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Original Article

# Classification of the Frailty Status of Community-Dwelling Older Adults Using Physical Activity Data Collected through Consumer Activity Trackers

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SUMMARY

*Backgrounds:* Engaging in light activity, moderate-to-vigorous physical activity (MVPA), or sedentary behavior can influence the health status of older adults. The purpose of this study was to examine the relationship between frailty and the daily amount of physical activity, as measured by an activity tracker, and to identify frail older adults based on the tracker data.
*Methods:* The participants were community-dwelling older adults (aged ≥ 65 years) classified as frail or non-frail. Frailty was defined by the presence of three or more of the following: weight loss, exhaustion, low energy expenditure, slow gait speed, and weak grip strength. Physical activity was monitored using the activity tracker, and the daily durations of MVPA, light activity, and sedentary activity were measured over a 7-day period.
*Results:* The duration of MVPA was significantly associated with frailty status (unadjusted odds ratio = .936, $p$ = .018; adjusted odds ratio = .935, $p$ = .039). There was no significant association between frailty and the duration of light or sedentary activity. However, classification and regression tree analysis generated cutoff points of ≤ 29.65 min/day and ≤ 156.93 min/day of MVPA and light activity, respectively, for determining frailty in older adults with an accuracy of 87.7%.
*Conclusions:* Durations of MVPA and light activity, as measured using an activity tracker, differentiated frail and non-frail older adults. The classification and regression tree analysis yielded cutoff points that could inform recommendations regarding the daily amount of physical activity for older people.



## 1. Introduction

As the global population ages, frailty is becoming an increasingly prevalent health-threatening clinical syndrome.[1] Frailty is characterized by a decline in function affecting multiple physiological systems, leading to adverse outcomes including falls, disability, hospitalization, and mortality.[2,3] Thus, preventing and managing frailty is an important public health issue.

Consumer activity trackers have been used to monitor physical activity in individuals in terms of daily step count, duration of physical activity, energy expenditure, and walking distance.[4–6] These devices are widely used by people of various ages; they have applications to medicine and healthcare, and are relatively inexpensive and convenient.[6] Previous studies have used activity trackers to examine physical activity patterns, and demonstrated that sedentary behavior and less moderate-to-vigorous physical activity (MVPA) characterize frail older adults.[7,8]

The amount of daily physical activity, as measured using a consumer activity tracker, could be used to identify frailty in older adults. Cutoff points for this metric could help clinicians and older adults manage and prevent frailty in everyday life. Thus, this study used a classification tree model to determine whether physical activity, including MVPA, light activity, and sedentary behavior, could discriminate older adults with and without frailty, and aimed to generate cutoff values. We hypothesized that the daily amounts of MVPA, light activity, and/or sedentary behavior, as measured by an activity tracker, would be enable differentiation of older adults with and without frailty.

## 2. Methods

### 2.1. Study design and participants

This study was a cross-sectional analysis and was conducted from March 1 to December 31, 2019 in South Korea. We recruited community-dwelling older adults aged 65–84 years living in urban areas. Individuals with cognitive impairment [Mini-Mental State Examination score (MMSE) < 24] or functional disability, such as difficulty walking or poor hand function, were excluded from the study. All data of this study were collected by the researchers during two visits. During the first visit, basic information of the participants, including age, height, weight, gender, body mass index (BMI), and cognitive level, was recorded, and a frailty assessment was conducted. Additionally, the participants were instructed on how to wear the wearable devices for physical activity measurement. On the second visit, one week later, the researchers recorded the physical activity levels collected by the wearable devices for one week.

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The study was designed and conducted according to Declaration of Helsinki, and approved by the institutional review board of Sangji University, South Korea. All participants received an explanation regarding the purpose and procedures of the study, and signed an informed consent form.

### *2.2. Frailty assessment*

The participants were classified into frail and non-frail subgroups using the frailty model, which includes the five following criteria: weight loss, exhaustion, low energy expenditure, slow gait speed, and weak grip strength.[9,10] Weight loss was defined as unintentional weight loss ≥ 4.5 kg or ≥ 5% of total body weight per year. Exhaustion was assessed by the question "Do you feel full of energy?". Low energy expenditure was defined as < 383 kcal/week for men and < 270 kcal/week for women. Gait speed was measured by asking the participants to walk 4.57 m, and the data were stratified by sex and height. Grip strength was measured using a hand dynamometer, and the data were stratified by sex and body mass index. Participants meeting at least three of the five criteria for frailty were assigned to the frail group; the others were assigned to the non-frail group.[11]

### *2.3. Physical activity measurement and data analysis*

We measured the duration of daily activity (MVPA, light activity, and sedentary activity) using an activity tracker (Fitbit Alta HR; Fitbit Inc., San Francisco, CA, USA). All participants were required to wear the activity tracker on their wrist for 7 consecutive days. They were shown how to wear the device and charge the battery. The device was equipped with a three-axis accelerometer and heart rate tracker. The data collected by the activity tracker were synchronized using web-based software (Fitabase; Small Steps Labs LLC, San Diego, CA, USA) and the duration of activity was recorded according to activity intensity based on metabolic equivalents (METs). MVPA, light activity, and sedentary activity were defined as ≥ 3, ≥ 1.5 and < 1.5 METs, respectively.[12] Data were included in the statistical analysis if the participant wore the device for > 10 hours/day on ≥ 4 of the 7 days comprising the experimental period.

### *2.4. Statistical analysis*

The SPSS statistic (SPSS ver. 26, Inc., Il., Chicago, IL., USA) for Windows was used to analyze the data with an alpha level of .05. The data were examined for normality using the Kolmogorov-Smirnov test. Participant's demographic characteristics and duration of MVPA, light, and sedentary activity measured by activity tracker were compared between frail and non-frail groups using independent t-test for parametric variables and Man-Whitney U test for non-parametric variables, and chi square tests for categorical variable, respectively.

We performed logistic regression (both unadjusted and adjusted for age, BMI, and MMSE scores) to evaluate the relationships between frailty and the durations of MVPA, light activity, and sedentary activity in older adults. The data are presented as odds ratios with 95% confidence intervals, with the non-frail group serving as the reference group. We used classification and regression tree (CART) analysis to develop a classification model for identifying frail older adults, and determined whether the durations of MVPA, light activity, and sedentary activity could predict frailty. The classification tree was used to identify significant predictors, and impurity was minimized using the Gini index. Validation methods help ensure the created model is not affected by either underfitting or overfitting.[13–15] Out-of sample errors for unseen data were calculated through 10-fold cross validation, when evaluating the CART model.[14] The dataset was randomly split into 10 subsets; 9 were used for training the model, while the 10$^{th}$ was used to evaluate out-of sample-error. This procedure was repeated for all subsets, such that they were all used as the testing set. To develop the model, a sufficient sample size of ten to fifteen participants per variable of interest was required, as recommended by previous studies.[16,17] To ensure an adequate sample size for this study, which consisted of three variables of interest, the researchers recruited a sufficient number of participants within the range of 30 to 45 individuals.

## 3. Results

Initially, 82 older adults were enrolled in this study. However, 25 were excluded because they did not consent to participate or the amount of time that they wore the activity tracker did not allow for sufficient data to be collected. Thus, 57 older adults were classified into the frail (n = 12) and non-frail (n = 45) groups and analyzed. The participants in the frail group were significantly shorter and had significantly lower MMSE scores, and were also older, than those in the non-frail group (Table 1). The average daily amount of time spent wearing the activity tracker, excluding sleep, during the 7-day period was not significantly different between the two groups, i.e., 898.44 min/day in the frail group and 926.73 min/day in the non-frail group. The amount of time spent engaged in MVPA and light activity was significantly greater in the non-frail group ($p$ < .05).

Table 2 shows the results of the unadjusted logistic regression analysis and that adjusted for age, BMI, and MMSE scores. The duration of MVPA was significantly associated with frailty. However, frailty was not significantly associated with the duration of light or sedentary activity in either model.

The classification tree for discriminating the presence of frailty included the duration of MVPA and light activity, as measured by the activity tracker, and had a total of five nodes and classification accuracy of 87.7%. Figure 1 shows the cutoff points for the predictors, and the percentages of individuals classified into the frail and non-frail groups. The duration of MVPA was the first predictor of frailty, with a cutoff point of 29.65 min/day. The second predictor was the duration of light activity, which had a cutoff of 156.93 min/day. After pruning, the model successfully identified 5 of the 12 older adults with frailty (41.7% accuracy) and 45 of the 45 older adults without frailty (100% accuracy) (Table 3).

**Table 1**
Demographic characteristics and independent variables.

| Variables | Frail (N = 12) | Non-frail (N = 45) | $p$ value |
|---|---|---|---|
| Age, year (SD) | 77.58 (5.90) | 71.20 (4.22) | .001 |
| Height, cm (SD) | 152.33 (7.28) | 161.04 (9.91) | .005 |
| Weight, kg (SD) | 62.00 (9.37) | 63.94 (9.29) | .439 |
| Women, n (%) | 10 (83.33) | 24 (53.33) | .060 |
| BMI, kg/m$^2$ (SD) | 26.78 (4.25) | 24.63 (2.74) | .108 |
| MMSE, score (SD) | 26.67 (2.31) | 28.22 (1.78) | .012 |
| MVPA, min/day (SD) | 20.41 (16.16) | 79.41 (49.79) | .000 |
| Light activity, min/day (SD) | 148.77 (88.94) | 243.29 (57.48) | .001 |
| Sedentary activity, min/day (SD) | 729.28 (106.57) | 605.04 (192.54) | .053 |

BMI = body mass index; MVPA = moderate to vigorous physical activity; SD = standard deviation; MMSE = mini-mental state examination.
Independent t-test for parametric variables, Man-Whitney U test for non-parametric variables, and chi square tests for categorical variable were used to detect group difference.

**Table 2**
Results of logistic regression analysis of the relationship between frailty and the duration of physical activity.

| | Unadjusted | | | Adjusted* | | |
|---|---|---|---|---|---|---|
| | OR | 95% CI | *p* value | OR | 95% CI | *p* value |
| MVPA | 0.936 | 0.887 to 0.989 | .018 | 0.935 | 0.876 to 0.997 | .039 |
| Light | 0.989 | 0.977 to 1.002 | .091 | 0.989 | 0.970 to 1.009 | .273 |
| Sedentary | 0.911 | 0.994 to 1.006 | 1.000 | 1.003 | 0.996 to 1.010 | .444 |

CI = confidence interval; MVPA = moderate to vigorous physical activity; OR = odds ratio.
* Adjusted for age, body mass index, and mini-mental state examination scores.

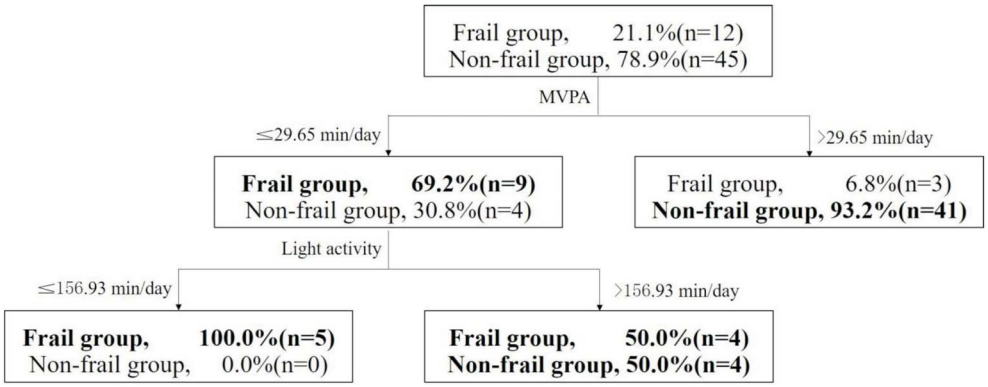


**Figure 1.** Classification tree for determining frailty status in older adults. MVPA = moderate to vigorous physical activity.

**Table 3**
Confusion matrix for the classification tree based on light and moderate-to-vigorous physical activity.

| | Prediction | | Accuracy | Overall accuracy |
|---|---|---|---|---|
| | Frail group | Non-frail group | | |
| Frail group | 5 | 7 | 41.7% | 87.7% |
| Non-frail group | 0 | 45 | 100% | |

## 4. Discussion

This study examined whether the duration of physical activity (MVPA or light activity) and sedentary behavior, as measured by an activity tracker, were associated with frailty and could be used to distinguish older adults with and without frailty. Short-duration MVPA was significantly associated with the presence of frailty, but that was not the case for light or sedentary behavior. Cutoffs for the duration of MVPA and light activity, generated using CART analysis, could be used to assign the participants to frail and non-frail groups. Thus, this study highlights the potential of using MVPA and light activity data from consumer activity trackers to identify frailty in older adults in daily life.

In the classification tree, the daily duration of MVPA was the first predictor of frailty, followed by the daily duration of light activity. Furthermore, there was an interaction between MVPA and light activity. Although the duration of light activity was not significantly associated with frailty according to the logistic regression analysis, short-duration MVPA (≤ 29.65 min/day) was a significant predictor of frailty among older adults with low light activity, i.e., < 156.93 min/day. Conversely, older adults with relatively high amounts of daily light activity were less likely to be frail even if they had low daily MVPA. Thus, the CART analysis provided new insight into the relationships among frailty, daily MVPA, and daily light activity.

This study revealed a relationship between the duration of physical activity, as measured by an activity tracker, and frailty, where older adults with a greater daily amount of MVPA were less likely to be frail. This finding is consistent with a previous study reporting less MVPA in frail compared with non-frail older adults, and that the duration of MVPA was independently associated with frailty.[18] Thus, MVPA appears to decrease the likelihood of frailty in older adults, and our data suggest that MVPA for 29.65 min/day could be sufficient to protect against frailty.

Previous studies reported guidelines for physical activity based on data obtained using activity trackers. Some of the guidelines for older adults with frailty are based on the number of steps, as well as the durations of light activity, MVPA, and sedentary behavior.[19,20] Chen et al.[19] reported that 43.25 min/day of MVPA, measured using a waist-mounted, tri-axial accelerometer, could discriminate frail from non-frail older adults. Yuki et al.[20] reported that 7.5 min/day of MVPA, measured using an uniaxial accelerometer, served as a cutoff value for frailty. There are several explanations for the differences between previous studies and our study in terms of the cutoff values for frailty. First, previous studies have utilized different assessment methods to identify frail older adults in each study. Due to these varying criteria, it is likely that the physical activity levels of frail older adults were influenced. Second, the participants recruited for this study may exhibit differences in levels of physical activity based on moderate or high intensity compared to the participants of the previous study. For example, individuals who engage in high-intensity activities are likely to require less time for physical activity compared to those who engage in moderate-intensity exercises, in order to achieve the same level of non-frail status. Third, previous studies used different instruments to track physical activity, i.e., single versus tri-axial accelerometers, and waist versus wrist-mounted devices. Older people are increasingly using activity trackers, such as the consumer activity tracker used in this study, and are increasingly likely to pay for devices that can help them manage their health.[21–23] As this study provides cutoff values for MVPA and light activity based on data collected using a consumer activity tracker, our findings may help individuals plan daily physical activity and reduce habitual sedentary behavior. However, our data should be interpreted with consideration of the type of activity tracker and participant activity levels.

We found no significant association between frailty and the duration of sedentary behavior. However, the frail older adults spent

more time engaged in sedentary activity in daily life. In a previous systematic review, 9 of 11 studies on this topic found that more sedentary activity per day was associated with greater frailty; the remaining 2 studies reported a non-significant association between sedentary behavior and frailty.[8] Although sedentary behavior has not been consistently associated with frailty, reallocating some of the time spent engaged in sedentary behavior to light or moderate-intensity activity could improve frailty status.[24] Additionally, more intense physical activity may reduce the risk of health problems associated with sedentary behavior such as frailty, death, cardiovascular disease, and cancer.[25–27] For example, individuals in the most active quartile (> 35.5 MET-h/week) who sat for > 8 h/day had a significantly lower risk of dying than those in the less active quartile (< 16 MET-h/week), even if the latter were seated for < 4 h/day.[28] Indeed, 27.25 min/day of MVPA offset the increased risk of frailty associated with sedentary behavior.[26] Further research is needed to examine the effect of activity durations above the MVPA cutoff values, as measured using a consumer activity tracker, on frailty status.

This study had several limitations. First, this study was a cross-sectional design. While logistic regression analysis revealed that duration of MVPA was significantly associated with the presence of frailty, it should be considered whether frailty itself could contribute to low physical activity levels. Previous research has also shown that frail older adults tend to engage in less MVPA and lead more sedentary lives compared to non-frail older adults.[18,29] Conducting a longitudinal study would provide further evidence on whether frailty has a significant impact on declining physical activity levels over time. A second limitation is that this study did not account for confounding variables such as chronic diseases, psychological states, impaired cognition, polypharmacy, and micronutrient deficits, which could be associated with frailty and physical activity levels in older adults.[2] Therefore, future research is needed to examine the relationship between frailty and physical activity in older adults while considering these confounding variables. Additionally, the frail group was relatively small compared with the non-frail group. Thus, further studies including more frail older adults are needed.

## 5. Conclusions

In this study, the duration of MVPA was associated with frailty status of older adults. In addition, the durations of MVPA and light activity, as measured using an activity tracker and analyzed using CART, identified the presence of frailty. Thus, using an activity tracker to monitor physical activity could be helpful in screening frailty among community-dwelling older adults. More research is needed to examine the relationship between MVPA/light activity and frailty, to help prevent and manage frailty.

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## Conflict of interest

No potential conflict of interest relevant to this article was reported.

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