Published in final edited form as:

Arthritis Rheum. 2011 January ; 63(1): 127–136. doi:10.1002/art.27760.

Physical activity levels and functional performance in the Osteoarthritis Initiative: a graded relationship

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Abstract

Objective—Physical activity improves function for adults with arthritis, but it is unknown if there is a graded relationship with functional benefit. We examine the cross-sectional and longitudinal relationship between self-reported physical activity and observed functional performance in adults with knee osteoarthritis.

Methods—The Osteoarthritis Initiative cohort included 2589 persons with knee osteoarthritis (2301 having longitudinal follow-up) aged 45 to 79 years at baseline. Two years of prospective annual functional performance was assessed from timed 20 meter walk tests. We used linear regression to estimate differences across physical activity quartiles in subsequent function (baseline and 1-year activity predicts 1- and 2-year function, respectively) adjusted for demographics (age, gender, race/ethnicity, education, marital status) and health factors (osteoarthritis severity, knee symptoms, knee pain, knee injury, body mass index, comorbidity, depression, smoking, alcohol use, other joint pain).

Results—Increasing physical activity levels had a significant graded relationship with functional performance. Adults in physical activity quartile groups, from least to most active, had average gait speed of 4.0, 4.2, 4.3, 4.5 feet/second respectively at baseline (p-value for trend <.001) and 4.1, 4.2, 4.3, 4.5 feet/second after one year (p-value for trend <.001); increasing trends remained significant after adjusting for covariates. Findings were similar within gender and age groups.

Conclusion—These prospective data showed a consistent graded relationship between physical activity level and better performance in adults with knee osteoarthritis. These findings support guidelines that encourage persons with arthritis who cannot attain minimum recommended physical activity to be as active as possible.

INTRODUCTION

Osteoarthritis (OA) is a major debilitating disease affecting more than 27 million persons in the U.S.¹ This number is expected to increase due to the growing obesity epidemic and

because the prevalence of arthritis is highest in older adults and greater numbers of adults are reaching older ages.^{2–4} Approximately 92% of persons with OA will see a physician at least once during the year.⁵ There were more than 11.1 million outpatient visits for OA and 632,000 joint replacements due to OA with accompanying hospital costs of \$22.6 billion in 2004.⁶ Knee OA is a leading cause of arthritis-related limitations, which, in turn, are a major driver of excess medical costs due to arthritis.^{7–8}

Physical activity is an important public health intervention to improve the health of persons with arthritis. Physical activity is so crucial to optimal health outcomes, there are now federal recommendations for the general public, including those with arthritis (www.health.gov/paguidelines)⁹. Evidence from randomized controlled trials (RCTs) has demonstrated general benefits and disease-specific benefits of physical activity. RCTs in the general adult population show that physical activity reduces mortality, improves cardiovascular fitness, and improves sleep.^{10–12} Physical activity can reduce the risk for developing many chronic conditions and can improve the quality of life.^{13–14–16} Among persons with knee OA, RCTs showed that physical activity programs are effective to reduce pain, improve physical performance, and prevent or delay disability. In addition, aerobic exercise prevented development of depression, and reduced depressive symptoms.^{17–19} While these studies demonstrated that physical activity is beneficial to improve health outcomes in persons with knee OA, those RCTs only tested single doses of physical activity.

Maintaining physical function is critical to independent community living for persons with arthritis. Towards that goal is a critical need to determine if physical activity has a graded relationship with functional outcomes in persons with arthritis. There is a gap in the OA literature to address the relationship between different doses of physical activity on health outcomes. The Department of Health and Human Services research priorities listed in its physical activity guideline report include the need to identify physical activity doses that can result in beneficial disease-specific outcomes.²⁰ The recent public health agenda for OA identified a lack of data on the amount and type of physical activity needed to improve and maintain function. This cross-sectional and short-term prospective study can fill this gap.²¹ Understanding the nature of the relationship of physical activity with function has important public health implications related to developing physical activity guidelines and clinical implications for counseling knee OA patients, particularly those to whom a recommended physical activity threshold appears unreachable. The aim of this study is to test if there is a graded relationship between physical activity and functional performance in persons with knee OA.

DATA AND METHODS

Data and Study Population

This study analyzed public data from the Osteoarthritis Initiative (OAI), a prospective natural history study investigating the development and progression of knee OA in men and women aged 45–79 years at enrollment. Annual OAI interviews began in 2004 at four clinical sites: Baltimore Maryland, Columbus Ohio, Pittsburgh Pennsylvania, and Pawtucket Rhode Island and are currently ongoing. The first two years of assessments are complete and those data are publically released.²² IRB approval at the participating sites and written informed consent was obtained from each participating subject. The baseline OAI visit identified 2678 participants with radiographic knee OA (i.e., radiographic evidence based on Kellgren-Lawrence [K–L] grade ≥ 2 in one or both knees) from the total OAI enrollment of 4796 persons. Excluded were persons with rheumatoid arthritis 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 MRI exam of the knee because of contraindications (including pacemaker, artificial valve, aneurysm clip or shunt, stent, implanted device, ocular metallic fragment) or inability to fit in the scanner or in the knee coil (including men over 285 lbs and women over 250 lbs); positive pregnancy test; unable to provide a blood sample for any reason; use of ambulatory aides other than a single straight cane for more than 50% of the time in ambulation; comorbid conditions that might interfere with the ability to participate in a 4-year study; current participation in a double-blind randomized trial.

Functional performance outcome

Functional performance was assessed by a timed 20 meter walk test at the baseline, Year 1 and Year 2 evaluations. The timed 20 meter walk is used in many epidemiological studies and is a standard outcome measure for osteoarthritis.^{23–24} The test was performed by certified OAI site assessors according to a standard protocol common to all sites that detailed the course setup, measurement procedures, and scripted instructions. A calculated gait speed measured in feet/second was based on the average speed over two 20 meter trials.

Physical activity

Self-reported physical activity was measured using the Physical Activity Scale for the Elderly (PASE)²⁵. The self-administered 26 question PASE systematically assesses a broad spectrum of activities during the previous 7-day period including lifestyle activity (housework, home repair, gardening, yard work, paid or volunteer work-related activity), purposeful exercise/sports (light, moderate, strenuous sport/recreation, and muscular strength and endurance), and walking outdoors.²⁶ Questionnaire responses are summarized into a continuous PASE score in which higher scores represent greater levels of activity. The OAI public data set includes the calculated PASE score based on the Washburn algorithm.²⁷ The PASE score has been validated based on a variety of objective measures^{25–26, 28} including objective accelerometer measurement in community dwelling older adults and in chronic disease populations.^{29–30} PASE scores from the baseline OAI radiographic knee OA cohort were used to determine physical activity groups from lowest to highest activity levels use quartiles: first level Q1 ≤ 93 ; second level Q2 (94–146); third level Q3 (147–206); fourth level Q4 > 206 . For the purpose of analysis, PASE scores from the baseline and Year 1 evaluations for each person in the analysis sample were categorized into one of these physical activity group levels.

Covariates

All covariates were assessed at baseline and annual visits except where noted. Baseline demographic factors included race/ethnicity, age, gender, marital status, and education. Individuals were classified as African-American, White, or other racial/ethnicity group based on self-report. Education was dichotomized as post high school versus less education.

Knee health was assessed radiographically and by self-report. All radiographs were acquired using a “fixed-flexion” knee radiography protocol (5), including bilateral, standing, posterior-anterior knee films with knees flexed to 20–30° and feet internally rotated 10° using a plexiglass positioning frame (SynaFlexer TM). Right and left knees were imaged together on 14 × 17 inch film using a focus-to-film distance of 72 inches.³¹ To assess OA disease severity within each tibiofemoral compartment, joint space was graded in the medial and lateral compartments separately using an adaptation of the OARSI atlas approach (4) in which 0 = none (OARSI grade 0), 1 = narrowed (OARSI grade 1 or 2), and 2 = severely narrowed (OARSI grade 3). For the purposes of analysis, disease severity was based on the maximum (worst) joint space grade from the two knees.

Self-reported knee pain was measured by a 5-point Likert scale from the WOMAC (Western Ontario and McMaster University OA Index, Likert version, 3.1) modified to ask about the right and left knee symptoms separately³² in the past 7 days. The WOMAC pain score range was 0–20; a higher number represents worse symptoms. For analysis, person-level scores were calculated from knee specific scores (i.e., WOMAC pain score) using the maximum value of the two knees. The presence of knee symptoms was ascertained from a positive response to “Do you have pain, aching, or stiffness on most days of a month during the past year” and a history of knee injury was ascertained (i.e. injury “...so bad, that it was difficult to walk for at least one week”).

General health parameters included the report of hip pain, ankle pain, foot pain, current smoking (baseline), current alcohol consumption (baseline), comorbidity (baseline), depressive symptoms, and body mass index (BMI). Comorbidity was ascertained from the Charlson index³³, and its presence was defined as a score > 0. Evidence of high depressive symptoms was based on a score ≥ 16 from the full 20 item Center for Epidemiological Studies Depression scale.³⁴ BMI was calculated from measured height and weight [weight (kg)/height (m)²].

Statistical analysis

Baseline analyses included the entire analysis sample (n=2589). Longitudinal analyses were restricted to individuals who also participated in the Year 1 (n=2301) and/or Year 2 (n=2013) OAI evaluations. Univariate analyses of baseline trend effects were evaluated by a Mantel Haenszel test for ordinal categories; a chi-square test for overall differences was applied to nominal variables and analysis of variance was applied to continuous variables. Standard epidemiologic methods are used to investigate a graded response between a risk factor (physical activity) and the outcome (gait speed) based on risk factor quartile groups.³⁵ Physical activity groups based on quartiles represent a parsimonious balance between the number of risk factor levels examined, interpretability, and sufficient sample size in each group. Descriptive statistics characterized the analysis sample by physical activity group membership. Cumulative frequency curves of functional performance displayed the proportion in each physical activity group with performance below the specific value on the horizontal axis. A graded response would be visually demonstrated by non-overlapping cumulative frequency curves. Multiple linear regression was used to statistically evaluate the baseline relationship between greater physical activity group levels and performance outcomes. A graded relationship was evaluated by a linear trend test across physical activity group levels.

Longitudinal analyses evaluated the relationship between physical activity groups and subsequent one year functional performance utilizing information from the full two year follow-up. For this purpose we simultaneously modeled Year 1 performance (n=2301 persons representing 89% of the baseline cohort) as a function of baseline physical activity level groups and covariates; and Year 2 performance (n=2013 persons, representing 87% of the Year 1 cohort) as a function of Year 1 physical activity level groups and covariates (if a covariate was not reassessed at Year 1, the baseline value was used). Graphical (unadjusted) cumulative frequency curves display a weighted average of the one year follow-up subsequent to the baseline and Year 1 visits. Multiple linear regression evaluated the relationship between physical activity group levels and subsequent one year functional performance using generalized estimating equations (GEE) to validly account for potentially correlated observations from the same individual. Recognizing that systematic differences between persons included and excluded from the analysis sample could influence our findings, we performed weighted analyses recommended by Hogan³⁶ and Robins³⁷. Results and statistical significance were very similar for weighted and unweighted analyses.

For simplicity, unweighted analyses were reported. Analyses were performed using SAS software version 9.2.38

RESULTS

Of 2678 OAI participants with baseline radiographic knee OA, 89 were excluded from analysis: 14 persons with incomplete baseline performance data, and 75 having incomplete baseline interview data, leaving 2589 available for baseline analyses. As shown in Figure 1, 2301 completed Year 1 assessments and 2013 completed Year 2 assessments.

A total of 2589 persons with radiographic knee OA at the baseline OAI visit (aged 45–79 years) participated in functional performance tests. This analytic sample was predominantly white (79%), female (58%) with an average age of 62.4 years. The 89 persons with radiographic knee OA who did not participate in performance tests and/or who had incomplete interview data were primarily female (63%) with an average baseline age of 62.1 years and tended to be non-white (62%).

Baseline physical activity measured by the total PASE score ranged from 0 to 465, with mean of 155 with a standard deviation (SD) of 80 which indicates this group with radiographic knee OA had substantial variability in physical activity behavior. Baseline characteristics of this cohort stratified by physical activity level groups are presented in Table 1. Adults with radiographic knee OA in the lowest physical activity group (level 1) compared to the more active levels tended to be older, non-white, female, less educated, and more frequently reported comorbidities but reported fewer prior knee symptoms and injuries and less alcohol consumption. There were no notable differences related to disease severity across the physical activity groups.

Baseline functional performance measured by gait speed ranged from 0.80 to 6.83 with a mean of 4.26 (SD=0.69). Gait speed had a moderate correlation=0.27 with raw PASE scores. A positive relationship between graded baseline physical activity level groups and baseline functional performance is shown graphically by cumulative gait speed frequency curves in Figure 1. For example, at a 4 feet/second corresponding to the minimum walking speed to safely cross a street for which many pedestrian traffic lights are timed³⁹, more than half (51%) of the lowest physical activity (level 1) group did not meet this threshold compared to only 37%, 29%, and 19% of the higher and more active group levels 2, 3, and 4, respectively. Notably the four lines are ordered by physical activity levels and are distinctly separated in the middle section of the distribution, which is consistent with a positive graded relationship between physical activity levels and gait speed performance.

Statistical analyses evaluating a cross-sectional graded relationship are summarized in Table 2. The average improvement in baseline functional performance when compared to the lowest group level increased with membership in higher baseline physical activity levels (baseline gait speeds: 4.0, 4.18, 4.29, 4.49 feet/second, respectively; P for trend <0.001). These trends remained significant in multivariate analyses that simultaneously controlled for baseline demographic (age, gender, race/ethnicity, marital status, education) and health factors (BMI, knee OA severity, knee pain, presence of knee symptoms, prior knee injury, hip pain, ankle pain, foot pain, current smoking, current alcohol consumption, comorbidity, high depressive symptoms). To provide perspective on the magnitude of these group differences, if each person in this cohort increased his/her gait speed by 0.2 feet/second, the proportion of this cohort that walked fast enough to safely cross a street would increase from 66% to 75%. Subgroup analyses demonstrated statistically significant trends for a graded relationship between baseline physical activity group levels and performance for both men and women as well as by age (45–64 and 65–79 years).

Prospective data were used to investigate if a graded physical activity relationship would persist with functional performance measured one year later. These analyses were restricted to 2301 persons with at least one year of follow-up; of these 2013 persons contributed two years of follow-up. Over one year, 48% of persons remained in the same PASE group; 23% improved, and 29% moved to a less active group. The average gait speed was fairly stable over time (year 1 mean =4.3 ft/second [SD=0.7], year 2 mean =4.3 ft/second [SD=0.7]). The cumulative frequency performance curves (Figure 3) demonstrated a positive graded relationship between physical activity group levels with subsequent gait speed one year later. Similar to Figure 2, a graded relationship is graphically depicted by distinct curves, which are ordered by physical activity group levels. Statistical analyses that utilized the full two years of longitudinal follow-up information to evaluate a graded relationship are summarized in Table 3. The average improvement in subsequent functional performance when compared to the lowest group level increased with membership in higher level physical activity groups (gait speed after one year: 4.0, 4.2, 4.3, 4.5 feet/second, respectively; P for trend <0.001). These trends persisted in multivariate analyses that simultaneously controlled for demographic and health factors. Further sensitivity analyses (not shown) that additionally adjusted for the baseline gait speed and that modeled gait speed at two years as a function of baseline physical activity level groups also confirmed a significant statistical trend. Similarly, subgroup analyses in both men and women as well as by age demonstrated statistically significant trends for a positive graded relationship between physical activity quartiles and subsequent gait speed one year later. Confirmatory analyses (not shown) using OAI objective performance data from timed chair stand tests showed the same trends. Taken together, these cross-sectional and longitudinal analyses consistently support a positive graded relationship between physical activity and functional performance.

DISCUSSION

These prospective data from a cohort of adults with confirmed radiographic knee OA indicate that greater levels of physical activity were significantly associated with higher functional performance objectively measured by gait speed. Moreover, we found a graded relationship between physical activity and functional performance which persisted after controlling for demographic and health factors. These findings add to the literature on the beneficial relationship of physical activity to function by systematically demonstrating higher performance was associated with greater levels of physical activity. These findings also provide encouragement for persons with arthritis who do not attain recommended physical activity levels; there was evidence of potential benefit to greater physical activity regardless of the level achieved. For example, even among people with low physical activity (i.e., below the median), persons in the level 2 physical activity group had better function than persons in the bottom level 1 group (73% versus 41% had gait speed faster than minimum walking 4 feet/second speed to safely cross a street).

Strengths of the study included prospective data collection, the large sample size, the objective assessment of performance, radiographic verification of knee OA, the detailed systematic assessment of physical activity based on a broad spectrum of activities, and the age and gender diversity of this OA cohort. The significant graded relationship observed between the physical-activity levels and the higher levels of objective performance as well as the consistency of the findings across strata of age and gender both cross-sectionally and longitudinally lend further credence to an underlying dose-response relationship between physical activity and function for adults with arthritis. Other strengths of the study include detailed information about potential confounding variables.

The literature contains compelling evidence on beneficial relationships between physical activity and cardiovascular outcomes in adults. Early evidence on a graded relationship between greater levels of physical activity and a lower risk of cardiovascular disease and premature mortality was an important factor that motivated the early 1995 federal physical activity recommendations.^{15, 40} A large body of evidence since 1995 affirms that greater levels of physical activity are related to reduced risk of cardiovascular risk and early mortality.^{35–41}

Health however is multifaceted and physical activity relationships can differ across health outcomes. A benchmark randomized controlled trial demonstrated a dose-response relationship between greater levels of physical activity and aerobic fitness quantified as peak absolute oxygen consumption among 464 sedentary, postmenopausal overweight or obese women.¹⁰ However, this same study found no relationship between physical activity and physiologic parameters related to change in blood pressure, lipid profile, or weight loss. A threshold relationship was described between health related quality of life (HRQOL) and physical activity using epidemiologic data on over 175,000 adults who participated in the Behavioral Risk Factor Surveillance System. Although persons who participated in some regular physical activity demonstrated better HRQOL, based on fewer reported unhealthy (physical or mental) days compared to persons who were essentially inactive (beyond a relatively low threshold), higher frequency or duration of activity was not associated with greater HRQOL benefit.⁴² Clearly, the relationship between physical activity and health can vary depending on the outcome of interest.

A prime objective for many older adults is to maintain function, which is basic to independent living.⁴³ It is well established that physical activity improves objective functional performance in the general population and among older adults.^{16, 44} Similarly, for persons with chronic diseases such as arthritis, physical activity has a beneficial effect on function.⁴⁵ For persons with knee OA, randomized clinical trials of exercise programs were shown to improve timed performance tests including chair stands, walking, and stair climbing.^{17, 46} However, these clinical trial data do not allow us to determine if there is a threshold of physical activity required to attain functional benefits or if the benefits increase with greater accumulation of physical activity irrespective of baseline physical activity levels. Our epidemiologic findings in this knee OA cohort support a graded response between physical activity and functional performance that is consistent with a dose-response relationship.

There are limitations to acknowledge related to these findings. Our physical activity measure is based on self report, which makes it difficult to determine the actual amount of physical activity performed by subjects. Our physical activity measure assessed by self report utilizing the PASE does not directly translate to a measure that can inform physical activity guideline attainment (e.g. minutes per week of physical activity). The mean reported PASE scores of the OAI participants are higher than the developer's studies, which likely reflects younger ages included in the OAI cohort (ages 45–70) than the original studies (ages 55 and older). However the validity of PASE is established for adults with knee pain and physical disability as a reasonable tool to discriminate those who are more physically active from those who are not.²⁸ Causality cannot be inferred from these observational data; the establishment of a dose-response relationship requires a controlled clinical trial. Also, the generalizability of this cohort merits consideration. It is recognized the OAI is not a probability sample and its participants met many exclusion criteria. However, OAI participants are recruited from multiple geographic sites using recruitment targets balanced for age and gender groups, and represent a broad spectrum of radiographic knee OA.

In conclusion, these prospective data from a large study of a diverse cohort of adults with knee OA showed a strong relationship between greater levels of physical activity and better functional performance. A graded relationship was observed in both men and women and across age groups. These findings lend support to current federal guidelines for persons with arthritis that encourage physical activity goals for persons with arthritis. These findings are also informative for persons with knee OA who perceive these goals are not attainable possibly due to pain or stiffness. There may be benefit to increasing physical activity even if the recommended levels are not achieved.

Acknowledgments

Grant Support: This study is supported in part by National Institute for Arthritis and Musculoskeletal Diseases (grant no. P60-AR48098, R01-AR055287, and R01-AR054155). The OAI is a public-private partnership comprised of five contracts (N01-AR-2-2258; N01-AR-2-2259; N01-AR-2-2260; N01-AR-2-2261; N01-AR-2-2262) funded by the National Institutes of Health, a branch of the Department of Health and Human Services, and conducted by the OAI Study Investigators. Private funding partners include Merck Research Laboratories; Novartis Pharmaceuticals Corporation, GlaxoSmithKline; and Pfizer, Inc. Private sector funding for the OAI is managed by the Foundation for the National Institutes of Health.

References

1. Helmick CG, Felson DT, Lawrence RC, et al. Estimates of the prevalence of arthritis and other rheumatic conditions in the United States. Part I. *Arthritis Rheum* 2008 Jan;58(1):15–25. [PubMed: 18163481]
2. Centers for Disease Control and Prevention. U.S. Obesity Trends. [Accessed March 17, 2010]. <http://www.cdc.gov/obesity/data/trends.html>.
3. U.S. Department of Commerce. Unprecedented Global Aging Examined in New Census Bureau Report Commissioned by the National Institute on Aging. U.S. Census Bureau News. [Accessed March 17, 2010]. http://www.census.gov/Press-Release/www/releases/archives/aging_population/013988.html.
4. Hootman JM, Helmick CG. Projections of US prevalence of arthritis and associated activity limitations. *Arthritis Rheum* 2006 Jan;54:226–229. [PubMed: 16385518]
5. Cisternas MG, Yelin E, Katz JN, Solomon DH, Wright EA, Losina E. Ambulatory visit utilization in a national, population-based sample of adults with osteoarthritis. *Arthritis Rheum* 2009 Nov 30;61(12):1694–1703. [PubMed: 19950315]
6. United States Bone and Joint Decade. The burden of musculoskeletal diseases in the United States. Rosemont, IL: American Academy of Orthopaedic Surgeons; 2008.
7. Felson DT, Lawrence RC, Dieppe PA, et al. Osteoarthritis: new insights. Part 1: the disease and its risk factors. *Ann Intern Med* 2000 Oct 17;133:635–646. [PubMed: 11033593]
8. Yelin E. Cost of musculoskeletal diseases: impact of work disability and functional decline. *J Rheumatol Suppl* 2003 Dec;68:8–11. [PubMed: 14712615]
9. Physical Activity Guidelines Advisory Committee. Physical Activity Guidelines Advisory Committee Report. Washington, DC: U.S. Department of Health and Human Services; 2008.
10. Church TS, Earnest CP, Skinner JS, Blair SN. Effects of different doses of physical activity on cardiorespiratory fitness among sedentary, overweight or obese postmenopausal women with elevated blood pressure: a randomized controlled trial. *Jama* 2007 May 16;297(19):2081–2091. [PubMed: 17507344]
11. Murphy MH, Nevill AM, Murtagh EM, Holder RL. The effect of walking on fitness, fatness and resting blood pressure: a meta-analysis of randomised, controlled trials. *Prev Med* 2007 May; 44(5):377–385. [PubMed: 17275896]
12. King AC, Oman RF, Brassington GS, Bliwise DL, Haskell WL. Moderate-intensity exercise and self-rated quality of sleep in older adults. A randomized controlled trial. *Jama* 1997 Jan 1;277(1): 32–37. [PubMed: 8980207]

13. Kesaniemi YK, Danforth E Jr, Jensen MD, Kopelman PG, Lefebvre P, Reeder BA. Dose-response issues concerning physical activity and health: an evidence-based symposium. *Med Sci Sports Exerc* 2001 Jun;33(6 Suppl):S351–S358. [PubMed: 11427759]
14. Brosse AL, Sheets ES, Lett HS, Blumenthal JA. Exercise and the treatment of clinical depression in adults: recent findings and future directions. *Sports Med* 2002;32(12):741–760. [PubMed: 12238939]
15. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc* 2007 Aug;39(8):1423–1434. [PubMed: 17762377]
16. de Vreede PL, Samson MM, van Meeteren NL, Duursma SA, Verhaar HJ. Functional-task exercise versus resistance strength exercise to improve daily function in older women: a randomized, controlled trial. *J Am Geriatr Soc* 2005 Jan;53(1):2–10. [PubMed: 15667369]
17. Ettinger WH Jr, Burns R, Messier SP, et al. A randomized trial comparing aerobic exercise and resistance exercise with a health education program in older adults with knee osteoarthritis. The Fitness Arthritis and Seniors Trial (FAST). *Jama* 1997 Jan 1;277:25–31. [PubMed: 8980206]
18. Penninx BW, Messier SP, Rejeski WJ, et al. Physical exercise and the prevention of disability in activities of daily living in older persons with osteoarthritis. *Arch Intern Med* 2001 Oct 22;161:2309–2316. [PubMed: 11606146]
19. Penninx BW, Rejeski WJ, Pandya J, et al. Exercise and depressive symptoms: a comparison of aerobic and resistance exercise effects on emotional and physical function in older persons with high and low depressive symptomatology. *J Gerontol B Psychol Sci Soc Sci* 2002 Mar;57:P124–P132. [PubMed: 11867660]
20. Physical Activity Guidelines Advisory Committee. Part H Research Recommendations, Physical Activity Guidelines Advisory Committee Report, 2008. Washington, DC: U.S. Department of Health and Human Services; 2008.
21. Centers for Disease Control and Prevention tAF. A National Public Health Agenda for Osteoarthritis 2010. Atlanta, GA: Centers for Disease Control and Prevention and the Arthritis Foundation; 2010.
22. Public data from the Osteoarthritis Initiative, a knee health study. 2008 [Accessed January 12, 2010]. <http://www.oai.ucsf.edu/datarelease/>.
23. Altman R, Brandt K, Hochberg M, et al. Design and conduct of clinical trials in patients with osteoarthritis: recommendations from a task force of the Osteoarthritis Research Society. Results from a workshop. *Osteoarthritis Cartilage* 1996 Dec;4(4):217–243. [PubMed: 11048620]
24. Bohannon RW. Population representative gait speed and its determinants. *J Geriatr Phys Ther* 2008;31(2):49–52. [PubMed: 19856549]
25. Washburn RA, Smith KW, Jette AM, Janney CA. The Physical Activity Scale for the Elderly (PASE): development and evaluation. *J Clin Epidemiol* 1993 Feb;46:153–162. [PubMed: 8437031]
26. Washburn RA, McAuley E, Katula J, Mihalko SL, Boileau RA. The physical activity scale for the elderly (PASE): evidence for validity. *J Clin Epidemiol* 1999 Jul;52:643–651. [PubMed: 10391658]
27. Scott, E. OAI Version 0.2.1 08/17/2007 Subject characteristics, risk factors Release Comments. San Francisco: Osteoarthritis Initiative Coordinating Center; 2007. p. 28-32.
28. Martin KA, Rejeski WJ, Miller ME, James MK, Ettinger WH Jr, Messier SP. Validation of the PASE in older adults with knee pain and physical disability. *Med Sci Sports Exerc* 1999 May; 31:627–633. [PubMed: 10331879]
29. Dinger MK, Oman RF, Taylor EL, Vesely SK, Able J. Stability and convergent validity of the Physical Activity Scale for the Elderly (PASE) 2. *J Sports Med Phys Fitness* 2004 Jun;44:186–192. [PubMed: 15470317]
30. Johansen KL, Painter P, Kent-Braun JA, et al. Validation of questionnaires to estimate physical activity and functioning in end-stage renal disease. *Kidney Int* 2001 Mar;59(3):1121–1127. [PubMed: 11231369]

31. Osteoarthritis Initiative. Radiographic procedure manual for OAI Protocol: Osteoarthritis Initiative: A Knee Health Study. 2006 [Accessed 3/22/2010].
<http://www.oai.ucsf.edu/datarelease/OperationsManuals.asp>.
32. McGroarty BJ, Harris WH. Can the western Ontario and McMaster Universities (WOMAC) osteoarthritis index be used to evaluate different hip joints in the same patient? 7. J Arthroplasty 1996 Oct;11:841–844. [PubMed: 8934324]
33. Katz JN, Chang LC, Sangha O, Fossel AH, Bates DW. Can comorbidity be measured by questionnaire rather than medical record review? Med Care 1996 Jan;34:73–84. [PubMed: 8551813]
34. Pandya R, Metz L, Patten SB. Predictive value of the CES-D in detecting depression among candidates for disease-modifying multiple sclerosis treatment. Psychosomatics 2005 Mar–Apr; 46(2):131–134. [PubMed: 15774951]
35. Manson JE, Greenland P, LaCroix AZ, et al. Walking compared with vigorous exercise for the prevention of cardiovascular events in women. N Engl J Med 2002 Sep 5;347(10):716–725. [PubMed: 12213942]
36. Hogan JW, Roy J, Korkontzelou C. Handling drop-out in longitudinal studies. Stat Med 2004 May 15;23(9):1455–1497. [PubMed: 15116353]
37. Robins JM, Rotnitzky A, Zhao LP. Analysis of semiparametric regression models for repeated outcomes in the presence of missing data. Journal of the American Statistical Association 1995;90:106–121.
38. SAS/STAT Software [computer program]. Version 9.02. Cary NC: SAS Institute Inc; 2008.
39. U.S. Department of Transportation. Manual on Uniform Traffic Control Devices for Streets and Highways. 2003.
40. Pate RR, Pratt M, Blair SN, et al. Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine 5. Jama 1995 Feb 1;273:402–407. [PubMed: 7823386]
41. Lee IM. Dose-response relation between physical activity and fitness: even a little is good; more is better. JAMA 2007 May 16;297(19):2137–2139. [PubMed: 17507351]
42. Brown DW, Brown DR, Heath GW, et al. Associations between physical activity dose and health-related quality of life. Med Sci Sports Exerc 2004 May;36(5):890–896. [PubMed: 15126726]
43. Bierman AS. Functional status: the six vital sign. J Gen Intern Med 2001 Nov;16(11):785–786. [PubMed: 11722694]
44. Capodaglio P, Capodaglio EM, Ferri A, Scaglioni G, Marchi A, Saibene F. Muscle function and functional ability improves more in community-dwelling older women with a mixed-strength training programme. Age Ageing 2005 Mar;34(2):141–147. [PubMed: 15713857]
45. Keysor JJ. Does late-life physical activity or exercise prevent or minimize disablement? A critical review of the scientific evidence. Am J Prev Med 2003 Oct;25:129–136. [PubMed: 14552936]
46. Topp R, Woolley S, Hornyak J 3rd, Khuder S, Kahaleh B. The effect of dynamic versus isometric resistance training on pain and functioning among adults with osteoarthritis of the knee. Arch Phys Med Rehabil 2002 Sep;83:1187–1195. [PubMed: 12235596]

Figure 1.
Analytical sample of radiographic knee OA participants

Figure 2.
Cross-sectional cumulative percentage of gait speed by physical activity quartile groups assessed at baseline (n=2589)

Figure 3.

Longitudinal cumulative percentage of subsequent (one year) gait speed (feet/second) by physical activity quartile groups (n= 2301 persons). Cumulative percentages are a weighted average of 2301 observations on Year 1 gait speed following baseline physical activity assessment and 2013 observations on Year 2 gait speed following Year 1 physical activity assessment

Table 1
Baseline Characteristics n=2589 persons with radiographic knee OA participating in OAI baseline

Baseline Characteristics	Quartile of Physical Activity (PASE Score)					
	1 (≤93) (n=644)	2 (93–146) (n=659)	3 (146–206) (n=641)	4 (>206) (n=645)	p-value (trend ^a)	
	%	%	%	%		
SOCIODEMOGRAPHICS						
Age in years	14.60	16.69	20.28	44.34	<.001	
55–64	27.48	28.22	34.17	40.78		
65 or older	57.92	55.08	45.55	14.88		
Race/Ethnicity: White	72.67	83.16	81.44	80.00	<.001	
African American	24.07	15.02	15.91	16.90		
Other	3.26	1.82	2.65	3.10		
Education: < high school	5.59	4.10	3.59	2.79	<.001	
High school graduate	42.39	41.73	37.75	37.36		
College graduate	52.02	54.17	58.66	58.66		
Female Gender	67.24	60.55	60.22	44.96	<.001	
Married	57.76	69.35	68.49	68.99	<.001	
HEALTH FACTORS						
Knee OA Severity					0.54	
Joint Space Narrowing 0	30.59	28.98	32.76	29.30		
Joint Space Narrowing 1	46.89	50.83	46.33	51.01		
Joint Space Narrowing 2	22.52	20.18	20.90	16.69		
Knee pain severity ^b mean (standard deviation)	4.26 (4.02)	3.86 (3.78)	3.87 (3.87)	4.05 (3.88)	0.22	
Presence of Knee Symptoms ^c	50.16	50.68	50.23	56.28	0.04	

Baseline Characteristics	Quartile of Physical Activity (PASE Score)				
	1 (≤93) (n=644)	2 (93–146) (n=659)	3 (146–206) (n=641)	4 (>206) (n=645)	p-value (trend ^a)
	%	%	%	%	
Prior Knee Injury	41.30	43.10	46.80	58.60	<.001
Any Hip Pain	57.14	57.06	56.01	54.73	0.34
Any Ankle Pain	12.89	11.99	10.76	9.77	0.06
Any Foot Pain	13.51	11.08	12.64	11.47	0.43
Body Mass Index					
<25	16.46	17.60	20.28	15.81	0.21
25–29.9	35.25	40.52	41.03	40.00	
≥30	48.29	41.88	38.69	44.19	
Presence of Comorbidity ^d	30.43	29.59	26.21	20.47	<.001
High Depressive Symptoms ^e	12.73	10.17	7.49	11.63	0.27
Current Smoker	6.52	4.70	6.08	7.29	0.38
Alcohol Usage					
0 drinks/day	24.69	20.03	17.00	16.74	<.001
<1 drinks/day	37.89	35.66	38.07	36.12	
1+ drinks/day	37.42	44.31	44.93	47.13	
PASE mean (SD)	62.29 (21.83)	120.47 (15.55)	173.15 (17.08)	265.47 (47.65)	<.001
Gait Speed feet/second mean (SD)	4.02 (0.73)	4.20 (0.69)	4.32 (0.62)	4.51 (0.64)	<.001

^a Mantel-Haenzel chi-square test for trend (1 .d.f.) except for race, gender, and marital status comparisons, which used a chi-square test for overall differences, and knee pain severity used an ANOVA.

^b Knee symptoms based on report of pain, aching, or stiffness most days in month past 12 mo

^c WOMAC pain score in the more symptomatic (painful) knee

^d Charlson Index >0

$\epsilon_{CESD\ score > 16}$

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Table 2A

Average Differences in baseline gait speed (feet/second) among physical activity groups

Sample	Difference	Quartile of Physical Activity				P-Value Linear Trend Test
		1 Lowest	2	3	4 Highest	
Complete Cohort (n=2589)	Unadjusted Mean Difference ^a (SE) ^b	Reference	0.18 (0.04)	0.29 (0.04)	0.49 (0.04)	<.001
	Adjusted ^c Mean Difference (SE)	Reference	0.09 (0.03)	0.16 (0.03)	0.25 (0.04)	<.001
Women (n=1508)	Unadjusted Mean Difference (SE)	Reference	0.24 (0.05)	0.33 (0.05)	0.51 (0.05)	<.001
	Adjusted ^d Mean Difference (SE)	Reference	0.14 (0.04)	0.20 (0.04)	0.32 (0.05)	<.001
Men (n=1081)	Unadjusted Mean Difference (SE)	Reference	0.03 (0.06)	0.18 (0.06)	0.33 (0.06)	<.001
	Adjusted ^d Mean Difference (SE)	Reference	-0.04 (0.06)	0.09 (0.06)	0.16 (0.06)	<.001
Age 45-64 Years (n=1465)	Unadjusted Mean Difference (SE)	Reference	0.22 (0.06)	0.24 (0.05)	0.43 (0.05)	<.001
	Adjusted ^e Mean Difference (SE)	Reference	0.08 (0.05)	0.10 (0.05)	0.26 (0.05)	<.001
Age 65-79 Years (n=1124)	Unadjusted Mean Difference (SE)	Reference	0.14 (0.05)	0.32 (0.05)	0.39 (0.08)	<.001
	Adjusted ^e Mean Difference (SE)	Reference	0.09 (0.04)	0.24 (0.05)	0.30 (0.07)	<.001

^a Mean Difference in average performance compared to lowest physical activity quartile group 1

^b Standard error of the difference in performance compared to Most Inactive (Q1) physical activity group assessed from multiple linear regression.

^c Demographic factors: age, gender, race/ethnicity, marital status, and education; Health factors: knee OA severity, knee pain, knee symptoms, knee injury, hip pain, ankle pain, foot pain, current smoking, current alcohol consumption, comorbidity, high depressive symptoms, and body mass index

^d Demographic factors: age, race/ethnicity, marital status, and education; and Health factors

^e Demographic factors: gender, race/ethnicity, marital status, and education; and Health factors

Table 3A

Longitudinal Analyses ^a: Average differences in subsequent (one year) gait speed (feet/second) among physical activity groups

Sample	Difference	Quartile of Physical Activity				P-Value Linear Trend Test
		1 Lowest	2	3	4 Highest	
Complete Cohort (n=2301)	Unadjusted Mean Difference ^b (SE) ^c	Reference	0.20 (0.03)	0.28 (0.03)	0.47 (0.03)	<.001
	Adjusted ^c Mean Difference (SE)	Reference	0.11 (0.03)	0.16 (0.03)	0.22 (0.03)	<.001
Women (n=1314)	Unadjusted Mean Difference (SE)	Reference	0.22 (0.03)	0.32 (0.04)	0.45 (0.05)	<.001
	Adjusted ^d Mean Difference (SE)	Reference	0.14 (0.03)	0.19 (0.04)	0.24 (0.04)	<.001
Men (n=987)	Unadjusted Mean Difference (SE)	Reference	0.12 (0.05)	0.18 (0.05)	0.37 (0.05)	<.001
	Adjusted ^d Mean Difference (SE)	Reference	0.04 (0.05)	0.09 (0.05)	0.18 (0.05)	<.001
Age 45–64 Years (n=1303)	Unadjusted Mean Difference (SE)	Reference	0.18 (0.05)	0.16 (0.05)	0.34 (0.05)	<.001
	Adjusted ^e Mean Difference (SE)	Reference	0.07 (0.04)	0.07 (0.04)	0.19 (0.04)	<.001
Age 65–79 Years (n=998)	Unadjusted Mean Difference (SE)	Reference	0.21 (0.04)	0.35 (0.05)	0.43 (0.06)	<.001
	Adjusted ^f Mean Difference (SE)	Reference	0.15 (0.04)	0.27 (0.04)	0.36 (0.06)	<.001

^aMultiple regression using generalized estimating equations utilized performance information from all two year follow-up available from 2301 individuals by modeling Year 1 gait speed (2301 observations) from baseline physical activity quartile groups and covariate values; and Year 2 gait speed (2013 observations) from Year 1 physical activity quartile groups and covariate values

^bMean Difference in average performance compared to lowest physical activity quartile group 1

^cStandard error of the difference in performance compared to Most Inactive (Q1) physical activity group assessed from multiple linear regression with generalized estimating equations.

^dDemographic factors: age, gender, race/ethnicity, marital status, and education; and Health factors: knee OA severity, knee pain, knee symptoms, knee injury, hip pain, ankle pain, foot pain, current smoking, current alcohol consumption, comorbidity, high depressive symptoms, and body mass index

^eDemographic factors: baseline age, race/ethnicity, marital status, education; and Health factors

^fDemographic factors: gender, race/ethnicity, marital status, and education; and Health factors