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# Association of different pain patterns with physical function in participants with knee osteoarthritis: data from the osteoarthritis initiative

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## Abstract

**Background** Pain is a multidimensional experience and a key symptoms of knee osteoarthritis (KOA). However, it remains unknown whether there is a specific pain pattern that is more strongly associated with physical function compared to other pain patterns among individuals with KOA. This study aimed to compare the correlations between different pain patterns and physical function, and identify the most related pain pattern with physical function in KOA.

**Methods** 412 participants with radiological KOA were included from the Osteoarthritis Initiative (OAI). Pain severity and four pain patterns were assessed, including intermittent, constant, weight-bearing, and non-weight-bearing pain patterns. Physical function was evaluated by the Western Ontario and McMaster Universities Arthritis Index physical function subscale (WOMAC-PF), Knee Injury and Osteoarthritis Outcome Score Function in Sport and Recreation (KOOS-FSR), 20-Meter Walking Test (20-MWT) and Repeated Chair Stand test (RCS).

**Results** Among pain severity and all pain patterns, the weight-bearing pain pattern had the strongest correlation with WOMAC-PF, and showed significant correlations with both WOMAC-PF and KOOS-FSR at baseline, year-2 follow up, and 2-year change ( $p < 0.001$ ). All pain patterns and pain severity showed weakly significant correlation with 20-MWT and RCS.

**Conclusions** Weight-bearing pain pattern was most closely associated with self-reported physical function. Therapeutic targets related to weight-bearing pain should be preferred when administering analgesic therapies to improve physical function in KOA.

**Keywords** Weight-bearing pain, Pain pattern, Physical function, Longitudinal study, Osteoarthritis Initiative (OAI)

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## Introduction

Knee osteoarthritis (KOA) is the most prevalent degenerative joint disease and a common disabling condition that affects approximately 250 million people globally [1]. People with KOA typically present with joint pain, stiffness, and functional limitations, which significantly impact their quality of life [2, 3]. Among these symptoms, pain is the major characteristic of symptomatic KOA and a leading cause of functional limitations [4–6], which serves as the chief impetus for clinical decision making and health care services [7]. Therefore, understanding the relationship between the characteristics of KOA-related pain and physical function is crucial for guiding clinical treatment and functional rehabilitation.

Pain is a multidimensional experience [8]. It encompasses various aspects, such as onset, frequency, duration, and changes in pain over time or activities [9]. KOA-related pain is typically a complicated chronic condition [10, 11]. Multiple factors, including inflammation, psychological factors, peripheral and central sensitization, interact within a biopsychosocial framework to influence the experience of KOA-related pain [12]. The clinical manifestations of KOA-related pain vary at different stages and may progress from predictable activity-related pain to persistent pain and unforeseen pain [11]. However, currently, there is no consensus regarding the best assessment technique for KOA-related pain [13]. Clinically, the severity of knee pain is the most important factor limiting physical function [14]. Although pain severity evaluates the global status of a patient's pain experience, it confounds the complex characteristics of KOA-related pain, leading to nonspecific results [15, 16].

Compared to pain severity, other pain patterns have not been suitably acknowledged. Existing literature describes several pain patterns in KOA, including different pain localizations, weight-bearing and non-weight-bearing pain [17], intermittent pain, and constant pain [18]. However, most previous studies have only analyzed the relationship between a single pain pattern and physical function [19, 20]. It remains unknown whether there is a specific pain pattern that is more strongly associated with physical function compared to other pain patterns. Identifying such a pain pattern could inform the development of more targeted pain assessments and guide the selection of analgesic therapies to improve physical function among those who with KOA.

The aim of this study is to comprehensively evaluate the relationship between pain patterns and physical function, and identify the specific pain pattern most strongly associated with physical function. We compared the cross-sectional and longitudinal correlations between different pain patterns (pain localizations, weight-bearing and non-weight-bearing pain, intermittent pain and

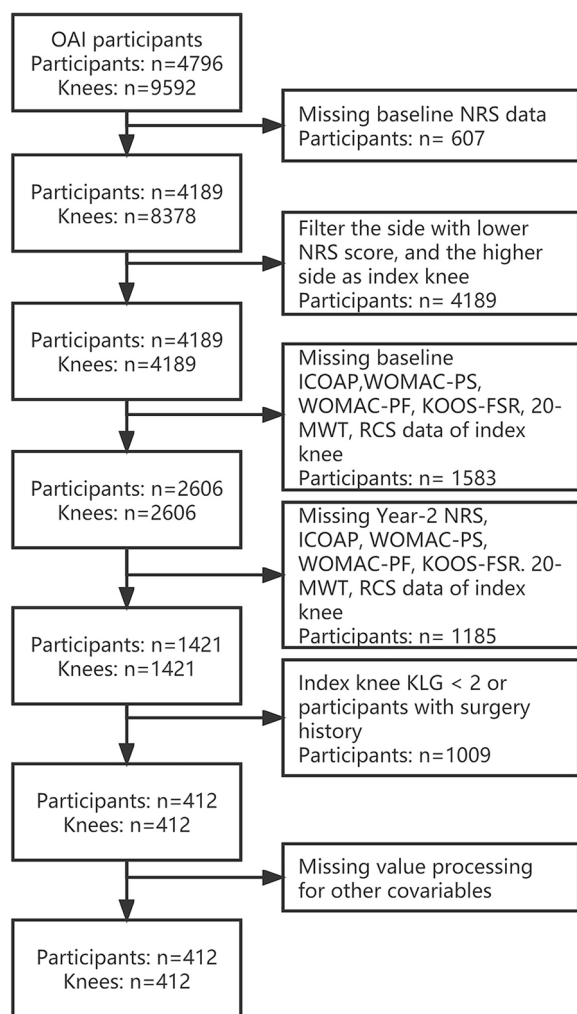
constant pain) and physical function in radiological KOA patients from the Osteoarthritis Initiative database. We hypothesized that there is a specific pain pattern that is most relevant to physical function among all the pain patterns mentioned above. Weight-bearing pain may be more effectively managed with biomechanical interventions, such as physical therapy or orthotics, while constant pain may require central pain modulation strategies. Therefore, our study helps to understand the relationship between different pain patterns and physical function, allowing clinicians to identify the specific pain pattern most strongly associated with functional limitation. Based on this knowledge, clinicians can select more targeted analgesic treatments and focus on interventions that address the most functionally disabling pain patterns, eventually developing more personalized treatment strategies to improve mobility and quality of life in patients with KOA.

## Methods

### Study data and sample

This study was a retrospective study within the OAI, a 10-year observational longitudinal study designed to identify risk factors for the occurrence and progression of symptomatic KOA (<http://oai.epi-ucsf.org/datarlease>), as a secondary data source [21]. A total of 4796 participants aged 45 to 79 years at-risk or with KOA were recruited from four clinical sites that conducted the OAI research. The Committee on Human Research and the Institutional Review Board at each clinical site approved the OAI study. All participants provided informed consent. The ICOAP questionnaire was first administered at the 48th-month visit. To extract complete information regarding knee pain severity and the four pain patterns, participant characteristics at the 48th-month visit were used as the baseline and the 72nd-month visit as the year-2 follow up.

The following criteria were used for inclusion: (1) participants with available Numerical Rating Scale (NRS), Western Ontario and McMaster Universities Arthritis Index Pain Scale (WOMAC-PS) and Physical Function subscales (WOMAC-PF), Knee Injury and Osteoarthritis Outcome Score Function in Sport and Recreation (KOOS-FSR), Intermittent and Constant OA Pain (ICOAP) scores, 20-Meter Walking Test (20-MWT) time, and Repeated Chair Stand test (RCS) at baseline and year-2 follow up; (2) participants who were diagnosed as radiological KOA (Kellgren-Lawrence Grade (KLG)  $\geq 2$ ); (3) no more than 5% missing values were observed for all covariables from all samples. Besides, participants with a history of knee surgery were excluded. The process of sample screening is as Fig. 1.



**Fig. 1** Flow chart of sample screening. OAI Osteoarthritis Initiative, NRS Numeric Rating Scale, ICOAP Intermittent and Constant OA Pain, WOMAC-PS Western Ontario and McMaster Osteoarthritis Index Pain Scale, WOMAC-PF Western Ontario and McMaster Osteoarthritis Index Physical Function, KOOS-FSR Knee Injury and Osteoarthritis Outcome Score Function in Sport and Recreation, 20-MWT 20-Meter Walking Test, KLG Kellgren-Lawrence Grade, RCS Repeated Chair Stand test

**Pain patterns**

We assessed four proposed pain patterns: intermittent pain, constant pain, weight-bearing pain, and non-weight-bearing pain. Intermittent and constant pain patterns were assessed using two ICOAP subscales [22], respectively. The two subscales assess pain intensity and how much the intermittent and constant pain affects sleep, quality of life, and emotions. Besides, the intermittent subscale also assesses the predictability and frequency of pain. Each ICOAP item is scored from 0 to 4, with higher scores indicating more extreme or more frequent symptoms. The total scores of the two subscales are transformed into centesimal systems using the

following formulas: constant pain pattern: (Total pain score/20)×100 and intermittent pain pattern: (total pain score/24)×100 [23].

WOMAC is a widely used measurement to evaluate OA-related symptoms [24, 25]. WOMAC-PS is a WOMAC subscale and includes five items providing activity-related pain details. Each item of WOMAC-PS is scored from 0 to 4 with higher scores indicating more severe symptoms. We calculated the sum of three pain items for weight-bearing pain pattern (pain during climbing stairs, walking, and standing) and two pain items of non-weight-bearing pain pattern (pain in bed, and during sitting or lying) [17].

**Pain severity**

We used the NRS to assess pain severity as a traditional reference for pain patterns [26]. Because of its comprehensibility and ease of administration clinically, NRS is the most commonly used tool for measuring pain severity in chronic pain patients as compared to other tools [27]. The participants reported the pain severity during the last 30 days ranging from 0 to 10. A higher number indicate a higher level of pain severity.

**Physical function**

We assessed both self-reported and performance-based physical Function of all participants. We used the 20-MWT to measure performance-based physical function, which is a valid tool frequently used in OA studies [28]. In this test, the participants were timed when they walked down a 20-m corridor without boundaries at their usual walking speed. Two trials were conducted at each visit, and the average time was used as the 20-MWT time. A longer 20-MWT time reflects greater physical functional limitations. Besides, we assessed performance-based physical function used RCS [29]. The RCS scoring is based on the amount of time (to the nearest decimal in seconds) a patient is able to transfer from a seated to a standing position and back to sitting five times. The lower the time to complete the test the better the outcome of the test.

To measure the self-reported physical Function, we used two different tools, WOMAC-PF and KOOS-FSR, to exclude the effect of recall bias for single measurement. WOMAC-PF is a subscale of WOMAC and includes 17 items about limitations in daily activities such as walking up and down the stairs, sitting station transfers, and taking off socks [24]. Each item is scored using a 0–4 Likert scale. The sum of scores of the 17 items was used to assess self-reported physical Function; higher scores indicate higher levels of physical Functional limitations. KOOS-FSR is a subscale of KOOS and includes 5 items about squatting, running, jumping, twisting and

kneeling (SP1–SP5) [30, 31]. Each item is scored using a 0–4 Likert scale. The final KOOS-FSR score:  $100 - \text{Mean score (SP1–SP5)} \times 100/4$ . A lower score indicates poor physical functional.

### Covariates

We adjusted for the following confounders at baseline: age, sex, body mass index (BMI), race, depressive symptoms, physical activity levels, comorbidities, non-steroidal antiinflammatory drugs (NSAIDs) usage, surgery history, pain catastrophizing, and KLG. Because White or Caucasian made up the vast majority in both OAI and our sample (81.3%), the race was categorized as “White” including White/Caucasian individuals, and “Other” which included individuals of any other race except for White/Caucasian. Depressive symptoms were ascertained when the Center for Epidemiologic Studies Depression Scale score was  $\geq 16$  [32]. Physical activity levels were measured by the Physical Activity Scale for the Elderly (PASE), which was scored ranging from 0 to 400, with higher scores indicating higher physical activity levels [33]. Comorbidity status was measured by Charlson Comorbidity Score (CCS), which examines serious systemic diseases such as diabetes and cancer etc. [34] It has a total score of 12 points with higher scores indicating more co-existing diseases. Comorbidity status was defined when the CCS was  $\geq 1$ . NSAID usage was defined as having used nonprescription or prescription NSAIDs for joint pain or arthritis on more than half of the days in the past 30 days. KLG is a widely used radiographic assessment for OA [35] measured based on fixed flexion radiograph readings in the OAI. KLG describes five severity grades (rated 0 to 4), and  $\text{KLG} \geq 2$  is diagnosed as radiological OA. We classified KLG results of radiological OA into three stages: grade 2 (mild radiographic OA), grade 3 (moderate radiographic OA), and grade 4 (severe radiographic OA) [35]. Pain catastrophization was determined using the Coping Strategies Questionnaire-Catastrophizing subscale (CSQ-CAT), which included six items that examined how often participants used this strategy when they experienced pain [36]. According to the CSQ-CAT score, we distinguished individuals with no pain catastrophizing (CSQ-CAT score = 0) from those who may have a tendency toward pain catastrophizing (CSQ-CAT score > 0).

### Statistical analysis

Missing data were filled used Random Forest multiple interpolation by R package “mice”. Descriptive statistics were computed for all covariates. Linear regression analyses were executed to investigate the cross-sectional and longitudinal correlations between pain and functions. Variance inflation factors (VIFs) were calculated

to exam the multicollinearity of covariates. Standardized  $\beta$  coefficients were calculated to compare the correlations between different patterns and physical functions, and the standardized  $\beta$  coefficients of each pain patterns in the regression model were visualized using heat map. Statistical significance was set at  $p < 0.05$ . All statistical analyses and plots were made using R (version 4.1.2). The R codes are available in the Supplementary materials Table S2.

## Results

### Participant characteristics

A total of 412 participants with 212 male and 200 female were included in the study sample. The sample had a mean  $\pm$  standard deviation age of  $59.6 \pm 8.7$  years, and BMI of  $29.08 \pm 4.77$  kg/m<sup>2</sup>. The complete descriptive statistics are shown in Table 1.

### Multicollinearity diagnosis

The results of collinearity diagnosis show that no multicollinearity was found among variables in all model (VIFs < 5), which meets the linear regression assumption (Supplementary materials Table S1).

### Cross-sectional linear relationships

The results of cross-sectional linear relationships between pain and physical function at baseline are shown in Table 2. Pain severity and all pain patterns scores showed a significant positive correlation with WOMAC-PF scores ( $p < 0.05$ ), and the weight-bearing pain pattern had the maximum absolute point estimate value of standard  $\beta$  coefficient ( $\beta = 0.340$ , 95% CI:  $[-0.024, 0.824]$ ). Pain patterns except for the non-weight-bearing pain showed a significant negative correlation with KOOS-FSR scores, and the weight-bearing pain pattern had the maximum absolute point estimate value of standard  $\beta$  coefficient ( $\beta = -0.370$ , 95% CI:  $[-1.778, 1.038]$ ;  $p < 0.001$ ). Regarding the 20-MWT time, no pain pattern showed significant correlation, but the weight-bearing pain pattern was closest to statistical threshold value ( $\beta = 0.144$ , 95% CI:  $[-0.030, 0.318]$ ;  $p = 0.079$ ). For RCS, only constant pain pattern showed significant correlation ( $\beta = 0.165$ , 95% CI:  $[0.141, 0.189]$ ;  $p = 0.007$ ).

### Linear relationships between baseline pain and year-2 physical function

The results of linear relationships between pain patterns and year-2 physical function are shown in Table 3. Weight-bearing pain, non-weight-bearing pain and pain severity were significantly related with WOMAC-PF scores ( $p < 0.05$ ), and the weight-bearing pain pattern had the maximum absolute point estimate value of standard  $\beta$  coefficient ( $\beta = 0.302$ , 95% CI:  $[-0.383, 0.986]$ ). As

**Table 1** Descriptive statistics for samples of 412 participants

Variable	Mean (SD)/n (%)	Missing Data (n, %)
Age, years	59.6 (8.7)	0, 0
Male	212 (51.5%)	0, 0
BMI, kg/m <sup>2</sup>	29.08 (4.77)	1, 0.24
White race	335 (81.3%)	1, 0.24
Depressive symptoms	32 (7.8%)	6, 1.46
Physical activity levels, scores	173.73 (83.36)	4, 0.97
Comorbidity status	105 (25.5%)	3, 0.73
NSAIDs usage	35 (8.5%)	0, 0
Strong prescription pain medications usage	8 (1.9%)	0, 0
Pain catastrophizing	146 (35.4%)	3, 0.73
KLG	-	
Grade 2 (mild radiographic OA)	254 (61.7%)	10, 2.43
Grade 3 (moderate radiographic OA)	110 (26.7%)	5, 1.21
Grade 4 (severe radiographic OA)	48 (11.7%)	4, 0.97
BL Intermittent pain pattern, scores	15.34 (17.27)	0, 0
BL Constant pain pattern, scores	3.76 (12.67)	0, 0
BL Weight-bearing pain pattern, scores	2.07 (2.14)	0, 0
BL Non-weight-bearing pain pattern, scores	0.64 (1.24)	0, 0
BL Pain severity, scores	3.3 (2.7)	0, 0
Year-2 Intermittent pain pattern, scores	14.42 (16.56)	0, 0
Year-2 Constant pain pattern, scores	4.13 (13.23)	0, 0
Year-2 Weight-bearing pain pattern, scores	1.90 (2.19)	0, 0
Year-2 Non-weight-bearing pain pattern, scores	0.64 (1.34)	0, 0
Year-2 Pain severity, scores	3.0 (2.8)	0, 0
BL WOMAC-PF, scores	8.49 (10.31)	0, 0
BL KOOS-FSR, scores	70.99 (25.96)	0, 0
BL 20-MWT, seconds	15.20 (2.33)	0, 0
BL RCS, seconds	10.17 (2.60)	0, 0
Year-2 WOMAC-PF, scores	8.78 (10.63)	0, 0
Year-2 KOOS-FSR, scores	69.32 (26.85)	0, 0
Year-2 20-MWT, seconds	15.48 (2.53)	0, 0
Year-2 RCS, seconds	10.54 (3.38)	0, 0

*BMI* body mass index, *PASE* Physical Activity Scale for the Elderly, *NSAIDs* Non-Steroidal Antiinflammatory Drugs, *KLG* Kellgren-Lawrence Grade, *BL* baseline, *WOMAC-PF* Western Ontario and McMaster Osteoarthritis Index Physical Function, *KOOS-FSR* Knee Injury and Osteoarthritis Outcome Score Function in Sport and Recreation, *20-MWT* 20-Meter Walking Test, and *RCS* Repeated Chair Stand

for KOOS-FSR, weight-bearing pain and pain severity showed significant correlations ( $p < 0.05$ ), and the weight-bearing pain pattern had the maximum absolute point estimate value of standard  $\beta$  coefficient ( $\beta = -0.324$ , 95% CI:  $[-2.085, 1.438]$ ). For the 20-MWT and RCS, no pain showed significant correlation ( $p > 0.05$ ).

#### Longitudinal linear relationships between 2-year changes in pain patterns and physical function

As shown in Table 4, the 2-year changes in all pain patterns except for pain severity showed significant positive correlations with 2-year changes in WOMAC-PF ( $p < 0.05$ ); the weight-bearing pain had the maximum absolute point

estimate value of standard  $\beta$  coefficient ( $\beta = 0.438$ , 95% CI  $[0.023, 0.854]$ ). For the 2-year changes in KOOS-FSR, pain except for non-weight-bearing pain patterns showed significant correlation ( $p < 0.05$ ). Only pain severity showed significant correlation with 20-MWT ( $\beta = 0.146$ , 95% CI:  $[-0.228, -0.063]$ ;  $p = 0.041$ ), and only constant pain pattern showed significant correlation with RCS ( $\beta = 0.165$ , 95% CI:  $[0.132, 0.198]$ ;  $p = 0.004$ ).

#### Visualization of standardized $\beta$ coefficients for all pain patterns in linear models

As shown in Fig. 2, colors blue or red represent the absolute value of the standardized  $\beta$  coefficient for each pain

**Table 2** Cross-sectional relationships between pain patterns and physical function at baseline

Pain patterns*	WOMAC-PF		KOOS-FSR		20-MWT		RCS	
	$\beta$ (95% CI)	p	$\beta$ (95% CI)	p	$\beta$ (95% CI)	p	$\beta$ (95% CI)	p
Constant pain pattern	0.169 (0.115, 0.223)	<0.001 <sup>†</sup>	-0.113 (-0.292, 0.067)	<0.011 <sup>†</sup>	0.033 (0.011, 0.055)	0.594	0.165 (0.141, 0.189)	0.007 <sup>†</sup>
Intermittent pain pattern	0.188 (0.143, 0.232)	<0.001 <sup>†</sup>	-0.124 (-0.271, 0.023)	<0.013 <sup>†</sup>	0.028 (0.010, 0.047)	0.679	0.093 (0.073, 0.113)	0.168
Weight-bearing pain pattern	0.34 (-0.024, 0.824)	<0.001 <sup>†</sup>	-0.37 (-1.778, 1.038)	<0.001 <sup>†</sup>	0.144 (-0.030, 0.318)	0.079	0.118 (-0.073, 0.309)	0.143
Non-weight-bearing pain pattern	0.147 (-0.406, 0.699)	<0.001 <sup>†</sup>	0.02 (-1.815, 1.854)	0.657	0.01 (-0.217, 0.238)	0.867	-0.012 (-0.261, 0.237)	0.84
Pain severity	0.099 (-0.223, 0.420)	0.022	-0.267 (-1.334, 0.801)	<0.001 <sup>†</sup>	-0.041 (-0.173, 0.091)	0.603	0.065 (-0.080, 0.210)	0.399

\* Adjusted for age, sex, BMI, race, depressive symptoms, physical activity levels, comorbidity status

NSAIDS usage, surgery history, KLG and pain catastrophizing at baseline

<sup>†</sup> Significant at  $p < 0.05$ . All  $\beta$  coefficients are standard

CI Confidence Interval

**Table 3** Linear relationships between baseline pain patterns and year-2 physical function

Pain patterns*	WOMAC-PF		KOOS-FSR		20-MWT		RCS	
	$\beta$ (95% CI)	p	$\beta$ (95% CI)	p	$\beta$ (95% CI)	p	$\beta$ (95% CI)	p
Constant pain pattern	0.102 (0.015, 0.189)	0.054	-0.01 (-0.235, 0.214)	0.849	0.036 (0.012, 0.059)	0.551	-0.058 (-0.094, -0.021)	0.405
Intermittent pain pattern	-0.023 (-0.095, 0.048)	0.695	0.036 (-0.148, 0.220)	0.547	0.04 (0.021, 0.059)	0.551	0.078 (0.049, 0.108)	0.311
Weight-bearing pain pattern	0.302 (-0.383, 0.986)	<0.001 <sup>†</sup>	-0.324 (-2.085, 1.438)	<0.001 <sup>†</sup>	0.086 (-0.099, 0.271)	0.28	0.02 (-0.261, 0.304)	0.827
Non-weight-bearing pain pattern	0.117 (-0.775, 1.010)	0.027 <sup>†</sup>	-0.03 (-2.325, 2.266)	0.583	0.009 (-0.232, 0.250)	0.883	0.038 (-0.332, 0.409)	0.578
Pain severity	0.173 (-0.346, 0.692)	0.011 <sup>†</sup>	-0.281 (-1.617, 1.054)	<0.001 <sup>†</sup>	0.024 (-0.117, 0.164)	0.757	-0.143 (-0.358, 0.073)	0.106

\* Adjusted for age, sex, BMI, race, depressive symptoms, physical activity levels, comorbidity status, NSAIDS usage, surgery history, KLG and pain catastrophizing at baseline

<sup>†</sup> Significant at  $p < 0.05$ . All  $\beta$  coefficients are standard

CI Confidence Interval

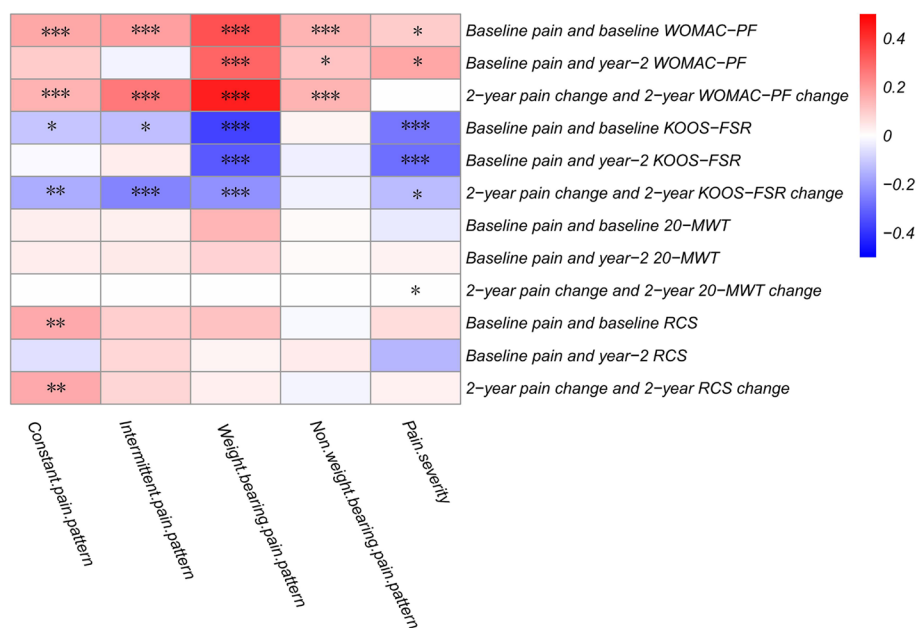
**Table 4** Longitudinal linear relationships between 2-year change in pain patterns and 2-year change in physical function

Pain patterns*	WOMAC-PF		KOOS-FSR		20-MWT		RCS	
	$\beta$ (95% CI)	p	$\beta$ (95% CI)	p	$\beta$ (95% CI)	p	$\beta$ (95% CI)	p
Constant pain pattern	0.148 (0.101, 0.195)	<0.001 <sup>†</sup>	-0.16 (-0.298, -0.023)	0.001 <sup>†</sup>	0.028 (0.017, 0.040)	0.626	0.165 (0.132, 0.198)	0.004 <sup>†</sup>
Intermittent pain pattern	0.261 (0.223, 0.299)	<0.001 <sup>†</sup>	-0.241 (-0.353, -0.130)	<0.001 <sup>†</sup>	0.091 (0.082, 0.101)	0.153	0.079 (0.053, 0.106)	0.211
Weight-bearing pain pattern	0.438 (0.023, 0.854)	<0.001 <sup>†</sup>	-0.214 (-1.431, 1.004)	<0.001 <sup>†</sup>	0.113 (0.009, 0.217)	0.092	0.031 (-0.260, 0.322)	0.643
Non-weight-bearing pain pattern	0.146 (-0.384, 0.677)	<0.001 <sup>†</sup>	-0.024 (-1.578, 1.530)	0.632	-0.005 (-0.138, 0.128)	0.925	-0.02 (-0.392, 0.352)	0.724
Pain severity	0.002 (-0.326, 0.330)	0.969	-0.133 (-1.093, 0.828)	0.031 <sup>†</sup>	0.146 (-0.228, -0.063)	0.041 <sup>†</sup>	0.026 (-0.204, 0.255)	0.716

\* Adjusted for age, sex, BMI, race, depressive symptoms, physical activity levels, comorbidity status, NSAIDS usage, surgery history, KLG and pain catastrophizing at baseline

<sup>†</sup> Significant at  $p < 0.05$ . All  $\beta$  coefficients are standard

CI Confidence Interval



**Fig. 2** Heat map of standardized  $\beta$  coefficient for each pain pattern and severity. The abscissa shows different pain patterns and pain severity, and the vertical axis represents the linear model at different time points and different functional indicators. Colors blue or red represent the absolute value of the standardized  $\beta$  coefficient for each pain pattern in the linear model. The number of “\*” indicates the significant level of pain pattern in certain model (“\*\*\*” means  $p < 0.001$ , “\*\*” means  $p < 0.01$ , “\*” means  $p < 0.05$ ). WOMAC-PF Western Ontario and McMaster Osteoarthritis Index Physical Function, KOOS-FSR Knee Injury and Osteoarthritis Outcome Score Function in Sport and Recreation, 20-MWT 20-Meter Walking Test, RCS Repeated Chair Stand test

pattern and pain severity in the Cross-sectional and longitudinal linear regression for WOMAC-PF, KOOS-PF, 20-MWT and RCS. It can be easily seen that the blocks of the weight-bearing pain pattern column have the deepest color, which means the weight-bearing pain pattern has the maximum absolute value of standardized  $\beta$  coefficient in all linear models. Besides, the area color of WOMAC-PF and KOOS-FSR are deeper than 20-MWT and RCS, which means the associations between pain and self-reported physical functions are stronger than performance-based physical function.

**Discussion**

In this study, we found that the weight-bearing pain pattern was most related to self-reported physical function among all patterns and pain severity. Additionally, all pain patterns and pain severity were weakly correlated with performance-based physical function, and the weight-bearing pain was always closest to the threshold of statistical significance. These findings suggest that clinicians should pay particular attention to weight-bearing pain when developing management strategies for patients with knee osteoarthritis. Identifying and addressing weight-bearing pain may help improve physical function, slow functional decline, and reduce the risk of disability.

On the whole, the weight-bearing pain pattern demonstrated the most significant with physical function among all pain assessments, which agrees with our first hypothesis. To the best of our knowledge, this is the first study that examines the association between weight-bearing pain or non-weight-bearing pain pattern and the physical function. From a  $p$  value point of view, in each pair of correlation analyses, the correlation between weight-bearing pain and subjective function reached statistical significance ( $p < 0.05$ ). This significant correlation can be explained by fear-avoidance beliefs of activity-related knee pain. Fear is an emotional reaction to a specific, identifiable threat, and induces defensive or escape behavior to remove the specific threat [35]. In the fear-avoidance model, musculoskeletal pain is perceived as threatening and leads to maladaptive behaviors including pain-related fear, avoidance, and hypervigilance [37]. Eventually, the fear and avoidance behaviors may increase disability through the detrimental effects of prolonged physical inactivity and weakening of the musculoskeletal system [38]. In patients with symptomatic KOA, the weight-bearing pain equals a specific and identifiable threat and is different from other pain patterns, such as non-weight-bearing pain, intermittent pain, and constant pain, which is not associated with specific and identifiable behaviors. Furthermore, avoiding activity can

immediately reduce weight-bearing pain, which in turn, enhances avoidance behavior leading to further disability [39]. This also explains the differences in correlations between self-reported and performance-based physical function. However, from the perspective of confidence interval, the above correlations are not stable, some  $p$  values are less than 0.05 but the confidence interval contains (see Table 2–4). We analyzed that the score of the scales (such as the WOMAC with Likert scale) may be too discrete and the range is narrow, which leads to the instability of the results of the interval estimation. Therefore, the currently used assessment tools may not be the most appropriate, and new targeted assessment tools need to be developed.

Most of the correlations between weight-bearing pain with the 20-MWT and RCS did not reach the level of statistical significance in our study. We inferred that the reason may be that performance-based physical function is more related to other factors than pain, and weight-bearing pain is more related to performance-based physical function than other types of pain patterns. Performance-based physical function was more associated with physiologic factors such as age and BMI, while the self-reported physical function was associated with psychosocial factors [40, 41], which were also observed in our study (Supplementary materials Table S3). Thus, performance-based physical function measures what a patient “can do,” whereas self-reported physical function measures what a patient “thinks he/she can do” [42]. Furthermore, this judgment of one’s own abilities in self-reported physical function rather than actual abilities in performance-based physical function is more likely influenced by fear-avoidance beliefs [43].

The intermittent and constant pain patterns, which were proven to be associated with physical function level in previous studies [22, 44], showed weaker correlations with physical function than the weight-bearing pain pattern in our study. Different pain mechanisms may account for the results. Intermittent pain that occurred in the early stages may be driven by nociceptive input, and constant pain found in more advanced disease severity stages may be a reflection of central pain sensitization [45]. Due to the discordance between OA disease stages and physical function [46, 47], the intermittent and constant pain patterns, which are marked by different disease stages, are not directly related to the physical function level. On the contrary, the presence of weight-bearing pain is consistent across time and space with performing functional activities. Weight-bearing pain occurs when performing functional activities that require knee loading and is more significantly associated with biomechanical factors [48]. Biomechanical forces in the knee cavity will activate subchondral nerves, which have

been sensitized by the subchondral bone marrow lesion, eventually leading to knee pain [49]. Therefore, individuals can reduce mechanical load stimulation by decreasing activity, thereby alleviating pain. This may be the reason why weight-bearing pain is more strongly associated with physical function. The measurement of weight-bearing/non-weight-bearing pain and intermittent/constant pain provides different dimensions of pain assessment. Intermittent/constant pain mainly reflects the temporal characteristics of pain, which may also occur at rest. Weight-bearing/non-weight-bearing pain is primarily based on whether the knee joint is subjected to mechanical load and is considered a functionally related pain. Weight-bearing pain may be more effectively managed with biomechanical interventions, such as physical therapy or orthotics, while constant pain may require central pain modulation strategies. In addition, for patients experiencing weight-bearing pain, special attention should be given to patient education to prevent pain-related fear of movement, which could further lead to a decline in physical function.

Pain severity, the most well-known chronic pain assessment item in clinical practice [27], showed a weaker correlation with physical Function than weight-bearing pain. Pain severity is a one-dimension assessment of the overall pain experience, and patients only reports the severity of one of the most painful experiences or an average in the past 30 days. Thus, characteristics associated with complicated pain attributes are missing, and different pain properties may mask one another, reducing the correlation between pain and physical function. This problem could be avoided when accompanied by appropriate, specific pain patterns, such as the weight-bearing pain pattern, for predicting the physical function in this study.

Due to the limitations of the OAI database, we could not consider the effects of medical intervention such as rehabilitation training; other pain patterns were not compared, and thus, other types of pain that were closely related to physical function besides weight-bearing pain could not be ruled out. The underlying cause of these correlations could not be accurately known in this study, and we could only reasonably speculate based on other research evidences. Additionally, other measurements such as quantitative sensory testing, climatic factors may provide more information since these measurements have been reported to be related to pain patterns [50, 51].

## Conclusions

Weight-bearing pain pattern was most closely associated with physical function. Therapeutic targets associated with weight-bearing pain should be preferred when prescribing or administering analgesic therapies to improve

physical function in KOA. Further research is warranted to clarify the mechanism underlying weight-bearing pain.

#### Abbreviations

20-MWT	20-Meter Walking Test
BMI	Body mass index
CCS	Charlson Comorbidity Score
CSQ-CAT	Coping Strategies Questionnaire Catastrophizing subscale
ICOAP	Intermittent and Constant OA Pain
KLG	Kellgren-Lawrence Grade
KOOS-FSR	Knee Injury and Osteoarthritis Outcome Score Function in Sport and Recreation
NRS	Numeric Rating Scale
NSAIDs	Non-Steroidal Antiinflammatory Drugs
OA	Osteoarthritis
OAI	Osteoarthritis Initiative
PASE	Physical Activity Scale for the Elderly
WOMAC	Western Ontario and McMaster Universities Arthritis Index
WOMAC-PF	Western Ontario and McMaster Osteoarthritis Index Physical Function
WOMAC-PS	Western Ontario and McMaster Universities Arthritis Index Pain Scale

#### Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13018-025-06146-8>.

Supplementary Material 1.

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#### Authors' contributions

SL: conceived and designed the study and were responsible for drafting the manuscript. GL and JZ: contributed to writing the manuscript and participated in the analysis of the study. ZG, ZH, YZ and TF: revised the study and wrote several sections of the manuscript. WF and ZZ: helped develop the data cleaning and reduction. MZ, GH and QZ: revised the study and control the quality of study. All authors have read and approved the final version of the manuscript.

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#### Data availability

This study used data from the OAI, a 10-year observational longitudinal study designed to identify risk factors for the occurrence and progression of symptomatic KOA (<http://oai.epi-ucsf.org/datarelease>), as a secondary data source.

#### Declarations

##### Ethics approval and consent to participate

All procedures performed in studies involving human participants had got the approval of the Institutional Review Board for the University of California, San Francisco and the Institutional Review Boards at each clinical site of OAI (Approval Number 10-00532), and were in accordance with the 1964 Helsinki declaration including its later amendments or comparable ethical standards. All participants provided informed consent.

#### Competing interests

All authors declare no conflict of interest.

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