Ecological Measurement of Fatigue and Fatigability in Older Adults With Osteoarthritis

Susan L. Murphy1,2 and Dylan M. Smith3,4

1Department of Physical Medicine and Rehabilitation, University of Michigan, Ann Arbor.
2Geriatric Research Education and Clinical Center, Veterans Affairs Ann Arbor Health Care System, Michigan.
3Department of Internal Medicine, University of Michigan, Ann Arbor.
4Veterans Affairs Ann Arbor Health Care System, Michigan.

**Background.** Fatigue is associated with loss of independence in older adults; however, little is known about optimal treatment or how fatigue manifests in daily life activities. “Fatigability” was recently proposed to clarify the fatigue–activity relationship. The purpose of this study was to present a new measurement method of fatigability and begin to test its validity.

**Methods.** Our sample included 40 adults with knee or hip osteoarthritis (OA) and 20 healthy controls. Fatigue was measured by ecological momentary assessment several times a day along with continuous measurement of physical activity using a wrist-worn accelerometer. Fatigability was measured as the fatigue increase after a period of high activity.

**Results.** Compared with controls, participants with OA were approximately four times more likely to have an increase in fatigue after a high activity interval (37.0% vs 9.8%). Among people with OA, average fatigue and fatigability were not highly related ($r=.13$). Fatigue was most strongly associated with reported physical function, pain, and vitality, whereas fatigability was most strongly associated with body mass index, OA severity, and knee strength.

**Conclusions.** Although fatigue among people with OA was more associated with subjective reports of physical function and symptoms, pairing fatigue reports with physical activity tapped objective factors that may be related to the biomechanical demands of daily life activities. Thus, fatigability measurement may help discern how symptoms relate to daily life function and help to refine treatment approaches in OA.

**Key Words:** Fatigue—Measurement—Aged.

Recently, fatigue has received increased attention in geriatric care. Fatigue in older adults (measured subjectively by self-report) is associated with worse physical function (1–3) and decreased performance in activities of daily living (2–4), and it is an independent predictor of mortality (5,6). Although fatigue is problematic in older adults, it remains unclear how to address it clinically, in part because we know little about its etiology in older adults. Research reports typically express fatigue in terms of a subjective experience or a performance decrement (such as muscle fatigue induced in a laboratory study); however, neither of these constructs provide a clear understanding of how the experience of fatigue impacts daily life activities (7). In two recent conferences on fatigue sponsored by the National Institute on Aging, the concept of “fatigability” was proposed to reconcile the two perspectives and has been recently defined as “the change in the feeling of tiredness as a function of the duration, intensity, or frequency of activity” (8). Embedding fatigue within activity performance provides an enhanced picture, in that it begins to disentangle the question: “When is fatigue a problem”? Treatment can then be refined based on this knowledge.

Among older adults with osteoarthritis (OA), fatigue is common and problematic. Clinically important fatigue has been reported in 41% of patients with OA 65 years or older (9), and in an older cohort (mean age 75), problematic fatigue or tiredness in the past week has been reported in moderate levels ($M=5.5/10$) (10). Fatigue in OA is often treated as a consequence of pain rather than an independent symptom, and therapy is mainly directed at pain reduction. In a previous study, however, we found that fatigue among adults with OA was reported as being more severe than pain and that fatigue had a much stronger association with objective physical activity during a home monitoring period than did pain (11). Given these findings, we sought to better understand the fatigue experience in OA. Our examination of within-day fatigue patterns over a series of days while continuously monitoring physical activity by accelerometer allowed us to link change in fatigue severity to objective physical activity (which we call fatigability).

**Fatigability in OA**

We hypothesized that, for people with OA, fatigability might manifest as a fatigue increase after a particularly high period of activity. For people with chronic pain conditions, this phenomena is referred to as the “overactivity–underactivity” cycle in which overdoing activity results in a symptom flare that people need to recover from, often during a prolonged rest period (12,13). Because our measurement method involved both the report of within-day fatigue and continuous...
physical activity, we felt that we could operationalize fatiguability according to our hypothesis. The dual measurement method is somewhat novel in the older adult population and will be described in more detail subsequently.

**Ecological Momentary Assessment**

Ecological momentary assessment (EMA) is a technique that involves “real-time” assessment of people’s behaviors, symptoms, or experiences repeatedly sampled over time within their natural environments (14). This technique has been used in many fields and to assess various phenomena (e.g., depression, stress, drug use, mood, pain, social interactions). EMA often involves the use of technology, such as palm pilots, computers, pagers, or cell phones, to prompt people to respond to questions in the moment.

There are several advantages to using EMA to measure fatigue and fatigability in older adults. First, the EMA method eliminates the biases of typical recall-based instruments in which symptoms are typically underreported (15,16) and can be biased by recent or peak experiences (15). Second, the repeated assessment within the day and over a series of days allows examination of fatigue patterns and fluctuations over time within a person or across people. Third, the rich data can be used to identify subsets of people who exhibit similar fatigue patterns, suggesting areas where it may be useful to refine interventions. Fourth, because the assessment is occurring in a person’s natural environment within daily routines, the data should generalize to real-life situations (14) making it clinically relevant.

**Physical Activity Assessment Using Accelerometry**

The Actiwatch-S device (Phillips Respironics, Bend, OR) used in this study is an enhanced wrist-worn accelerometer that allows measurement of fatigue and pain by EMA at several points across a day along with continuous measurement of physical activity. There are different types of accelerometers available, and a comprehensive review of these devices for use in older adult research has recently been published (17). Accelerometers generate activity counts over a series of days based on movement that can be aggregated in different ways. Often, researchers examine average physical activity (measured as activity counts per minute), peak physical activity (highest activity counts over some time interval), and total daily activity (cumulative activity counts).

Accelerometers provide a sensitive real-time assessment of physical activity that occurs in daily life and are now commonly used in clinical studies. In addition, this objective measure of physical activity is not prone to problems with self-report physical activity instruments such as recall bias and factors such as mood, changes in health, anxiety, and cognitive status that influence responses by older adults (18).

Accelerometers can be positioned at different sites on the body (e.g., wrist, hip, waist, ankle) for data collection. The wrist-worn accelerometer used in our study had some advantages, such as the capability of dual data capture of momentary symptoms, high compliance with wearing the device all 5 days (97% of our sample, N=60), and likely a lower chance of problems with proper placement over the series of days compared with positioning the accelerometer at other sites. The main limitation of using a wrist-worn device is the lack of reliability and validity studies for estimating daytime energy expenditure in older adults. In previous studies of younger adults, the wrist-worn Actiwatch underestimated lower body activities such as walking compared with a hip-worn device (19,20). Devices worn at the hip and wrist together were found to best estimate energy expenditure (20,21), and there was only a minor contribution of the wrist-worn device above and beyond the hip-worn device (21).

Despite some limitations of the wrist-worn accelerometer, it does provide information about activity patterns from which we can glean periods of high activity as well as overall daily activity. In preliminary support of the validity of the Actiwatch-S to measure daytime physical activity, studies have shown that compared with control groups, activity patterns (specifically peak or highest activity counts over an interval) were significantly lower in people with fibromyalgia (22) and OA (11). Peak physical activity was also found to be significantly higher after an occupational therapy intervention promoting physical activity compared with a health education intervention (23). We also found that increased frequency of activity pacing behaviors (i.e., breaking activities into smaller pieces and taking breaks) was also significantly associated with lower physical activity (24).

In this study, we describe how we operationalized fatigability in a sample of adults with OA. The following research questions were proposed to begin to evaluate validity of our fatigability measure:

1. Did participants with OA have more occasions where fatigue increased after high activity intervals compared with age-matched controls?
2. Among participants with OA, how was fatigability related to average fatigue and to other measures?

**Methods**

**Participants**

Details on the sample and methods have been published elsewhere (11). In brief, women with OA (n=40) and healthy female controls (n=20) age matched at a 2:1 ratio participated. Women between the ages of 55 and 80 were recruited and were included if they had radiographic evidence of OA in at least one hip or knee, reported at least mild pain that lasted for 3 or more months, had adequate...
cognition, were ambulatory, could operate the device used in the study, had no medical conditions that interfered with activity performance or caused pain and fatigue, had no current psychiatric disorders, and had no joint replacement surgery in the previous 6 months. Healthy female controls were included if they had no radiographic evidence of OA and no reported knee or hip pain (11).

Procedure and Measures
Participants first underwent an x-ray of their hips and knees to determine OA severity (using the Kellgren–Lawrence Scale; 25) and then participated in two lab visits in which health assessments and physical performance tests were conducted. In between the lab visits, there was a 5-day home monitoring period in which participants wore the Actiwatch-S on their nondominant wrist. Fatigue, defined as tiredness or weariness, and pain were measured on a 0–4 scale of severity and sampled at six specific time points each day (waking; +2, +6, +10, and +14 hours; and 30 minutes before bed). Audible prompts on the Actiwatch-S were preprogrammed based on each individual’s usual wake-up time. Participants entered their levels of fatigue and pain into the Actiwatch-S after hearing the prompt. Fatigue and pain were averaged across all time points for analysis.

At the lab visits, physical function was assessed by using the Six-Minute Walk (26) and Timed Up and Go Test (27) and by using the Western Ontario and McMaster Universities OA Index physical disability subscale (WOMAC; 28). Depression was assessed using the Geriatric Depression Scale (GDS; 29). The vitality index of the Medical Outcomes Study Short Form-36 (SF-36) (30) was used to assess another fatigue dimension, particularly low energy. In addition, we measured knee strength by measuring isometric extension torque of the right knee using an isokinetic dynamometer (Biodex Multisystem 2AP; Biodex Medical, Shirley, NJ).

Measurement of Fatigability
Our measure of fatigability involves the increase in fatigue severity after a period of high activity. We were interested in the idea of measuring the influence of the performance of more intense activities (those that might be more physically fatiguing) on the fatigue experience. We defined an “activity interval” as the average activity (in units of activity counts per minute) that occurred between any two symptom reporting time points. Because of the variation across individuals in activity counts, “high” activity intervals were calculated individually. For each participant, the mean activity across the week was calculated. Intervals where activity level was 1 SD above the participant’s mean activity were deemed “high activity” intervals. Each participant’s fatigability score was then calculated as the difference in fatigue severity during the subsequent time interval. Therefore, fatigability was defined as the increase in fatigue in the 4-hour period after a high activity interval. Figure 1 shows a diagram of this calculation.

In our initial testing of a fatigability measure, we also examined the operationalization of fatigability as fatigue increase during a high activity interval. We tested this operationalization because the activity intervals were somewhat arbitrary in our study (i.e., they were simply the time periods that occurred between symptom reporting), and we could not be sure when high activity occurred within each block of time. For example, if the high activity occurred early in a 4-hour interval, then fatigue increase during that interval might be a meaningful measure of fatigability. When we examined this operationalization, we found that it was not significantly associated with any of our other measures, so we dropped it from further analysis.

Analyses
To address research question 1, we first calculated high activity intervals for each person and then examined if fatigue increased in the subsequent 4-hour period following the high interval. To address research question 2, we first performed bivariate correlations between variables and next performed regression analyses, which allowed us to examine the unique relationship between fatigability and each outcome variable among participants with OA, controlling for any effect of average fatigue.

RESULTS
There were 226 high activity intervals identified in the sample (157 in OA and 69 in controls). Although the average activity counts per minute of these high intervals were higher for controls compared with participants with OA across the 5-day period (601.98 vs 488.58), participants with OA were approximately four times more likely to have an increase in fatigue after a high activity interval (37.0% vs 9.8%). Table 1 compares participants with OA and controls across all of our outcome variables. Both average fatigue and fatigability were significantly higher for participants with OA compared with controls.

Table 2 shows the bivariate correlations between fatigability, average fatigue levels, and the other outcome variables within the OA group (n=40). Of note, there was almost no association between average fatigue and fatigability (r=.13). Fatigability was most strongly associated

![Fatigability measurement using ecological momentary assessment and concurrent physical activity monitoring.](https://academic.oup.com/biomedgerontology/article-abstract/65A/2/184/557175)
with OA severity \((r = .35, p < .05)\), body mass index (BMI; \(r = .29, p < .10\)), and knee strength \((r = .27, p < .10)\), whereas average fatigue levels were most strongly associated with subjective measures of pain (average EMA pain, \(r = .68, p < .01\)), physical function (WOMAC, \(r = .65, p < .01\)), and vitality (SF-36 Vitality, \(r = .50, p < .01\)).

In Table 3, a separate regression model was performed for each outcome variable, represented as rows in the table. We entered average fatigue as a predictor variable and then fatigability on a second step, which allowed us to look at the incremental predictive variance added by including fatigability \((R^2\) change). Consistent with the results in Table 2, the strongest associations of fatigability were with OA severity, BMI, and knee strength, after controlling for the effect of average fatigue.

**Discussion and Implications**

In this preliminary investigation, our most significant finding is that we found a difference between the concepts of fatigue and fatigability among participants with OA. Average fatigue was most highly associated with reported physical function, average pain, and vitality, whereas fatigability appeared to be a response to physical activity that was more related to objective factors: OA severity, BMI, and knee strength. These findings suggest that for people with OA, the pairing of subjective fatigue reports with physical activity tapped factors that might reflect the biomechanical demands of activity performance. Average fatigue without reference to physical activity appeared to reflect general symptoms and reported physical function.

Some issues and limitations should be mentioned. First, our measure of fatigability showed fairly modest associations with other variables. This may be due to the lack of refinement of the fatigability measure. Given the preliminary stage of this research and the constraints imposed by the existing study methods, we chose a logical but fairly crude operational definition of high activity intervals. Thus, it may be that the study-defined timing of activity intervals and symptom reporting limited our sensitivity in determining more specific peak activity bouts and subsequent fatigue increases. Second, although the wrist-worn assessment has distinct advantages in terms of feasibility and compliance, it will be important to further examine the validity of this method for measuring physical activity intensity and to test other physical activity measures, perhaps by conducting a dual device study using wrist- and hip-worn accelerometers. Third, because fatigability was associated with biomechanical factors, the results suggest that high activity intervals are physically fatiguing. However, because fatigue has several dimensions (i.e., mental, social) and these were not specified, we still do not know what contributes to the overall fatigue experience in OA. In our current work, we are examining the immediate and carryover effects of performing lab-based activities designed to elicit physical or mental fatigue in a home monitoring period. We are also asking participants to report not only general fatigue (tiredness) but also physical and mental fatigue to determine if we can capture different fatigue domains during the home period. Fourth, our sample was

### Table 1. Group Differences Between Participants With OA and Controls

<table>
<thead>
<tr>
<th></th>
<th>OA (n=40) M (SD)</th>
<th>Control (n=20) M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue***</td>
<td>1.13 (0.71)</td>
<td>0.34 (0.47)</td>
</tr>
<tr>
<td>Fatigability*</td>
<td>0.31 (0.62)</td>
<td>0.01 (0.30)</td>
</tr>
<tr>
<td>Pain***</td>
<td>1.17 (0.70)</td>
<td>0.04 (0.05)</td>
</tr>
<tr>
<td>Six-min walk (feet)</td>
<td>1300.42 (247.78)</td>
<td>1403.90 (197.47)</td>
</tr>
<tr>
<td>TUG (s)**</td>
<td>9.77 (2.34)</td>
<td>7.99 (1.20)</td>
</tr>
<tr>
<td>GDS**</td>
<td>2.10 (2.53)</td>
<td>0.53 (0.70)</td>
</tr>
<tr>
<td>OA severity***</td>
<td>2.25 (0.81)</td>
<td>0.95 (0.51)</td>
</tr>
<tr>
<td>SF-36 Vitality</td>
<td>56.72 (20.33)</td>
<td>63.44 (34.78)</td>
</tr>
<tr>
<td>BMI***</td>
<td>30.97 (5.57)</td>
<td>24.71 (3.80)</td>
</tr>
<tr>
<td>Knee strength (N.m)</td>
<td>91.13 (36.80)</td>
<td>95.80 (30.53)</td>
</tr>
</tbody>
</table>

Notes: Some of these group differences have been previously reported in Murphy and colleagues (11). BMI = body mass index; GDS = Geriatric Depression Scale; Nm = Newton-meters; OA = osteoarthritis; TUG = Timed Up and Go Test.

*p < .05.

**p < .01.

***p < .001.

### Table 2. Correlations Between Fatigue, Fatigability, and Other Outcome Variables Among Participants With OA \((N=40)\)

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
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<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fatigue</td>
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<tr>
<td>2. Fatigability</td>
<td>.13</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3. Pain</td>
<td>.68**</td>
<td>.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4. Six-min walk</td>
<td>-28</td>
<td>.02</td>
<td>.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5. TUG score</td>
<td>.19</td>
<td>.03</td>
<td>.29</td>
<td>-74**</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>6. GDS</td>
<td>.10</td>
<td>.03</td>
<td>.35</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. OA severity</td>
<td>.27</td>
<td>.24</td>
<td>.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>8. WOMAC</td>
<td>.65**</td>
<td>.26</td>
<td>.35</td>
<td>-32**</td>
<td>.33**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. SF-36 Vitality</td>
<td>-50**</td>
<td>.25</td>
<td>.30</td>
<td>-30</td>
<td>-38*</td>
<td>.39**</td>
<td>-31**</td>
<td>-43**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. BMI</td>
<td>.38</td>
<td>.29</td>
<td>.30</td>
<td>-50**</td>
<td>.34</td>
<td>-03</td>
<td>.14</td>
<td>.50**</td>
<td>-31*</td>
<td></td>
</tr>
<tr>
<td>11. Knee strength</td>
<td>.06</td>
<td>.27</td>
<td>.25</td>
<td>.43</td>
<td>-48**</td>
<td>.03</td>
<td>.03</td>
<td>.18</td>
<td>-17</td>
<td>.004</td>
</tr>
</tbody>
</table>

Notes: BMI = body mass index; GDS = Geriatric Depression Scale; Nm = Newton-meters; OA = osteoarthritis; TUG = Timed Up and Go Test; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index physical disability subscale.

1 p < .10

*p < .05

**p < .01
relatively young (mean age=63) and largely free of other comorbidities, so we may find that fatigability is different among older adults with OA who present with additional health issues. If there are other distinct disease-specific contributors to fatigability, it will be important to select samples with similar comorbidity profiles in future studies of older adults. Lastly, future replication work will be necessary with male samples and an older sample of people with OA.

This measurement method of fatigability has some potential clinical implications. We may be able to identify who becomes more fatigable in daily routines. In our study, 15 of the 40 OA participants had an increase in their fatigue after half or more of their high activity intervals, which may be an important subgroup to target for intervention. We may also be able to refine and tailor symptom management strategies by identifying when fatiguing episodes happen for each person. For instance, over the 5-day period, one participant had three high activity intervals followed by an increase in fatigue that all occurred between 11 AM and 3 PM. This may be a key time period for a health care professional, such as an occupational therapist, to target and address activity pacing and symptom management.

In conclusion, we believe that this new approach to measurement of fatigability—combining momentary subjective assessments with objective measures of high activity intervals—has great potential to provide important information about how fatigue is manifested in daily routines of older adults. Future refinements in defining and measuring high activity bouts, as we are exploring in ongoing work, should help this approach reach its potential. Although increased fatigue severity has been a traditional indicator of a problem, our findings suggest that fatigability may also help discern problems in how symptoms relate to function and help refine treatment approaches in OA.

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**Correspondence**

Address correspondence to Susan L. Murphy, ScD, OTR/L, 300 North Ingalls Street, 9th floor, Ann Arbor, MI 48109-2007; Email: sumurphy@umich.edu

**References**


**Table 3. Stepwise Linear Regression With Fatigue and Fatigability as Predictors in Participants With OA (N=40)**

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Step 1: Fatigue</th>
<th>Step 2: Fatigability Added</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β* p</td>
<td>R² change p</td>
</tr>
<tr>
<td>Pain</td>
<td>.674 .000</td>
<td>.000 .910</td>
</tr>
<tr>
<td>Six-min walk</td>
<td>−.280 .092</td>
<td>.000 .963</td>
</tr>
<tr>
<td>TUG score</td>
<td>.199 .235</td>
<td>.000 .928</td>
</tr>
<tr>
<td>GDS</td>
<td>.196 .248</td>
<td>.000 .905</td>
</tr>
<tr>
<td>OA severity</td>
<td>.235 .132</td>
<td>.102 .042</td>
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<tr>
<td>WOMAC</td>
<td>.617 .000</td>
<td>.030 .174</td>
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<tr>
<td>SF-36 Vitality</td>
<td>−.472 .002</td>
<td>.034 .199</td>
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<tr>
<td>BMI</td>
<td>.344 .028</td>
<td>.060 .107</td>
</tr>
<tr>
<td>Knee strength</td>
<td>.02 .90</td>
<td>.070 .11</td>
</tr>
</tbody>
</table>

Notes: BMI = body mass index; GDS = Geriatric Depression Scale; OA = osteoarthritis; TUG = Timed Up and Go Test; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index physical disability subscale.

* Standardized regression coefficient.

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