Published in final edited form as:
Disabil Rehabil. 2014 ; 36(4): 300–306. doi:10.3109/09638288.2013.790490.

Composite measures of multi-joint symptoms, but not of radiographic osteoarthritis, are associated with functional outcomes: *The Johnston County Osteoarthritis Project*

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Abstract

Purpose—To determine associations between multiple joint symptoms and radiographic osteoarthritis (rOA) and functional outcomes.

Methods—Complete cross-sectional data for multi-joint symptoms and radiographs, Health Assessment Questionnaire (HAQ) scores, and gait speed were available for 1307 Johnston County Osteoarthritis Project participants (34% men, 32% African American, mean age 66 years). Factor analysis of symptom scores and radiographic grades for the lumbosacral spine, bilateral hands, knees, and hips provided composite scores. Regression models were used to determine associations between composite scores, HAQ, and gait speed, adjusting for age, body mass index, gender, and race.

Results—Five rOA factors were identified: 1) IP/CMC factor (carpometacarpal [CMC] and all interphalangeal [IP] joints); 2) MCP factor (metacarpophalangeal joints 2–5); 3) Knee factor (tibiofemoral and patellofemoral joints); 4) Spine factor (L1/2 to L5/S1); and 5) Symptom factor. After adjustment, only the Symptom composite was significantly associated with HAQ and gait speed; a 1-standard deviation increase in Symptom score was associated with 9 times higher odds of having poorer function on the HAQ (odds ratio 9.32, 95% confidence interval [CI] 6.80, 12.77), and a clinically significant decline in gait speed (0.06 m/s, 95%CI −0.07, −0.05).

Conclusions—A novel Symptom composite score was associated with poorer functional outcomes.

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Keywords

osteoarthritis; health assessment questionnaire (HAQ); gait speed; factor analysis

INTRODUCTION

Arthritis is the most common cause of disability in the United States [1]. Osteoarthritis (OA) is the most common form of arthritis and affects 27 million Americans [2]. Although radiographic osteoarthritis (rOA) often involves multiple joints, the lack of an accepted definition for what constitutes "generalized OA" makes it difficult to effectively quantify the effects of multiple joint involvement on outcomes in OA. Many important clinical and research features, such as disability, serum and urine biomarkers, genetic markers, and most performance-based measures, are a function of the whole-body burden of OA rather than single joint involvement. Functional outcomes, both self-reported (HAQ), and performance-based (gait speed), are of interest as they represent the impact of OA on daily life and function of affected individuals [3–5]. We have previously reported the factor structure underlying multiple joint rOA grades [6] and presented composite scores as a potential method to include information about multiple joint sites in models of systemic outcomes. By combining variables that represent a common, empirically determined, underlying construct, for example by including a sum of radiographic grades from 20 hand joints as a single variable in a model, we can account for the impact of rOA at all of these sites on a given outcome.

In addition to considering multiple joint rOA, it is important to consider symptoms, as there is an imperfect correlation between these two constructs (e.g., an individual with rOA may or may not have symptoms), symptoms may predate the appearance of rOA, and symptoms are likely to be the more important factor in functional outcomes [7, 8]. While various magnitudes of discordance between symptoms and rOA at the knee have been reported over the years [8–14], there has been relatively little investigation regarding associations between symptoms and rOA of other individual joint sites such as the hand [7, 15–18], hip [19], or low back [20, 21], and fewer studies into simultaneous multiple joint site rOA and symptoms [22].

Prior studies have explored associations between general musculoskeletal pain and disability. A population-based study of older adults in the Boston area found that those participants with pain at more than one joint site had poorer results on the Short Physical Performance Battery (SPPB; includes gait speed, balance, chair stands) than those without such pain [23]. Buchman et al found that the risk of mobility disability based on gait speed was increased by 13% for each additional painful area reported in their elderly cohort [24]. Two studies using data from the community-based North Staffordshire Osteoarthritis Project, which used mailed survey questionnaires to collect data on musculoskeletal pain, found that most of the participants had pain in more than one site, and that multiple site pain was associated with reduced self-reported physical function [25, 26].

Despite these efforts, there remains a gap in understanding regarding the effect of rOA and symptoms in multiple joint sites on disability. Studies to date have generally used "number of painful sites" with or without a severity measure to account for pain; none of the above-mentioned studies had radiographs for assessment of structural damage, and they varied by population assessed and in measures used. To better address the potential impact of multiple joint rOA and symptoms, across multiple joints simultaneously, on systemic outcomes, we utilized factor analysis to formulate composite scores of both rOA and symptoms in multiple joint sites. Use of these composite scores in models of validated functional outcomes then

allowed us to determine the associations of whole-body burden of joint symptoms and rOA with Health Assessment Questionnaire (HAQ) scores [27] and gait speed [28].

PARTICIPANTS AND METHODS

Participants—All data are from a cross-sectional subset of the Johnston County OA Project (*JoCo OA*), an ongoing, community-based prospective cohort study of OA and its risk factors in North Carolina. The *JoCo OA* includes African American (AA) and White men and women aged 45 years and older, who completed home interviews and a clinic examination administered by trained personnel [29]. Age, gender, and race were obtained by interviewer-administered questionnaires. During the clinic examination, we obtained radiographs, physical performance-based measures, and body mass index (BMI, calculated in kg/m^2 from measured height (cm) and weight (kg)). Individuals included in these analyses had complete multi-joint radiographic data (obtained 2003–4 and 2006–10, n=1373, see also [6]), symptom and outcome data, resulting in 1307 individuals available for the HAQ outcome and 1303 individuals for the gait speed outcome (although 3 were excluded for implausible gait speed values before analysis, table 1). The *JoCo OA* study has been continuously approved by the Institutional Review Boards of the University of North Carolina and the Centers for Disease Control and Prevention in Atlanta, GA.

Radiographs of the bilateral hands, tibiofemoral (TF), and hip joints were read for global Kellgren-Lawrence (KL) grades, where a score of 0 indicates no OA features, 1 is a minute osteophyte of doubtful significance, 2 is a definite osteophyte without joint space narrowing, 3 is moderate joint space narrowing, and a 4 indicates severe joint space narrowing with bony sclerosis [30]. Patellofemoral (PF) joints and lumbosacral spine were read for osteophytes (0–3, where 0 is no osteophyte and 3 is a large osteophyte), and spine was additionally read for disc space narrowing (0–3, none to severe), using the Burnett atlas [31], as previously described [6] by a musculoskeletal radiologist with high reliability (inter-rater weighted kappa 0.86, intra-rater 0.89 [32]). Joints that had undergone replacement were not included in factor analysis, as no score could be assigned. In order to account for both presence and severity of radiographic change, the full range of KL grades (0–4) and Burnett grades (0–3) were used as continuous variables for the factor analysis.

Symptom presence in the lower back and right and left hands, knees, or hips, was based on a positive answer to interviewer-administered questions, such as “On MOST days, do you have pain, aching or stiffness in your [right, left] [knee, hip]?” For those with a positive response, the symptoms were graded as mild, moderate, or severe, resulting in a score from 0 (none) to 3 (severe) for each of the 7 joint sites.

Outcome measures

HAQ—Each of 20 individual activities in 8 domains (such as dressing, eating, walking, reach, and grip) was scored using self-report from 0 (no difficulty) to 3 (unable to do), with those requiring assistive devices assigned a 2 [27]. Within each domain, the highest score was taken as the domain score, and the average score of the 8 domains was determined as the total HAQ score. This self-reported functional status measure has been used by our group [3] and others [4] in OA populations. HAQ scores were categorized into 3 mutually exclusive categories: 0, between 0 and 1, and at least 1 [3].

Gait speed—Two trials of an 8-foot walk were completed by each participant at his/her usual walking pace [28]. The trials were timed in seconds, averaged, and converted to meters/second. Three individuals with implausible values were excluded from the analysis resulting in n=1300 for this outcome. Gait speed has been assessed as a performance-based

marker of functional limitation in geriatric conditions including OA [3, 5, 33, 34], and the 8-foot walk test is a reliable measure in older adults (intra-observer ICC >0.7, inter-observer ICC>0.5 [35, 36]).

Factor analysis

All radiographic variables (KL 0–4 or Burnett atlas grade 0–3, as previously reported [6]) and, new to this analysis, symptom scores (0–3), were entered all together into an exploratory common factor analysis simultaneously. Differences in the number of response categories can sometimes yield artifacts. For example, 4-response items could form one factor and 5-response items another factor. In this case, however, no such artifacts were detected. Factors were selected based on eigenvalues and screeplots; variables with low loadings (<0.4) were dropped. An oblique rotation, allowing factors to correlate with each other, was applied. Cronbach's coefficient alpha was calculated as a measure of internal consistency for each factor. Stratified analyses by gender, race, age (<65 versus 65 years or older) and BMI (<30 kg/m^2 versus 30 kg/m^2 or higher) were performed to assess for subgroup differences in factor structure and reliability.

Since loadings were fairly equal among variables loading onto each factor, the scores were created by simply summing the scores for each variable included in the factor without any weighting procedure. Average scores were created by dividing the sum scores by the number of included variables; these scores were standardized by dividing each mean score by its standard deviation (*SD*) to make a 1-unit change comparable among factors; these standardized scores were included in models as continuous independent variables. Pearson correlation coefficients were calculated between the 5 factor scores and each of the 2 outcomes (HAQ and gait speed).

Regression models

By including all rOA composite scores simultaneously in all models, our goal was to estimate the associations between whole-body burden of rOA and each of the outcome measures. Partial proportional odds regression models were used to determine associations (as cumulative odds ratios [cOR]) between rOA and symptoms variables (1-*SD* change) and HAQ scores in 3 levels, via a user-defined program (gologit2, see [37]) in Stata 11.0 (StataCorp, College Station, TX). The proportional odds assumption estimates a single cOR for each explanatory variable which represents the comparison for the best category (HAQ=0) versus the other 2 pooled categories, as well as for the better 2 categories pooled versus the worst category (HAQ ≥1). Partial proportional odds models allow for flexibility in applying the proportional odds assumption separately for each explanatory variable. Linear regression was used to determine associations between a 1-*SD* change in rOA and Symptom score (or the presence of rOA for binary hip rOA) and gait speed as a continuous outcome variable (m/s). This model was also used, in an exploratory analysis, to predict effects of hypothetical combinations of rOA and symptoms on gait speed.

The Symptom score was added to the regression models containing rOA scores first, followed by adjustment for all covariates (age, BMI, gender, and race). All pairwise interactions were assessed using product-term interactions. Likelihood ratio tests between models with all and models without any interactions (e.g. joint tests) were used to determine significant interactions. A p-value of <0.1 was used to indicate a significant difference between models and therefore better model fit with inclusion of the interaction terms.

RESULTS

Following factor analysis, a 5-factor solution was selected based on eigenvalues and screeplots; variables with low loadings (rOA of the hips and 1st MCPs) were not included in any factors. Four rOA factors were evident from the final factor analysis, consistent with our previous report which did not include any symptom variables [6]. The rotated factor structure, including loadings of each variable onto the factors, as well as the eigenvalues, alpha coefficients, and inter-item correlations, is available in table 2.

The IP/CMC factor consisted of the 1st CMCs, 1st IPs, distal and proximal IPs 2–5 (20 joints). The MCP factor included MCP joints 2–5 (8 joints). The Knee factor consisted of the rOA variables for the bilateral TF and PF joints (4 joints). The Spine factor included DN and OST variables from 5 levels (L1/2 to L5/S1). The symptom scores from 7 joint sites (lower back and bilateral hands, knees, and hips) loaded together onto a 5th, Symptom factor, without substantial cross-loading onto the radiographic factors. Because hip rOA is a possible contributor to functional outcomes, hip rOA was used as a separate indicator variable in the models, defined as present if a KL grade ≥2 was present in either hip, or if by patient report a hip replacement had been performed for OA.

The high alphas (≥ 0.8) for these 5 factors indicate good reliability. There were no substantial differences in factor structure or for Cronbach's alpha by subgroups of gender, race, age, or BMI. The between-factor correlations after rotation were low to moderate (ranging from 0.04 between the Knee rOA and Symptom factors, to 0.45 between the IP/CMC and MCP rOA factors). In particular, the correlations between the rOA factors and Symptom factor were quite low (r=0.04 for Knee, 0.07 for MCP, 0.09 for Spine, and 0.12 for IP/CMC). Therefore, the 5 factors (4 radiographic and 1 symptom) are reliable, distinct, and robust across subgroups.

The complete case sample (n=1307) included 34% men / 66% women and 32% African American / 68% white participants with a mean age of 66 years; nearly half had a BMI of at least 30 kg/m^2. Median scores and ranges for each factor score (computed as the average of all variables loading onto each factor), and the percentage with hip rOA, are presented in table 1.

HAQ

Proportions of the sample by HAQ category were 30% (0), 24% (>0 to <1) and 46% (≥1, Table 1). Significant positive correlations between HAQ and the rOA scores were observed, indicating higher HAQ scores (more difficulty with activities of daily living) with an increasing burden of rOA. However, the positive correlation was much stronger with the composite Symptom score (r=0.43) than with any of the rOA scores (r ≤ 0.24, table 3).

An unadjusted partial proportional odds model including only rOA scores showed a significant positive association between HAQ category and scores for the IP/CMC, Knee, and Spine factor (table 4).

For example, the odds of having a HAQ score ≥1 compared to a HAQ score <1, or a HAQ score >0 versus HAQ score equal to 0, were 51% higher for every 1-*SD* increase in the IP/CMC factor score (cOR 1.51, 95% CI [1.33, 1.71]). The addition of the Symptom score to the model reduced the cOR for the knee factor to a statistically non-significant level, but the cORs for the IP/CMC and Spine factors were essentially unchanged. More importantly, the cORs for the Symptom factor were substantially higher than those for any of the rOA scores. For each 1-*SD* increase in the Symptom score, the odds of being in a HAQ category >0 increased substantially (cOR 7.65, 95% CI [5.68, 10.29]), while the odds of being in the

worst category compared to the better two categories more than doubled (cOR 2.27, 95% CI [1.96, 2.63], table 3). After adjustment for the covariates, the associations between the rOA scores and HAQ categories were no longer significant, but those for the Symptom score actually *increased* in magnitude. No interactions were significant in the final model as shown by the non-significant likelihood ratio test result (p=0.26) comparing a model with all interactions to one with none. Therefore, it appears that the composite Symptom score is more predictive than rOA of poorer function as reported by the HAQ.

Gait speed

The mean gait speed in the sample was 0.7 ± 0.2 m/s, with median 0.7 m/s and range from 0.1 to 1.6 m/s. Significant negative correlations were found between all rOA scores and gait speed such that higher factor scores, indicating greater rOA burden, were associated with lower values for gait speed (table 3). Again, the correlation between the Symptom score and gait speed was stronger than that for the rOA scores.

Gait speed was significantly negatively associated with all 4 factors and hip rOA in the unadjusted model (table 5).

Even after including the Symptom score, most of the associations between rOA scores and gait speed remained significant, but the magnitude of the association was stronger for the Symptom score compared to the rOA scores. After adjustment for the covariates, the rOA scores were no longer significantly associated with gait speed, while the association with the Symptom score increased in magnitude, with the model predicting a decline of 0.06 m/s (95% CI: −0.07, −0.05) for each 1-*SD* increase in Symptom score. No significant interactions were identified (p=0.50 for a likelihood ratio test for a model with all interactions compared to one with none). As seen for HAQ, a higher composite Symptom score is more strongly associated with poorer gait speed than are the rOA scores.

We used the final unadjusted linear regression equation to calculate, in an exploratory fashion, the predicted effect of combinations of the composite rOA and Symptom score on gait speed. In the absence of symptoms, for no rOA at any site (minimum factor scores and no hip rOA), the model predicted a gait speed of 0.82 m/s (95% CI 0.80, 0.84) compared to 0.31 m/s (95% CI 0.19, 0.44) for an individual with a maximum score for all 4 rOA factors and hip rOA (difference: 0.51 m/s [95% CI 0.37, 0.65]). However, when the mean Symptom score for the sample was substituted in place of no symptoms, the predicted gait speed for an individual with maximal rOA scores dropped to 0.26 m/s (95% CI 0.14, 0.39), again demonstrating the higher impact of symptoms compared with structural rOA.

DISCUSSION

Using data from a community-based cohort of African American and White men and women both with and without rOA, we created 4 composite factors reflective of multi-joint rOA at the hands, knees, and spine (37 distinct joints), and 1 new composite factor representing symptoms at the hands, knees, hips, and low back. Summary scores for these 5 factors yield composite measures including information on both presence and severity of multiple site rOA and multiple site joint symptoms. We found the expected relationships between rOA variables and the outcomes (HAQ and gait speed), although all were attenuated by the covariates age, BMI, gender, and race. The associations with the function-related outcomes, both self-reported (HAQ) and performance-based (gait speed) were notably stronger for the Symptom score than for the rOA factors. This novel composite Symptom score, representative of symptoms at the hands, knees, hips and low back, provides a straightforward method to include information about presence and severity of

multiple joint symptoms in a single variable, and was strongly associated with both self-reported and performance based functional status in this analysis.

We used factor analysis, which identified 4 composite factors of rOA that provided composite scores for IP/CMC, MCP, Knee, and Spine OA, allowing significant reduction in dimensionality of models by using these 4 factors rather than the 42 underlying variable values (at 37 distinct joint sites) that the factors represent, as previously described [6]. In this report, we also describe loadings of symptoms variables onto one distinct Symptom factor. Interestingly, the addition of symptoms to the factor analysis did not change the factor structure initially defined for rOA alone [6]. Furthermore, the symptoms variables formed a distinct Symptom factor rather than loading onto the associated rOA factor for that joint site. Although the joint sites considered were essentially the same as those included for rOA (hand, knee, hip, back), there were minimal correlations and no substantial cross-loading of the symptoms for a given joint site with the corresponding rOA grade, or its factor score, in this community-based population unselected for OA or musculoskeletal symptoms. This is likely a function of several contributing factors: 1) insensitivity of measures of both symptoms [38] and of structural damage by conventional radiography [39] in OA, particularly for semi-quantitative measures such as the KL grade; 2) potential anatomic inaccuracy of self-reported symptoms [40, 41]; and 3) imperfect agreement between structural findings and symptoms. Another potential cause of discordance between structure and symptoms could be a genetic contribution to symptoms: Williams et al [42] reported that a single genetic factor underlies self-reported musculoskeletal pain at multiple sites in the TwinsUK cohort, with a heritability of 46% (95% CI 40–52%). In a subset of participants with radiographs, the authors also reported weak correlations between pain and knee or hand rOA ($r<0.1$, [42]). This discordance is likely most important in the mild to moderate structural damage that is most often seen in community or population-based studies; associations between pain and imaging pathology tend to increase for more severe radiographic joint damage [15, 19, 43, 44].

HAQ scores reflect the self-reported level of difficulty (higher scores=more difficulty) an individual has with activities of daily living [27]. Increasing IP/CMC, Knee, and Spine factor scores, reflective of rOA burden, were associated with significantly increased odds of being in a higher HAQ score category in unadjusted models. However, symptoms were far more powerful predictors of HAQ category than any of the rOA variables, and in the fully adjusted model, only the Symptom score remained predictive. This result is consistent with prior work in this cohort [43], where higher HAQ scores were associated with knee rOA before, but not after, adjustment for knee pain severity and other covariates. Odding et al, using data from the Rotterdam study, found that knee and hip pain were stronger determinants of locomotor disability (using a subset of the HAQ) compared to rOA in these sites; knee and hip pain also demonstrated stronger associations with disability than did combinations of rOA and pain [44]. Urwin, et al, in a community-based study, reported that two thirds of participants self-reported pain in more than one site; those with 3 or more painful joint sites had the highest proportion of disability by the mHAQ [45]. Therefore, we can confirm that the multiple joint symptom composite factor provides a novel method of assessing symptom presence and severity, and is a more important predictor of self-reported functional status than radiographically determined structural damage.

Gait speed is affected by general health status in addition to other factors [5, 28], and has been assessed in OA primarily in the setting of knee disease. A “small” meaningful effect on this measure is estimated at 0.05 m/s [46], while 0.1 m/s represents a “substantial” effect associated with impact on health care utilization, health status, and overall survival [33, 46, 47]. While the rOA variables in the current analysis did not reach this level of effect, the

association of the Symptom factor with gait speed was consistent with a “small” meaningful effect (reduction of 0.06 m/s in adjusted models).

Of greater interest is the predicted gait speed based on combinations of rOA and symptom scores, where “substantial” effects were seen, consistent with a cumulative effect of rOA and symptom burden on gait speed. For example, the model predicts a decrease in gait speed of 0.51 m/s when comparing a hypothetical situation of no rOA to one with maximal rOA factor scores and hip rOA; if an average level of symptoms is included in the model, it predicts a decline of 0.56 m/s, which likely represents a clinically relevant change [46]. Our group has previously reported significant associations between slower gait speed and finger joint symptoms, after adjustment for hip and knee symptoms and rOA [3]. The vast majority of studies using gait speed in OA focus on knee OA, with fewer looking at hip involvement [34]. One study assessing knee and ankle rOA and symptoms at these two sites found that knee rOA was independently associated with reduced gait speed [48]. Several other studies have identified inverse associations between gait speed and pain in multiple joint sites, although without radiographic assessments [23, 24, 49]. We find herein that the overall burden of rOA, and especially of multiple joint symptoms, using composite measures that simultaneously account for both presence and severity, is more predictive of declines in gait speed than rOA of any joint site, suggesting that consideration of the burden of symptomatic disease is of value for functional outcomes in OA. Rehabilitation planning may be better served by a thorough review of OA patients' symptoms rather than multiple joint imaging, and interventions directed at symptom management (joint protection, exercise, weight loss, education) are likely important for reducing, and potentially preventing, functional decline.

Limitations of this work include its cross-sectional nature (which prevents understanding of the temporal relationships), although future longitudinal studies are possible in this cohort. The observed factor structure was generated for this particular sample and has not yet been replicated in other populations, so cannot be translated to other groups without further research for confirmation. The overall observed gait speed in our study is slower than that seen in other OA studies [5], which may represent a unique and possibly non-generalizable aspect of our population. Foot and ankle radiographs were not available for this sample but will be collected in the future. The considerable strengths of the current analysis include the use of a community-based cohort with extensive radiographic, symptomatic, and functional data, inclusion of African American and White men and women with and without rOA, and the use of a methodologically rigorous procedure to obtain multi-joint scores.

CONCLUSIONS

Composite factors, simultaneously representing both the presence and severity of multi-joint symptoms and rOA involvement, were associated with reduced gait speed and higher HAQ scores, although only the composite Symptom score was significantly associated after adjustment for covariates. Exploratory modeling suggested cumulative negative impact on function from increasing burden of symptoms and rOA at multiple sites. Such composite factors, incorporating information from numerous variables, allow more precise estimation of the effects of multi-joint OA involvement on systemic outcomes for researchers. Clinically, symptom assessment is more cost-effective and accessible to rehabilitation providers, and in our analysis is also more strongly associated with functional assessments than is more costly radiographic assessment, particularly for evaluation of multiple joint sites.

Acknowledgments

We would like to thank the participants and staff of the *JoCo OA Project*, without whom this work would not have been possible.

Declarations of interest. The funding sources had no role in data collection, analysis, interpretation, or in manuscript writing or the decision to submit the manuscript. This research was supported in part by the Clinical Investigator Fellowship Award from the American College of Rheumatology Research and Education Foundation (Nelson), NIH/NIAMS Loan repayment award LRP 1L30 AR056604 (Nelson), UNC CTSA via NCRR UL1RR025747 (Nelson, Elstad), Arthritis Foundation Postdoctoral Fellowship Award (Golightly), NIH/NIA Claude D. Pepper 5-P30-AG028716 and P01 AR050245 (Kraus), CDC/Association of Schools of Public Health S043 and S3486 (Jordan, Renner), and NIAMS 5-P60-AR30701 (Jordan, Renner, Schwartz).

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Implications for Rehabilitation

- Osteoarthritis (OA) commonly affects multiple joints and is the most common form of arthritis.
- Symptomatic assessments, which can be easily executed by rehabilitation practitioners, are more closely related to self-reported and performance-based functional status than are less accessible and more costly radiographs.
- Symptomatic assessments are likely to be more informative for understanding, treating, and potentially preventing functional limitations than radiographic assessments.

Table 1

Sample characteristics, complete case analysis (n=1307*).

	Mean ± SD	Median	(Observed range); *(Possible range)*
Age (years)	67.2 ± 9.7	66.1	(45.2–95.3)
IP/CMC Factor †	0.7 ± 0.7	0.5	(0–3.7); *(0–4)*
MCP Factor	0.3 ± 0.4	0.3	(0–4.0); *(0–4)*
Knee Factor	0.5 ± 0.4	0.4	(0–2.5); *(0–3.2)*
Spine Factor	0.5 ± 0.4	0.4	(0–2.8); *(0–3)*
Symptom Factor	0.5 ± 0.6	0.3	(0–3); *(0–3)*
Gait speed (m/s)	0.7 ±0.2	0.7	(0.1–1.6)

	n (%)
Hip rOA present ‡	451 (34.5%)
Male	445 (34.1%)
African American	418 (32.0%)
BMI (kg/m^2)	
<25	208 (16.0%)
≥25 and <30	472 (36.1%)
≥30	626 (47.9%)
HAQ	
=0	391 (29.9%)
>0 to <1	317 (24.3%)
≥1	599 (45.8%)

*Gait speed n=1300; n=1 missing BMI.

†Factor scores represent average radiographic grades across all included joints (e.g. the MCP factor is calculated as the summed KL grade for MCP 2–5 on both hands divided by the number of joints included (sum MCP KL grades/8)).

‡Hip rOA is presented separately as hip is not included in any of the factor scores.

Table 2

Factor analysis results after oblique rotation*

Variable	Loading of Variables onto Individual Factors				
	IP/CMC	MCP	Knee	Spine	Symptom
L 1st IP	**0.527**	0.117	0.068	0.022	− 0.083
R 1st IP	**0.556**	0.129	0.046	0.045	− 0.030
L CMC 1	**0.454**	0.001	0.160	0.153	0.069
R CMC 1	**0.424**	0.020	0.150	0.128	0.065
L 2nd DIP	**0.830**	− 0.154	− 0.016	0.044	− 0.020
L 3rd DIP	**0.837**	− 0.067	− 0.004	− 0.013	0.021
L 4th DIP	**0.821**	− 0.026	− 0.015	− 0.081	− 0.008
L 5th DIP	**0.774**	− 0.035	− 0.042	0.005	0.002
R 2nd DIP	**0.802**	− 0.083	− 0.038	0.083	0.012
R 3rd DIP	**0.810**	− 0.028	0.022	0.012	− 0.016
R 4th DIP	**0.821**	− 0.032	− 0.017	− 0.003	− 0.012
R 5th DIP	**0.787**	− 0.067	− 0.025	0.012	0.001
L 2nd PIP	**0.686**	0.052	0.008	− 0.001	0.005
L 3rd PIP	**0.723**	0.078	− 0.006	− 0.028	0.048
L 4th PIP	**0.721**	0.066	− 0.028	− 0.031	0.032
L 5th PIP	**0.685**	0.062	0.048	− 0.016	0.004
R 2nd PIP	**0.684**	0.053	0.001	0.025	− 0.029
R 3rd PIP	**0.708**	0.070	0.030	− 0.036	0.003
R 4th PIP	**0.764**	0.041	− 0.022	− 0.027	− 0.008
R 5th PIP	**0.646**	0.078	0.088	− 0.014	− 0.006
L 2nd MCP	− 0.100	**0.609**	0.026	0.033	− 0.005
L 3rd MCP	− 0.087	**0.667**	0.019	0.005	0.025
L 4th MCP	0.056	**0.646**	− 0.025	− 0.075	0.023
L 5th MCP	0.038	**0.631**	0.002	− 0.059	− 0.028
R 2nd MCP	0.019	**0.547**	0.026	0.064	0.036
R 3rd MCP	− 0.022	**0.590**	0.057	0.070	0.009
R 4th MCP	0.038	**0.673**	− 0.032	− 0.017	0.004
R 5th MCP	0.065	**0.625**	− 0.047	− 0.038	− 0.031
Right TFJ	0.059	0.047	**0.706**	− 0.014	0.021
Left TFJ	0.100	− 0.013	**0.750**	− 0.034	0.022
Right PFJ avg †	− 0.018	0.001	**0.795**	− 0.004	− 0.027
Left PFJ avg †	− 0.037	− 0.014	**0.822**	− 0.014	0.004
L1/2 DN	0.116	0.010	− 0.114	**0.571**	0.027
L2/3 DN	0.087	− 0.012	− 0.133	**0.677**	0.001
L3/4 DN	0.012	0.014	− 0.085	**0.603**	0.022
L4/5 DN	0.024	0.105	0.023	**0.466**	− 0.021

Variable	Loading of Variables onto Individual Factors				
	IP/CMC	MCP	Knee	Spine	Symptom
L5/S1 DN	*0.032*	*− 0.032*	*0.085*	**0.418**	*− 0.045*
L1/2 OST	*0.027*	*− 0.058*	*0.064*	**0.554**	*− 0.008*
L2/3 OST	*− 0.015*	*− 0.078*	*0.023*	**0.624**	*0.025*
L3/4 OST	*− 0.152*	*0.013*	*0.117*	**0.554**	*− 0.017*
L4/5 OST	*− 0.169*	*0.085*	*0.143*	**0.398**	*− 0.038*
L5/S1 OST	*− 0.117*	*− 0.010*	*0.193*	**0.366**	*− 0.067*
L Hand symptoms	*0.105*	*0.039*	*− 0.092*	*0.002*	**0.720**
R Hand symptoms	*0.130*	*0.018*	*− 0.102*	*0.002*	**0.733**
L Knee symptoms	*− 0.062*	*− 0.054*	*0.377*	*− 0.111*	**0.648**
R Knee symptoms	*− 0.076*	*− 0.045*	*0.339*	*− 0.103*	**0.663**
L Hip symptoms	*− 0.047*	*0.036*	*− 0.137*	*0.096*	**0.662**
R Hip symptoms	*− 0.022*	*0.027*	*− 0.077*	*0.037*	**0.643**
Back symptoms	*− 0.081*	*− 0.015*	*− 0.113*	*0.127*	**0.583**
Factor statistics					
Eigenvalue	**11.684**	**6.118**	**4.460**	**4.496**	**3.366**
Alpha	**0.953**	**0.829**	**0.872**	**0.792**	**0.836**
Interitem correlation	**0.505**	**0.377**	**0.405**	**0.276**	**0.421**

IP=interphalangeal joint; CMC1=1st carpometacarpal joint; DIP=distal interphalangeal joint; PIP=proximal interphalangeal joint; MCP=metacarpophalangeal joint; TFJ=tibiofemoral joint; PFJ=patellofemoral joint osteophytes; L1/2, etc=lumbosacral spine level; DN=disc narrowing; OST=osteophytes

*Variables are all for rOA unless "symptoms" is stated; low loading variables are excluded (bilateral 1st MCPs < 0.4, and bilateral hip rOA <0.2)

†PFJ presented for simplicity as average osteophytes across 4 surfaces (lateral femoral, lateral patellar, medial femoral, medial patellar), nearly identical loadings are obtained for individual surface scores.

Table 3

Correlations between factor scores and HAQ or Gait speed.

Factor Score[†]	HAQ(n=1307) *Pearson r*[*]	Gait speed (n=1300) *Pearson r*[*]
IP/CMC	0.236	−0.210
MCP	0.088	−0.162
Knee	0.159	−0.202
Hip rOA	0.098	−0.149
Spine	0.144	−0.164
Symptom	0.431	−0.252

[*] p value for all correlations ≤ 0.001

[†] Factor scores represent average radiographic grades across all included joints (e.g. the MCP factor is calculated as the summed KL grade for MCP 2–5 on both hands divided by the number of joints included (sum MCP KL grades/8)). Hip rOA is not included in a factor so is listed separately.

Table 4

Cumulative Odds Ratios (cOR) between 1-SD changes in factor scores and HAQ by Partial Proportional Odds (n=1307).

Factor score	*Model 1 (rOA)*		*Model 2 (rOA + Symptom)*		*Full model (Model 2 + covariates*)*	
	cOR	*95% CI*	*cOR*	*95% CI*	*cOR*	*95% CI*
IP/CMC	**1.51**	**1.33, 1.71**	**1.47**	**1.29, 1.67** †	1.11	0.95, 1.28
MCP	0.92	0.82, 1.04	0.90	0.80, 1.02	0.93	0.81, 1.06
Knee	**1.18**	**1.05, 1.33**	1.12	0.99, 1.27	1.07	0.94, 1.22
Hip rOA	1.18	0.94, 1.47	1.08	0.86, 1.37	0.91	0.71, 1.16
Spine	**1.16**	**1.03, 1.30**	**1.17**	**1.04, 1.32**	1.08	0.94, 1.23
Symptom	--	--	**7.65** †	**5.68, 10.29**	**9.32**	**6.80, 12.77**
			2.27	**1.96, 2.63**	**2.54**	**2.18, 2.98**

*Covariates: age, BMI, gender, and race.

†Proportional odds assumption met if only one cOR given. If two cORs, first is for HAQ>0 (upper 2 categories pooled) vs. HAQ=0, 2nd is for HAQ ≥1 vs. HAQ<1 (the lower two categories pooled).

Table 5

Associations between 1-SD changes in factor scores and Gait speed by Linear Regression (n=1300).

Factor score	*Model 1 (rOA)*		*Model 2 (rOA + Symptom)*		*Full model (Model 2 + covariates*)*	
	Beta	**95% CI**	**Beta**	**95% CI**	**Beta**	**95% CI**
IP/CMC	**− 0.026**	**− 0.039, −0.013**	**− 0.022**	**− 0.035, −0.009**	0.002	−0.011, 0.016
MCP	**− 0.011**	**− 0.024, −0.002**	−0.010	−0.022, 0.003	−0.001	−0.013, 0.010
Knee	**− 0.027**	**− 0.040, −0.014**	**− 0.022**	**− 0.035, −0.009**	−0.005	−0.017, 0.007
Hip rOA	**− 0.043**	**− 0.069, −0.017**	**− 0.039**	**− 0.065, −0.014**	−0.007	−0.030, 0.016
Spine	**− 0.017**	**− 0.030, −0.004**	**− 0.016**	**− 0.029, −0.004**	−0.003	−0.015, 0.009
Symptom	--	--	**− 0.051**	**− 0.064, −0.039**	**− 0.063**	**− 0.074, −0.051**

*Covariates: age, BMI, gender, and race.