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# Consumer wearable device-based measures of physical activity and energy expenditure in community-dwelling older adults with different levels of frailty

## A STROBE compliant study

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**Abstract**

Physical activity is important for positive health outcomes, and wearable activity devices are useful for tracking physical activity patterns and energy expenditure. This study investigated differences in, and correlations of, duration of physical activity according to activity intensity and energy expenditure among community-dwelling older adults with different levels of frailty. This cross-sectional study enrolled 88 adults older than 65 years from communities between June 2019 and January 2020. The participants were divided into non-frail, pre-frail, and frail groups according to the frailty criteria. Outcomes included the frailty score, duration of physical activity according to the intensity of activity (sedentary, light, fairly active, fairly to very active, and very active), and energy expenditure measured by a consumer wearable device. The duration of physical activity according to the intensity of activity and energy expenditure were compared among non-frail, pre-frail, and frail groups. In addition, linear correlation analysis was used to identify significant associations of objectively measured physical activity and energy expenditure with frailty. Non-frail older adults showed significantly longer daily duration of light to very active physical activity and increased energy expenditure compared to the frail group ($P < .05$). Additionally, non-frail older adults engaged in significantly more light and fairly to very active physical activity, and showed increased energy expenditure, compared to the pre-frail group ($P < .05$). The non-frail group showed a significantly lower duration of sedentary behavior compared to the pre-frail group. Correlation analysis showed that frailty was significantly associated with decreased light to very active physical activity and energy expenditure, as well as increased sedentary behavior ($P < .05$). This study provides evidence of differences in objectively measured physical activity and energy expenditure between frail and non-frail older adults, and reveals an association of frailty with physical activity and energy expenditure. Daily physical activity that exceeds low-intensity, low-energy expenditure activity should be encouraged among older adults with frailty.

**Abbreviations:** BMI = body mass index, MET = metabolic equivalent task.

**Keywords:** aging, energy expenditure, frailty, older adults, physical activity, wearable device

### 1. Introduction

Frailty is a biological syndrome that predisposes to stressors because of underlying multisystem physiological dysregulation, leading to adverse outcomes such as decline in physical function, hospitalization, and falls.[1–4] Frailty is reported in 3.9% to 51.4% and prefrailty in 13.4% to 49.3% of people over 60 years of age.[5] In addition, frailty is strongly associated with increased risks for chronic diseases and mortality.[6,7]

Regular physical activity reduces the risk for cardiovascular diseases, hypertension, osteoporosis, obesity, depression, falls, and functional disability in older adults.[8,9] Previous studies have demonstrated that sedentary behavior and decreased high-intensity physical activity (such as running, aerobics, and cycling) have negative effects on frailty.[10,11] Research-based accelerometers such as ActiGraphs have been used extensively to monitor physical activity in frailty research; however, these devices are expensive and specific software is required to download and use the data. Recently, there is increasing demand for consumer-grade wearable devices that track physical activity.[12] Additionally, older people have positive attitudes and perspectives toward technologies that assess frailty, such as smartwatches.[13]

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*The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.*

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Although previous studies have investigated the association between frailty in older adults and the duration of physical activity according to activity intensity, few studies have analyzed physical activity using consumer-grade activity devices in free-living. The purpose of this study was to determine differences in, and correlation of, duration of physical activity according to activity intensity and energy expenditure using consumer-grade activity devices in community-dwelling older adults with different levels of frailty. We hypothesized that frail older adults will have decreased moderate-to-vigorous physical activity, and increased frailty will be associated with a decrease in high-intensity physical activity and sedentary lifestyle.

## 2. Methods

### 2.1. Study design, setting, and participants

This cross-sectional and observational study was conducted between June 1, 2019, and January 31, 2020 in Wonju-si, South Korea. A convenience sampling technique was used to recruit older community-dwelling adults. The participants were recruited through flyers and posters at the local senior center, recreational facilities, and personal contact. We included participants aged over 65 years without walking difficulty or neurocognitive disorders. Participants were excluded if they had a physical or mental disability or a Mini-Mental State Examination score < 23.

### 2.2. Procedures

A brief questionnaire was used to determine the baseline characteristics (sex, age, education, living arrangement, smoking and alcohol habit) and frailty score of participants was assessed by trained examiner. The participants were required to wear wrist bands to measure weekly physical activity and energy expenditure. The data of duration of physical activity and energy expenditure were collected over a 7-day period.

### 2.3. Assessment of frailty level

Frailty level was evaluated using the 5 criteria proposed by Fried et al.[4] First, weight loss was defined as self-reported unintentional weight loss of > 4.5 kg or recorded weight loss of ≥ 5% per year. Second, exhaustion was defined as self-reported exhaustion on 3 to 4 days/week or most of the time. Third, low energy expenditure was defined as energy expenditure ≤ 383 kcal/week in men or ≤ 270 kcal/week in women. Fourth, slow gait was defined as the participant taking more than the cutoff time to walk 4.57 m, which was stratified by sex and body mass index (BMI) (men: ≥ 7 seconds if height ≤ 173 cm or ≥ 6 seconds if height > 173 cm; women: ≥ 7 seconds if height ≤ 159 cm or ≥ 6 seconds if height > 159 cm). Fifth, weak grip strength was defined as weak grip strength compared with standardized values stratified by sex and BMI (men: ≤ 29 kg if BMI ≤ 24, ≤ 30 kg if BMI 24.1–28, or ≤ 32 kg if BMI > 28; women: ≤ 17 kg if BMI ≤ 23, ≤ 17.3 kg if BMI 23.1–26, ≤ 18 kg if BMI 26.1–29, or ≤ 21 kg if BMI > 29). Frailty was scored from 0 to 5 points. Scores for each participant were used to classify them into non-frail, pre-frail, and frail groups and to analyze correlations with the duration of physical activity level and energy expenditure. Participants meeting none of the above criteria were non-frail, those meeting 1 or 2 criteria were pre-frail, and those meeting ≥ 3 criteria were frail.

### 2.4. Physical activity assessment

Duration of physical activity and exergy expenditure were quantified over a 7-day period using a wearable activity device (Fitbit Alta HR; Fitbit Inc., San Francisco, CA). Wearable activity devices are wireless wristband devices that use a 3-axis accelerometer and an optical heartrate tracker to estimate the physical activity level and energy expenditure. Fitabase software (Small Steps Labs LLC, San Diego, CA) was used to divide the divice data into 4 physical activity levels based on the metabolic equivalent task (MET).[14,15] These activity levels included "sedentary active" (activity < 1.5 METs), "light active" (1.5 METs ≤ activity < 3 METs), "fairly active" (3 METs ≤ activity < 6 METs), "fairly-to-very active" (activity between that in fairly and very active levels), and "very active" (activity ≥ 6 METs or ≥ 145 steps/min in ≥ 10-minute bouts). The outcomes included daily duration spent in each physical activity level and energy expenditure in calories to compare among non-frail, pre-frail, and frail groups. During the periods of data collection, examiners verified that the device was connected to the smartphone application 2 to 3 times/day. If the data from the device were not synchronized with the smartphone application daily, participants were requested to connect them. The data collected were valid if the device was worn for ≥ 4 days out of 7 days or > 10 hours/day.

### 2.5. Ethics statement

This study received ethical approval from the Institutional Review Board of Sangji University, South Korea. The purpose and procedures of this study were explained to all the participants and written informed consent was obtained.

### 2.6. Statistical analysis

All statistical analyses were conducted using SPSS Statistics software (version 22; IBM Corp., Armonk, NY). An alpha level of 0.05 was used to determine statistical significance. The Kolmogorov-Smirnov test was used to confirm the normal distribution of variables. Univariate analysis was conducted to evaluate the differences of participant characteristics, duration of physical activity, and energy expenditure among the frailty groups. The time duration spent in physical activity levels and energy expenditure were compared among the frailty groups (non-frail, pre-frail, and frail) using 1-way analysis of variance for parametric variables or Kruskal-Wallis test for non-parametric variables with post-hot analysis. Correlations between frailty score, duration of physical activity, and energy expenditure were analyzed using Pearson or Spearman's correlation coefficients. A correlation coefficient $r > 0.75$ was considered "good to excellent," 0.50 to 0.75 was "moderate-to-good," 0.25 to 0.50 was "fair," and 0.00 to 0.25 was "little or no" relationship.[16]

## 3. Results

Table 1 summarizes the baseline characteristics of participants. We analyzed the data from 88 out of 98 individuals to examine the differences in, and correlation of, duration of physical activity and exergy expenditure among frailty groups (Fig. 1). We excluded 10 individuals because of wearing the device for an inadequate duration of time. Differences in sex, age, height, BMI, education, and mini-mental state examination scores were statistically significant across groups.

### 3.1. Comparison between duration of physical activity and energy expenditure

The time duration of physical activity and energy expenditure showed significant differences among frailty groups (Table 2). The post hoc analysis showed that the frail group had significantly decreased daily duration of light, fairly, very, and fairly-to-very active physical activity as well as decreased energy expenditure compared to the non-frail group (Fig. 2). In addition, the pre-frail group showed significantly decreased daily

**Table 1**

**Subject characteristics.**

| Variable | Non-frail | Pre-frail | Frail | P |
|---|---|---|---|---|
| No. of participants | 47 | 30 | 11 | - |
| Male, No (%) | 24 (51.1)* | 11 (36.7)* | 1 (9.1) | .033 |
| Age, mean (SD), y | 70.72 (3.64)* | 72.50 (5.73)* | 77.73 (6.17) | .003 |
| Height, mean (SD), cm | 162.12 (8.95)* | 158.17 (9.18)* | 150.64 (4.50) | .001 |
| Weight, mean (SD), kg | 62.95 (10.49) | 61.28 (8.89) | 61.64 (9.74) | .756 |
| BMI, mean (SD), kg/m$^2$ | 23.82 (2.50)* | 24.56 (3.56) | 27.16 (4.23) | .008 |
| Education (less than high school), No. (%) | 16 (34)* | 16 (46.7)* | 9 (81.8) | .011 |
| Living alone, No. (%) | 3 (6.4) | 2 (6.7) | 3 (27.3) | .081 |
| Smoking (Never), No. (%) | 29 (61.7) | 23 (76.7) | 10 (90.9) | .106 |
| Alcohol (None), No. (%) | 32 (68.1) | 25 (83.3) | 10 (90.9) | .146 |
| MMSE, mean (SD), scores | 28.68 (1.18) * | 28.27 (1.68) * | 26.45 (2.30) | .004 |

BMI = body mass index, MMSE = mini-mental state examination, SD = standard deviation.
$\chi^2$ tests for categorical variables, nonparametric Kruskal-Wallis tests, and parametric 1-way analysis of variance tests were used to detect group difference.
*Significant difference with frail group.

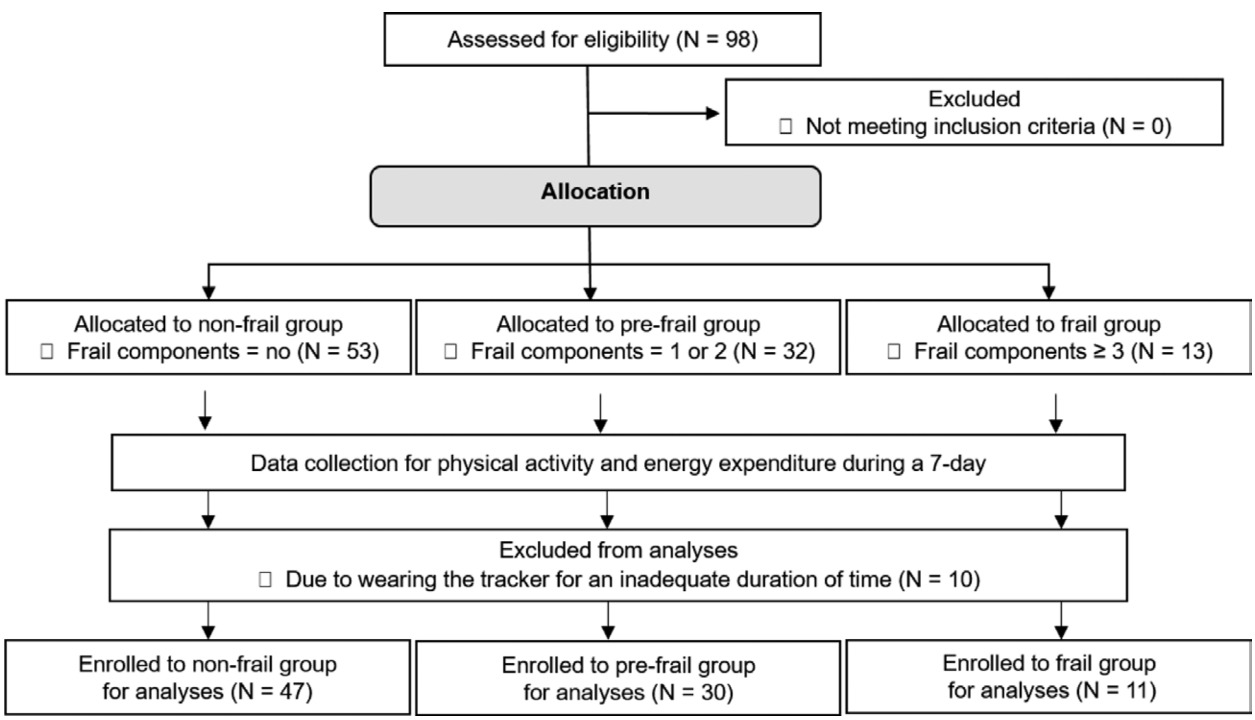


**Figure 1.** Flowchart showing the allocation of participants and experimental procedure.

duration of light and fairly-to-very active physical activity as well as decreased energy expenditure compared to the non-frail group. There was significant increase in the daily sedentary duration in the pre-frail group compared to the non-frail group.

### *3.2. Correlation between frailty, physical activity, and energy expenditure*

Frailty score had a fair correlation with the durations of physical activity levels and energy expenditure (Table 3). Energy expenditure also had a fair correlation with the duration of sedentary state and light physical activity and a moderate-to-good correlation with duration of fairly, very active, and fair-to-very active physical activity (Table 3).

## 4. Discussion

The major study finding was the difference in physical activity duration according to the intensity of physical activity and energy expenditure using a consumer-grade activity device in frail, pre-frail, and non-frail older adults aged 65 years or more. Previous prevalence studies have reported that using self-administered questionnaires to measure physical activity overestimated the activity compared to objective measurements of physical activity (e.g., accelerometer-based estimates), probably because of social desirability.[17] Consumer-grade activity devices (Fitbit, Garmin, Misfit, Apple, and Samsung) that track physical activity are increasing in popularity and commercial availability.[12] The Fitbit activity device, used in our study, is one of the products that track physical activity and energy expenditure. Therefore, physical activity can be monitored easily and usefully in frail older adults using consumer-grade activity devices.

This study found that there was significant decrease in the duration of light, fairly, and very active physical activity as well as a decrease in energy expenditure in frail adults compared to non-frail adults. Importantly, the duration of the sedentary state was increased in pre-frail adults compared to non-frail older adults. Older adults with more severity of frailty had significantly lower durations of light-to-very active physical activity and lower energy expenditure. Some studies have reported that light physical activity was associated with decreased risk of the onset and progression of disability and improved cognition.[18,19] Increasing the physical activity from sedentary behavior to moderate-to-vigorous activity may have a positive impact on frailty.[20] Our results suggested that the duration of physical activity more intense than light activity should be increased for managing and preventing the risks for frailty.

In our study, energy expenditure, measured using wearable activity devices, positively correlated with the duration of physical activity and negatively correlated with frailty score. Additionally, the energy expenditure decreased significantly in frail and pre-frail older adults compared to non-frail older adults. Total energy expenditure is determined by the resting

**Table 2**

**Differences in daily duration of physical activity and energy expenditure among frailty groups.**

| Variable | Non-frail | Pre-frail | Frail | Statistics | P | Mean difference (95% CI) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Non-frail vs Pre-frail | Non-frail vs Frail | Pre-frail vs Frail |
| Activity levels (min/d) | | | | | | | | |
| Sedentary | 655.06 ± 136.90 | 740.82 ± 163.53 | 728.50 ± 111.74 | 7.965 | .019 | −85.76 (−167.94 to -3.58) | −73.44 (−191.23 to 44.35) | 12.32 (−111.64 to 136.28) |
| Light | 252.66 ± 66.71 | 202.23 ± 67.37 | 159.08 ± 85.43 | 10.297 | <.001 | 50.43 (10.82 to 90.03) | 93.58 (36.81 to 150.34) | 43.15 (−16.59 to 102.89) |
| Fairly | 28.81 ± 21.65 | 21.45 ± 22.78 | 7.31 ± 6.51 | 15.669 | <.001 | 7.36 (−4.56 to 19.27) | 21.50 (4.43 to 38.58) | 14.14 (−3.83 to 32.11) |
| Very active | 31.65 ± 24.30 | 23.17 ± 28.10 | 11.45 ± 10.58 | 9.667 | .008 | 8.49 (−5.52 to 22.49) | 20.20 (0.13 to 40.28) | 11.72 (−9.41 to 32.84) |
| Fairly to very active | 60.47 ± 40.78 | 44.62 ± 49.09 | 18.76 ± 15.85 | 15.237 | <.001 | 15.85 (−8.04 to 39.73) | 41.71 (7.47 to 75.94) | 25.86 (−10.17 to 61.89) |
| Energy expenditure (calories/d) | 2094.94 ± 456.96 | 1827.66 ± 547.99 | 1427.21 ± 222.43 | 9.864 | <.001 | 267.28 (−1.19 to 535.76) | 667.73 (282.93 to 1052.53) | 400.45 (−4.50 to 805.40) |

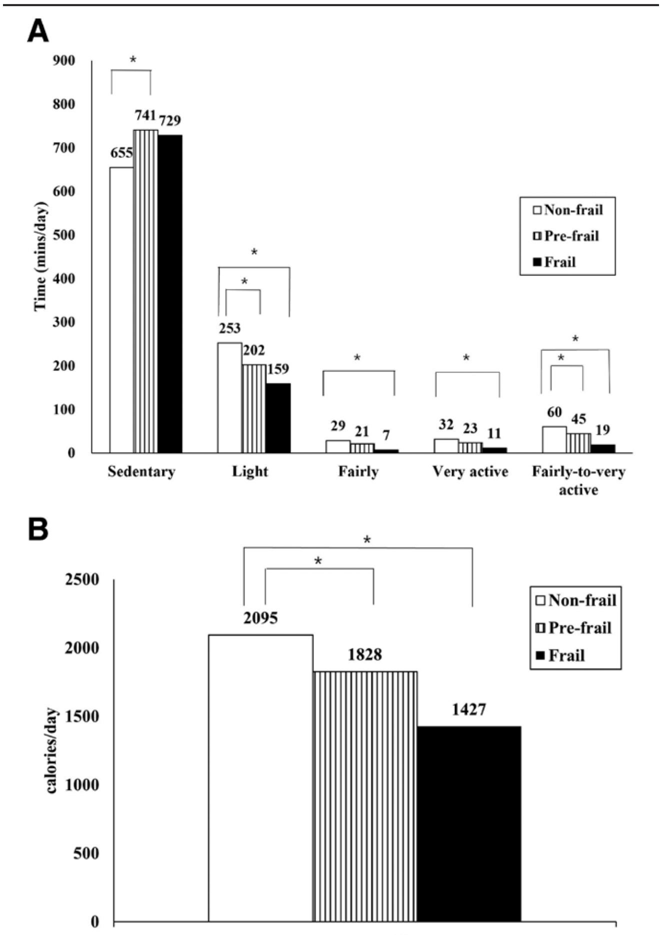


Figure 2. Post hoc comparison of duration of physical activity (A) and energy expenditure (B) among frailty groups in older adults (*$P < .05$, significant difference with non-frail group).

metabolic rate, thermic effect of food, and physical activity. The total energy expenditure decreases with age, accompanied by reduced physical activity and resting metabolic rate.[21] The decline in energy expenditure is caused by decreased physical activity levels and reduced organ mass and/or whole-body fat-free mass.[22,23] Low energy expenditure has been documented to be a risk factor of mortality in healthy older adults.[22,24] More intense physical activity had a stronger correlation with energy expenditure. Therefore, our results suggested that higher daily energy expenditure was associated with benefits in frail older adults. Future studies should evaluate whether frailty of community-dwelling older adults improves with an increase in energy expenditure that accompanies an increase in physical activity.

In our study, the mean fairly-to-very active duration was 60.47 min/day, 44.62 min/day, and 18.76 min/day in non-frail, pre-frail, and frail groups, respectively (Table 2). The World Health Organization recommends a minimum of 150 min of moderate-intensity aerobic physical activity or 75 min of vigorous-intensity aerobic physical activity per week.[25] Tribess et al reported that adults aged over 60 years require 140 min/week and 145 min/week of moderate-to-vigorous intensity physical activity for men and women, respectively, to prevent frailty.[26] The frail group in this study had insufficient physical activity duration suggested by World Health Organization and Tribess et al.[25,26] Therefore, frail older adults are needed to increase the amount and intensity of their physical activity.

### *4.1. Strength and Limitation*

One strength of this study is the use of a consumer-grade activity device in frail older adults, which provides data on physical activity duration and energy expenditure in a free-living setting. Older adults tend to engage in insufficient physical activity and spend most of their time engaged in sedentary activities, such as sitting or watching television. Sedentary lifestyle is associated with increased risk for all-cause mortality, chronic vascular disease, and cancer mortality.[27] A consumer-grade activity device would be useful for monitoring the amount of physical activity of frail older adults and facilitate change in their physical activity patterns, to manage their frailty.

This study had several limitations. First, this was a cross-sectional study. Therefore, we cannot derive conclusions regarding the cause and effect relationships of decreased physical activity and energy expenditure with frailty in older adults. Second, the study participants were community-dwelling older adults who were divided into frail, pre-frail, and non-frail groups. Because of the relatively small sample size of our study, especially in the frailty group, our results should be interpreted carefully. Further studies with large sample sizes are needed to validate the results of this study.

## 5. Conclusion

This cross-sectional study demonstrated the difference in, and correlation of, duration of physical activity according to activity intensity and energy expenditure among community-dwelling older adults with different levels of frailty. Frail older adults had reduced physical activity that was more intense than light activity, and reduced energy expenditure. Physical activity and

Table 3

**Correlation (*P* value) between frailty score, duration of physical activity, and energy expenditure.**

| | Sedentary | Light | Fairly | Very active | Fairly-to-very active | Energy expenditure |
|---|---|---|---|---|---|---|
| Frailty score | 0.347 (.001) | −0.418 (<.001) | −0.349 (.001) | −0.460 (<.001) | −0.451 (<.001) | −0.491 (<.001) |
| Energy expenditure | −0.326 (.002) | 0.310 (.003) | 0.687 (<.001) | 0.647 (<.001) | 0.715 (<.001) | - |

energy expenditure had fair and moderate-to-good correlations with frailty. The results of this study suggest that physical activity and energy expenditure should be considered in older adults to improve or manage frailty and consumer wearable devices could provide advantages for monitoring physical activity in a free-living setting.

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## Author contributions

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**Writing – review & editing:** Kyue-nam Park, Si-hyun Kim.

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