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Sedentary behavior and physical function: Objective Evidence from the Osteoarthritis Initiative

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Abstract

Objective—Investigate the relationship between sedentary behavior and physical function in adults with knee osteoarthritis (OA), controlling for moderate-vigorous physical activity () levels.

Methods—Sedentary behavior was objectively measured by accelerometer on 1,168 participants in the Osteoarthritis Initiative aged 49–83 years with radiographic knee OA at the 48 month clinic visit. Physical function was assessed using 20-meter walk and chair stand testing. Sedentary behavior was identified by accelerometer activity counts/minute <100. The cross-sectional association between sedentary quartiles and physical function was examined by multiple linear regression adjusting for demographic factors (age, sex, race/ethnicity, education level), health factors (comorbidity, body mass index, knee pain, knee OA severity, presence of knee symptoms) and average daily MVPA minutes.

Results—Adults with knee OA spent 2/3 their daily time in sedentary behavior. The average gait speed among the most sedentary quartile was 3.88 feet/second, which was significantly slower than the speed of the less sedentary groups (4.23, 4.33, 4.33 feet/second, respectively). The average chair stand rate among the most sedentary group was significantly lower (25.9 stands/minute) than the rates of the less sedentary behavior groups (28.9, 29.1, 31.1 stands/minute, respectively). These trends remained significant in multivariable analyses adjusted for demographic factors, health factors and average daily MVPA minutes.

Conclusion—Being less sedentary was related to better physical function in adults with knee OA independent of MVPA time. These findings support guidelines to encourage adults with knee OA to decrease time spent in sedentary behavior in order to improve physical function.

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INTRODUCTION

Osteoarthritis (OA) affects an estimated 12.1% of the US adult population[1], being one of the most common forms of arthritis[2] and a leading cause of disability in the elderly[3]. Disability due to arthritis is associated with an extremely high economic burden, increased risk of hospitalization, institutionalization, and mortality.[4–6] While osteoarthritis can occur in any joint, the knee is the most common site of clinically significant involvement, and knee OA affects more than 9 million US adults.

Maintaining physical function is critical to independent community living for persons with knee OA.[7,8] In general, participation in regular physical activity confers many health benefits, including reduced risk of heart disease, hypertension, stroke, dyslipidemia, obesity, diabetes, osteoporosis, certain cancers, and all-cause mortality.[9–12] Physical activity has also been shown to be associated with improved physical function.[13–15]

Current physical activity interventions to improve health outcomes have largely focused on increasing physical activity, but have paid little attention to sedentary behavior. Sedentary behavior is defined as engaging in activities at the resting level of energy expenditure and includes activities such as sleeping, sitting, lying down, playing on the computer, and watching television[16]. Prolonged sedentary time has been associated with increased risk of many diseases and conditions including obesity, metabolic syndrome, type 2 diabetes, and insulin resistance.[17,18] A recent study reported a relationship between sedentary behavior and functional loss, but relied on self-reported physical activity, which can be subject to bias.[19] This relationship has yet to be demonstrated from objectively measured outcomes. Self-reported sedentary time from questionnaires are easy to administer and inexpensive, but are subject to response bias such as imprecise recall and influence of social desirability.[20] The advantages to objectively measured sedentary time by accelerometers are 1) not subject to desirability bias, and 2) due to technological advances (e.g. device smaller, lighter, and less expensive), easy to measure without subject burden (compared to self-report diaries). The strength of the relationship between sedentary behavior (or physical activity) and health outcomes in population-based studies is reliant on accurate measurement of activity behavior. Poor methods increase chances of misclassification and can mask or distort the true underlying relationship between physical activity and health.[21,22]

The purpose of our study was therefore to objectively quantify time spent in sedentary behavior as well as levels of physical activity from accelerometer monitoring and examine its relationship with measures from physical function tests in adults with radiographic knee OA. Our study used data from the accelerometer substudy of the Osteoarthritis Initiative (OAI).

SUBJECTS AND METHODS

Study Design and Participants

Participants were a subcohort from the Osteoarthritis Initiative (OAI), which recruited adults with or at high risk for developing knee osteoarthritis. The OAI longitudinal study enrolled 4,796 men and women aged 45–79 years at 4 clinical sites (Baltimore, Maryland, Columbus, Ohio, Pittsburgh, Pennsylvania, and Pawtucket, Rhode Island) between 2004 and 2006. Institutional Review Board (IRB) approval was obtained at each of the participating sites. Each participant provided written informed consent. Adults eligible for the OAI were either required to have symptomatic osteoarthritis in at least one knee (a definite tibiofemoral osteophyte [osteophyte grade ≥ 1] and pain, aching, or stiffness on most days for at least one month during the past 12 months) or were required to have at least one from a set of established knee osteoarthritis risk factors (e.g., overweight/obese, prior knee injury, prior knee surgery, family history of knee replacement or hand OA). The OAI excluded individuals with rheumatoid or inflammatory arthritis; severe joint space narrowing in both knees on the baseline knee radiograph, or unilateral total knee replacement and severe joint space narrowing in the other knee; bilateral total knee replacement or plans to have bilateral knee replacement in the next 3 years; inability to undergo a 3.0T magnetic resonance imaging (MRI) exam of the knee because of contraindications; positive pregnancy test; inability to provide a blood sample; use of ambulatory aides other than a single straight cane for more than 50% of the time during ambulation; comorbid conditions that might interfere with the ability to participate in a 4-year study; current participation in a double-blind randomized trial. The OAI eligibility criteria have been detailed elsewhere.[23]

The study population for this study was drawn from 2,127 persons enrolled in an OAI accelerometer monitoring substudy at the OAI 48 month follow-up visit (2008–2010), which was baseline for this study (Figure 1). Participants with radiographic knee OA, defined as a Kellgren-Lawrence (KL) grade ≥2 in at least one knee, were included in the present analysis. We used the most recent annual assessment as a proxy for missing health factors (n=21, <3%). For analysis purposes, we excluded 130 participants with less than 4 valid days of accelerometer monitoring, leaving 1,168 for analyses (Figure 1). Accelerometer data were merged with the OAI public data[24] containing information on physical function performance measurements and participant characteristics.

Measurements

Assessment of Physical Function Outcomes—Physical function was assessed by rates of 20-meter walk and chair stand test completion at OAI 48 month clinic visit. Gait speed was measured in feet/second based on the average speed over two 20-meter walk tests. The timed 20-meter walk is used in many epidemiologic studies and is a standard outcome measure for OA.[25, 26] Chair stand was measured in number of stands/minute based on time required for 5 repetitions of rising from a chair and sitting down. The tests were performed by certified OAI clinic assessors according to the standard protocol common to all sites that detailed the course setup, measurement procedures, and scripted instructions.

Measurement of Sedentary Behavior and Physical Activity—Physical activity was objectively measured following the 48 month clinic visit using a GT1M ActiGraph accelerometer, a small uniaxial accelerometer that measures vertical accelerations.[27] Uniaxial accelerometer validation studies against whole-body indirect calorimetry showed high correlation with metabolic equivalent (r=0.93) and total energy expenditure (r=0.93).[28] The accuracy[29] and test-retest reliability[30] of ActiGraph accelerometers under field conditions are established in many populations including persons with OA.[31]

Accelerometers output an activity count, which is the weighted sum of the number of accelerations measured over 1 minute periods, where the weights are proportional to the magnitude of measured acceleration.

Trained research personnel gave participants uniform scripted instructions to wear the unit on a belt at the natural waistline on the right hip in line with the right axilla upon arising in the morning and continuously until retiring at night, except during water activities, for seven consecutive days. Participants maintained a daily log to record time spent in water and cycling activities, which may not be fully captured by accelerometers. Accelerometers were returned to the clinic by mail.

Accelerometer data were analytically filtered using methodology validated in adults with rheumatic disease.[32–34] Non-wear periods were defined as ≥90 minutes with zero activity counts (allowing for two interrupted minutes with counts<100).[33] Accelerometer data included at least 4 or more valid days for each participant. A valid day was defined as 10 or more wear hours in a day.[32] Total daily minutes of MVPA were calculated using methodology from the National Institute of Health (counts ≥2020/minute).

Sedentary behavior, defined by activity counts/minute <100, was used to calculate average daily time spent in sedentary behavior. Minutes of sedentary behavior were translated on a minute-by-minute basis from accelerometer output (>10,000 minutes of data per person). Sedentary behavior quartiles are based on average daily sedentary behavior percentage, determined by average daily time spent in sedentary behavior divided by wear time.

Covariates—Covariates were measured at the 48 month clinic visit. Demographic factors included age, gender, race/ethnicity (white, black, Hispanic, other, defined by participant), education, and income level. Health factors included comorbidity, body mass index (BMI) status, knee pain, knee OA severity, and presence of knee symptoms. MV activity minutes were also included. Comorbidities were assessed by the modified Charlson comorbidity index[35]. BMI was calculated from measured height and weight [weight (kg)/height (m)^2]. BMI was classified as normal weight (BMI=18.5–24.9), overweight (BMI=25.0–29.9), or obese (BMI≥30). Self-reported current knee pain in the past 7 days was obtained from the WOMAC (Western Ontario and McMaster University OA Index, Likert version 3.1, modified in the OAI to be specific to each knee).[35] Person-level scores used the maximum WOMAC value of the two knees. Knee OA severity was obtained from maximum Kellgren-Lawrence grade of the two knees (2, 3, or 4). Frequent knee symptoms were ascertained from a positive response to “During the past 12 months, have you had pain, aching, or stiffness in or around your right/left knee on most days for at least one month?” in either knee.

Statistical Analyses—Analyses were restricted to individuals who participated in the 48 month clinic visit with 4 or more valid days of accelerometer data. Descriptive statistics characterized the sample by quartiles of daily average of time spent in sedentary behavior during waking hours. The association between physical function and sedentary behavior percentage quartiles was examined by multiple linear regression adjusted for demographic factors (age, sex, race/ethnicity, education, and income), health factors (comorbidity, BMI, knee pain, knee OA severity, and presence of knee symptoms) and average daily MVPA minutes. Recognizing systematic differences between persons included and excluded from the analysis sample could influence our findings, we performed weighted analyses recommended by Hogan[36] but the results were similar to unweighted analyses and we report only unweighted analyses. All analyses were performed using SAS software version 9.2 (Cary, NC).

RESULTS

Over the seven day period, the average accelerometer monitoring of these 1,168 adults with radiographic knee OA during waking time was 14.8 hours/day. Adults with knee OA spent on average 67% (SD=8.7) of their daily time in sedentary behavior (range 28~91%). The average daily hours of sedentary behavior was 9.8 (SD=1.5) and ranged from 4 to 14. These 1,168 adults had mean age of 66.0 years, were primarily female (55%), white (80%), had post high school education (85%) and income >$50K (67%).

Table 1 shows characteristics of this cohort stratified by sedentary behavior groups. Compared to adults in the less sedentary groups, those in the most sedentary group (quartile 1) tended to be older, nonwhite, male, and they more frequently reported comorbidities. The most sedentary group had more participants with KL grades of 3 or 4. There were no notable differences related to disease severity across the sedentary behavior groups. As expected the most sedentary individuals engaged in the least amount of moderate-to-vigorous activity.

Physical function measured by gait speed on the 20 meter walk ranged from 2.21 to 7.05 feet/second with a mean ± SD of 4.30 ± 0.68 feet/second. A positive relationship between sedentary behavior groups and physical function is shown graphically by cumulative gait speed frequency curves in Figure 2. The average gait speed among the most sedentary group was 3.88 feet/second, which was significantly slower than the speed of the less sedentary groups (4.23, 4.33, 4.33 feet/second, respectively). More than two thirds (72%) of the participants in the most sedentary behavior group (quartile 1) did not meet the threshold of a 4 feet/second walking speed corresponding to the minimum walking speed required to safely cross a street for which many pedestrian traffic lights are timed. In comparison, only 52%, 51%, and 52% of the participants in the less sedentary behavior quartiles 2, 3, and 4, respectively, did not meet this threshold. Notably, the line for the most sedentary behavior group (quartile 1) in Figure 2 is distinctly separated by lines for less sedentary behavior groups in the middle section of the distribution. Similarly, in Figure 3, the average chair stand rate among the most sedentary group (25.9 stands/minute) was significantly slower than the rates of the less sedentary groups (28.9, 29.1, 31.1 stands/minute, respectively).

Statistical analyses evaluating cross-sectional relationships are summarized in Table 2. Compared to the most sedentary group (quartile 1), average physical function was significantly better in less sedentary behavior groups (mean differences in gait speed compared to quartile 1 were 0.35, 0.44, and 0.44 feet/second, respectively, $P<0.0001$ for all comparisons; mean differences in chair stand rate compared to quartile 1 were 3.00, 3.28, and 5.30 stands/minute, P<0.0001 for all comparisons). These trends remained significant in multivariable analyses that simultaneously controlled for demographic factors (age, sex, race/ethnicity, education and income level) and health factors (comorbidity, BMI, knee pain, knee OA severity, presence of knee symptoms, and average daily minutes of MVPA).

DISCUSSION

In this cross-sectional data from adults with confirmed radiographic knee OA, we found that more sedentary time is significantly associated with poorer physical function. Moreover, this relationship persisted after controlling for average daily minutes of MVPA, demographic factors, and other health factors. Being in the most sedentary group was associated with worse physical function compared to the other groups; this relationship held for both objective physical function measures, gait speed and chair stand rates. Notably, each of the less sedentary groups had similar and significantly better function than the most sedentary group. This relationship supports a threshold effect between the sedentary behavior and physical function.

There is growing interest in the role of sedentary behavior as a risk factor for poor health. Greater sedentary time is related to poor health outcomes measured by an increased risk for obesity, metabolic syndrome, and type 2 diabetes.[2,18,37] In population-based samples from the National Health and Nutrition Examination Survey (NHANES), objectively assessed sedentary time was associated with objectively measured BMI and waist circumference, and self-reported task limitations independent of time spent in moderate or vigorous activity.[38–40]

An important question is whether the relationship of sedentary behavior to poor health is independent of engaging in moderate or vigorous physical activity. For example, extreme sedentary behavior could possibly negate some of the beneficial effects of engaging in exercise. Federal physical activity guidelines based on MV activity are based on recognized health benefits from these activities. Those benefits include a strong relationship between greater physical activity and better physical function.[14] It follows that a detrimental relationship of sedentary behavior to function may merely reflect less time spent in beneficial moderate activities. However, there is emerging evidence supporting that sedentary behavior is an independent risk factor for poor health outcomes.[41,42] Initial investigations focused on obesity, which found an increased risk with greater sedentary time independent of physical activity.[43,44] Recently the relationship between greater sedentary behavior with metabolic syndrome and mortality was shown to be independent of MV activity.[18,45]

Because physical functioning is basic to maintaining independence in older adults, it is important to investigate whether sedentary time may represent an intervention target distinct from moderate physical activity. To our knowledge, this question has been addressed by only one study, which was limited to women. Those findings from the Women's Health Initiative (n=61,609) showed greater reported sedentary time was significantly related to poorer assessments of function.[46] That study, however, relied on self-reported sedentary behavior and function data. Our study adds to the literature by demonstrating that objectively measured sedentary behavior has a distinct relationship to objectively measured physical function, separate from the time spent in MVPA. Notably, MVPA was not significantly related to function when sedentary time was included in the model. Importantly our findings pertain to adults with knee OA who are at elevated risk for poor functional outcomes.

These findings support health promotion efforts that target reduction in time spent sedentary and not just to increase time spent in MVPA. This broader focus relates to both policy and clinical practice. Expanding public health messages to reduce sedentary time and increase activity levels are likely to impart the greater health benefits. Targeted messages to reduce time spent in sedentary activities may have greatest impact when paired with current physical activity recommendations for adults with knee OA. This study in conjunction with other findings provides a platform for healthcare providers to communicate with knee OA patients about the benefits of general household and daily activities, irrespective of participation in a regular physical activity program. Although engaging in formal exercise is beneficial, there appears to be a clear need for new and separate recommendations aimed at reducing sedentary activities among adults with knee OA which may result in improving physical function.

Strengths of the study included the large sample size, the objective assessment of sedentary behavior and physical function by accelerometry, and the age and sex diversity of this OA cohort. However, it is recognized that accelerometers cannot capture water activities and may underestimate activities with minimal vertical acceleration/deceleration, such as cycling. Uniaxial accelerometers cannot accurately detect posture of the participant due to only capturing up and down movement and intensity. Also, causality cannot be inferred from these cross-sectional data as sedentary time and physical function are measured simultaneously. These limitations must be balanced against the substantial strengths of this study.

In conclusion, the results demonstrated a strong relationship between the most sedentary behavior group and worse physical function in adults with knee OA. This relationship was demonstrated independent of moderate activity levels. These findings support recommendations and interventions to encourage adults with knee OA to decrease time spent in sedentary behavior for improving health outcomes.

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Significance & Innovations

- More sedentary behavior is significantly associated with poorer physical function independent of moderate-vigorous physical activity levels in adults with radiographic knee OA.
- Objective measurements of sedentary time and physical function were used.
- More than two thirds (72%) of the participants in the most sedentary behavior group did not meet the threshold of a 4 feet/second walking speed corresponding to the minimum walking speed required to safely cross a street for which many pedestrian traffic lights are timed.

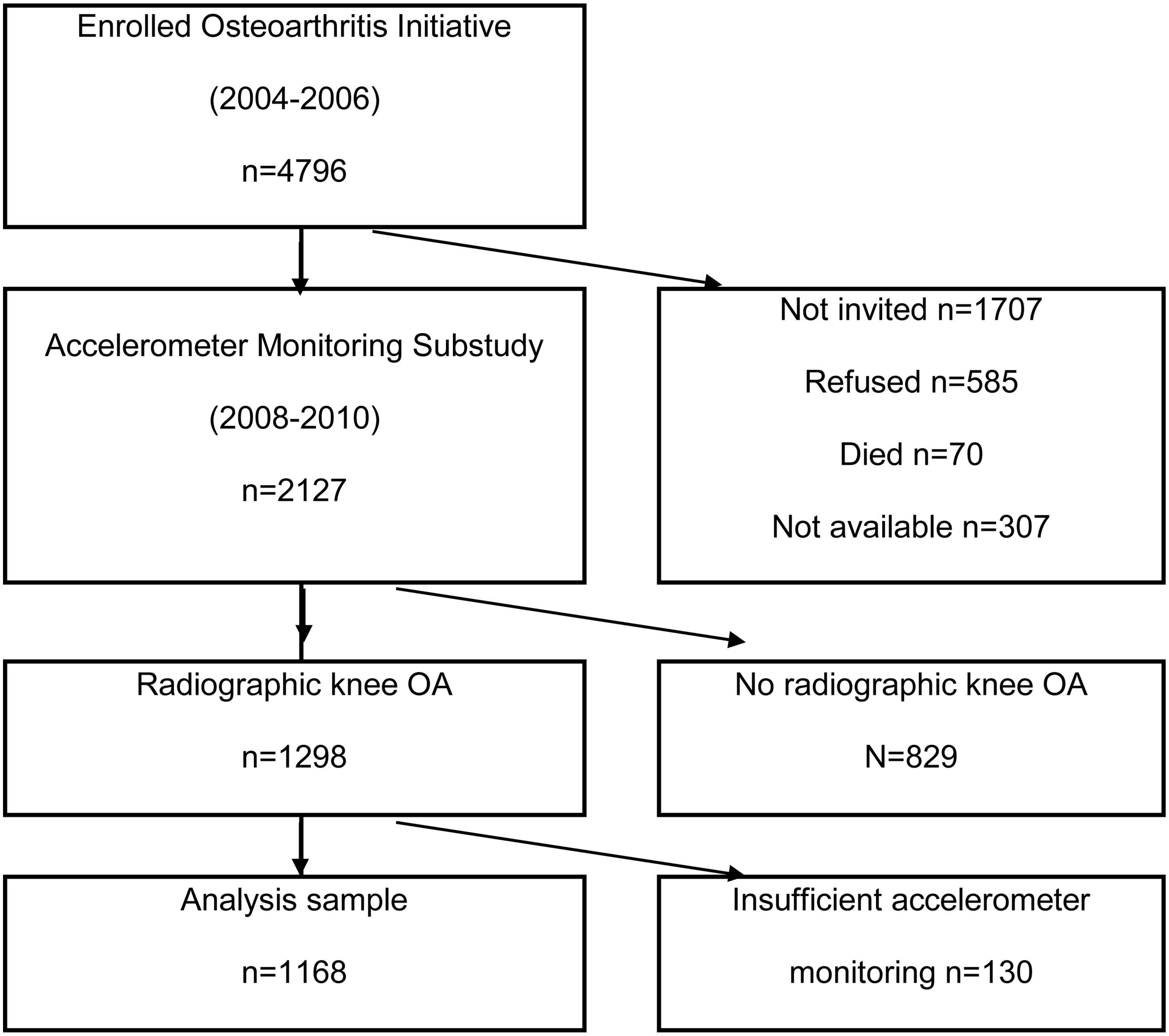

FIGURE 1.
Analytical sample of accelerometer study participants with radiographic knee osteoarthritis

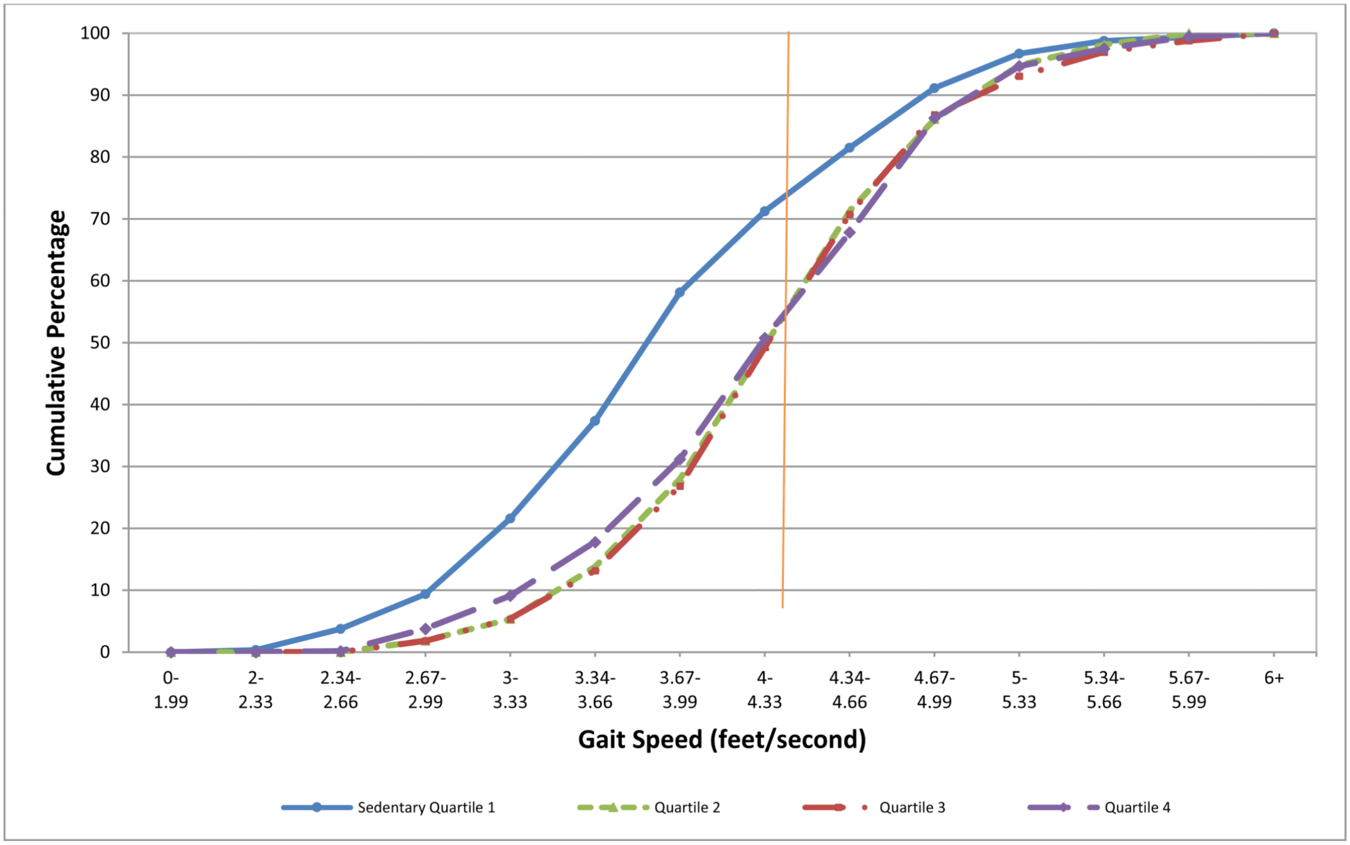

FIGURE 2.

Cumulative percentage of 1,168 participants in each sedentary behavior quartile‡ with the indicated gait speed (feet/second) at 48 month clinic visit. Participants in sedentary quartile 1 were the most sedentary, and those in quartile 4 were the least sedentary.

* Quartile cut-points (%): Quartile 1≥72.7%; 67.13%≤Quartile 2<72.7%; 61.1%≤Quartile 3<67.13%; Quartile 4<61.1%.

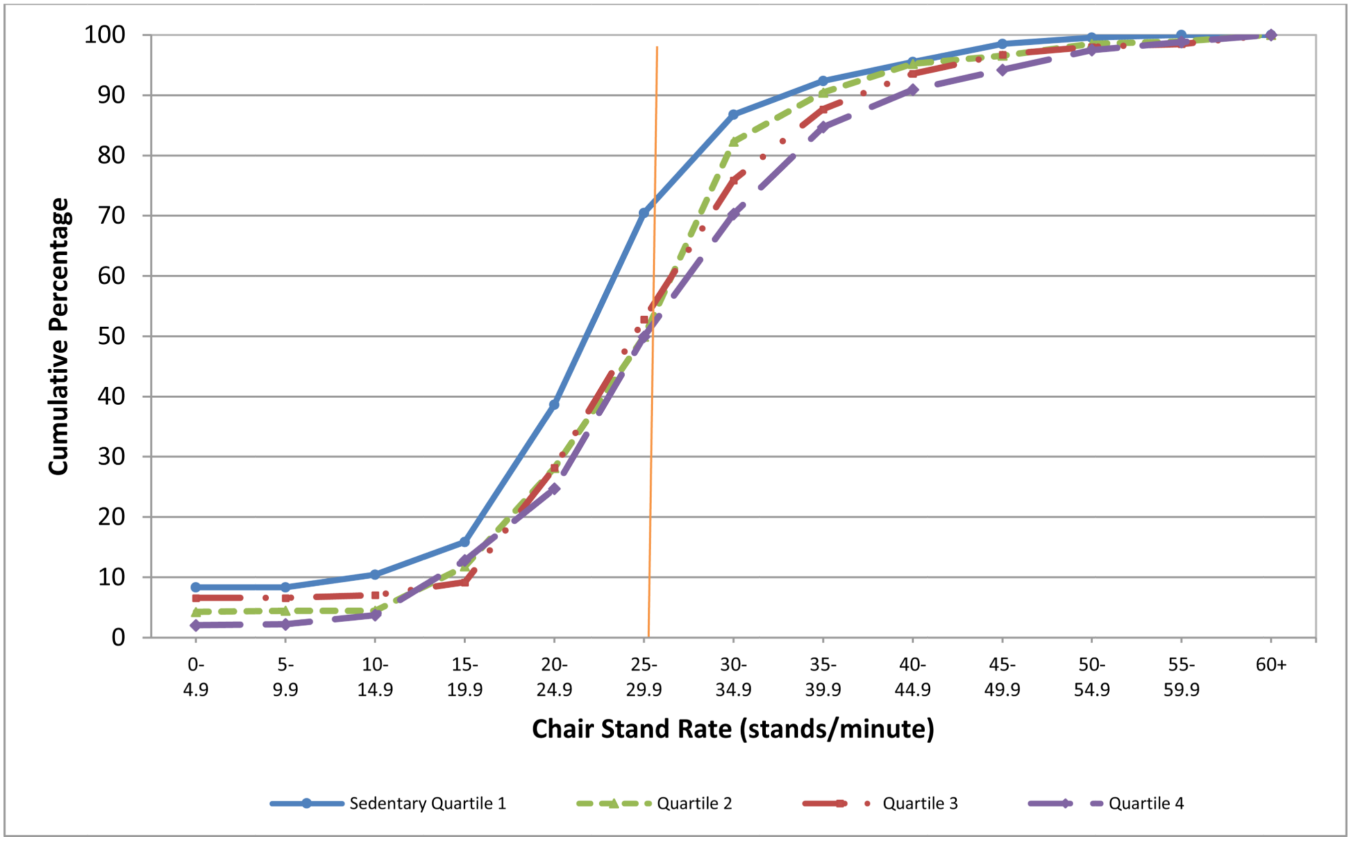

FIGURE 3.

Cumulative percentage of 1,168 participants in each sedentary behavior quartile* with the indicated chair stand rate (stand/minute) at 48 month clinic visit. Participants in sedentary quartile 1 were the most sedentary, and those in quartile 4 were the least sedentary.

* Quartile cut-points (%): Quartile 1≥72.7%; 67.13%≤Quartile 2<72.7%; 61.1%≤Quartile 3<67.13%; Quartile 4<61.1%.

TABLE 1

Characteristics of 1168 adults participating in accelerometer monitoring by sedentary behavior quartiles*

Characteristic (% or mean ± SD)	Quartile 1 (most sedentary) (n=292)	Quartile 2 (n=292)	Quartile 3 (n=292)	Quartile 4 (least sedentary) (n=292)	P for trend†
Socio-demographics					
Age 65 years or older	70	59	50	39	<.0001
Gender Women	46	55	57	62	<.0001
Race Caucasian	83	83	80	74	0.009
Education post high school	84	89	86	82	0.56
Income <$50K	31	31	33	36	0.16
Health Factors					
Presence of comorbidity	48	39	34	36	0.0009
Body Mass Index, kg/m^2					
<25	18	19	23	20	0.08
25.0–29.9	35	44	39	42	
>30	48	37	38	37	
WOMAC knee pain	3.6 ± 3.8	3.0 ± 3.3	3.0 ± 3.5	3.4 ± 3.9	0.55
Presence of knee symptoms	49	48	47	43	0.12
KL max 2	43	54	56	52	0.001
3	36	29	33	37	
4	21	17	11	11	
Objective Physical Activity					
Average daily minutes of moderate-to-vigorous activity	6 ± 9	14 ± 14	21 ± 21	24 ± 21	<0.0001
Average daily sedentary hours	11.2 ± 1.2	10.4 ± 1.0	9.6 ± 0.9	8.3 ± 1.1	<0.0001
Average daily sedentary percentage	77.2 ± 3.7	69.9 ± 1.6	64.2 ± 1.8	55.2 ± 5.4	NA

*Quartile cut-points (%): Quartile 1≥72.7%; 67.13%≤Quartile 2<72.7%; 61.1%≤Quartile 3<67.13%; Quartile 4<61.1%.

†Determined by Mantel-Haenszel chi-square test for trend (with 1 df), except for comparisons of race and sex, which were determined by chi-square test for overall differences, and knee pain severity, which was determined by analysis of variance.

TABLE 2

Average differences in gait speed (feet/second) and chair stand rate (stands/minute) at 48 month clinic visit*

	Difference in function			
	Q2 vs. Q1	Q3 vs. Q1	Q4 vs. Q1	P-value†
Gait speed (feet/second)				
Unadjusted difference	0.35 ± 0.08	0.44 ± 0.08	0.44 ± 0.08	<0.0001
Adjusted difference‡	0.20 ± 0.07	0.21 ± 0.08	0.21 ± 0.08	<0.0001
Chair stand rate (stands/minute)				
Unadjusted difference	3.00 ± 0.95	3.28 ± 0.98	5.30 ± 0.95	<0.0001
Adjusted difference‡	1.85 ± 0.90	1.46 ± 0.96	3.43 ± 0.98	0.0016

*Values are the mean ± SEM difference in average gait speed or chair stand rate compared to the most sedentary behavior quartile (quartile 1), as determined by multiple linear regression.

†P-values compare most sedentary Quartile 1(Q1) and average of Quartiles 2–4 (Q2–Q4). Quartile cut-points (%): Quartile 1≥72.7%; 67.13%≤Quartile 2<72.7%; 61.1%≤Quartile 3<67.13%; Quartile 4<61.1%.

‡Adjusted for demographics (age, gender, race, education, income), health factors (comorbidity, BMI status, WOMAC knee pain, knee symptoms, Kellgren-Lawrence grade), and average daily minutes of moderate-to-vigorous activity.