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Objective Assessment of Activity, Energy Expenditure, and Functional Limitations in Older Men: The Osteoporotic Fractures in Men Study

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Background. The relationship between objectively assessed activity, energy expenditure, and the development of functional limitations is unknown.

Methods. Energy expenditure and activity levels were measured objectively using the multisensor SenseWear Pro Armband worn for greater than or equal to 5 days in 1,983 MrOS men (aged ≥78.3 years) free of functional limitations. Validated algorithms calculated energy expenditure; standard cut points defined moderate or greater activity (≥3.0 METS); and sedentary behavior (time awake ≤ 1.5 METS). Self-reported functional limitation was determined at the activity assessment and 2.0 years later as inability to perform instrumental activities of daily living (managing money, managing medications, shopping, housework, and meal preparation) and activities of daily living (climb stairs, walk two to three blocks, transfer, or bathe).

Results. Each standard deviation decrease in total energy expenditure (420.6 kcal/day) increased the likelihood of inability to perform an instrumental activity of daily living (multivariate odds ratio [mOR]: 1.61, 95% CI: 1.30–2.00) or activity of daily living (mOR: 1.35, 95% CI: 1.12–1.63). Each standard deviation decrease in moderate or greater activity (61.1 minutes/day) increased the likelihood of inability to perform an instrumental activity of daily living (mOR: 1.47, 95% CI: 1.22–1.78) or activity of daily living (mOR: 1.36, 95% CI: 1.14–1.61). Each standard deviation increase in minutes of sedentary behavior (105.2 minutes/day) increased the likelihood of inability to perform an instrumental activity of daily living (mOR: 1.20, 95% CI: 1.03–1.40) or activity of daily living (mOR: 1.17, 95% CI: 1.01–1.35).

Conclusion. Older men with lower total energy expenditure, lower moderate activity, or greater sedentary time were more likely to develop a functional limitation.

Key Words: Physical activity—Physical function—Physical performance—Functional performance.

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APPROXIMATELY 20% of U.S. adults aged 70 and older report at least some difficulty in activities of daily living (ADLs) or instrumental ADLs (IADLs) (1). While the proportion of older persons reporting a disability may be decreasing over time (2), the size of the population aged more than 65 years continues to increase and will reach 88.5 million by 2050 (3), resulting in a significant number of persons at risk of becoming disabled and unable to care for themselves.

Many studies have demonstrated that physical activity is associated with several health benefits, including a reduced risk of all-cause mortality and disability (4–8). However, most of these studies have used self-reported questionnaire data that are only modestly associated with objective measurements of total energy expenditure (9,10). In addition, self-reported activity questionnaires generally gather information regarding specific and predetermined types of activity performed (such as sports, housework, and walking), which are subject recall and other biases that are likely influenced by participant characteristics. On the other hand, objective monitors record data in real time that are then processed to estimate broad types of activity and energy expenditure. Thus, questionnaire and objective assessment of activity are measuring different factors, and objective activity monitors more accurately estimate total energy expenditure. Little is known about the relation between the key measures and activity monitors, namely, total energy expenditure and time spent at various activity levels, with health and functional status. Accordingly, we used data from the Osteoporotic Fractures in Men (MrOS) study to determine whether objectively measured total energy expenditure, time spent in moderate or greater activity, or time spent in sedentary behavior was associated with the risk of self-reported functional limitations in older men.

Methods

Participants

In 2000–2002, 5,994 community-dwelling men joined MrOS study, a multicenter cohort study of aging and osteoporosis (11,12). At baseline, men were aged 65 and older, independent in ambulation and without bilateral hip replacements. From 2007 to 2009, surviving men were invited to participate in a third study visit where information about functional limitations was gathered and an activity monitor was worn. On average, 2.0 years (SD = 0.11) after the third clinic visit, participants were again asked to complete a self-administered questionnaire to update information about functional limitations. Of the 4,681 men at Visit 3, a total of 1,327 men who completed the questionnaire-based information for Visit 3 did not complete the objective activity assessment, leaving 3,354 with activity monitor data (Figure 1). Of these, there were 436 men with invalid activity data, leaving 2,918 men with valid activity monitor data. Men with invalid activity data were older and had lower cognitive function and more medical conditions than those with valid data. Of these, 18 men were missing information on functional limitations. Of the 2,900 men with valid data for both functional limitations and activity data, 2,157 were free of functional limitations at Visit 3. Of these, 174 were missing data at the follow-up assessment of functional limitation and/or were missing covariate data at Visit 3, leaving an analysis subset of 1,983.

Written informed consent was obtained and the protocol was approved by all appropriate institutional review boards.

Activity Monitor and Questionnaire

Participants were instructed to wear the SenseWear Pro Armband (Body Media, Inc., Pittsburgh, PA) at all times, including while sleeping, over the right triceps muscle for a typical 7-day period and to remove it only for brief periods for bathing and water activities. Data were sampled in 1-minute epochs over 24-hour periods to estimate energy expenditure (EE) in kilocalories (13) per day from a heat flux sensor, a galvanic skin response sensor, a skin temperature sensor, a near body temperature sensor, and a body movement sensor (two-axis accelerometer); these data were used in proprietary algorithms (Innerview Professional 5.1 software) along with height, weight, handedness, and smoking status to estimate EE, METS, and time asleep. Resting metabolic rate was estimated using the Harris Benedict Equation (14). A validation study comparing the SenseWear Pro Armband with the criterion method of doubly labeled water showed excellent levels of agreement for total EE older adults (interclass correlation coefficient = 0.90) (15). BodyMedia data indicate that overall agreement for time asleep between the SenseWear Pro Armband and PSG/self-reported activity was greater than 90% in a small internal validation study (http://www.bodymedia.com/Professionals/Whitepapers/The-SenseWear-armband-as-a-Sleep-Detection-Device, last accessed March 8, 2013).

Variables used in analysis were (a) *total energy expenditure (total EE: kcal/day)*: total amount of energy expended per 24 hours; (b) *moderate or greater activity (minutes/day)*: time spent in activity with METS greater than or equal to 3.0; and (c) *sedentary behavior (minutes/day)*: time spent at METS ≤ 1.5 while not asleep. All variables reflect average daily experience in order to obtain a more representative characterization of usual activity patterns and were averaged over all days to limit variability in the measures. A 24-hour period was excluded from this average if the participant wore the activity monitor for less than 90% of the period because estimates of daily total energy expenditure may be underestimated if the monitor is worn for less than this amount of time. Men were required to have greater than or equal to five 24-hour periods of data to be considered as having valid activity data; this time period was selected to ensure that the activity monitor recorded a time spent in daily activity that was reflective of the participant's usual life.

Self-Reported Functional Limitations

Men completed a self-administered questionnaire at the time of activity assessment and again a mean of 2.0 years later about IADLs (tasks of managing money, managing medications, shopping for groceries or clothes, performing housework/chores, and meal preparation) and ADLs (tasks of climbing 10 stairs, walking two to three blocks, bathing, and transferring). The questionnaire as described previously (16) includes questions about each task, from which participants were classified as *able* or *unable* to complete.

Each task was considered separately as an outcome. Two summary scales were also created: *inability to complete greater than or equal to one IADL* and *inability to complete greater than or equal to one ADL.*

Statistical Analyses

Characteristics of MrOS participants were compared by presence of any inability versus no limitation at the time of activity assessment, using t tests, Wilcoxon's rank-sum tests, or chi-squared tests as appropriate. Among participants in the longitudinal analyses, characteristics were compared

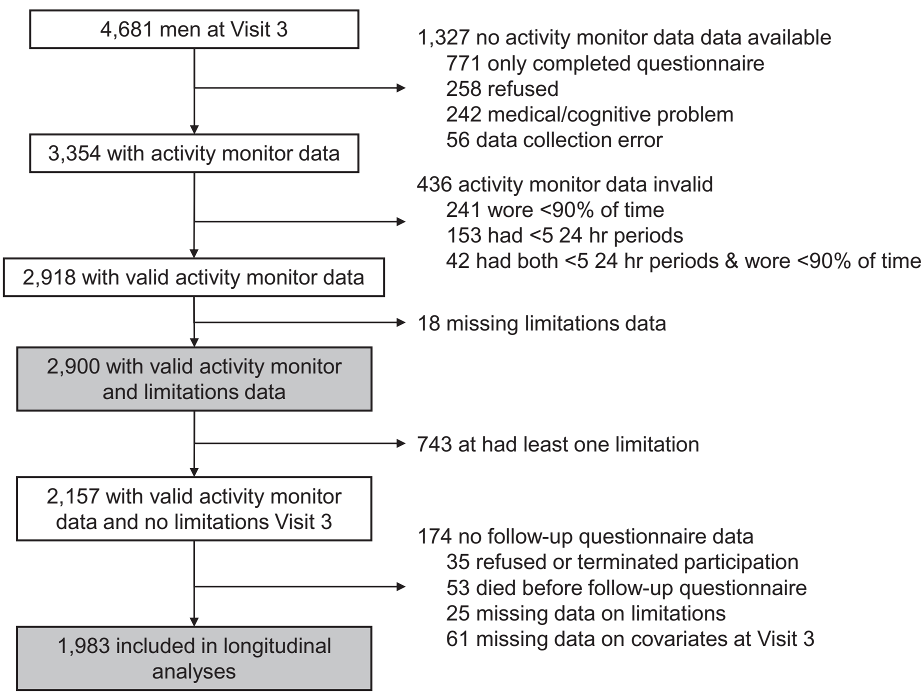

Figure 1. Participants included in analyses.

across quartiles of time spent in sedentary behavior; analysis of variance, Kruskal–Wallis tests, and chi-squared tests were used as appropriate.

Logistic regression was used to model the association between the activity variables and likelihood of developing a limitation. Activity variables were modeled as continuous variables and as quartiles (derived from the entire population at the time of activity assessment). For total EE and moderate or greater activity, the highest quartile served as reference; for sedentary time, the lowest quartile was referent. A test for trend across quartiles was also completed with quartile entered into the model as a single multilevel variable. Models were adjusted for factors that were selected *a priori* to be likely confounders of the association between activity and the development of a limitation. These covariates were age; clinical center; season of activity assessment; obesity (measured as percent body fat from DXA scans) (17); race (white vs non-white); weight; geriatric depression score (18) (higher score indicates worse symptoms); marital status; self-rated health (excellent or good vs fair/poor/very poor); cognitive function (3MS score) (19); smoking status (modeled as current vs past vs never); and number of comorbid medical conditions (modeled as 0/1, 2/3, or 4+ from the list of self-reported physician diagnosis of history of cardiovascular disease, hypertension, diabetes, chronic obstructive pulmonary disease, dementia, Parkinson's disease, chronic kidney disease, liver disease, and nonskin [melanoma] cancer). Measures of physical function (such as walking speed) were excluded as covariates as these may be on the causal pathway.

All significance levels reported were two sided and all analyses were conducted using SAS version 9.2 (SAS Institute Inc., Cary, NC).

Results

Of those men at Visit 3 with activity data, participants with at least one limitation were older; had lower total EE and minutes of moderate or greater activity; and spent more time in sedentary behavior (Table 1) compared with those without a limitation. Men with limitations also had more medical conditions, more depressive symptoms, and lower cognitive function and had greater weight and percent body fat than did their nonlimited counterparts.

Longitudinal Analyses: Participant Characteristics

Among the participants included in the longitudinal analyses (Table 2), men who spent more time in sedentary behavior were older; had greater body fat and body mass index; had more medical conditions; had lower levels of total EE; and spent less time in moderate or greater activity than those who spent less time in sedentary behavior. There was no significant association between time spent in sedentary behavior and self-reported health status, number of depressive symptoms, cognition, smoking status, marriage status, race, or education. Average time in physical activity (METS > 3.0) was 92.8 minutes/day (*SD*: 61.1 minutes/day); average EE per day was 2395 kcal/day (*SD*: 420.6 kcal/day); and average time in sedentary behavior was 13.8 hours/day (*SD*: 1.8 hours/day).

Table 1. Characteristics of MrOS Participants at the Time of Activity Assessment, by Inability to Complete ≥1 Instrumental Activities of Daily Living or Activities of Daily Living ($M \pm SD$ or N [%])

Characteristics	No Reported Inability (N = 2,157)	At Least One Reported Inability (N = 743)
Total energy expenditure, kcal/d*	2,383.4 ± 421.2	2,220.6 ± 452.9
Sedentary behavior (≤1.5 METS), min/d*	831.9 ± 105.8	875.4 ± 118.7
Moderate or greater activity (≥3 METS), min/d*	90.8 ± 60.7	58.6 ± 53.2
Age, y*	78.5 ± 4.8	80.6 ± 5.6
White race	1,939 (89.9)	680 (91.5)
Married*	1,745 (80.9)	533 (71.7)
Education†		
Less than high school	85 (3.9)	47 (6.3)
High school	324 (15.0)	143 (19.3)
College/grad school	1,748 (81.0)	553 (74.4)
Smoking†		
Never	902 (41.8)	269 (36.2)
Past	1,217 (56.5)	458 (61.6)
Current	37 (1.7)	16 (2.2)
Good or excellent self-reported health status*	1,995 (92.6)	536 (72.1)
Selected medical conditions*		
0–1	1,324 (61.4)	288 (38.8)
2–3	777 (36.0)	392 (52.8)
4+	56 (2.6)	62 (8.4)
Geriatric depression score (range 0–15)*	1.3 ± 1.6	3.0 ± 2.5
3MS score (range 0–100)*	93.3 ± 5.2	90.9 ± 8.0
Body mass index, kg/m^2*	26.8 ± 3.4	28.0 ± 4.4
Height, cm‡	173.5 ± 6.8	173.0 ± 7.0
Weight, kg*	80.7 ± 12.2	84.0 ± 15.4
Percent body fat*	26.1 ± 5.21	28.2 ± 6.0

Note: Selected medical conditions include self-reported physician diagnosis of history of cardiovascular disease, hypertension, diabetes, chronic obstructive pulmonary disease, dementia, Parkinson's disease, chronic kidney disease, liver disease, and nonskin (melanoma) cancer.

*$p < .001$; †$p < .05$; ‡$p < .1$.

Longitudinal Analyses: Inability to Complete One or More IADL, or One or More ADL

Among men initially free of limitations, decreased total EE and fewer minutes spent in moderate or greater activity were associated in a graded manner (p-trend ≤ .001) with an increased likelihood of both ADL and IADL limitations at follow-up after multivariate adjustment: compared with men in the highest quartile, men in the lowest quartile of total of either measure were two to three times more likely to report inability to complete an ADL or inability to complete an IADL compared with those in the lowest quartile. The associations between minutes of sedentary behavior and development of an inability to complete IADL were similar (a twofold association between quartiles 1 and 4) and borderline significant for inability to complete an ADL (p for trend = .052) (Table 3).

Longitudinal Analyses: Inability to Complete Specific Functional Tasks

Each of the three measures of activity was related to inability to walk two to three blocks; the relation between the activity measures and other ADLs was less consistent (Table 4). Among the IADLs, the measures of activity were most strongly related to inability to complete housework; the other associations were not consistent, but inability to complete some of these tasks was rare.

Discussion

In this study of older men, those with lower levels of total EE and who spent less time in moderate or greater activity were more likely to develop a functional limitation over time. Men with greater time in sedentary behavior also had an increased likelihood of developing a functional limitation. These associations tended to be graded in nature, with likelihood of limitation increasing across quartiles of decreasing activity level.

Among the specific ADLs and IADLs that we investigated, inability to walk two to three blocks or to complete housework was most consistently and strongly related to the physical activity and energy measures that we evaluated. These tasks are likely to be early manifestations in the disablement process (20) and were most common in our cohort, both of which may explain the stronger relationship with activity levels than between the other tasks and activity.

The tasks included as outcomes in these analyses are varied—some are mostly physical (eg, walking), others mostly cognitive (eg, managing money), and some integrative (eg, meal preparation). We initially postulated

Table 2. Characteristics (*M* ± *SD* or *N* [%]) of MrOS Participants Included in Longitudinal Analyses by Quartile of Time Spent in Sedentary Behavior (min/d)

Characteristics	Quartile 1 (<772.0) (*N* = 557)	Quartile 2 (≥772.0 to <844.4) (*N* = 530)	Quartile 3 (≥844.4 to < 915.0) (*N* = 485)	Quartile 4 (≥915.0) (*N* = 411)
Total energy expenditure, kcal/d*	2,649.4 ± 470.3	2,388.7 ± 376.5	2,281.7 ± 329.8	2,194.8 ± 317.4
Sedentary behavior (≤1.5 METS), min/d*	701.4 ± 58.9	810.2 ± 20.6	878.4 ± 19.6	969.6 ± 49.0
Moderate or greater activity (≥3 METS), min/d*	147.1 ± 69.4	89.0 ± 44.1	69.4 ± 36.9	51.8 ± 32.6
Age, y*	77.5 ± 4.5	78.2 ± 4.6	78.9 ± 5.1	79.0 ± 4.9
White race	512 (91.9)	479 (90.4)	427 (88.0)	368 (89.5)
Married	466 (83.7)	420 (79.3)	392 (80.8)	340 (82.7)
Education				
Less than high school	23 (4.1)	19 (3.6)	15 (3.1)	17 (4.1)
High school	91 (16.3)	73 (13.8)	83 (17.1)	56 (13.6)
College/grad school	443 (79.5)	438 (82.6)	387 (79.8)	338 (82.2)
Smoking				
Never	239 (42.9)	228 (43.0)	195 (40.2)	178 (43.3)
Past	310 (55.7)	294 (55.5)	253 (52.2)	224 (54.5)
Current	8 (1.4)	8 (1.5)	7 (1.4)	9 (2.2)
Good or excellent self-reported health status	523 (93.9)	500 (94.3)	453 (93.4)	378 (92.0)
Selected medical conditions†				
0–1	382 (68.6)	340 (64.2)	282 (58.1)	232 (56.5)
2–3	165 (29.6)	177 (33.4)	187 (38.6)	168 (40.9)
4+	10 (1.8)	13 (2.5)	16 (3.3)	11 (2.7)
Geriatric depression score (range 0–15)	1.2 ± 1.5	1.2 ± 1.5	1.3 ± 1.5	1.3 ± 1.6
3MS score (range 0–100)	93.6 ± 5.1	93.5 ± 5.1	93.4 ± 5.2	93.6 ± 4.7
Body mass index, kg/m^2*	25.9 ± 3.2	26.8 ± 3.3	27.0 ± 3.4	27.5 ± 3.5
Height, cm	173.3 ± 6.6	173.8 ± 6.7	173.9 ± 6.6	173.3 ± 7.1
Weight, kg*	77.9 ± 11.1	81.0 ± 11.8	81.8 ± 11.9	82.9 ± 12.9
Percent body fat*	24.4 ± 5.2	26.2 ± 5.0	26.6 ± 5.1	27.4 ± 5.1

Notes: Selected medical conditions include self-reported physician diagnosis of history of cardiovascular disease, hypertension, diabetes, chronic obstructive pulmonary disease, dementia, Parkinson's disease, chronic kidney disease, liver disease, and nonskin (melanoma) cancer.

*$p < .001$; †$p < .05$.

Table 3. Likelihood (Odds Ratio, 95% CI) of Inability to Complete ADL or IADL an Average of 2.02 y (*SD*: 0.1 y) After Objective Activity Assessment, Among Those Initially Able to Complete ADLs/IADLs (*N* = 1,983)

Activity Variable	Inability for Any ADL, *N* = 314 (16%)	Inability for Any IADL, *N* = 263 (13%)
Total energy expenditure (kcal/d)		
Per standard deviation decrease (420.6)	1.35 (1.12–1.63)	1.61 (1.30–2.00)
Quartile 1 (<2,025.8)	2.43 (1.49–3.94)	2.91 (1.71–4.95)
Quartile 2 (≥2,025.8 to <2,294.2)	1.24 (0.81–1.89)	1.91 (1.19–3.05)
Quartile 3 (≥2,294.2–2,599.3)	1.21 (0.82–1.78)	1.45 (0.91–2.30)
Quartile 4 (≥2,599.3)	1.0 (reference)	1.0 (reference)
p for trend	.001	<.001
Minutes of sedentary behavior (METS ≤ 1.5, min/d)		
Per standard deviation increase (105.2)	1.17 (1.01–1.35)	1.20 (1.03–1.40)
Quartile 1 (<772.0)	1.0 (reference)	1.0 (reference)
Quartile 2 (≥772.0 to <844.4)	1.83 (1.25–2.69)	1.51 (1.00–2.29)
Quartile 3 (≥844.4 to <915.0)	1.36 (0.91–2.03)	1.62 (1.06–2.47)
Quartile 4 (≥915.0)	1.75 (1.17–2.62)	2.06 (1.34–3.17)
p for trend	.052	.001
Minutes of moderate or greater activity (METS ≥ 3.0, min/d)		
Per standard deviation decrease (61.1)	1.36 (1.14–1.61)	1.47 (1.22–1.78)
Quartile 1 (<37.8)	2.17 (1.40–3.36)	2.69 (1.66–4.36)
Quartile 2 (≥37.8–68.8)	1.70 (1.14–2.54)	2.17 (1.40–3.36)
Quartile 3 (≥68.8–114.7)	1.63 (1.10–2.43)	1.99 (1.28–3.08)
Quartile 4 (≥114.7)	1.0 (reference)	1.0 (reference)
p for trend	.001	<.001

Notes: Models were adjusted for age, clinical center, season of activity measurement, percent body fat, race, weight, depressive symptoms, marital status, self-rated health, cognitive function, smoking status, and number of co-morbid medical conditions.

ADL = activity of daily living; IADL = instrumental ADL.

Table 4. Likelihood of Specific Limitations in ADL or IADL, an Average of 2.02 y (*SD*: 0.1 y) After Objective Activity Assessment, Among Those Initially Able to Complete ADL/IADLs (*N* = 1,983)

		ADL				IADL				
Activity Variable	Unit Change	Walk Two to Three Blocks, *N* = 206 (10.4%)	Climb 10 Steps, *N* = 114 (5.8%)	Transfer, *N* = 152 (7.7%)	Bathe, *N* = 40 (2.0%)	Meals, *N* = 39 (2.0%)	Housework, *N* = 222 (11.2%)	Shopping, *N* = 52 (2.6%)	Manage money, *N* = 43 (2.2%)	Manage medications, *N* = 32 (1.6%)
Total energy expenditure (kcal/d)	−420.6	1.52 (1.20–1.91)	1.40 (1.03–1.90)	1.20 (0.94–1.54)	1.53 (0.89–2.61)	1.99 (1.10–3.60)	1.70 (1.34–2.16)	1.11 (0.73–1.69)	1.57 (0.93–2.65)	1.46 (0.82–2.61)
Sedentary behavior (METS ≤ 1.5, min/d)	105.2	1.27 (1.08–1.51)	1.07 (0.87–1.33)	1.17 (0.97–1.41)	1.53 (1.07–2.17)	1.10 (0.77–1.56)	1.26 (1.08–1.48)	1.22 (0.90–1.67)	1.17 (0.83–1.64)	1.15 (0.79–1.70)
Moderate or greater activity (METS ≥ 3.0, min/d)	−61.1	1.51 (1.21–1.87)	1.35 (1.02–1.79)	1.21 (0.97–1.52)	1.40 (0.88–2.23)	1.51 (0.92–2.49)	1.57 (1.27–1.93)	0.97 (0.69–1.36)	1.45 (0.91–2.29)	1.19 (0.75–1.88)

Notes: Models were adjusted for age, clinical center, season of activity measurement, percent body fat, race, weight, depressive symptoms, marital status, self-rated health, cognitive function, smoking status, and number of comorbid medical conditions.

ADL = activity of daily living; IADL = instrumental ADL.

that activity level would be related to both physical and cognitive tasks, as previous research has shown that lower objectively measured activity is related to cognitive impairment (21). However, among the individual tasks, we only found significant associations with tasks that were physical in nature. This finding could be because there is truly no association between activity level and limitations in tasks that rely primarily on intact cognitive function. However, those types of limitations were rare in our cohort (<2.5%) and we had limited power to detect an association. This question should be further addressed in other studies with larger numbers of participants who develop limitations.

Evaluating total daily activity measures from objective devices such as pedometers and accelerometers is clinically important because these devices are now relatively inexpensive and feasible for use by older adults residing in the community. Physicians may recommend that patients engage in a given number of minutes of activity per week (or use a given amount of energy per week) and track such activity using these devices.

MrOS is a healthy cohort of older men with high activity levels. Most men had more than 30 minutes/day in moderate or greater activity although whether this activity came from short bouts (such as 1- to 2-minute periods of activity) or bouts of longer duration (such as 20- to 30-minute periods of sustained activity) was not analyzed. Further research should determine whether duration of bouts of activity (eg, three or more bouts of 10 minutes minimum duration) or total accumulated activity (as we analyzed here) is more important for health outcomes. In addition, population-based studies using different devices to objectively measure activity have found generally lower levels of activity than seen in MrOS study (22); differences between those studies and ours could be due to cohort differences or the activity monitors utilized.

There are several strengths to our study. MrOS is a large, longitudinal study with excellent objective assessment of activity level, ADLS and IADLs, and important covariates. However, a few limitations must be noted. First, the exact nature of activity is not recorded by the devices we used. For example, we did not know what activity or activities (such as walking, sports, or housework) contributed to a participant's time in moderate activity, so specific inferences regarding the types of activities that are most important cannot be made. Men included in this analysis were free of functional limitation at the time of the activity monitoring. Therefore, our results may not generalize to other populations such as women, the infirm or the institutionalized. Second, we do not have data regarding the living location (eg, community dwelling, institutionalized) of participants at follow-up. Such information could have been informative as those in institutionalized settings may report difficulty with ADLs and IADLs differently than community-dwelling adults and we could have accounted for this in our results. Third, as with any observational study, we cannot establish a causal relationship using these data. Large randomized controlled trials of exercise, such as the ongoing Lifestyle Intervention and Independence for Elders study (23), are designed to test whether a specific exercise intervention is associated with health outcomes, not whether overall free-living energy expenditure or activity level over several days is associated with such outcomes. It is difficult to imagine how our study could be performed in a randomized setting because we tested the associations of the overall, total amount of activity in daily life, not just the activity that was due to a single exercise prescription or other intervention. Although smaller randomized trials have evaluated the effect of exercise interventions (usually group-based exercise programs) in reducing functional limitations (8), those studies did not evaluate the role of overall total daily activity that occurs outside of the activity intervention in developing functional limitations as we have in these analyses. Finally, inaccuracy in the estimation of EE, METS, or time asleep may have resulted in misclassification that would have biased our results.

As life expectancy in the United States continues to rise, the maintenance of physical independence among older persons has emerged as a major clinical and public health priority. Our findings show that objective measures of both physical activity and sedentary time are independently associated with the development of functional limitations.

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