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# Understanding the biopsychosocial knee osteoarthritis pain experience: an ecological momentary assessment

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**Abstract**

**Introduction:** Psychological, social, and lifestyle factors contribute to the knee osteoarthritis (OA) pain experience. These factors could be measured more accurately using smartphone ecological momentary assessment (EMA).

**Objectives:** The objective of this study was to characterise the pain experiences of those with knee OA by a smartphone EMA survey and explain how momentary psychological and social states influence knee OA pain experiences.

**Methods:** A smartphone EMA survey was designed and piloted. Eligible participants completed smartphone EMA assessing the knee OA pain experience 3 times daily for 2 weeks. Descriptive statistics were used to characterise factors involved in knee OA pain followed by the development of mixed-effects location scale models to explore heterogeneity and relationships between symptoms involved in the knee OA pain experience.

**Results:** Eighty-six community-dwelling volunteers with knee OA were recruited. Pain, psychosocial, and lifestyle factors involved in knee OA pain experience were heterogeneous and variable. Those with greater variability in pain, fatigue, negative affect, and stress had worse levels of these symptoms overall. In addition, fatigue, negative affect, stress, anxiety, loneliness, and joint stiffness demonstrated within-person relationships with knee OA pain outcomes.

**Conclusions:** Knee OA pain is a heterogeneous biopsychosocial condition. Momentary experiences of psychological, social, fatigue, and joint stiffness explain individual and between-individual differences in momentary knee OA pain experiences. Addressing these momentary factors could improve pain and functional outcomes in those with knee OA. Validation studies, including individuals with more severe knee OA presentations, are required to support findings and guide clinical interventions to improve outcomes for those with knee OA.

**Keywords:** Knee osteoarthritis, Biopsychosocial, Pain, Smartphone, Ecological momentary assessment

## 1. Introduction

Knee osteoarthritis (OA) is a prevalent musculoskeletal condition that affects approximately 16% of the adult population.[17] Knee OA pain and disability are complex with biological, psychological, social, and lifestyle factors playing a role in knee OA lived experiences.[27,40,48] An assessment method that may better and more accurately capture the range of symptoms and experiences involved in the knee OA pain experience is the ecological momentary assessment (EMA).[76,92,97] A defining characteristic of this research method is that measures are repeated multiple times daily to reveal patterns of transient, fluctuating symptoms such as pain, fatigue, and mood in real-time, real-life contexts.[64,65,76,92,97] Ecological momentary assessment methods continue to evolve, relying less on paper diaries and more on technology, including smartphones and wearable devices. These

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technological advancements have further assisted with the robustness of the data collected.[64,101] Strengths of EMA include its ability to reduce recall bias and measurement errors while also offering greater ecological validity with measurement occurring in the environment and context of patients' lives.[65,92,97,98] Furthermore, repeated measurements collected during EMA allow for within-person relationships to be explored in "real-life" contexts.[64,65]

Knee OA pain outcomes traditionally include collecting recalled average pain ratings. However, solely considering recalled averages has the potential to overlook the dynamic, fluctuating nature of symptoms in individuals with painful knee OA.[1,2,6,20,31,35,47,53,60,64,77,81,82,87,88] Symptom variability is a normal part of the pain experience. Because EMA involves repeatedly measuring the dynamic pain experience over time, within-person variability can be explored.[20,34,35,65,82] Exploring within-person variability in knee OA symptoms may reflect a different, yet clinically important aspect of the knee OA pain experience.[34] Especially considering that variability in pain intensity has been linked with disability, work, sleep, psychological, and quality of life outcomes.[1,2,4,6,41,47,53,60,77,81,82,88]

Studies are yet to widely use EMA methods to explore the pain experiences of those with knee OA.[24,28,54,81,94,107] In the few EMA studies that have been performed on this population, these focus on fatigue and self-efficacy and their impact on functioning.[24,69,71,72,94,103,107] In addition, daily pain and functioning have also been explored in mixed OA populations, for short durations and using nonrandom EMA methods.[2,28,81] To the best of our knowledge, EMA studies are yet to capture the biopsychosocial knee OA pain experience and explore within-person relationships using smartphone technology. A better understanding of momentary psychosocial and lifestyle factors and how these influence knee OA pain experiences would provide a more in-depth understanding of the complex, dynamic factors involved in knee OA pain and identify potential targets for treatment.

Therefore, this study aims to characterise the pain experiences of those with knee OA by a smartphone EMA survey and explain how momentary psychological and social states influence knee OA pain experiences. This exploratory investigation was carried out in 2 stages. Stage 1: Develop and pilot a smartphone EMA survey to explore the knee OA pain experience. Stage 2: Using the smartphone EMA survey, characterise the pain experiences of those with knee OA and explain how psychological and social states influence knee OA pain experiences.

### 1.1. Objectives

(1) To develop and pilot a prototype of a smartphone EMA survey to assess usability, clarity, and time to complete the survey in a sample of individuals with knee OA.
(2) To characterise the biopsychosocial knee OA pain experience using smartphone EMA.
(3) To determine within-person variability (scale) and its relationship with within-person mean (location) in knee OA symptoms.
(4) To examine whether participants' momentary psychological and social states demonstrate relationships with momentary pain intensity, interference, and bothersomeness.

## 2. Methods

### 2.1. Study design

This article presents findings from a 2-week smartphone EMA study which was developed in consultation with the Checklist for Reporting Ecological Momentary Assessment Studies (CREMAS) and EMA literature.[14,55,91,99,100] Ethical approval was obtained from the Central Health and Disability Ethics Committee of New Zealand (21/CEN/89).

### 2.2. Participants

Participants were eligible for inclusion if aged 45 to 85 years with a diagnosis of knee OA and had experienced knee pain on most days for at least 3 months. Participants fulfilling NICE guidelines for a clinical diagnosis of knee OA were also included.[74]

Participants were excluded if they reported being a non-English speaker, unable to use a smartphone, had other rheumatological and autoimmune conditions, had uncontrolled hypertension, skin conditions, lower limb sensory loss, had undergone or were scheduled for knee arthroplasty, had a separate leg injury, had a neurological condition, impaired cognition, or psychiatric illness.

Participants were recruited from hospital outpatient settings and the community. Participants involved in this study were provided with a $100 supermarket voucher to recognise any costs involved with participation.

### 2.3. Baseline assessment

Participant characteristics, including demographic information (age, sex, ethnicity, knee OA duration, educational level, residential address, and work status), were collected. The Montreal Cognitive Assessment (MoCA) was administered to participants to detect mild cognitive impairment.[73] Participants scoring $<16$ were excluded from this study.[67]

#### 2.3.1. Stage 1: development and piloting of survey

A narrative review of the literature identified pain-related measures and psychosocial, behavioural, and lifestyle constructs related to the knee OA pain experience.[10–13,19,23,28–30,32,36,37,44,45,50,52,56,62-64,84,103–105] Validated single-item measures or single-item measures used in previous published EMA studies were used to reduce participant burden.[10–13,19,23,28–30,32,36,37,44,45,50,52,56,62–64,84,103–105] Primary variables of interest included pain intensity and pain interference. Additional variables included pain bothersomeness, physical activity, sedentary time, flare-up status, positive and negative affect, stiffness, sleep quality, fatigue, stress, anxiety, social contact, and loneliness. A preliminary EMA survey and protocol was developed (**Table 1**), which included EMA for 2 weeks, whereby participants received a survey 3 times daily.

The objectives of the EMA piloting process included improving survey usability, question clarity, and limiting participant burden. Five volunteers with knee OA were screened for eligibility and, following training, were invited to complete the first version of the smartphone EMA survey and provide feedback by a questionnaire and through the "think-aloud" method, where participants immediately verbalised their thoughts.[43] The primary investigator recorded "think-aloud" data using an audio recorder. Written feedback was also sought on the survey duration, question clarity, comprehensiveness, or any other barriers. Clarity was rated on an 11-point scale where 0 was "Not at all clear" and 10 was "Extremely clear." Participants were also able to provide free-text comments.

Audio from the "think-aloud" process was transcribed verbatim. Transcripts were reviewed to identify common themes, and written feedback was considered to inform the final survey design. The mean numeric clarity rating was calculated with ratings below 7/10, resulting in the question being amended.

**Table 1**

**U-KOPE ecological momentary assessment survey items and schedule.**

| EMA question | Morning | Day | Evening | Response |
|---|---|---|---|---|
| What is your level of pain right now?[22,88] | ✓ | ✓ | ✓ | 11-point NRS (0 = No pain, 10 = Worst pain imaginable) |
| How much is your pain interfering with what you are doing right now?[22] | ✓ | ✓ | ✓ | 11-point NRS (0 = No interference, 10 = Totally interfering) |
| How bothersome is your knee pain currently?[32,87] | ✓ | ✓ | ✓ | 5-item ordinal scale (Not at all, Slightly, Moderately, Very Much, Extremely) |
| How many hours did you spend sitting yesterday (eg, sitting at work, watching TV, driving, seated leisure)?[53,74] | ✓ | | | Numeric |
| Have you done 30 minutes or more of physical activity today, which was enough to raise your breathing rate (ie, sport, exercise, brisk walking, cycling)?[48] | | | ✓ | Yes/No |
| Have you experienced an osteoarthritis flare-up today ("… different from usual state… worsening of pain, swelling, stiffness which impacts on sleep, activity, functioning and psychological aspects…")?[46] | | | ✓ | Yes/No |
| How severe is your knee stiffness currently?[16,17] | ✓ | ✓ | ✓ | 5-item ordinal scale (None, Mild, Moderate, Severe, Extreme) |
| What best describes how well you slept last night?[53,140] | ✓ | | | 5-item ordinal scale (Very Bad, Bad, Fair, Good, Very Good) |
| What number best describes how fatigued or tired you are right now?[140] | ✓ | ✓ | ✓ | 11-point NRS (0 = Not fatigued, 10 = Fatigued as bad as I can imagine) |
| Please rate your current level of happiness[15,52,53,72] | ✓ | ✓ | ✓ | 11-point NRS (0 = Not at all, 10 = Extremely) |
| Please rate your current level of frustration[15,52,53,72] | ✓ | ✓ | ✓ | 11-point NRS (0 = Not at all, 10 = Extremely) |
| Are you currently experiencing feelings of panic, worry, or anxiety?[53,72,113] | ✓ | ✓ | ✓ | 5-item ordinal scale (Not at all, Slightly, Moderately, Very Much, Extremely) |
| How much stress do you feel right now?[44,45,79] | ✓ | ✓ | ✓ | 11-point NRS (0 = No stress, 10 = Extreme stress) |
| Who are you currently with?[15,37,45,86,142] | ✓ | ✓ | ✓ | Multiple choice (Alone or with strangers only, Spouse/partner, Children, Other family, Colleagues, Clients/customers, Friends, Other people you know) |
| Please rate your current level of loneliness[63,64,144] | ✓ | ✓ | ✓ | 5-item ordinal scale (Not at all, Slightly, Moderately, Very Much, Extremely) |

EMA, ecological momentary assessment; NRS, numeric rating scale; U-KOPE, understanding knee osteoarthritis pain experiences.

#### *2.3.2. Stage 2: administering the smartphone ecological momentary assessment survey*

Participants underwent 10 to 15 minutes of EMA training to aid in familiarising themselves with the smartphone, the EMA application, and survey questions and to ensure that survey notifications were being received. Participants were either provided with a smartphone or could choose to use their own device and download the freely available m-Path application (**Fig. 1**). The researcher-provided smartphone was a Nokia 2.3, Nokia Corporation which used an Android 12 operating system (Snow Cone). In participants choosing to use their own smartphone, a range of devices were used. Following training, participants were provided with an instructional handout and signed a statement of commitment.

Eligible volunteers participated in 14 consecutive days of smartphone EMA monitoring (one wave; 10 weekdays and 4 weekend days).[64] Participants were required to complete the smartphone survey 3 times daily.[49,66] Ecological momentary assessment prompting occurred in a random-stratified manner, with participants being notified randomly within 3 prespecified time blocks throughout their day. This ensured that symptoms after waking, during the day, and in the evening were collected to get a representative dataset. The random-stratified blocks were scheduled as follows:

(1) Morning: A 2-hour block was placed immediately following the usual wake time.
(2) Day: A 5-hour block was placed from 11 AM (or 2 hours following usual wake time).[61]
(3) Evening: A 2-hour block was placed immediately before the usual bedtime.

Therefore, each participant was sent 42 surveys to complete during the study. Latency was <60 minutes, with responses >60 minutes being considered missing. Reminder prompting after 30 minutes and "snooze" features for up to 60 minutes were also incorporated to improve compliance.[55] Question ordering differed between morning, afternoon, and evening surveys with prior responses not being viewable.

### *2.4. Data management*

The full data management and analysis plan can be found in Appendix A, http://links.lww.com/PR9/A236. Missing data trends for EMA data were analysed to determine potential patterns of missingness.[7]

**Table 2**

**Clarity ratings for preliminary smartphone survey items.**

| Smartphone EMA construct measured | Clarity rating* |
|---|---|
| Pain intensity | 9.8 ± 0.4 |
| Pain interference | 9.8 ± 0.4 |
| Pain bothersomeness | 5.6 ± 3.3 |
| Stiffness | 9.4 ± 1.3 |
| Fatigue | 10 ± 0 |
| Sleep quality | 9.8 ± 0.4 |
| Positive affect | 10 ± 0 |
| Negative affect | 9.8 ± 0.4 |
| Anxiety | 10 ± 0 |
| Stress | 10 ± 0 |
| Social contact | 9.8 ± 0.4 |
| Loneliness | 10 ± 0 |
| Flare-up | 9 ± 1.4 |
| Physical activity | 9.8 ± 0.4 |
| Sedentary time | 9.4 ± 1.3 |

* Data are presented as mean ± standard deviation.
EMA, ecological momentary assessment.

### 2.5. Statistical analysis plan

A series of multilevel mixed-effects location scale (MELS) models were performed using Mixed models With Intensive Longitudinal Data (MixWILD), Version 1 allowing for the assessment of within-person location (mean) and scale (variability) effects.[22,33] Empty MELS models (models without predictors) were completed to calculate the random log-transformed scale standard deviation and location–scale relationship. Mixed-effects location scale models were then completed, exploring the within- and between-person effects of momentary fatigue, stiffness, loneliness, negative affect, anxiety and stress on pain intensity, interference, and bothersomeness outcomes. The level of error considered acceptable for statistical significance was set at $P \leq 0.05$.

## 3. Results

### 3.1. Objective 1: ecological momentary assessment piloting outcomes

A prototype of the smartphone EMA survey was piloted on 5 participants with knee OA. Four of the pilot participants were men. These participants had a mean age of 58.2 ± 11 years and reported experiencing knee OA for a mean duration of 8 ± 7.4 years. Overall, the smartphone EMA survey was endorsed with no significant issues reported. Clarity ratings for the first version of the smartphone EMA survey are presented in **Table 2**.

Participants estimated that the average time to complete the survey was 4.9 ± 3.1 minutes. All participants deemed smartphone EMA and the questions as being acceptable and relevant to their knee OA experiences. One recommendation included asking about specific activities that pain had interfered with. This was, therefore, included as a checkbox item in the final EMA survey. Three of the 5 participants (60%) reported that the original pain bothersomeness question was confusing and difficult to understand. Therefore, "Before prompt" was removed and replaced with "Currently." All included pilot participants reported that they would prefer to use their own smartphones.

### 3.2. Objective 2: characterising knee osteoarthritis using smartphone ecological momentary assessment

#### 3.2.1. Participant characteristics

A final sample size of 86 participants was included, with no loss to follow-up. The participant flow diagram is presented in **Figure 2**.

Characteristics of study participants are presented in **Table 3**.

#### 3.2.2. Ecological momentary assessment participation and compliance

Average compliance across the two-week monitoring period was 90.7% ± 8.8. Eighty participants (93%) used their own phones. All participants completed the study.

Nonparametric correlations (Kendall Tau and Spearman) were completed to explore whether compliance was related to demographic variables. Only gender demonstrated a fair relationship with EMA compliance: with women responding to more of the smartphone EMA surveys ($r = 0.3$, $P = 0.02$). Nonresponse was deemed to be MAR with no evidence of relationships between data missingness and variables including pain intensity ($P = 0.4$), pain interference ($P = 1$), fatigue ($P = 0.4$), negative affect ($P = 0.5$), and the number of flare-up days ($P = 0.9$). There was no evidence of measurement reactivity with no statistically significant change in pain intensity ratings between weeks of EMA monitoring ($P = 0.5$).

**Table 3**

**Characteristics of included participants.**

| Characteristic | Value* |
|---|---|
| Age (y) | 67.3 ± 9.1 |
| Sex | Female: 55 [64]<br>Male: 31 [36] |
| Ethnicity | NZ European: 78 [90.6]<br>New Zealand Māori: 4 [4.7]<br>Indian: 2 [2.3]<br>English European: 1 [1.2]<br>Egyptian: 1 [1.2] |
| BMI (kg/m$^2$) | 32 ± 6.8 |
| Handedness | Right: 80 [93]<br>Left: 6 [7] |
| Knee OA duration (y) | 9.2 ± 9.1 |
| Bilateral OA | Yes: 48 [55.8]<br>No: 38 [44.2] |
| Worst knee | Right: 46 [53.5]<br>Left: 40 [46.5] |
| Highest level of education | No formal qualification: 12 [14]<br>Year 10: 1 [1.2]<br>Year 13: 12 [14]<br>Trade/apprenticeship: 7 [8.1]<br>Certificate/diploma: 19 [22.1]<br>University degree: 19 [22.1]<br>Postgraduate degree: 16 [18.6] |
| Work status | Full-time employed: 21 [24.4]<br>Part-time employed: 9 [10.5]<br>Self-employed: 7 [8.1]<br>Homemaker: 1 [1.2]<br>Retired: 47 [54.7]<br>Unable to work: 1 [1.2] |

* Data are presented as mean ± standard deviation or number [%].
BMI, body mass index; kg, kilograms; m, metres; OA osteoarthritis.

**Table 4**

**U-KOPE aggregated ecological momentary assessment data.**

| Aggregated measure | Mean ± SD |
|---|---|
| Pain intensity | |
| Current | 2.7 ± 1.9 |
| Maximum | 5.6 ± 2.3 |
| Minimum | 0.9 ± 1.2 |
| Variability (SD) | 1.2 ± 0.5 |
| Time high (%) | 3.3 ± 11.2 |
| Time low (%) | 65.2 ± 28.1 |
| Pain interference | |
| Current | 2 ± 1.6 |
| Maximum | 5.2 ± 2.7 |
| Minimum | 0.3 ± 0.6 |
| Variability (SD) | 1.3 ± 0.7 |
| Time high (%) | 2.1 ± 6.5 |
| Time low (%) | 73.2 ± 22.1 |
| Pain bothersomeness (total number [%]) | |
| Not at all | 725 [22.1] |
| Slightly | 1533 [46.8] |
| Moderately | 836 [25.5] |
| Very Much | 167 [5.1] |
| Extremely | 16 [0.5] |
| Knee OA flares (total number [%]) | |
| Total flare days | 265 [24.4] |
| Average flare days per person | 3.1 ± 3 |
| Stiffness (total number [%]) | |
| None | 682 [20.8] |
| Mild | 1515 [46.2] |
| Moderate | 951 [29] |
| Severe | 120 [3.7] |
| Extreme | 9 [0.3] |
| Fatigue | |
| Current | 3.4 ± 1.9 |
| Maximum | 6.8 ± 2.1 |
| Minimum | 0.8 ± 1.1 |
| Variability (SD) | 1.7 ± 0.7 |
| Time high (%) | 6.1 ± 10.9 |
| Time low (%) | 52.7 ± 29.7 |
| Sleep quality (total number [%]) | |
| Very bad | 25 [2.2] |
| Bad | 114 [10.2] |
| Fair | 406 [36.5] |
| Good | 435 [39.1] |
| Very good | 133 [12] |
| Positive affect | |
| Current | 7.5 ± 1.3 |
| Maximum | 9 ± 1 |
| Minimum | 4.5 ± 2.5 |
| Variability (SD) | 1.1 ± 0.6 |
| Time high (%) | 53.9 ± 33.3 |
| Time low (%) | 3.2 ± 6.8 |
| Negative affect | |
| Current | 2.1 ± 1.7 |
| Maximum | 5.9 ± 2.8 |
| Minimum | 0.4 ± 0.7 |
| Variability | 1.4 ± 0.8 |
| Time high (%) | 3.4 ± 8.9 |
| Time low (%) | 72.2 ± 25.2 |
| Anxiety (total number [%]) | |
| Not at all | 2424 [74] |
| Slightly | 725 [22.1] |
| Moderately | 114 [3.5] |
| Very Much | 14 [0.4] |
| Extremely | 0 |
| Stress | |
| Current | 1.8 ± 1.6 |
| Maximum | 4.8 ± 2.8 |
| Minimum | 0.3 ± 0.7 |
| Variability (SD) | 1.1 ± 0.7 |
| Time high (%) | 1.8 ± 6.9 |
| Time low (%) | 77.1 ± 22.8 |
| Loneliness (total number [%]) | |
| Not at all | 3086 [94.2] |
| Slightly | 153 [4.7] |
| Moderately | 30 [0.9] |
| Very Much | 8 [0.2] |
| Extremely | 0 |
| Physical activity | |
| 30 min achieved | 639 [58.8] |
| Average days PA achieved per person | 7.4 ± 4.1 |
| Sedentary time (h) | |
| Daily sedentary time | 6.6 ± 2.3 |
| Maximum | 8.7 ± 2.9 |
| Minimum | 4.2 ± 1.8 |
| Variability (SD) | 1.4 ± 0.6 |

Variability is the average of each participant's standard deviation. Time in high (%) is the percentage of ratings ≥7.5/10. Time in low (%) is the percentage of ratings ≤3.5/10.

PA, physical activity; SD, standard deviation; U-KOPE, understanding knee osteoarthritis pain experiences.

#### 3.2.3. Aggregated ecological momentary assessment measures

The repeated measures from the smartphone EMA allowed for the aggregation of pain intensity ratings.[87] Aggregation was also performed for other constructs collected. Aggregated data are presented in **Table 4**.

### 3.3. Objective 3: knee osteoarthritis symptom variability

Using MixWILD, variability in scale and associations between within-person means and standard deviations (location–scale relationships) were explored. Findings are presented in **Table 5**.

Participants significantly differed from one another in terms of their symptom variability for all measures collected by smartphone EMA. Location–scale relationships were demonstrated for pain intensity, fatigue, negative affect, stress, and sedentary time meaning that those reporting greater average levels, also demonstrated greater variability in these variables. Alternatively, inverse location–scale relationships were demonstrated for positive affect and sleep quality, meaning that better average positive affect and sleep quality were associated with less variability in these variables. Nonsignificant location–scale relationships were found for pain interference, bothersomeness, and anxiety.

### 3.4. Objective 4: influence of momentary psychosocial and lifestyle factors on knee osteoarthritis pain experiences

The relationship between momentary psychosocial and lifestyle factors and the pain experiences of those with knee OA was explored. These are presented in **Table 6**.

#### 3.4.1. Pain intensity

Within-person relationships were demonstrated between pain intensity and fatigue, negative affect, knee stiffness, stress, and anxiety. Between-person relationships were demonstrated between pain intensity and fatigue, negative affect, knee stiffness, and stress.

#### 3.4.2. Pain interference

Within-person relationships were demonstrated between pain interference and fatigue, negative affect, stress, anxiety, and loneliness. Between-person relationships were demonstrated

**Table 5**

**Variability in scale and location–scale relationships for ecological momentary assessment variables.**

| EMA variable | Random scale SD* | Random location† effect on scale |
|---|---|---|
| Pain intensity | 0.7*** | 0.6*** |
| Pain interference | 1.4*** | −0.1 |
| Pain bothersomeness | 0.3*** | 0.1 |
| Stiffness | 0.4*** | 0 |
| Fatigue | 0.7*** | 0.3*** |
| Negative affect | 0.9*** | 0.6*** |
| Anxiety | 0.4*** | 0 |
| Stress | 1*** | 0.9*** |
| Loneliness | 0.5** | 0.3 |
| Positive affect | 1.1*** | −0.4** |
| Sleep quality | 0.3*** | −0.2** |
| Sedentary time | 0.6*** | 0.5*** |

***$P < 0.001$; **$P < 0.01$.

* Random scale SD reflects variability in scale represented as log-transformed standard deviation.

† Random location reflects within-in participant mean.

EMA, ecological momentary assessment; SD, standard deviation.

between pain interference and fatigue, negative affect, stress, and loneliness.

### 3.4.3. Pain bothersomeness

Both within- and between-person relationships were demonstrated between pain bothersomeness and fatigue, negative affect, stress, anxiety, and loneliness.

## 4. Discussion

The aim of this study was to characterise the pain experiences of those with knee OA by smartphone EMA and explain how participants' momentary psychological and social states and other experiences, such as fatigue and joint stiffness, influence pain experiences. This study showed that the knee OA pain experience was variable and unique to the individual. In addition, the knee OA pain experience was shown to be influenced by individual psychosocial and lifestyle factors.

Symptom variability is a normal part of the pain experience, demonstrated in several populations.[1,2,6,47,53,60,77,81,88] This study adds to previous findings, demonstrating symptom heterogeneity in those with knee OA using robust smartphone EMA methods.[2,41,80] Incidentally, greater variability in many knee OA symptoms (ie, pain intensity) was related to greater average symptom levels overall highlighted by location–scale relationships. Studies across multiple patient populations have shown that pain variably is related to poorer function, quality of life, sleep, work absence, and psychological and health resource use outcomes.[4,41,88] This suggests that targeting pain variability may result in improvements across multiple patient outcomes.[4,41,88] Furthermore, as pain variability is typically unpredictable and can cause a decrease in locus of control, patients may cope better if they experienced less pain variability.[88] Management strategies which address pain aggravations such as proactive supported self-management strategies, analgesia regimes, and psychological coping interventions may be beneficial.[2,41] However, further research exploring whether the impact of pain variability can be improved in those with knee OA is required.[2,88]

Most participants reported mild pain across the two-week monitoring period. Minimal time in high pain (≥7.5/10 on the

**Table 6**

**Effect of ecological momentary assessment variables on knee osteoarthritis pain outcomes.**

| Variable | Effect | ß—pain intensity | ß—pain interference | ß—pain bothersomeness |
|---|---|---|---|---|
| Fatigue | Between | 0.6*** | 0.5*** | 0.9*** |
| | Within | 0.2*** | 0.2*** | 0.3*** |
| Negative affect | Between | 0.5*** | 0.5*** | 0.7*** |
| | Within | 0.3*** | 0.4*** | 0.5*** |
| Stiffness | Between | 1.5*** | 1.5***,‡ | 3.6*** |
| | Within | 1.1*** | 1.1***,‡ | 3*** |
| Anxiety | Between | 0.3 | 0.3† | 1.2* |
| | Within | 0.4*** | 0.2***,† | 0.5*** |
| Stress | Between | 0.5*** | 0.5*** | 0.7*** |
| | Within | 0.3*** | 0.4*** | 0.4*** |
| Loneliness | Between | 0.4**,† | 2.2***,‡ | 2.5* |
| | Within | 0† | 0.4**,‡ | 0.4* |

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$.

Between-person estimate represents a participant's average level relative to the group mean.

Within-person estimate represents participants' momentary ratings relative to their own mean.

† Standardised.

‡ Scale parameters.

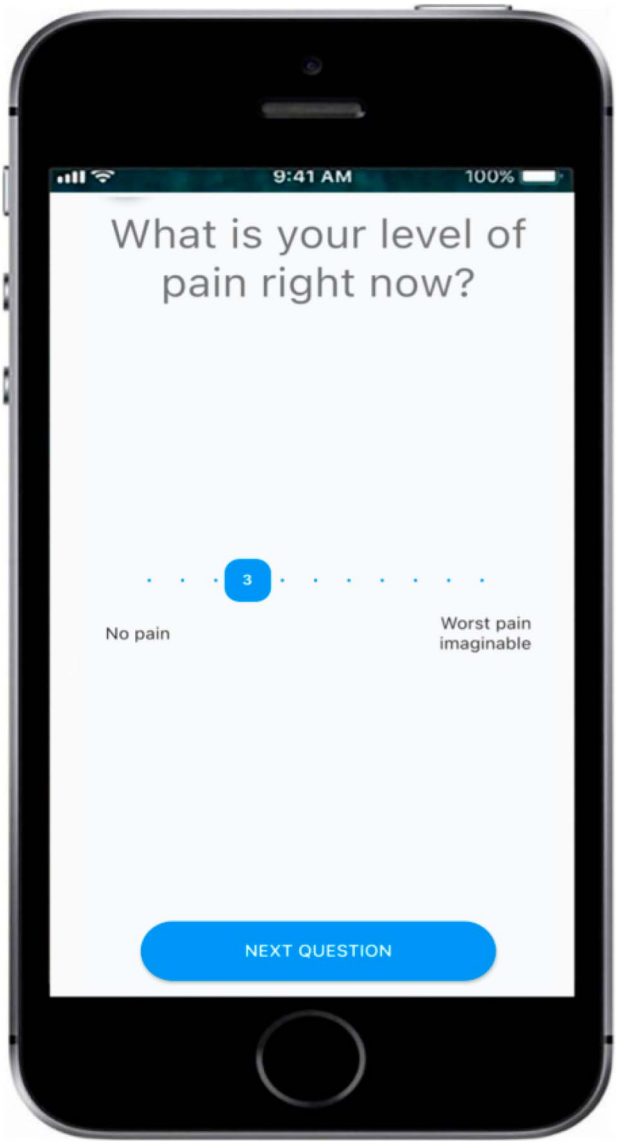


Figure 1. Screenshot of the smartphone EMA survey using the m-Path application. EMA, ecological momentary assessment.

NPRS) was reported, with the participants reporting low pain (≤3.5/10 on the NPRS) most of the time. Although time in high pain was low in this study, this may have important clinical consequences. A recent meta-analysis demonstrated relationships between time in high pain and clinical outcomes including worse functioning which could negatively impact quality of life.[77,87] Furthermore, time in high pain may reflect the presence of knee OA flare-ups or underlying pain mechanisms such as sensitization.[87] Identifying those with more time in high pain may assist with prioritizing those in greatest need of intervention, subgrouping the knee OA population, and be an important target for treatment.[87] More research is required to explore the implications of time in high pain and better address this to improve clinical outcomes.

In this study, participants rated whether they experienced a flare-up day. On average, participants reported of having a flare-up day on almost 25% of the two-week monitoring period. This suggests that flare-up occurrence reported by previous studies (2.4 annually) may underestimate the incidence of OA flare-ups.[8] In addition, participants may have rated even minor symptom interference based on the provided definition of OA flare-ups. This may reflect heterogeneity in OA flare-up presentations with different severities and durations of flare-ups presenting in the OA population. Flare-ups play a significant role in the knee OA pain experience, contributing to functional, sleep, and psychological consequences.[30] Reducing the magnitude and number of flare-ups could significantly reduce disability and improve quality of life. Consequently, future research should investigate treatments that target OA flares, including triggers and outcomes.

Fatigue is a complex, multifactorial symptom experienced by those with knee OA which negatively impacts functioning and quality of life.[25,26,70–72] A recent systematic review reported that factors contributing to fatigue in this population include lower levels of functioning, comorbidities, pain, sleep quality, and depression.[85] Fatigue was highlighted by this study as a heterogeneous symptom that also contributes to the knee OA pain experience. Factors contributing to fatigue in the knee OA pain experience include systemic inflammation, prolonged sympathetic nervous system activity, and sensitization making fatigue, pain, and sleep quality interrelated symptoms.[5,21,51,57,78,79,83,86,95,102,103] With these many complex factors contributing to the knee OA presentation, a vicious cycle of worsening pain, fatigue, and disability could develop endorsing the need for intervention.[25,26,85,103]

Psychological factors play an important role in predicting pain and functional outcomes in those with knee OA.[16,38,39,90,96] In this study, most participants reported low overall levels of negative affect, anxiety, and stress; however, these symptoms were shown to be heterogeneous across the sample. Those who reported worse mood and stress were shown to have greater symptom variability. By contrast, those reporting greater positive mood presented with less variability in positive mood. When compared with pain outcomes, participants who reported worse-than-usual mood, anxiety, and stress also reported higher pain intensity, interference, and bothersomeness. A recent review confirms the high prevalence of anxiety and depression in those with knee OA, with psychological factors being associated with greater levels of pain and disability.[42,58,89] In addition, greater pain and disability have been shown to prospectively predict the incidence of future depression.[108] These findings highlight that psychological factors may be strongly related to an individual's knee OA pain experience, whereby knee OA pain, disability, depression, distress, and anxiety could influence each other, contributing to a vicious cycle.[106]

Chronic pain, disability, and depression are risk factors for social isolation and loneliness.[75,93,96] Therefore, those with knee OA may be at greater risk. In this study, loneliness was shown to be variable and demonstrated relationships with worse pain intensity, interference, and bothersomeness. Knee OA pain may limit individuals from socialising while reduced social participation may result in functional decline and increased knee OA symptoms.[46] Consequently, interventions that aim to improve social connection and perceived loneliness may be worthwhile to improve pain, functioning, and psychological status in those with knee OA.[75,93,96]

The findings from this study suggest that targeting symptom stability, reducing time in high pain, and improving lifestyle and psychosocial status may improve knee OA symptoms, functioning, and quality of life. Interventions such as prophylactic analgesic medication regimes and the implementation of proactive self-management strategies, psychological coping strategy implementation, physical activity prescription, sleep hygiene interventions, and meditation or relaxation could be effective in improving the knee OA pain experience.[43–45]

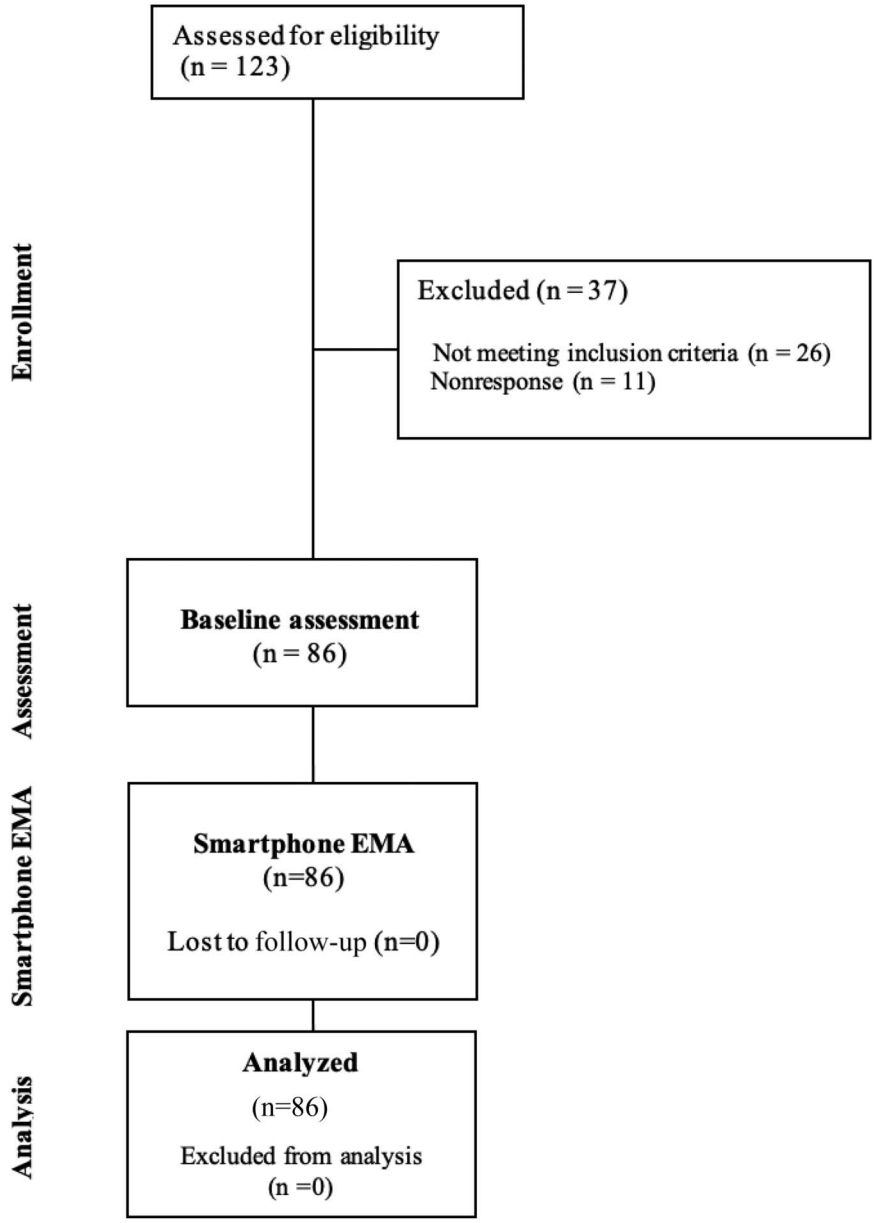


Figure 2. Participant flow diagram.

The strengths of this study included study design adherence to the CREMAS to limit potential sources of bias[55] and high compliance of study participants. In addition, pain, psychosocial, and lifestyle factors were captured via a momentary (or close to momentary) single-item questionnaire. This allowed these constructs to be collected in a manner that reduced the burden and requirements for recall. The survey items were piloted on a small group of study participants with written and "think-aloud" feedback collected to inform the final EMA survey design. Design features to reduce participant burden and improve the quality of the data were also incorporated (ie, training, individualised notification schedule, reminder or snooze features, use of own devices) to enhance the EMA experience. Other novel areas explored in this investigation include the role of loneliness, an important social construct on momentary pain experiences, suggesting a potential role of social referral as part of the holistic management of knee OA.[15] Finally, a multilevel modelling approach using the recently developed MELS model was used to analyse the repeated, nested data and allow for the exploration of the novel within- and between-person relationships involved in the biopsychosocial knee OA pain experience.[22,53]

This study solely included participants from the community who mainly presented with a mild knee OA presentation on average. Despite attempts, no participants were recruited from the hospital's orthopaedic outpatient department. Reports suggest that individuals with more severe symptoms may present with more variable symptoms, including the presence of additional psychosocial factors.[3,18] In this study, more mild presentations likely meant that there was less potential distribution of variables. This inevitably meant that participants with a milder presentation overall would have lower momentary reports of symptoms, resulting in less variability. Therefore, further research on knee OA populations with moderate and severe knee OA pain experiences which controls for overall pain levels is needed to fully conclude that variability is the driving factor. Study participants presented with a large degree of variability in knee OA duration. Including knee OA duration in future MELS models may suggest the possible impact that knee

OA duration has on pain experiences. The power analysis completed was not specific to the EMA data and MELS modelling. However, within-person analyses are often reported to improve power.[59,68] Therefore, the included sample was larger than many EMA studies exploring populations with pain.[64,76] With this being an exploratory study, larger and longer validation studies are required to support findings and further explore the statistical and clinical significance of demonstrated relationships. Testing hypotheses informed by this study using lagged effect models is also required.

Ecological momentary assessment surveys were only administered 3 times daily. Therefore, these may have potentially missed times of high or low symptoms. A few items included in the EMA survey did not have established psychometric properties. Although reducing the burden, using single-item questions to capture complex experiences may fail to adequately capture constructs of interest.[9] Therefore, psychometric properties of single-item measures need to be established for use in future EMA studies.

Overall, data from this study suggest that pain, psychosocial, and lifestyle factors involved in knee OA pain experience are heterogeneous and variable in real-life contexts and circumstances. Those with greater variability in pain, fatigue, negative affect, and stress had worse levels of these symptoms overall. This highlights that knee OA is not a static, homogenous condition. Instead, knee OA differs between individuals, with symptoms fluctuating over hours and days. Furthermore, momentary psychosocial and lifestyle factors, such as low mood, stress, anxiety, and loneliness, and bodily experiences, such as fatigue and joint stiffness, were shown to demonstrate relationships with variable pain experiences at an individual level. These are important findings for clinical practice, endorsing the need to provide treatments that better manage symptom stability and address individualised psychosocial and lifestyle factors that have been shown to contribute to the knee OA pain experience.

## Disclosures

The authors have no conflict of interest to declare.

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## Supplemental digital content

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