasks than while in working life, leading to lower mental fatigue (5). In the future, it will be important to carefully evaluate and develop the assessment methods of mental fatigability in different contexts and age groups to gain knowledge whether mental fatigability declines with increasing age or not. The Pittsburgh Fatigability Scale has been developed specifically for older adults and designed to overcome some of the pitfalls involved with the SFS, such as including items not normally performed by older people and failure to normalize activities to intensity levels (39). However, the mental subscale may not be able to capture fatigue related to mental work (40), further supporting the need for methodological development of self-reported mental fatigability tools among older people. Another interesting observation in the current study was that a third of the participants felt mentally more fatigued after performing a mainly physical task, the 6MWT, compared to before the task. This provides further evidence for an earlier suggestion that the perception of fatigability can cross over into different domains (5), i.e. a physical task can lead also to mental fatigue, and vice versa. However, the measure that was available for us to rate mental fatigability before and after the 6MWT has not been originally validated as a measure of mental fatigability, but is a measure of perceived change in tiredness related to a walk test, which we modified for the purpose of assessing changes in perceived mental alertness (32). Nevertheless, the current study supports methodological development for perceived mental fatigability assessment and further studies on mental fatigability with aging.

To the authors' best knowledge, this is the first study that has studied activity fragmentation based on posture estimation. A few previous studies have studied activity fragmentation based on accelerations representing at least light activity (10,22). In the present study, we evaluated activity fragmentation among older people by comparing both of these measures. The two ASTP measures showed only a moderate correlation with each other and would, therefore, seem to describe different aspects of physical activity patterns. However, we found similar associations between both ways of measuring activity fragmentation and fatigability, and thus ASTP based on posture also shows promise as a way of identifying older people at risk for high fatigability. Both measures were associated with lower overall activity minutes and shorter active bouts, which translates into more time spent in sedentary or stationary behaviors. However, some participants showed significant differences in their MAD- and posture-based total activity minutes (e.g., 142.3 minutes vs. 556.0 minutes). Furthermore, while the highest MAD-ASTP tertile contained more women than men, women were more likely to be in the lowest tertile of Posture-ASTP. These differences may be explained by the lower physical capacity of women and/or by differences in the kinds of activities that men and women engage in. Women may be more involved in household chores than men, which may include more stopping while remaining in an upright posture.

The strengths of this study include a relatively large probability sample of community-dwelling participants. This will alleviate selection bias often evident in convenience samples. Participants wore an accelerometer continuously for three to seven days, which provides an opportunity to control for day-to-day variation in physical activity volume and patterns. The possibility to assess physical activity objectively using both MAD and posture was a further strength, as it enabled us to compare these different activity fragmentation measures. Furthermore, using several measures of fatigability strengthened our findings, and we were able to distinguish between self-reported physical, perceived exertion fatigability, performance fatigability severity, and self-reported and perceived mental fatigability, and their associations with activity fragmentation. In addition, we used a modified version of the performance fatigability scale, which was able to better incorporate performance deterioration measured as slowing down during the 6MWT.

The study also has limitations. First, the data were cross-sectional and thus do not permit conclusions on the temporal associations between activity fragmentation and fatigability. Therefore, future longitudinal studies are called for. Second, the fatigability measures that we used involve some limitations. The Situational Fatigue Scale has been validated among 18- to 60-year-olds and thus may not be ideal for assessing fatigability among older adults. The PFS includes activities that may not be typically performed by older people, such as jogging and playing ball games, and the distribution of the MFS suggests that the subscale may not be the ideal instrument for evaluating mental fatigability among older people. Nevertheless, these results were in line with our other results, and thus strengthen our findings. Furthermore, we used modified versions of the originally validated measures for perceived exertion fatigability and mental fatigability during the 6MWT which may affect our findings. However, the original validated calculation method for perceived exertion fatigability was problematic in our study, as all participants with no change in perceived exertion regardless of walking speed and initial RPE rating, would get a score of zero. Using the slightly modified version of the method partly solved this issue and showed moderate to high correlations with the PFS subscale and performance fatigability severity scores (r=0.42 and 0.72, respectively). Third, we utilized an acceleration cut point that has been originally developed for a waist-mounted device (34). As the accelerations on the thigh are generally higher than on the waist (41), using this cut point may overestimate the amount of at least light physical activity. However, since using intensity-based cut points for older people with decreasing physical function poses challenges (17-19), and similar intensity in different physical activities produce different accelerometer readings, we wanted to use a cut point low enough to capture all slow movement. The average active minutes using the MAD-based cut point of 16.7 mg was fairly comparable to those determined by posture estimation (350 minutes vs. 329 minutes), and thus, large overestimations of active minutes seem unlikely. Future studies targeting the differences between posture- and cut point -based measures of physical activity patterns are warranted. Finally, the older adults who participated in our study had generally better health than those not willing to participate (27) and thus, our findings may underestimate fatigability among community-dwelling older population.

Conclusions

More fragmented patterns of activity are associated with higher self-reported physical, perceived exertion fatigability and performance fatigability severity among community-dwelling older persons. The findings on activity fragmentation and performance fatigability severity were similar even among those who accrued relatively high mean levels of physical activity. Thus, activity fragmentation can be a sign of impending fatigability even though activity levels continue to remain high. The findings of this study are in line with earlier discoveries that studying fragmented activity patterns can be useful in identifying those at higher risk for high fatigability, although future longitudinal studies are needed to study the temporal associations between activity fragmentation and fatigability. Although we did not find associations between activity fragmentation and mental fatigability in the fully adjusted models, the findings also suggest that physical activities can be experienced as mentally fatiguing, and vice versa. This suggests that it may be beneficial to pay more attention to mental fatigue in the physical activity context, but may also require further development of methods of studying perceived mental fatigability among older population. In addition, studying activity fragmentation based on both acceleration and body posture may be fruitful in future research, since these methods seem to describe somewhat different aspects of physical activity patterns.

Conflict of interest

The authors declare no competing interests.

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References

1. Ream E, Richardson A. Fatigue: A concept analysis. *Int J Nurs Stud*. 1996;33(5):519-529. https://doi.org/10.1016/0020-7489(96)00004-1

2. Kowal J, Fortier MS. Physical activity behavior change in middle-aged and older women: The role of barriers and of environmental characteristics. *J Behav Med*. 2007;30(3):233-242. https://doi.org/10.1007/s10865-007-9102-y

3. Gill TM, Desai MM, Gahbauer EA, Holford TR, Williams CS. Restricted activity among community-living older persons: Incidence, precipitants, and health care utilization. *Ann Intern Med*. 2001;135(5):313-321. doi: 10.7326/0003-4819-135-5-200109040-00007

4. Schrack JA, Simonsick EM, Ferrucci L. The energetic pathway to mobility loss: An emerging new framework for longitudinal studies on aging. *J Am Geriatr Soc*. 2010;58:S329-S336. https://doi.org/10.1111/j.1532-5415.2010.02913.x

5. Kratz AL, Murphy SL, Braley TJ, et al. Development of a person-centered conceptual model of perceived fatigability. *Quality of Life Research*. 2019:1-11. https://doi.org/10.1007/s11136-018-2093-z

6. Eldadah BA. Fatigue and fatigability in older adults. *PM&R*. 2010;2(5):406-413. https://doi.org/10.1016/j.pmrj.2010.03.022

7. Kluger BM, Krupp LB, Enoka RM. Fatigue and fatigability in neurologic illnesses: Proposal for a unified taxonomy. *Neurology*. 2013;80(4):409-416. https://doi.org/10.1212/WNL.0b013e31827f07be

8. Alexander NB, Taffet GE, Horne FM, et al. Bedside- to- bench conference: Research agenda for idiopathic fatigue and aging. *J Am Geriatr Soc*. 2010;58(5):967-975. https://doi.org/10.1111/j.1532-5415.2010.02811.x

9. Skantz H, Rantanen T, Palmberg L, et al. Outdoor mobility and use of adaptive or maladaptive walking modifications among older people. *The Journals of Gerontology: Series A*. 2019. https://doi.org/10.1093/gerona/glz172

10. Schrack JA, Kuo P, Wanigatunga AA, et al. Active-to-sedentary behavior transitions, fatigability, and physical functioning in older adults. *The Journals of Gerontology: Series A*. 2019;74(4):560-567. https://doi.org/10.1093/gerona/gly243

11. Manns P, Ezeugwu V, Armijo- Olivo S, Vallance J, Healy GN. Accelerometer- Derived pattern of sedentary and physical activity time in persons with mobility disability: National health and nutrition examination survey 2003 to 2006. *J Am Geriatr Soc*. 2015;63(7):1314-1323. https://doi.org/10.1111/jgs.13490

12. Wanigatunga AA, Di J, Zipunnikov V, et al. Association of total daily physical activity and fragmented physical activity with mortality in older adults. *JAMA Network Open*. 2019;2(10):e1912352. doi:10.1001/jamanetworkopen.2019.12352

13. Wanigatunga AA, Simonsick EM, Zipunnikov V, et al. Perceived fatigability and objective physical activity in mid-to late-life. *The Journals of Gerontology: Series A*. 2017. https://doi.org/10.1093/gerona/glx181

14. Simonsick EM, Glynn NW, Jerome GJ, Shardell M, Schrack JA, Ferrucci L. Fatigued, but not frail: Perceived fatigability as a marker of impending decline in Mobility- Intact older adults. *J Am Geriatr Soc*. 2016;64(6):1287-1292. https://doi.org/10.1111/jgs.14138

15. Simonsick EM, Schrack JA, Santanasto AJ, Studenski SA, Ferrucci L, Glynn NW. Pittsburgh fatigability scale: One- Page predictor of mobility decline in Mobility- Intact older adults. *J Am Geriatr Soc*. 2018;66(11):2092-2096. https://doi.org/10.1111/jgs.15531

16. Van Cutsem J, Marcora S, De Pauw K, Bailey S, Meeusen R, Roelands B. The effects of mental fatigue on physical performance: A systematic review. *Sports medicine*. 2017;47(8):1569-1588. https://doi.org/10.1007/s40279-016-0672-0

17. Schrack JA, Cooper R, Koster A, et al. Assessing daily physical activity in older adults: Unraveling the complexity of monitors, measures, and methods. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*. 2016;71(8):1039-1048. https://doi.org/10.1093/gerona/glw026

18. Schrack JA, Leroux A, Fleg JL, et al. Using heart rate and accelerometry to define quantity and intensity of physical activity in older adults. *The Journals of Gerontology: Series A*. 2018;73(5):668-675. https://doi.org/10.1093/gerona/gly029

19. Kujala U, Pietilä J, Myllymäki T, et al. Physical activity: Absolute intensity vs. relative-to-fitness-level volumes. *Med Sci Sports Exerc*. 2017;49. doi:10.1249/MSS.0000000000001134

20. Schrack JA, Zipunnikov V, Simonsick EM, Studenski S, Ferrucci L. Rising energetic cost of walking predicts gait speed decline with aging. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*. 2016;71(7):947-953. https://doi.org/10.1093/gerona/glw002

21. Kowalski K, Rhodes R, Naylor P, Tuokko H, MacDonald S. Direct and indirect measurement of physical activity in older adults: A systematic review of the literature.

International Journal of Behavioral Nutrition and Physical Activity. 2012;9(1):148. https://doi.org/10.1186/1479-5868-9-148

22. Wanigatunga AA, Gresham GK, Kuo P, et al. Contrasting characteristics of daily physical activity in older adults by cancer history. *Cancer*. 2018;124(24):4692-4699. https://doi.org/10.1002/cncr.31745

23. McCullagh R, Brady NM, Dillon C, Horgan NF, Timmons S. A review of the accuracy and utility of motion sensors to measure physical activity of frail, older hospitalized patients. *J Aging Phys Act*. 2016;24(3):465-475. https://doi.org/10.1123/japa.2014-0190

24. Tremblay MS, Aubert S, Barnes JD, et al. Sedentary behavior research network (SBRN)–terminology consensus project process and outcome. *International Journal of Behavioral Nutrition and Physical Activity*. 2017;14(1):75. https://doi.org/10.1186/s12966-017-0525-8

25. Mansoubi M, Pearson N, Clemes SA, et al. Energy expenditure during common sitting and standing tasks: Examining the 1.5 MET definition of sedentary behaviour. *BMC Public Health*. 2015;15(1):516. https://doi.org/10.1186/s12889-015-1851-x

26. Rantanen T, Saajanaho M, Karavirta L, et al. Active aging–resilience and external support as modifiers of the disablement outcome: AGNES cohort study protocol. *BMC Public Health*. 2018;18(1):565. https://doi.org/10.1186/s12889-018-5487-5

27. Portegijs E, Karavirta L, Saajanaho M, Rantalainen T, Rantanen T. Assessing physical performance and physical activity in large population-based aging studies: Home-based assessments or visits to the research center? *BMC Public Health*. 2019;19(1):1570. https://doi.org/10.1186/s12889-019-7869-8

28. Yang C, Wu C. The situational fatigue scale: A different approach to measuring fatigue. *Quality of life research*. 2005;14(5):1357-1362. https://doi.org/10.1007/s11136-004-5680-0

29. Rubin DB. Multiple imputation after 18 years. *Journal of the American statistical Association*. 1996;91(434):473-489.

30. Murphy SL, Kratz AL, Schepens Niemiec SL. Assessing fatigability in the lab and in daily life in older adults with osteoarthritis using perceived, performance, and ecological measures. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*. 2017;72(1):115-120. https://doi.org/10.1093/gerona/glw173

31. Borg G. Ratings of perceived exertion and heart rates during short-term cycle exercise and their use in a new cycling strength test. *Int J Sports Med*. 1982;3(03):153-158. doi: 10.1055/s-2008-1026080

32. Schnelle JF, Buchowski MS, Ikizler TA, Durkin DW, Beuscher L, Simmons SF. Evaluation of two fatigability severity measures in elderly adults. *J Am Geriatr Soc*. 2012;60(8):1527-1533. https://doi.org/10.1111/j.1532-5415.2012.04062.x

33. Simonsick EM, Schrack JA, Glynn NW, Ferrucci L. Assessing fatigability in mobility-intact older adults. *J Am Geriatr Soc*. 2014;62(2):347-351. doi: 10.1111/jgs.12638 [doi].

34. Vähä- Ypyä H, Vasankari T, Husu P, Suni J, Sievänen H. A universal, accurate intensity- based classification of different physical activities using raw data of accelerometer. *Clinical physiology and functional imaging*. 2015;35(1):64-70. https://doi.org/10.1111/cpf.12127

35. Vähä- Ypyä H, Husu P, Suni J, Vasankari T, Sievänen H. Reliable recognition of lying, sitting, and standing with a hip- worn accelerometer. *Scand J Med Sci Sports*. 2018;28(3):1092-1102. https://doi.org/10.1111/sms.13017

36. Guralnik JM, Simonsick EM, Ferrucci L, et al. A short physical performance battery assessing lower extremity function: Association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol*. 1994;49(2):85. https://doi.org/10.1093/geronj/49.2.M85

37. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res*. 1975;12(3):189-198.

38. Radloff LS. The CES-D scale: A self-report depression scale for research in the general population. *Applied psychological measurement*. 1977;1(3):385-401.

39. Glynn NW, Santanasto AJ, Simonsick EM, et al. The pittsburgh fatigability scale for older adults: Development and validation. *J Am Geriatr Soc*. 2015;63(1):130-135. doi: 10.1111/jgs.13191

40. Burke SE, Samuel IBH, Zhao Q, et al. Task-based cognitive fatigability for older adults and validation of mental fatigability subscore of pittsburgh fatigability scale. *Frontiers in aging neuroscience*. 2018;10. https://doi.org/10.3389/fnagi.2018.00327

41. Fortune E, Lugade VA, Kaufman KR. Posture and movement classification: The comparison of tri-axial accelerometer numbers and anatomical placement. *J Biomech Eng*. 2014;136(5):051003. https://doi.org/10.1115/1.4026230

Table 1. Descriptive characteristics of participants by activity fragmentation (ASTP) tertiles based on posture

	Low tertile (n=163)	Middle tertile (n=161)	High tertile (n=161)	
	Mean (SD)	Mean (SD)	Mean (SD)	p-value
Age	78.3 (3.2)	78.4 (3.5)	78.3 (3.6)	.856[a]
Years of education	11.6 (4.2)	11.9 (4.2)	11.4 (4.4)	.303[a]
Lower extremity function	10.6 (1.8)	10.5 (1.6)	9.9 (2.2)	.032[a]
Cognitive function	27.8 (2.2)	27.4 (2.4)	27.0 (2.6)	.020[a]
Depressive symptoms	7.8 (6.6)	7.1 (6.5)	8.5 (6.7)	.079[a]
Number of chronic conditions	2.9 (1.9)	3.1 (2.1)	3.7 (2.0)	.002[a]
Female %	67.5	61.7	49.7	.004[b]

Note; ASTP= Active-To-Sedentary Transition Probability, [a]Kruskal-Wallis test [b]Chi-Square test

Table 2. Physical fatigability, mental fatigability and physical activity characteristics of participants according to activity fragmentation (ASTP) tertiles based on posture

	Low tertile (n=163)	Middle tertile (n=161)	High tertile (n=161)	
	Mean (SD)	Mean (SD)	Mean (SD)	p-value
Fatigability				
PFS Subscale (range 0-20)	7.5 (4.5)	8.3 (4.2)	10.3 (5.0)	<.001[b]
Perceived exertion fatigability	2.8 (0.7)	3.1 (0.8)	3.5 (1.6)	<.001[a]
Performance fatigability severity	2.3 (0.4)	2.5 (0.6)	2.7 (0.7)	<.001[a]
Higher perceived mental fatigability after the 6MWT (%)	31.3	26.3	41.7	.013[c]
Self-reported mental fatigability quartiles (%)				0.103[c*]
Lowest	36	31	25	
Lower middle	22	27	21	
Higher middle	26	27	29	
Highest	16	15	25	
Physical activity				
Bouts per day				

Posture	36.2 (6.3)	41.1 (7.9)	44.2 (10.0)	<.001[b]
MAD	82.4 (15.5)	78.6 (14.0)	76.2 (16.3)	.001[b]
Active minutes per day				
Posture	424.5 (79.6)	327.3 (60.7)	238.3 (70.0)	<.001[b]
MAD	399.9 (87.7)	351.4 (76.8)	302.5 (88.0)	<.001[b]
Average Bout length				
Posture	12.0 (2.7)	8.0 (0.7)	5.4 (1.1)	<.001[b]
MAD	5.0 (1.3)	4.5 (0.9)	4.0 (0.9)	<.001[b]
6-minute walk test (m)	443.4 (68.6)	420.3 (72.1)	390.3 (92.6)	<.001[b]

Note; ASTP= Active-To-Sedentary Transition Probability, MAD= Mean Amplitude Deviation, SD=Standard deviation, [a]Kruskal-Wallis test [b]One-Way ANOVA [c]Chi-Square test [*]The median of imputed p-values reported

Table 3. Associations of activity fragmentation (ASTP) based on posture and MAD values with physical fatigability

	Model 1				Model 2				Model 3				
	B	S.E.	β	p	B	S.E.	β	p	B	S.E.	β	p	R^2*
Self-reported physical fatigability, range 0-20													
Posture-ASTP	2.89	0.34	0.36	<0.001	2.02	0.33	0.25	<0.001	1.53	0.52	0.19	0.003	0.35
MAD-ASTP	2.65	0.32	0.36	<0.001	1.57	0.33	0.21	<0.001	0.92	0.46	0.13	0.046	0.33
Perceived exertion fatigability													
Posture-ASTP	0.70	0.09	0.32	<0.001	0.57	0.10	0.26	<0.001	0.66	0.16	0.31	<0.001	0.20
MAD-ASTP	0.62	0.08	0.33	<0.001	0.49	0.09	0.26	<0.001	0.43	0.13	0.23	0.001	0.19
Performance fatigability severity													

Posture-ASTP	0.44	0.05	0.40	<0.001	0.31	0.04	0.28	<0.001	0.37	0.07	0.33	<0.001	0.50
MAD-ASTP	0.35	0.04	0.36	<0.001	0.21	0.04	0.21	<0.001	0.16	0.06	0.17	0.004	0.47

Note; ASTP= Active-To-Sedentary Transition Probability, MAD=Mean Amplitude Deviation, B=Unstandardized regression coefficient, S.E.=Standard error, β=Standardized regression coefficient, Posture-ASTP and Mad-ASTP reported per 0.1 unit increase; Model 1 adjusted for age and sex, Model 2 adjusted for age, sex, education, physical performance, cognition, depressive symptoms, number of chronic diseases, Model 3 total activity minutes added to the fully adjusted model. *R^2 for fully adjusted model

Table 4. The associations of activity fragmentation (ASTP) based on posture and MAD values with mental fatigability

	Model 1	Model 2	Model 3
	OR (95% CI)	OR (95% CI)	OR (95% CI)
Higher perceived mental fatigability after 6MWT vs. no change[a]			
ASTP (posture)	1.78 (1.23-2.59)	1.47 (0.99-2.19)	1.79 (0.94-3.40)
ASTP (MAD)	1.20 (0.87-1.66)	0.91 (0.63-1.32)	0.88 (0.52-1.48)
Self-reported mental fatigability quartiles[b]			
ASTP (posture)	1.67 (1.23-2.28)	1.19 (0.86-1.64)	1.12 (0.68-1.86)
ASTP (MAD)	1.63 (1.24-2.15)	1.09 (0.80-1.49)	0.92 (0.59-1.42)

Note; ASTP= Active-To-Sedentary Transition Probability, MAD=Mean Amplitude Deviation, OR=Odds ratio, CI=Confidence interval, Posture-ASTP and Mad-ASTP reported per 0.1 unit increase; Model 1 adjusted for age and sex, Model 2 adjusted for age, sex, education, physical performance, cognition, depressive symptoms, number of chronic diseases, Model 3 total activity minutes added to the fully adjusted model; [a]Data were analyzed with binary logistic regression analysis; [b]Data were analyzed with ordinal logistic regression analysis